ISGF
India Smart Grid Forum

COMPENDIUM OF TECHNICAL PAPERS

ISUW 2023

India SMART UTILITY Week 2023

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Compendium of Technical Papers ISUW 2023

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WOODHEAD PUBLISHING INDIA PVT LTD

New Delhi

Published by Woodhead Publishing India Pvt. Ltd.
Woodhead Publishing India Pvt. Ltd.,
303, Vardaan House, 7/28, Ansari Road,
Daryaganj, New Delhi - 110002, India
www.woodheadpublishingindia.com

2024, Woodhead Publishing India Pvt. Ltd.

Woodhead Publishing India Pvt. Ltd. ISBN : 978-81-968480-6-4
Woodhead Publishing India Pvt. Ltd. e-ISBN : 978-81-968480-1-9

This Edition is for sale in India, Pakistan, Nepal, Bhutan,
Bangladesh & Sri Lanka

Preface

The India Smart Grid Forum (ISGF) is a Think-Tank of global repute on Smart Energy, Electric Mobility and Smart Cities. ISGF, established as a Public Private Partnership initiative of Government of India in 2011, is spearheading the mission to accelerate electric grid modernization and energy transition in India. ISGF has over 170 members comprising of ministries, government institutions, utilities, technology providers, academia, and research. Mandate of ISGF is to accelerate energy transition through smart energy, electric grid modernization and electric mobility; work with national and international agencies in standards development and help utilities, regulators and the industry in technology selection, training, and capacity building.

Since 2016, ISGF invites Technical Papers on the latest themes related to Power Sector to recognize the best Technical Papers in the industry as part of its annual flagship event India Smart Utility Week (ISUW) an International Conference and Exhibition on Smart Energy and Smart Mobility. The authors of the top 25 technical papers selected by an expert jury panel get the opportunity to present their papers at India Smart Utility Week (ISUW) which witnesses participation of Visionary Leaders, Utility CEOs, Regulators, Policy Makers, and Subject Matter Experts from 50+ Countries every year. Top 50 Authors get the opportunity to get their technical papers published with renowned publishing house/ISGF Portal.

Sr. No	Theme of Technical Papers
1	**INDIA @ 100 in 2047: Vision for the Indian Power System** • Net Zero Power Sector • Electric Highways and the Electric Grids • Super Grids for Energy Transition • Role of ICT in Energy Transition
2	**Evolving Architecture of the 21st Century Grid with Two Way Power Flows** • Planning And Design of Transmission Grid • Planning And Design of Distribution Grid with Prosumers and Electric Vehicles and Distributed Energy Resources • Communication Systems and Technologies for Fast Response- 1/50 (or) 1/60 Seconds • Separate Control Bus for IT and OT Systems • Climate Proofing of Future Grids
3	**Electric Mobility** • Vehicle Grid Integration (VGI) • New Infrastructure Planning with Integrated EVSE • EVs as Virtual Power Plants (VPP) • Business Models for EV Charging Stations

4	**Foundational Blocks for Smart Grids** • Learnings from Smart Grid Projects • Smart Microgrids for Campuses, Railway Stations, Sea Ports, Airports, Industrial Parks, Military Bases, Hotels, Hospitals, Slums and Commercial Complexes • Cyber Physical Security of the Critical Infrastructure • Standards and Interoperability of Equipment and Systems • Communication Solutions for Smart Grids and Smart Cities • Flexibility in Power Systems • Energy Storage Systems - Applications and Business cases • 250 million Smart Meters in India – Rollout Strategies and Business Models
5	**Disruptive Innovations for Utilities** • Artificial Intelligence and Robotics, Drones • Virtual Reality, Augmented Reality, and Mixed Reality Technologies for the Smart Grids and Smart Cities • Machine Learning • Wearable Devices • Blockchain Applications for Utilities • Robotic Process Automation (RPA) for Utilities • “Paper-less” and “Contact-less” Operations of Utilities • Digitalization, New Services and Revenue Streams • Voice of the Customer - What the Digital Customers Wants? • Customer Engagement Strategies and social media for Utilities - Customer Portal, Chat-bot, Voice-bot • 5G Rollout and its Impact for Smart Grid Technologies • Grid Interactive Buildings and Campuses
6	**Smart Grids for Smart Cities** • Common Automation and IT Layer for Smart City Infrastructure Domains • Unlocking the Value of Street Light Poles for Multiple Smart City Applications • Smart Home and Smart Appliances • Smart Grid as Anchor Infrastructure for Smart Cities • Smart Energy Communities • Distributed Generation • Combined Billing and Customer Care Systems for all Utilities in a Smart City • Common GIS Map for all Domains in a Smart City • Digital Twins
7	**New and Emerging Technologies and Trends** • DG Set Replacement with Battery Energy Storage Systems (BESS) • Green Hydrogen • District Cooling System • Electric Cooking • Urban Air Mobility Systems (UAM)

8	**Regulations for the Evolving Smart Energy Systems** • 100% Renewables • Flexibility Solutions • Retail Competition • Green Power Markets • Ancillary Services
9	**Smart Water** • Smart Solutions for Water Production, Transmission and Distribution • Smart Technologies to Address India's Urban Water Crisis
10	**Smart City Gas Distribution** • **Solutions for Gas Transmission and Distribution Networks**
11	**Cyber Security for the Digitalized Grids**

For the year 2023, total of 195 abstracts were received out of which 118 abstracts were shortlisted by esteemed Jury Panel for full technical paper submission. As per the guidelines given by Jury Members, 84 Full Papers were further evaluated by Jury Members out of which 55 Papers were shortlisted this year. Top 25 Papers were given an opportunity to present at ISUW 2023, organized from 28 Feb – 04 March 2023. Top 55 selected Technical Papers are published in this compendium of Technical Papers.

Esteemed Juries for ISUW 2023 Technical Papers

Jury Panel	Brief Profile of Jury Panel
 **Ms. Anjuli Chandra** **Former Member, Punjab Electricity Regulatory Commission (PERC)**	Anjuli Chandra, former member, Punjab State Electricity Regulatory Commission (PSERC), brings to the table four decades of experience in the power sector. Her areas of expertise include distribution and transmission network planning, formulating standards, devising regulatory frameworks and load forecasting. Prior to joining PSERC, Chandra was principal chief engineer at the Central Electricity Authority (CEA), where she was responsible for power survey and load forecasting, power system monitoring, project appraisal and distribution planning and development. She has also served as executive director, tariff, and engineering, at the Delhi Electricity Regulatory Commission.

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Mr. N MURUGESAN Former Director General, CPRI, 38 Years of experience in Power Systems
SCADA, Substation, Distribution Automation and Smart Metering
</td>
<td>Mr. N MURUGESAN Former Director General, CPRI, 38 Years of experience in Power Systems, SCADA, Substation, Distribution Automation and Smart Metering N.Murugesan holds MSc (Engg) and MBA. He has more than 38 years of experience in the area of Smart Metering, Smart Grid, Advanced Metering Infrastructure (AMI), Power Systems, Transmission & Distribution system, SCADA, Substation & Distribution Automation, Switchgear testing & Certification (Low & High voltage equipment) as per National & International standards. Managed one of the largest Power Engineering Research Institute in the world as Director General. He added many infrastructures to carry out Research and for certification of electrical equipment from Low Voltage to EHV Class equipment to meet International and National standards. Managed various laboratories located 7 cities across India (Bangalore, Hyderabad, Nagpur, Bhopal, Noida, Kolkata, Guwahati). Organised more than 400 workshop/ Training / Conferences in the area of Power Engineering. Supervised varieties of Consulting works covering Generation, Transmission and Distribution and managed various Research & Development projects in the above areas. He established Communication Protocol conformance laboratories for the first time in Asia in 2003 and 2008 for Energy Meter and Substation Automation as per IEC 62056 and 61850 respectively. Established other laboratories as per IEC 60870 series, Modbus etc. Certified largest number of products as per above IEC and helped to produce in India. Played an active role in drafting specification under RAPDRP. He was the Chairman to bring Smart Meter standard -BIS 16444 and CBIP Manual for Energy Meter.</td>
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Mr. Ravi Seethapathy
Ambassador Americas, Global Smart Grid Federation, Honorary Member and WG Chair
ISGF and Chairman, Biosirus Inc. Canada
</td>
<td>After 35+ year career in Electric Utilities/Power Systems, Ravi Seethapathy is now an Advisor to the Utility/Industry, and sits on the Boards of Power Transmission & Distribution (IC) Division of Larsen & Toubro, India; Biosirus Inc., Canada; Smart Grid Canada, and India Smart Grid Forum. His current international activities include (1) “Ambassador for the Americas”, Global Smart Grid Forum; (2) CIGRE Convener WGC6.28-Remote Grids; (3) IEA PVPS Taskforce 14 – Large Scale Solar Integration; (4) IEC TC 120 – Energy Storage; (5) IEC SEG4-LVDC; and (6) Chair, India Smart Grid Forum WG 5-RE & Micro-grids. He an invited speaker internationally and has co-authored over 50 technical papers in the areas of Smart Grid. He Founder/ Executive Chair of Biosirus Inc. in Canada. Retired in 2014 after 31-year career in Hydro One/Ontario Hydro (a leading utility in Canada), where he managed leading portfolios in R&D, Innovation, Smart Grid Projects, Energy Storage, Renewable Energy Integration, Asset Management, Corporate Operations/Technical Audit, M&A (500M$), Field Operations, and Relaying and Control. His past corporate directorships include Toronto Atmospheric Fund, Ryerson University, TV Ontario, Scarborough Hospital, Nevaro Capital Corp, Engineers Without Borders (Chair), Canadian Club of Toronto (President), Indo-Canada Chamber of Commerce (President). Ravi has received numerous honours and citations including Queen Elizabeth Diamond Jubilee Medal (2012), Fellow Canadian Academy of Engineering (2012), Hydro One President’s Award (2008), Honour Roll of the Shastri Institute (2008), Honorary Fellow, Centennial College (2005), and Indo-Canada Chamber of Commerce (1996) to name a few. Ravi’s education includes a B. Tech (Hons) in Electrical Power from IIT, Kharagpur, India; an M. Eng. in Electrical Power from the University of Toronto; and an MBA from the Schulich School of Business, York University. His family/he have endowed an IEEE Award in “Rural Electrification Excellence.”</td>
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Mr. BP Singh
Former Member
Delhi Electricity Regulatory Commission (DERC)</td><td>Mr. BP Singh Former Member Delhi Electricity Regulatory Commission (DERC) Mr. BP Singh is a graduate in Mining Engineering from Indian School of Mines, Dhanbad and has over 40 years of experience in the power & energy sector. He was a Former Member in DERC (Delhi Electricity Regulatory Commission). He has issued three successive Tariff Orders for the period 2014 to 2018, being consumer friendly, were highly acclaimed at all levels. As a part of Power sector Reforms, formulated progressive Regulations on Tariff, Net Metering and Demand Side Management and Modified SOP to make it more consumer friendly. Efficacious remedy for redressal of Consumer's Grievance has been enhanced by making the Regulations consumer friendly and initiated action for creation of legal aid cell for the benefit of the Consumer's. Prior to taking up the assignment as Member DERC, he rose to the position of Director (Projects) in NTPC, where he additionally had also held assignments viz, Chairman, BRBCL; Chairman NTPC SCCL Global Ventures Pvt. Ltd.; whole time Director of NTPC Hydro Ltd.; BFSNL Ltd. etc. He has been part of numerous high-level committees constituted by the Government of India for formulation of Plan proposals and Policies including Energy Policy, pricing of Coal etc. He has actively participated in formulation of policies for the Regulatory Commissions under the aegis of Forum of India Regulators. He has been associated with numerous professional institutions, viz 1. "Institute Senate Member' – Dr BR Ambedkar National Institute of Technology, Jalandhar; 2. Member of General Body & Peer Review Committee of National Institute of Rock Mechanics under Ministry of Mines, 3 Member of the Board of Construction Industry Development Council, joint council by Indian Construction industry and Planning Commission, He had been adjudged and awarded Best Director Projects Corporate Excellence Award 2012-13 – GEOMINTECH; Awarded at Brisbane Dadari Project – awarded for project excellence in 25th IPMA World Congress at Brisbane in 2011 .</td></tr>
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Mr. Vijay Sonavane
Former Member
MERCB</td><td>Mr. Vijay Sonavane Former Member, MERC Shri Vijay Sonavane is Former member to Maharashtra Electricity Regulatory Commission (MERC). He retired as a Member, MERC in August 2014. Sh. Sonavane is BE / ME (ELECTRICAL) from Pune University. On 20th August 2009, he was appointed by Govt. of Maharashtra as Member (Technical) in MERC for a period of Five years. He is the Member of the Committee set up by Govt. of India for preparing Regulations for Smart Grids. He is the Mentor for MAHA-Smart Grid Coordination Committee, set up by MERC for development of Smart Grid projects in Maharashtra. During his previous assignments, he was associated with Power System Planning, PLC Communication, Load Dispatching, Hardware/ Application Software maintenance for Energy Control Centre, Distribution Systems Improvement, Energy Auditing System, 400KV planning, HVDC erection & Commissioning, Tariff petition formation, Internal Reform, Corporate Planning, System Operation, Distribution Project monitoring. He worked as Dy EE, EE, SE, CE, ED(CP) & finally promoted as Director (Projects) from March to August 2009. (Total: over 33 years' experience in MSEB/ MSEDCL).</td></tr>
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 **Mr. Reji Kumar Pillai President, ISGF Chairman GSEF**	Reji is the President of India Smart Grid Forum (www.indiasmartgrid.org) since its inception in 2011 and is also the Chairman of Global Smart Energy Federation since November 2016. He an internationally renowned expert with nearly four decades of experience in the electricity sector in diverse functions covering the entire value chain and across continents. He is spearheading a mission to leverage technology to transform the electric grids and provide clean and reliable electricity to every citizen 24x7 at affordable cost. He is actively advocating for the "Right to Electricity Act" that will ensure lifeline supply of electricity to all; and advocating for a "Right to Sleep Act" to provide climate-controlled sleeping pods in low-income communities. Reji has played pivotal role in several ground breaking initiatives related to renewable energy, electric grid modernization, electric mobility, energy storage and digitalization in India during the past two decades. His current areas of research and work spans: Grid Integrated Vehicles, District Cooling Systems, Electric Cooking, Smart Grids as Anchor Infrastructure for Smart Cities, Grid Interactive Buildings and Campuses; Artificial Intelligence, Robotics, Blockchain, Web 3.0 and Metaverse Applications for Utilities; Urban Air Mobility (UAM) Systems and the Future of Transportation; and Interconnection of Regional Grids in Asia - ASEAN, SAARC and GCC grids. In November 2016, Reji was unanimously elected as Chairman of Global Smart Grid Federation, now renamed as Global Smart Energy Federation (GSEF), a global umbrella organization of smart energy associations and utilities from 16 countries and the European Union headquartered in Washington DC, USA.
 **Ms. Reena Suri, Executive Director, ISGF**	Reena Suri, Executive Director with India Smart Grid Forum (ISGF) since 2013, brings over 19 years of experience in the Energy Sector. She is responsible for the research projects, advisory services, business development, training and capacity building programs, customer outreach activities, members relations and finances of ISGF. Reena has contributed to the various advisory services, whitepapers and research reports of ISGF such as: Implementation Plan for Electrification of Public Transportation in Kolkata City; Smart Grid Handbook for Regulators and other Stakeholder; Blockchain for Electric Utilities; Energy Storage Roadmap for India; Smart Grid Roadmap for Bangalore Electricity Supply Company Ltd; Development of Roadmap for Implementation of Smart Grid – Concepts, Practices and Technologies in SAARC Region; Study on Infrastructure and Enabling Environment for Road Electric Transport in SAARC Member States; and World Bank EV Project: EV Ecosystem Support for Kolkata.

ISGF Secretariat

ISGF Team	Brief Profile
 Sneha Singhania Senior Manager- Digital Communication and Marketing, ISGF	Sneha Tibrewal Singhania is working as Senior Manager- Digital Communications and Marketing at India Smart Grid Forum (ISGF) since 2015. She holds 11+ years of work experience and Master's in Business Administration (MBA) in International Business from Amity University, Noida. She holds a Certificate from Google in Digital Marketing and Certificate from Wharton Business School (USA) in Viral Marketing and How to Craft Contagious Content. She is the Editor of the ISGF Smart Grid Bulletin published by ISGF every month as a newsletter with circulation to over 75,000+ senior professionals in 100+ countries.
 Parul Shribatham Assistant Manager-Technical Services, ISGF	Parul is an Assistant Manager – Technical Services with ISGF with an experience of more than 4+ years in the Energy Sector. She has worked on various projects including various areas like Peer-to-Peer energy trading, Power Quality, ToU, AMI etc. Her current research interests are Advance metering Infrastructure (AMI), Communications in Smart Grid Technologies, and Electric Vehicles, Artificial Intelligence in Energy, Advance technologies like DCS and Electric cooking etc.
 Vivek Kumar Manager - Technical Services, ISGF	In his current role at India Smart Grid Forum, Vivek provides technical expertise and support in the implementation of smart grid projects. He collaborates with stakeholders to develop and implement smart grid standards and policies. He conducts technical assessments and evaluations of smart grid technologies and solutions. He also coordinates with project teams and oversees the successful execution of smart grid initiatives.

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Power Quality Monitoring & Analysis for Optimized Quality Power Delivery

Vandana Singhal
Central Electricity Authority
Rajen Mehta
Efficienergi Consulting Pvt Ltd
Manas Kundu
Asia Power Quality Initiative

Abstract

Purpose/Motivation

The motivation for this paper is the upcoming national standard on 'Power Quality Measurement and Monitoring Methods' soon to be released by Bureau of Indian Standards (BIS). As there is an increasing focus on Quality of the Power Supply even at national policy level; this standard is an important and timely effort of BIS to help the utilities and consumers make a positive shift towards quality of power. This along with other standards in the Power Quality (PQ) domain like IS 17036, Model PQ Regulations by the Forum of Regulators among other international standards can now play a greater role in the Indian context of PQ awareness, actions and benefits if used objectively. Effective implementation and awareness creation of the standards, a weak area as such, is done in earnest by various stakeholders such as regulators, utilities, auditors, consultants among others to improve our outlook to Quality in everything that we do. This makes us ready as a nation with global aspiration. While the key driver for the need for mass adoption of these standards and regulations is the tsunami of digitization of the Indian economy that one is witnessing, it also brings the promise of multiple benefits to all key players. Among one of the many benefits, this will help the utilities to implement "The Polluter pays principle" as well as consumers to get clarity on PQ pollution generated within and outside. This would further ensure unambiguous outcomes, allow zeroing on root causes, or help predict failures of key assets well in advance, thus allowing PQ interventions to be judiciously selected based on thorough PQ measurement and data driven analysis. It is a popular dictum 'You cannot manage what you cannot measure, while the new age dictum is 'You cannot manage what you cannot analyze.' So, time is ripe for DISCOM's and consumers alike to measure, analyze and manage PQ with the help of these standards and allow for a much more reliable and quality delivery of power.

Keywords

Utilities, power quality, reliability, power quality measuring and monitoring, analytics, PQ standards & regulations, Power Quality issues, voltage sags, voltage swells, unplanned interruptions, power quality pollutants, PQ monitoring and IOT, processing and analytics software.

1. INTRODUCTION

India is the third largest producer of electricity in the world of which industrial and commercial consumers contribute to more than 50% of the national electricity consumption. Although India now boasts of surplus availability in the power supply, the quality and reliability of the power supply is far from the standards defined by the statutory bodies or any international benchmarks those we often refer to. Harmonics, Voltage dips, sags, swells, under voltage & interruptions are still major problems affecting Indian distribution grids. Any disturbances on the grid in the form of huge load variations, unbalances & usage of nonlinear loads are the major factors affecting power quality. The consumer side almost form 70% of the issues that comprise power quality variations/disturbances but they are not aware of consequences which are economic in nature. The utility contributes the remaining 30%, but the means to discern these and find out the true causes / origin of the PQ pollutants is not done in a methodical fashion, thus leaving implementation of solutions carried out in a haphazard or reactionary way while leaving the actual root causes unattended by a large number of times. It also results in utilities being blamed for issues which are generally a result of the neighboring loads or consumers. Utilities & consumers both being unaware of this fact pay the penalty with loss in production, loss of revenue, brand damage, productivity costs, decreased competitiveness, lost opportunities, product damage, wasted energy, decreased equipment life among many others. Collectively, it is a national loss of economy and global competitiveness.

This paper by looking from the lens of the challenges due to poor power quality that both utility as well as industry face, attempts to showcase how having the standards and regulations as a guide and handy reference can allow a structured and scientific approach to arrive at the root causes affecting the myriad issues that consumers and utilities face. It further provides multiple facets from which to evaluate the data, providing different layers that need to be removed and solved before the actual problem can be resolved.

It allows prioritizing actions based on the severity of the non-compliances and thus helping in achieving small wins through immediate actions on the ground and slowly moving towards the most capital intensive but necessary actions backed by sound scientific analysis.

At the core of this analysis are the standards designed by national / international statutory bodies that play a vital role from beginning to the end of Power Quality Monitoring and Analysis activities, covering monitoring methods, equipment requirements, data processing guidelines, compliances, and permissible limits for critical electrical parameters, etc.

IS 17036:2018 [1] defines standards, a maiden standard on PQ but still unknown at many quarters, exclusively for the voltage quality at the users supply terminals. The characteristics of the supply voltage considered by this standard are:

1. Frequency
2. Magnitude
3. Waveform
4. Symmetry of the line voltage

IS 17036 specifies a range for both continuous phenomena that is a deviation from the nominal value that occurs continuously with time due to load pattern and voltage events that is sudden & significant deviation from the desired value or shape. Voltage levels are classified into

1. Low Voltage (LV) - Voltage whose nominal root mean square value is Un≤1kV.
2. Medium Voltage (MV) - Voltage whose nominal root mean square value is 1k V<Un≤33kV.
3. High Voltage (HV) - Voltage whose nominal root mean square value is 33kV<Un≤150kV

This standard comprises limits defined for parameters related to supply voltage such as frequency, variation, unbalance, events, flickers as well as harmonic content for various network connections.

IS 17036, fully recognizing the Indian field conditions, provides a framework to evaluate voltage quality issues faced by consumers while at the same time allowing utilities to understand areas where improvements or further measurements and monitoring need to be undertaken.

Further there is an upcoming standard that lays down the requirements for measurement and monitoring methods for Power Quality monitoring. This standard defines measurement methods, maximum measurement uncertainty, measurement ranges, time aggregation, along with a PQ monitoring framework which suit Indian requirements.

The below table (i.e., table – 1) as part of the upcoming Power Quality standard provides a ready reference with respect to the periodicity of the power quality monitoring frequency and duration to be incorporated along with the key parameters to be included. It provides for both consumers and utilities to have a common platform in terms of including the key power quality parameters and at the same time addressing the dynamicity of the power quality conditions that the modern grid as well as loads exhibit.

Parameter	Minimum assessment period	Recommended frequency of reporting to authorities
Supply frequency	1-week	Quarterly
Magnitude of Supply Voltage	1-week	Monthly
Flicker	1-week	Quarterly
Supply Voltage unbalance	1-week	Quarterly
Harmonic voltages	1-week	Quarterly
Voltage interruptions	1-year	Yearly with monthly sliding window
Dips and swells	1-year	Yearly with monthly sliding window
Magnitude of Current	1-week	Quarterly
Current unbalance	1-week	Quarterly
Current Harmonic	1-week	Quarterly

Table 1 - Recommended Minimum Assessment Periods & Frequency of Reporting [2]

The new upcoming standard provides a measurement method to be applied to each Power Quality parameter. (Table – 2)

Table 2 - Measurement details as per Power Quality parameters [2]

Parameter	Time aggregation	Maximum measurement uncertainty	Measuring ranges
Frequency	not mandatory	±10 MHz	42.5 Hz to 57.5 Hz
Supply Voltage	10 cycles, 150 cycles, 10 min	±0.1 % of Uc	10% to 150 % of Uc
Flicker	see IEC 61000-4-15	see IEC 61000-4-15	0.2 Pst to 10 Pst
Harmonic Voltages	10 cycles, 150 cycles, 10 min interval	IEC 61000-4-7 Class I	10% to 200% of Class 3 of IEC 61000-2-4
Current	In accordance with corresponding voltage channel	±1 % of reading	10% to 100 % of the specified full-scale rms current
Harmonic Current	10 cycles,150 cycles,10 min	IEC 61000-4-7 Class I	10% to 200% of Class 3 of IEC 61000-2-4
Voltage dips & swell	-	Amplitude ±0.2 % of Uc, Duration measurement uncertainty ± 1 cycle	As per IEC 61000-4-30

The new PQ standard also throws light on the monitoring locations i.e., where power quality meter is to be connected, quantities to be measured in the meter & the connection of meter.

As per the new PQ standard, the choice of location of the Power Quality meter will depend on the objective of the survey. For compliance monitoring related to the service contracts, a monitoring location should be Point of Common Coupling (PCC) between the system and the customer. If the monitoring objective is to diagnose an equipment performance issue, then the meter should be placed as close as possible to the load apart from monitoring at PCC to facilitate origin of the PQ parameter which might be the cause of the equipment performance issues [2].

The quantities to measure will depend on the monitoring objective & relevant compliance standard.

The decision for connecting equipment depend on [2]

1. Single phase versus three phase measurements
2. Line to line versus line to neutral or line to ground connection
3. High voltage side versus low voltage side near transformer

Central Electricity Authority (Technical Standards for Connectivity) 2019 amendment regulations provides guidelines for power quality monitoring at grid level for both bulk consumers & licensees (Discoms). These grid connectivity regulations basically provide the framework to be implemented by state regulatory commissions for 33kV & 11kV connected consumers. Some of the key takeaways are [5][6]

1. The limits laid for the voltage harmonics in the network or grid is the responsibility of the licensee which can be achieved by measuring and metering of the harmonics at Point of Common coupling (PCC) with meters complying with provisions of IEC 61000-4-30 Class A
2. The limits for the injection of current harmonics by bulk consumers at PCC should be ensured by installing power quality meters at their facility and sharing of the harmonics data with utility at regular intervals.
3. Periodic measurement of other power quality parameters such as voltage sag, swell, flicker, disruptions shall be done by the licensee as per relevant IEC standard and the reports thereof shall be shared with the consumer.

2. CASE STUDY – Food and Beverage Industry

2.1 Challenge

A bottling facility with a manufacturing capacity 2400+ bottles per minute, 6 lines were suffering poor supply voltage quality fed from a 220 kV Substation that was 25 km away. The unscheduled power cuts and voltage events led to frequent stoppage of production lines, electronic card failures and huge financial losses over a span of a few years.

As can be seen in Table - 3, during the time period of just January to April there were a total of 250 voltage events that impacted the bottling plant.

The plant had installed DGs with automatic switchover system and forward-reverse synchronization as a corrective measure, which would run the DGs half an hour before and after the scheduled interruption to ensure a continuous supply of power to the production lines. Even though it was successful in keeping the production uninterrupted, it was of little help when it came to unplanned interruptions.

The DG was being utilized to provide 60% of the total energy usage, leading to additional energy costs and CO_2eq release.
The voltage events presented in Table - 3 had a direct impact on the productivity of the plant.

Month	Unscheduled Power Cut	Unbalanced Voltage	Total No of Occurrences
	No of Occurrences	No of Occurrences	
Jan	10	9	19
Feb	17	8	25
Mar	45	42	87
Apr	68	51	119

Table 3 - Voltage events over a span of 4 months

For example, once the supply interruptions were resolved, there was some time required to resume productivity varying from 10 to 15 minutes for each production line. Table - 4 goes into detail with respect to financial losses related to each line.

Sl No	Line	Line running time after power resume in mins	Production Capacity per hour (No of cases per hour)	Load factor	Actual Cases Lost	Monetary Loss in Rs per event
1	Krones	15	1500	80%	300	3168
2	Maaza	12	1500	80%	240	2534.4
3	RGB	10	1500	80%	200	2112
4	Kinley	10	300	80%	40	422.4
5	PET-140	15	933	80%	187	1970.496
Total Loss						10207

Table 4 - Financial losses per supply interruption

The plant faced the possibility of shutting down given the tremendous financial losses represented in Table - 5; leading to the risk of unemployment to all the local workers.

Note - in Table - 5, Financial losses due to environmental impact are not considered.

Sr No	Loss type	Value	Unit
1	Productivity Loss	INR 7.5 million	Annual
2	DG running cost	INR 54 million	Annual
3	CO2 eq released	180 tons	Annual
4.	Total Monetary Loss (approx.)	INR 62 million	Annual

Table 5 - Monetary Impact of Poor Voltage Quality

2.2 Monitoring Methodology

The plant management had a SCADA system installed at the main incomer to monitor the voltage profile closely, as a corrective measure. Additional to this data, Power Quality Monitoring and Analysis was carried out on the feeders that are critical to plant operation; to get to the actual cause of these voltage events and to check Power Quality compliance with respect to the plant loads.

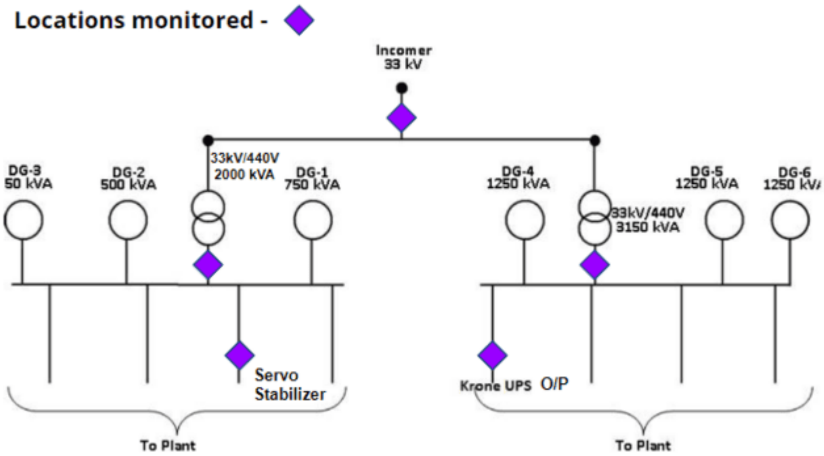

Figure 1 - Simplified plant SLD & PQ monitoring setup

These five locations below were monitored over an extended period with an IEC 61000-4-30 Class A Power Quality Analyzer.

1. Incomer – 33kV
2. TX 1 Low Voltage Side (2 MVA)
3. TX 2 Low Voltage Side (3.15 MVA)
4. UPS (Krone line)
5. 1600 A Servo Stabilizer

2.3 Findings

Incomer – 33kV

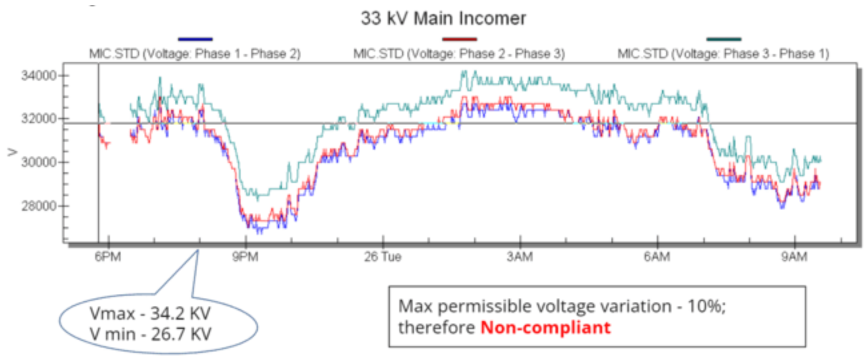

Figure 2 - Voltage trend 33 kV incomer

The 33 kV supply voltage was observed to have severe voltage variations ranging from 26.7 kV to 34.2 kV.

Table 6 Supply Voltage Variation Limits for HV Systems
Interconnected with Transmission system.

Supply Voltage Characteristic	Reference Time Frame	Limits
Mean r.m.s value of the supply voltage over 10 min	100 percent of time	Un ± 10 percent

NOTE — According with IS 12360, network users' appliances have to tolerate supply voltages of ± 10 percent around the nominal system voltage, but generally appliances allow wider voltage variations.

Table 6 – Supply Voltage Variation Limits for HV System as per IS 17036

Requirement	Measured L1-L2 Voltage	Measured L2-L3 Voltage	Measured L3-L1 Voltage	Result
100% of day:29700V ~ 36300V	26700V ~ 34550V	26700V ~ 33000V	28300V ~ 34200V	NON-COMPLIANT

Table 7 - IS 17036 Compliance table 33 kV feeder

As per IS 17036 in the case of high voltage 33kV, voltage variation should not be more than 10 per cent i.e., 29.7 kV to 36.3 kV (table - 6). Here (figure - 2) the voltage trend can be seen crossing the lower threshold, thereby becoming IS 17036 non - compliant.

2. TX 1 (2 MVA)

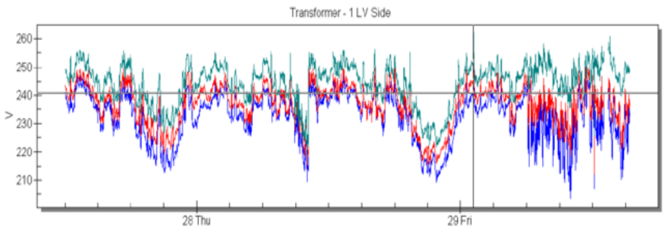

Figure 3 - Voltage trend TX 1 (2 MVA)

Table 3 Supply Voltage Variation Limits for LV Systems
Interconnected with Transmission System

Supply Voltage Characteristic	Reference Time Frame	Limits
Mean r.m.s. value of the supply voltage over 10 min	95 percent of each period of one week	Un ± 10 percent
	100 percent of time	Un +10 percent / - 15 percent

Table 8 - Supply Voltage Variation Limits for LV System as per IS 17036

The secondary side of Transformer 1 (2 MVA) had similar voltage variations ranging from 203 V to 261 V, also non-compliant to IS 17036 as the tolerance limit with respect to voltage variations for LV is 204 to 264 V.

Requirement	Measured L1 Voltage	Measured L2 Voltage	Measured L3 Voltage	Result
100% of day:204.0V ~ 264.0V	203V ~ 247V	211V ~ 254V	221V ~ 261V	NON-COMPLIANT

Table 9 - IS 17036 Compliance table for TX 1 (2 MVA)

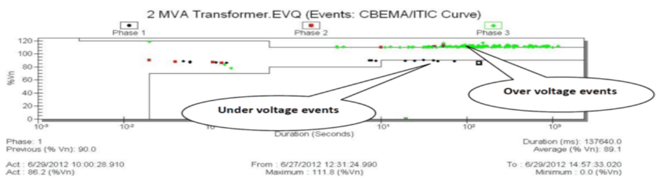

Figure 4 - Voltage events - TX 1 (2 MVA)

All the under voltage and over voltage events such as Sags, Swells, Fluctuations, and interruptions were plotted on the ITIC curve to verify their capability to inflict damage on the load. Numerous events were found present in the prohibition region.

3. TX 2 (3.15 MVA)

Figure 5 - Voltage trend – TX 2 (3.15 MVA)

Like Transformer 1 (2 MVA), the secondary side of Transformer 2 (3.15 MVA) also had a voltage supply that was non-compliant to IS 17036 with the voltage variations reaching 199 V to 266 V.

Requirement	Measured L1 Voltage	Measured L2 Voltage	Measured L3 Voltage	Result
100% of day:204.0V ~ 264.0V	199V ~ 248V	210V ~ 248V	243V ~ 266V	NON-COMPLIANT

Table 10 - IS 17036 Compliance table for TX 2 (3.15 MVA)

The ITIC Curve for Transformer 2 (3.15 MVA) as can be seen in figure - 6 indicates that many of the voltage events occurring at the location were also in the prohibition region.

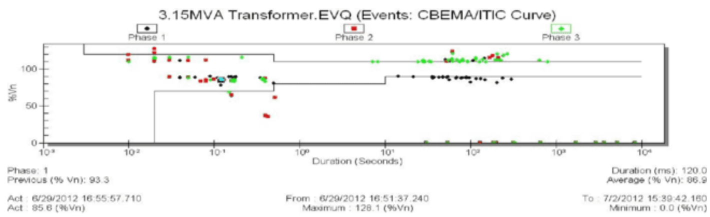

Figure 6 - Voltage events - TX 2 LV (3.15 MVA)

1. Krone UPS Output

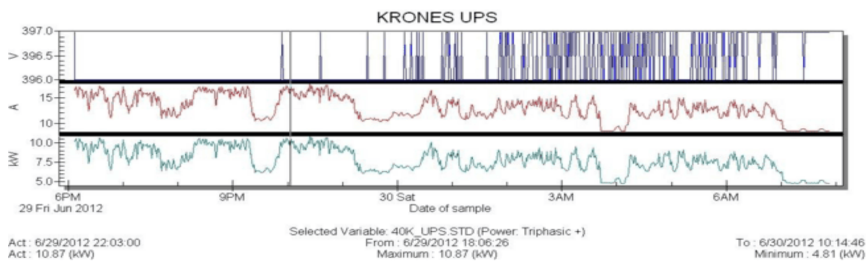

Figure 7 - Voltage trend - Krone UPS Output

Some of the Krone line's sections were running on the UPS; therefore, UPS output voltage was monitored to verify the impact of voltage events occurring at the UPS input on the load.

The voltage variation at the UPS output feeder turned out to be negligible; varying just 1 volt i.e., from 396 V to 397 V thereby complying fully with the IS 17036 voltage variation limits.

2. 1600 A Servo Stabilizer

Along with the transformers and the UPS, the outgoing feeder of a 1600 kVA servo stabilizer was also monitored for voltage events to assess their impact, and it can be seen in figure – 8 that even the servo stabilizer was unable to control the voltage events.

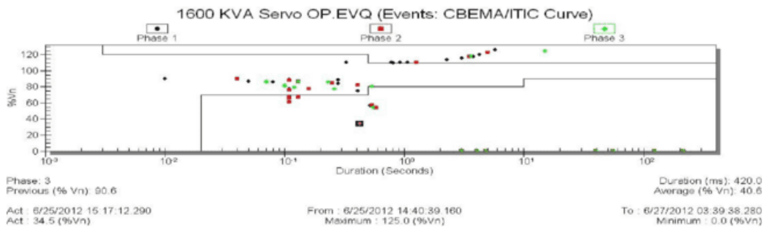

Figure 8 - Voltage events - 1600 kVA Servo stabilizer

2.3 Results and Recommendations

After the analysis of all the PQ data that was gathered while monitoring, following conclusive observations were made -

1. Voltage fluctuations, over voltages, and sags were causing critical equipment failures
2. The traction load connected on the same 33 kV industrial feeder that is supplying to the bottling plant caused huge voltage variations due to operation of trains
3. The traction load was also introducing 2nd 3rd and 5th harmonics causing Voltage Amplification at the 33 kV incomer
4. Severe voltage dips found in SCADA were directly correlated with tripping incidents in the plant's electrical network
5. Voltage Interruptions were found to be alarmingly high – reaching up to 60 unplanned interruptions in a month

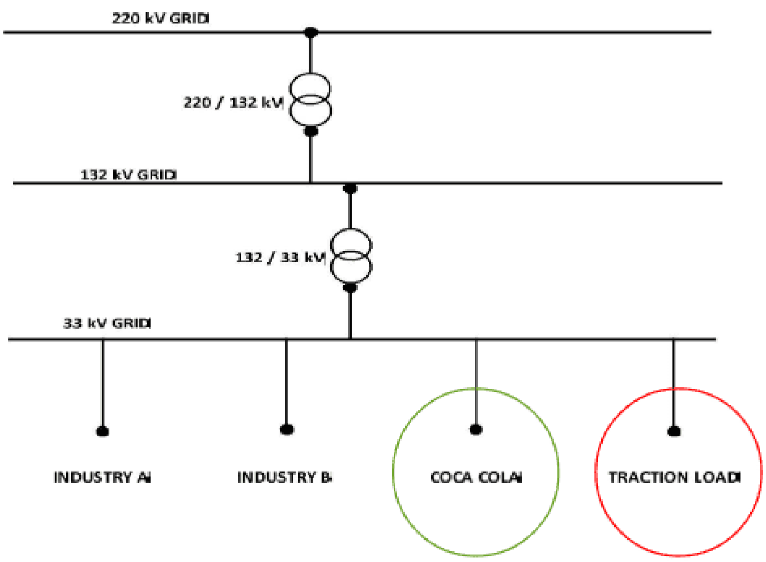

Figure 9 - 33 kV neighboring loads

Based on all these findings made through Power Quality Monitoring and Analysis, a few recommendations were given to the stakeholders that would help them mitigate the variety of issues faced by the bottling plant.

1. Install 2 no. of UPS each of 600 kVA at critical locations as an Immediate measure to keep the plant operational
2. DISCOM needs to separate the Traction feeder from all Industrial feeders
3. Protective device settings should be verified and re-coordinated if required
4. Further investigation is required for 2ms voltage dips
5. A Static VAR Compensator with 'Load balancing control' can balance out the voltage supply fluctuations caused by variations in inductive load
6. Plant needs to be powered by two reliable HV feeders and through an RMU so that auto changeover is implemented in case of interruptions/power failures
7. Monitoring of power quality indices as per the frequency stated in upcoming new PQ standard will give upper hand in mitigating issues pertaining to power quality.

2.4 Case Study - 1 Conclusion

Before Power Quality Monitoring and Analysis, the consumer was facing huge financial losses. DG power was required to run the bottling plant for more than half the time. Due to these challenges the local workers were at risk of unemployment and the utility was held directly responsible for poor Power Quality.

Once the PQ data was analyzed, the voltage events occurring at the critical feeders of the bottling plant were identified and verified for compliances through various PQ standards, and actual sources of the issues were captured. Actions were taken by the DISCOM to provide a separate 33 kV feeder to the traction load. The incoming supply to the bottling plant became much smoother and compatible. The plant was able to remain operational, thereby saving the employment of many local workers. Consumer's faith was restored in the utility's capability to deliver reliable Quality of Power.

CASE STUDY – DATA CENTER

3.1 Challenge

A Data Center service provider decided to carry out Power Quality Monitoring and Analysis on the feeder that was supposed to power their upcoming new 50 MW Data Center. The purpose of the activity was to verify if the utility Power Quality (100kV) is healthy and compatible enough to feed a sensitive load profile such as Semiconductor/SMPS loads.

Power Quality is critical to Data Centers as it directly impacts the server downtime. Power Quality issues such as electromagnetic interference, harmonics leading to heating and energy wastage, voltage sags/swells/transients and unplanned interruptions, all lead to massive financial losses due to equipment malfunction, fire hazards, equipment breakdown, equipment damage and power failures.

The Power Quality should match tier 3/tier 4 availability expectations of the Data Center industry as the facility needs to provide continual compatible power supply to its servers in order to avoid downtime penalties and brand damage.

3.2 Monitoring Methodology

A steel plant was being fed by the same 100 kV feeder that is supposed to supply power to the upcoming Data Center.

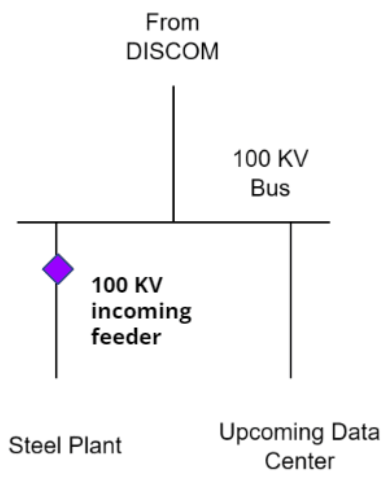

Figure 10 - Simplified DC HV SLD

The 100 kV incoming feeder for the steel plant was monitored over a span of 30 days; focusing on standards compliance with respect to IS 17036 and the new PQ Standard.

The location was monitored with an IEC 61000-4-30 class A advanced Power Quality Analyzer.

3.3 Findings

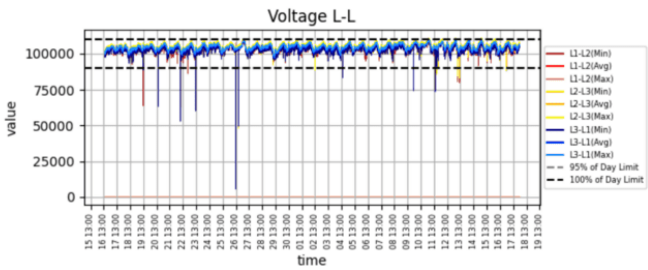

Figure 11 - Voltage trend for 100 kV incomer

The voltage variation (figure – 11) over a period of 30 days was found to be within tolerable limits defined in IS 17036.

Table 6 Supply Voltage Variation Limits for HV Systems Interconnected with Transmission system.

Supply Voltage Characteristic	Reference Time Frame	Limits
Mean r.m.s value of the supply voltage over 10 min	100 percent of time	Un ± 10 percent

NOTE — According with IS 12360, network users' appliances have to tolerate supply voltages of ± 10 percent around the nominal system voltage, but generally appliances allow wider voltage variations.

Table 11 - Supply Voltage Variation Limits for HV System as per IS 17036

Requirement	Measured L1-L2 Voltage	Measured L2-L3 Voltage	Measured L3-L1 Voltage	Result
100% of day:90000.0V ~ 110000.0V	94310.4V ~ 109273.7V	96033.3V ~ 109975.6V	93129.9V ~ 108859.0V	COMPLIANT

Parameter	Min[V]	Avg[V]	Max[V]
Voltage L1-L2	94310.4	104204.21	109273.7
Voltage L2-L3	96033.3	105258.26	109975.6
Voltage L3-L1	93129.9	104225.25	108859.0

Table 12 - IS 17036 Compliance table for 100 kV incomer

The load profile of the steel plant (figure - 12) expectedly was highly fluctuating, with the plant operating in all the 4 quadrants of active and reactive power flows. The load on the electrical network was choppy in nature; as it typically is with furnaces, rolling mill drives, winders, etc. High rate of change of power was observed due to large variation in reactive power in a short period of time.

Parameter	Min[kW]	Avg[kW]	Max[kW]
Real Power (L1)	-25959.28	5347.61	30794.9
Real Power (L2)	-12368.58	5500.47	45642.9
Real Power (L3)	-10492.1	5928.09	23176.48
Total Real Power	-2382.41	16776.21	55342.15

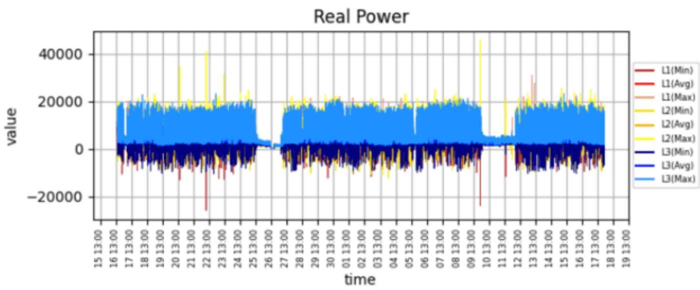

Figure 12 - Real power trend for 100 kV incomer

This nature of the load led to short term and long-term flickers propagating in the electrical network that were found to be non-compliant to the IS 17036 Flicker severity limits.

Table 7 Supply Voltage Flicker Severity Limits

Supply Voltage Characteristic	Reference Time Frame	Limits
Long term flicker severity P_{lt} caused by voltage fluctuation	95 percent of each period of one week	≤ 1

Table 13 - Supply Voltage flicker severity limits as per IS 17036

Requirement	Measured L1 Pst	Measured L2 Pst	Measured L3 Pst	Result
95% of day:Pst <_1	1.43	1.52	1.49	NON-COMPLIANT

Parameter	Min	Avg	Max
Flicker Pst L1	0.0	0.64	7.95
Flicker Pst L2	0.0	0.67	7.95
Flicker Pst L3	0.0	0.66	7.9

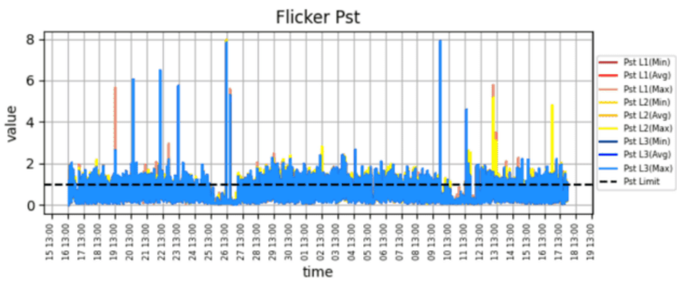

Figure 13 - Short term flickers 100kV incomer

Flickers are a nuisance for the operations personnel as it affects the LED lights and reduces shop floor productivity.

Requirement	Measured L1 Pst	Measured L2 Pst	Measured L3 Pst	Result
95% of day:Plt <_1	1.2	1.4	1.3	NON-COMPLIANT

Parameter	Min	Avg	Max
Flicker Plt L1	0.0	0.82	3.47
Flicker Plt L2	0.0	0.88	3.47
Flicker Plt L3	0.0	0.86	3.46

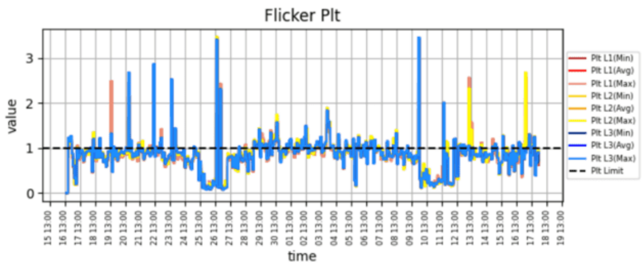

Figure 14 - Long term flickers 100kV incomer

Further, as seen in table – 14, a total of 73 voltage events were captured during the Power Quality monitoring; sources of which were both upstream as well as downstream.

Sr.no	Event	Origin of PQ Events	Event Count
1	Sag	Upstream Sag Events	1
		Downstream Sag Events	10
2	Swell	Upstream Swell Events	14
		Downstream Swell Events	34
3	RVC	Upstream RVC Events	11
4	Interruption	NA	0
		NA	0
5	Transients/Waveshape changes	NA	03

Table 14 - Voltage events 100 kV incomer

Based on the directional analysis, almost all the sags were load generated which were ranging from 52% to 88% of residual voltage magnitude. This was a very important finding which will allow corrective actions for voltage sags that typically form 60-70% of power quality related problems to be taken at the right point in the grid by the pollutant, which is the steel plant in this case.

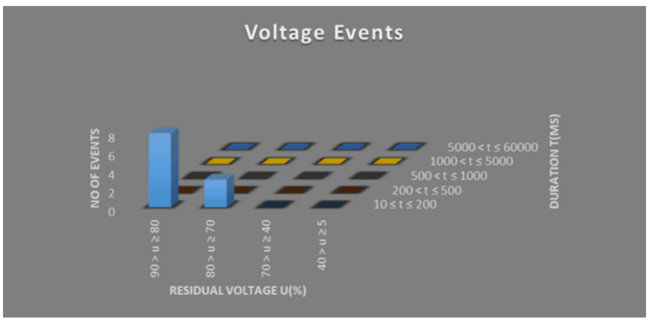

Figure 15 - Magnitude, Duration and Count of Sags

Residual Voltage u(%) vs Duration t(ms)	10 ≤ t ≤ 200	200 < t ≤ 500	500 < t ≤ 1000	1000 < t ≤ 5000	5000 < t ≤ 60000
90 > u ≥ 80	8	0	0	0	0
80 > u ≥ 70	3	0	0	0	0
70 > u ≥ 40	0	0	0	0	0
40 > u ≥ 5	0	0	0	0	0

Table 15 – Magnitude and duration of the Voltage Sags

All the sags were plotted in SEMI-F47, a standard that specifies the required voltage sag tolerance for semiconductor fabrication equipment; given the most critical load in a Data Center electrical network environment is the server load.

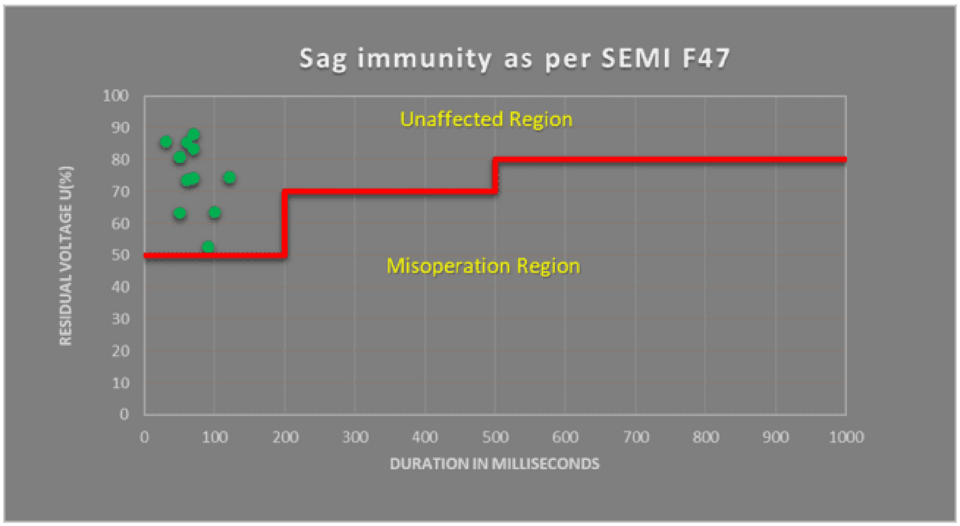

Figure 16 - SEMI F47 for 100 kV incomer

All the sag events fell under the unaffected region, which indicates that the semiconductor load will not be harmed due to the sag events of this magnitude and duration.

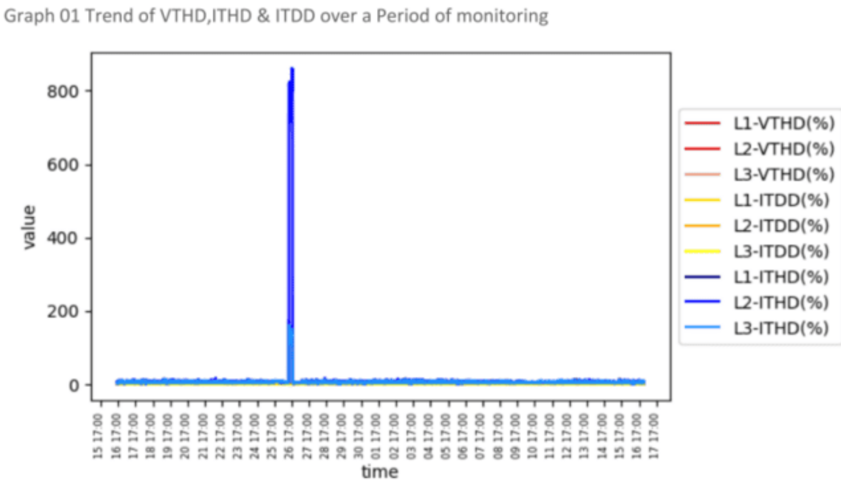

Figure 17 - Current & Voltage harmonics 100 kV incomer

The voltage harmonics at the incoming feeder were within limits defined by IEEE 519-2014, but the current harmonics were found to be non-compliant, specifically 2nd harmonic which is usually generated by arc furnace load.

3.3 Results and Recommendations

After the analysis of all the PQ data that was gathered while monitoring, following conclusive observations were made -

1. Both short term and long-term Flickers exceeded limits defined by IS 17036 and were observed to be non - compliant
2. As per IEEE 519-2014 over the entire duration of monitoring, the 2nd harmonic was exceeding limits defined for current harmonics
3. Total 11 voltage sags, 48 voltage swells, 11 Rapid voltage change events and 3 voltage transients were recorded over a period of 30 days

Based on all these findings made through Power Quality Monitoring and Analysis, a few recommendations were given to the stakeholders that would help them achieve a compatible supply of power for the upcoming data center.

To dampen the impact of load profile on the grid Power Quality, especially flickers, a number of solutions can be implemented

Equipment level solutions could be implemented - For e.g., using series reactors with arc furnaces, supplying welding loads from a dedicated transformer, using soft start etc.

Increasing Short circuit power w.r.t load power.

Voltage stabilization which would involve installing dynamic voltage regulators.

1. Continuous Power Quality monitoring should be carried out at grid level to establish correlations between any Power Quality parameters and any events related to critical loads. The monitoring should be as per the frequency stated in the new PQ standard for various power quality indices.
2. While the voltage sags are within the safe zone of SEMI F47 standard, the number of voltage sags can be a point of concern at the 100kV side for the data center loads. Selection of equipment e.g., HVAC should be with stringent compliance to SEMI F47 norms and their commissioning is to be ensured to lessen the impact of such voltage sags
3. Arrive in detail the exact direction of these sags by having simultaneous monitoring at downstream and upstream locations

3.4 Case Study - 2 Conclusion

Investment in a 50 MW data center is a huge decision and the data center company required assurance with respect to the availability and reliability of power. In case these decisions were left open ended after the capital investment was made, it would be a huge effort to retrofit and/or reorient infrastructure of such a huge size to mitigate power quality conditions at a later stage.

The exercise allowed PQ related non-compliances and risks due to the neighboring steel plant to be captured well in time. Grid level mitigation actions became clear to the utility which it can now implement to make their Quality of Power compatible with data center expectations. The data center too can take proactive actions at their end knowing the intensity and frequency of PQ trends and events.

PQ Monitoring and IOT

The case studies display the capability of Power Quality Monitoring and Analysis based on Standards to provide accurate results and actionable recommendations. Now to reach its true potential of being an extremely versatile application across multiple industry segments and resolving various kinds of challenges, automation and cloud infrastructure is proving to be a key asset.

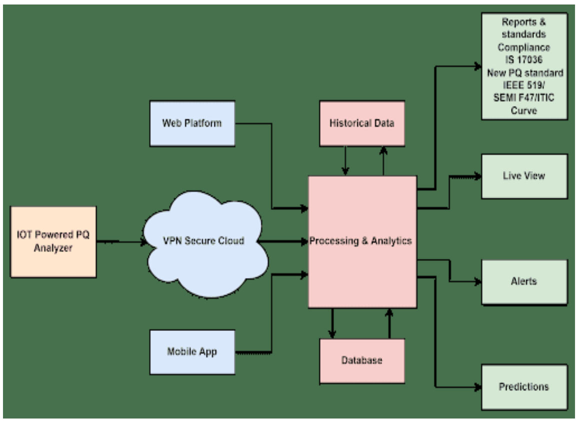

Figure 18 - PQ Monitoring powered by IoT

As can be seen in the Figure - 18 above, a VPN cloud enables collecting Power Quality data from IOT enabled advanced PQ analyzers easily, securely and in a tactile manner.

An infrastructure that is streamlined from sensors all the way to the reports can be created by pairing this technology with a processing and analytics software with following qualities -

1. Multiple inputs such as the Cloud, web platforms and mobile applications
2. Uses PQ standards and intelligence gathered from 100's of previous PQ monitoring exercises as framework for analysis
3. generates the output automatically, and in an actionable format

The output can also be in multiple formats including but not limited to compliance reports generated at specific time intervals consisting of compliance to national and international standards, event analysis and alerts, live view of the Power Quality parameters at various points in an electrical network, and predictions with respect to reliability risks making it an ideal solution for the utilities as well as consumers alike.

4. CONCLUSION

The Power Quality Measurement and Monitoring methodologies defined by the new upcoming PQ Standard along with IS 17036 and the foundation laid by the Model PQ regulation prepared by the Forum of Regulators combined with Power Quality analyzers and analytics tools prove to be effective in providing benefits related to Infrastructure optimization, prudent asset management and Quality Power delivery for both utilities and consumers in a transparent manner.

With its versatility of being effective in various industries, for various challenges and at various locations in the transmission and distribution network; It can go a long way in raising the resilience of the grid in a regulated environment.

While this solution is applied, the monitoring devices must not be subjected to differing communication protocols but a harmonious one while taking adequate care of threats from cyber-attacks to secure our national future.

As a path forward integration of reliability indices, sag immunity standards, event discrimination, distributed energy resource integration and its impact on power quality should be also covered in further amendments to cater to the practical challenges expected with the exponential clean energy transition happening within the country.

In order to adapt with this transition, it is also the right time for DISCOMs to begin making data driven decisions.

5. ACKNOWLEDGEMENT

The authors thank Asia Power Quality Initiative and Efficienergi Consulting Pvt. Ltd. for sharing the valuable data. We are grateful to Aditya Joshi and Smita Kurdekar for their help with the data collection and collation.

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Impact of Harmonics on Distribution Transformers

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Abstract

With wide use of modern technology requirement and industry needs which utilize non-linear loads such as computers, variable speed drives, ventilation, and air conditioning (HVAC) systems, electric vehicles battery chargers, uninterrupted power supply (UPS), and any other equipment powered by switched-mode power supply (SMPS) unit current and voltage harmonic distortions have increased in power system. Distribution transformers (DTs) in electrical power systems are usually designed for utilizing at rated frequency and linear load. A different performance, compared with that of the one a transformer is designed occur, when these non-linear loads introduce harmonics to the supply. Both No load and Load losses are affected by the presence of harmonics in load currents. The increased losses in the transformer due to harmonic distortion can cause unnecessary winding loss and typical temperature rise and insulation stress.

This paper presents an evaluation of the possible effects of increasing the harmonic current distortion on the transformer temperature rise, additional energy losses, and impact on its aging. Putting all the listed phenomenon together, the operation conditions related to loading, voltage and current harmonics in transformers can be analyzed in order to establish proper maintenance routine.

Keywords
Harmonics, Distribution transformers Harmonics, THDI, energy loss.

1. Introduction

With introduction of non-linear loads in this increasing load trend new power quality issues have surfaced. Thus, it is necessary to perform power quality study, so that inferences brought out from these studies will serve as the inputs to utility to take necessary action to ensure reliable operation of power system network. Transformers are major components of the distribution system which are expensive and difficult to replace. The failure of such equipment would therefore cause long power supply interruptions with consequent loss of revenue, entailing costly repairs besides loss of reliability of power system**.** With the presence of non- linear load, transformer leads to higher losses and reduction of useful life. The increased losses due to harmonics can cause excessive winding loss and temperature rise which reduces transformer standard lifetime expectancy and hence economic loss.

In this study the harmonics data at two distribution transformers of 400 KVA ratings have been measured which supply a mix of Industrial and commercial consumers. Further investigations have been made about transformer losses, energy losses, and loss of transformer life due to harmonics.

II. Harmonic and K-Factor Definition

A component of a period wave having frequency that is an integral multiple of the fundamental power line frequency of 50 Hz, causing distortion to pure sinusoidal waveform of voltage or current.

Total Harmonic Distortion (THD): The ratio of the root mean square of the harmonic content, considering harmonic components up to the 50th order and specifically excluding interharmonics, expressed as a percent of the fundamental. Harmonic components of order greater than 50 may be included when necessary [1].

K-Factor: K-Factor calculation depends upon the fundamental current and the harmonic current components, and it is an indicative value of the harmonic content in the power system i.e., a higher value of K-Factor means presence of higher harmonic currents in the transformer [3].

III. Transformer Losses

Transformers are designed to deliver the required power to the connected loads with minimum losses at fundamental frequency. Transformer losses are generally classified into no load losses and load losses as shown below [2]:

$$P_T = P_{NL} + P_{LL} \tag{1}$$

Where,
P_T = total loss (watt)
P_{NL} = no load loss (watt)
P_{LL} = load loss (watt)
The no load loss or excitation loss are the losses due to the voltage excitation of the core and magnetic hysteresis and eddy currents. The load loss or impedance loss is subdivided into I^2R loss and stray loss caused by electromagnetic flux in the windings, core, core clamps, and magnetic shield, enclosure, or tanks walls. Thus, the total stray loss is subdivided into winding stray loss and stray loss in components other than the windings (P_{OSL}). The windings stray loss includes winding conductor strand loss and loss due to circulating currents between strands or parallel winding circuits. The total load loss can be stated as follows:

$$P_{LL} = P_{I^2R} + P_{EC} + P_{OSL} \tag{2}$$

Where,
P_{LL} = load loss
= loss in the winding
= eddy current loss
= other stray loss
Initially, the rated current at the primary and secondary sides are calculated as follows;

$$I_{1-rated} = \frac{S\ (KVA)}{\sqrt{3}\,V_1}$$

$$I_{2-rated} = \frac{S\ (KVA)}{\sqrt{3}\,V_2} \tag{4}$$

Where,
$I_{1\text{-rated}}$ = rated current in primary side of transformer
$I_{2\text{-rated}}$ = rated current in secondary side of transformer
V_1 = rated voltage in primary side of transformer
V_2 = rated voltage in secondary side of transformer
S (KVA) = rating of transformer
The I^2R losses are calculated as below:

$$P_{I^2R-rated} = K[{I_{1-rated}}^2 R_1 + {I_{2-rated}}^2 R_2] \tag{5}$$

Where,
K = 1 for single phase transformer

K = 1.5 for 3 phase transformers
R_1 = primary DC resistance
R_2 = secondary DC resistance

$$P_{LL-rated} = P_{I^2R-rated} + P_{TSL-rated}$$

$$P_{TSL-rated} = P_{EC-rated} + P_{OSL-rated} \quad (7)$$

Where,
P_{TSL} = total stray loss
The eddy current loss is assumed to be about 0.33 of the total stray losses [4].

$$P_{EC-rated} = 0.33P_{TSL-rated}$$

$$P_{OSL-rated} = P_{TSL-rated} - P_{EC-rated} \quad (9)$$

A. Harmonic Loss Factor

Harmonic loss factor, F_{HL} is a key indicator of the current harmonic impact on the winding eddy loss and other stray loss. The harmonic loss factor is normalized to either the fundamental or the r.m.s current.

FHL for winding eddy current is the ratio of the total eddy current losses due to the harmonics, to the eddy current losses at the power frequency. The FHL-STR is the ratio of the other stray loss due to the harmonic to the other stray loss at power frequency. The eddy current loss is increased by a factor of FHL and the other stray loss are increased by a factor of FHL-STR in the presence of harmonics. The transformer load losses in non-sinusoidal condition are as shown below:

$$P_{LL} = P_{I^2R-rated} + F_{HL}P_{EC-rated} + F_{HL-STR}P_{OSL-rated} \quad (10)$$

This factor is calculated by the following equations:

$$F_{HL} = \frac{\sum_{h=1}^{h=h_{max}}\left[\frac{I_h}{I_1}\right]^2 h^2}{\sum_{h=1}^{h=h_{max}}\left[\frac{I_h}{I_1}\right]^2}$$

$$F_{HL-STR} = \frac{\sum_{h=1}^{h=h_{max}}\left[\frac{I_h}{I_1}\right]^2 h^{0.8}}{\sum_{h=1}^{h=h_{max}}\left[\frac{I_h}{I_1}\right]^2} \quad (12)$$

Where,

F_{HL} = harmonic factor for eddy current loss

F_{HL-STR} = harmonic factor for other stray loss

h = harmonic order

h_{max} = maximum harmonic order

The PU load losses and rated per unit eddy loss is given by the expression below [2]:

$$P_{LL-pu} = P_{LL-\ rated}\,(pu)^2 \times \sum_{h=1}^{h=h_{max}} \left(\frac{I_h}{I_1}\right)^2 \tag{13}$$

$$P_{EC-rated\ -pu} = \frac{2.8\,(P_{EC-rated}\,)}{1.5\,(I_{2-rated})^2 \times R_2} \tag{14}$$

Where,

I_1 = r.m.s current of fundamental component

pu = per unit quantities

Temperature Rise in transformer and its loss of life:

The transformer loss of life estimation is based on the deterioration rate achieved by insulating materials [5, 6]. The hottest spot winding temperature is calculated as follows [2]:

$$\theta_{TO} = \theta_{TO-rated}\left(\frac{P_{LL-C}+P_{NL}}{P_{NL-rated}+P_{NL}}\right)^{0.8} \tag{15}$$

$$\theta_g = (\theta_W - \theta_{TO-rated})\left(1 + \frac{F_{HL}(PEC - rated\ pu)}{1+P_{EC\,-\,rated\,pu}} \times P_{LL-pu}\right)^{0.8} \tag{16}$$

The hot spot temperature is:

$$\theta_H = \theta_{TO} + \theta_g + \theta_A \tag{17}$$

Where,

= top oil temperature rises above ambient temperature under rated condition

= winding temperature rise above ambient temperature under rated condition

= ambient temperature

= hottest spot conductor rises over top oil temperature

= hot spot temperature

The relative aging factor, the loss of life and real life of a transformer can be expressed in the following manner [7]:

$$F_{AA} = exp\left(\frac{15000}{383} - \frac{15000}{\theta_H+273}\right) \tag{18}$$

$$\%LOL = \frac{F_{AA} \times t \times 1000}{Normal\ insulation\ life} \tag{19}$$

$$Life\ (PU) = 9.8 \times 10^{-18}\, e^{\left(\frac{15000}{\theta_H+273}\right)} \tag{20}$$

$$Real\ life = Life\,(pu) \times normal\ insulation\ life \tag{21}$$

$$Real\ life = normal\ insulation\ life\ (year)/F_{AA} \tag{22}$$

Where,

= relative aging factor

%LOL = loss of life in in percent

t = given time period

IV. MEASUREMENT

To carry out this study, portable power quality analyser was used for measurement of data. The study was carried out for two different distribution transformers having different harmonic levels. The first site is a 400 KVA DT with 36.29% of current harmonics (THDI) and second another 400 KVA DT with 21.45 % THDI recording. For both the DTs type of loads connected include industrial machinery. For both the cases the data was logged for 2 hours with 10min intervals. Table I shows the specifications of both the DTs. comparison to the standard. Both the transformers were operating at 30% loading.

Table 1 SITE SPECIFICATIONS

	DT I	**DT II**
Rating	400 KVA	400 KVA
Primary voltage	11000 V	11000 V
Secondary voltage	433 V	433 V
Rated Primary current	21 A	21 A
Rated secondary current	533 A	533 A
Winding temperature rise	45 °C	45 °C
Ambient temperature	40 °C	40 °C
Transformer normal life	25 Years	25 Years

V. RESULTS AND ANALYSIS

Table II shows current harmonic data for both the cases in comparison with IEC 61000-3-4:1998 standard [8] and table III shows harmonic loss factor for eddy current loss and harmonic factor for other stray loss which are calculated using equation (11) and equation (12) respectively.

Table II CURRENT HARMONIC DISTORTION

Harmonic no.	**Harmonic Current (% of fundamental) (DT I)**	**Harmonic Current (% of fundamental) (DT II)**	**Max Limit (IEC 61000-3-4:1998)**
3	0.73	4.25	21.6
5	30.68	15.41	10.7
7	21.8	8.09	7.2
9	3.49	2.09	3.8
11	2.5	13.83	3.1
13	0.87	4.33	2
15	0.3	1.12	0.7
% THDI	36.29%	21.45%	25.72%

Table III HARMONIC LOSS FACTOR

	DT I	DT II
Harmonic Factor for eddy current loss (FHL)	5.2	4.53
Harmonic Factor for eddy current loss (FHL-STR)	1.4	1.21

The load losses are also calculated considering the actual load and the effects of harmonic. The total eddy current loss and other stray loss are determined using harmonic loss factor for eddy current loss and harmonic factor for other stray losses. The result of this calculation for DT I is summarized in table IV and table V for 30% and 90% loading conditions. The results shows that harmonic load current can be detrimental for distribution transformer with drastic increase in transformer losses. Thus, increased losses block transformer capacity and lead to energy loss as the data depicts in table VI.

Table IV. TRANSFORMER LOSSES IN PRESENCE OF HARMONICS (30% LOADING)

Loss type	Rated Loss (Watt)	Operating Loss at 30% Loading (Watt)	Harmonic multiplier	Corrected Loss (Watt)
No Load	850	850		850
Eddy	925.39	78.93	5.2	409.64
Other Stray	1878.82	160.25	1.4	221.14
I2R	2675.79	240.82		240.82
Total	6330	1190		1721.61

Table V. Transformer Losses in Presence of Harmonics (90% Loading)

Loss type	Rated Loss (Watt)	Operating Loss at 90% Loading (Watt)	Harmonic multiplier	Corrected Loss
No Load	850	850		850
Eddy	925.38	749.96	5.2	3899.80
Stray	1878.82	1522.65	1.4	2131.71
I2R	2675.79	2167.39		2167.39
Total	6330	1190		9048.89

Table VI. Transformer Losses and Annual Energy Loss

	DT I	DT II
Increase in losses due to harmonic current	44.67%	38.01%
Annual energy loss	1448 units per year	1231 units per year

Table VII and table VIII shows increase in transformer temperature and hence loss of its life. Results shows that with 0.3 per unit loading, for both the transformers' life will not be less than their normal life. However, with the same harmonic levels, if the load is increases to .90 pu loading, the pu unit life will be 1 and 2.8 for DT I and DT II respectively. It means that for the total harmonic distortion of 36.29% the transformer will have a normal life with loading smaller that 90 %, but if the loading exceeds 90%, the transformer life will decrease dramatically, for 100% loading transformer life will drastically decrease from 25 years to 15 years as shown below:

$\theta_{TO} = 59.56\ °C$

θ_g = 15.50 °C
θ_H = 115.06 °C
Life (pu) = 0.59

Real life of the transformer = 15 years

Table VII. TEMPERATURE RISE AND LOSS OF LIFE IN TRANSFORMER (30% LOADING)

	DT I	DT II
Oil temperature rise over ambient temperature	14.11 °C	13.60 °C
Hottest spot conductor rises over top oil	16 °C	13.66 °C
Hot spot temperature	69.62 °C	67.25 °C

Table VIII. TEMPERATURE RISE AND LOSS OF LIFE IN TRANSFORMER (90% LOADING)

	DT I	DT II
Oil temperature rise over ambient temperature	54 °C	49.47 °C
Hottest spot conductor rises over top oil	16 °C	13.66 °C
Hot spot temperature	110 °C	103.1°C
Life (pu)	1.00	2.8

CONCLUSION

The study shows that higher current harmonics causes energy loss and loss of transformer life due to increase of transformer losses and temperature. In case I transformer will maintain its normal life until loading exceeds 90%. For case II transformer will maintain its normal life for 100% loading. Thus, the study of harmonic impact on distribution transformers are important because they are the most expensive and the most critical equipment in power system.

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A Framework for Vulnerability Assessment & Penetration Testing in Digital Substations

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Abstract

Modern substations use Substation Automation Systems (SAS) technology for protection actions like fault detection and trip circuit control. Integrating various automation and communication technologies makes the system vulnerable to cyber-attacks. To analyze the security of a digital substation, an Operational Technology (OT) based Vulnerability Assessment and Penetration Testing (VAPT) of each device and the overall network is necessary. Several cybersecurity systems being marketed for use in SAS communications from various businesses lead to a complicated system. Though several standards are available for cyber security studies, there is no standard tool or framework for VAPT that focuses on the SAS assets and the design. This study proposes a tool for the VAPT of SAS systems to analyze the cyber risk of the available technologies and assess the reliability and privacy of digital control and protection circuits. The proposed vulnerability assessment provides a detailed step-by-step implementation procedure by combining various standards from NIST, IEC, and NESCOR guidelines. The penetration testing uses attacks derived from the MITRE ATT&CK framework, which has an exhaustive list of possible threats. The vulnerability assessment focuses not only on the IT-based protocols but also on the vulnerabilities associated with IEC 61850-based GOOSE and MMS packets, which is a significant focus of the VAPT tool. The paper also provides details of the VAPT report and the inferences to be made from each report. Substation operators and information security personnel can use this document and VAPT tool to identify the substation cyber vulnerabilities and secure their system based on the reports generated.

Index Terms

Substation Automation, Cyber Security, Vulnerability Assessment, Penetration Testing, IEC-61850

1. INTRODUCTION

Substations are one of power grid network's most fundamental and critical components. While conventional substations rely upon hard-wired connections and electromechanical or solid-state relays; modern substations are highly digitized and automated using IEC-61850 protocol for communication. While the IEC-61850 protocol has high communication speed and offers interoperability, it lacks security features such as encryption. This is primarily because of the time critical nature of the messages in the protocol. With increased automation and digitalization, substations are vulnerable to cyber-attacks that could disrupt an entire grid system and affect multiple other linked sectors. Thus, it is essential to implement a defense- in-depth cyber security system for the protection, control, and automation system of a digital substation.

Table 1: SAS RELEVENT CYBER-SECURITY DOCUMENTS

Authority	**Document/ Tool**	**Domain**	**Details**
National Institute of Standards & Technology (NIST)	NIST-Special Publication-800-30 Guide for Conducting Risk Assessments [1]	Critical Infrastructure	Risk assessments of federal information systems and organizations.
	NIST-Special Publication-800-82 Guide to Operational Technology (OT) Security [2]	OT	Industrial Control Systems (ICS; risk management; security controls; SCADA systems
North American Electric Reliability Corporation (NERC)	NERC-Critical Infrastructure Protection (NERC-CIP) CIP-002 to CIP- 014	Bulk electric systems	Set of cybersecurity standards to reduce the risk of compromise to electrical resources

Cybersecurity and Infrastructure Security Agency (CISA)	CISA Cyber Security Evaluation Tool (CSET) CISA ICS Alerts, Advisories and Reports	ICS, OT	Tools and reports for vulnerability and security assessments
MITRE	ATT&CK for ICS [3]	ICS	Threat Modelling tool
Electric Power Research Institute (EPRI)	National Electric Sector Cybersecurity Resource (NESCOR) [4], [5]	Electric Sector	Tools and guidelines for electric sector Penetration testing guide- lines, attack, failure scenarios & mitigation for electric sector
International Electrotechnical Commission	IEC TS 62443-1 to 62443-4 [6]	Industrial Automation systems	Secure industrial automation and control systems (IACS) throughout their lifecycle.

The first step in any cyber security analysis on a cyber- physical system, is to find the potential attack surface and identify vulnerabilities in the system. Penetration testing is a method of injecting attacks into the system and analyzing the impacts. There are several penetration testing and vulnerability assessment technologies available for IT systems. However, no standardized procedure applies to all Operational Technology (OT) systems. Another limitation for the OT systems is that it is not possible to perform penetration testing on the live OT systems, as these could lead to catastrophic impacts. Thus, a suitable VAPT framework must be developed that is suitable to the SAS system to analyze the vulnerabilities in the system and provide appropriate patching for cyber security.

Multiple cyber security standards and guidelines focus on various areas of Industrial Control Systems (ICS) in general and electrical systems. Table. I compare various cyber security standards dealing with the power system. It is evident from above table that though there are multiple standards and guidelines available, no single approach deals with the substation protection, control and automation system Vulnerability Assessment and Penetration Testing (VAPT).

This paper describes the development of a tool for the VAPT of substation protection, control, and automation systems. The objective of the VAPT is to examine the cyber security risk levels beginning from the lowest level of digital control and protection circuits in the substation and analyze the cyber risk of accessible technologies. The suggested vulnerability assessment provides a complete step-by-step implementation approach by merging several standards from NIST [2], IEC [6], and NESCOR [4], [5] recommendations.

The penetration testing employs attacks drawn from the MITRE ATT&CK [3], which has a comprehensive list of potential threats. The evaluation presented in this paper focuses on vulnerabilities in the IEC 61850-based packets. The paper also describes the risk assessment and the conclusions to be drawn from each report. The framework and tool presented in the paper shall be utilized by substation operators and information security staff to identify substation cyber risks and secure their systems. The work given in this article is built on several attacks, threat, and security paradigms.

II. OVERVIEW OF DIGITAL SUBSTATION AND VAPT FRAMEWORK

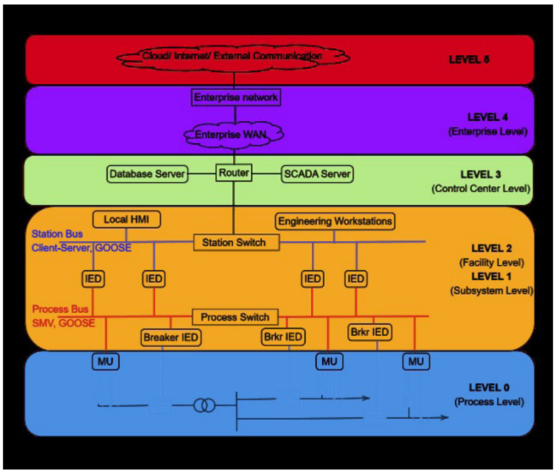

Fig. 1. Substation Automation System with Purdue Model

Fig.1 shows the overview of a simple substation automation system with multiple IEDs, merging units, HMI, and station layer and process layer networks. The outputs of Current transformers (CTs) and voltage transformers (PTs) from field are connected to the process level IEDs through merging units (MU). These IEDs perform various protection functions such as breaker trip, lockout, breaker failure initiation, and reclosing initiation. At the process level, the communication is through IEC 61850-8-1 GOOSE messaging, thereby eliminating hardwired connections. Multiple dedicated bay-level IEDs are connected through the station switch LAN using optical fibers. At the station level, IEC 61850 GOOSE and MMS services are used for communicating among IEDs and between IEDs and the central HMI.

The SAS is mapped to the Purdue model [7] [8] which is a standard communication model used to define the various levels of communication. The level zero or process level involves sensors, current transformers, potential transformers, and merging units (MU) that digitize these analog values. Level 1 consists of the IEDs, and Level 2 involves the gateways, local HMI, and engineering workstations. The Control center devices such as database, SCADA/Application servers are included at level 3. Level 4 includes the enterprise network followed by the external network or the internet in level 5.

In this paper, we focus on the VAPT of the substation at the lower layers of the SAS, specifically from levels 0 to IT based VAPT services and guidelines have been well established in literature and these are applicable at the layers 4 and 5. The proposed VAPT process for the substation has the following steps:

1. **Create:** Create Exploits for penetration testing based on NESCOR Guidelines.
2. **Map:** Map the exploits to MITRE threat model for vulnerability assessment.
3. **Analyze:** Determine the likelihood, impact and risk scores using NIST-800-30 and attack trees.

The advantage of following the above procedure is that it covers all the necessary stages of the vulnerability assessment process, and each stage is based on the guidelines developed by standard organizations.

III. CREATE EXPLOITS USING NESCOR GUIDELINES

The first step in the VAPT process is to model the attacks or exploits that can be injected into the system for penetration testing. The NESCOR Guide to Penetration Testing for Electric Utilities [5] is a comprehensive guide to penetration testing that focuses on the electric sector. It was developed with the intention of giving electric utilities instructions on how to conduct penetration tests on Smart Grid systems.

Using guidance from the NESCOR framework the following penetration testing modules are created:

1. Network Penetration Testing
2. SCADA system Penetration testing
3. Protection & Control system Penetration Testing

Further, the penetration testing tool focuses on the IEC- 61850 protocol that includes MMS (Manufacturing Message Specification), GOOSE (Generic Object-Oriented Substation Event), and SMV (Sampled Measured Values) message types. To implement the exploits a combination of various tools was utilized. Tools such as Nessus and Wireshark, were used for initial vulnerability assessment and packet capturing. Further python programming and bash scripting was used for creation of automated penetration testing modules. The Kali Linux operating system has several built-in tools that can further aid in the process of penetration testing. Thus, it is preferred to use a Kali Linux based System for pentesting.

A. Network Penetration Testing

Network Penetration Testing involves testing the station bus and process bus network data flow. The objective is to find security holes that let an attacker manipulate the data protocol to control network traffic.

Exploits are created to capture traffic, decode protocol messages, and manipulate them to give out wrong commands to field devices. At process level, GOOSE is the most prominent message type due to its speed. Other message types, such as MMS and SMVs, are also widely used at the station bus level.

B. SCADA System Penetration Testing

The SCADA system comprises various servers and applications that operate and configure the IEDs and other control devices within the substation. SCADA involves tasks such as information gathering (through interrogation, port scanning, and packet sniffing), vulnerability analysis, and creating exploits based on the identified vulnerabilities.

C. Protection & Control system Penetration testing

The penetration testing for protection and control systems mainly involves embedded systems such as IEDs, gateways, and Phasor Data Concentrators. The major tasks involved are electronic component analysis and firmware analysis.

Once the exploits are created, they are to be mapped to standard threat models to determine the path an attacker follows to cause desired impact. This threat modeling using MITRE ATT&CK framework is discussed in next section.

IV. MAP EXPLOITS TO THREAT MODEL

A. Threat Modelling

The substation typically has many sensors and actuators, processing units with numerous functions, external connectivity, and equipment that are not correctly set, which will increase cyber threats and attack vectors. Recent studies have demonstrated that cyber-attacks on substations are feasible and potentially cause significant financial, privacy, and safety risks. Threats are frequently referred to as anti-requirements that enable an attacker or hostile agent to misuse a CPS.

The MITRE's ATT&CK (Adversarial Tactics, Techniques, and Common Knowledge) [3], a threat-based model, is one of the most utilized cybersecurity concepts. It is described as a risk and vulnerability assessment tool to analyze real-world threat behaviors based on their connections with various entities in a CPS. It is a detailed model that describes the strategies and tactics used by attackers to impede the delivery of critical services by interfering with ICS operations, from initial access and execution to command and control and data exfiltration. It is a matrix of various attack patterns or stages, outlining progressive strategies and related methodologies (drawn from the Cyber Kill Chain model). The concept emphasizes how the attackers know the adversaries' tactics, methods, and procedures. With the help of this expertise, cyber defense teams may centralize research reports for threat intelligence based on real-time attacking tactics and then develop efficient plans to safeguard the infrastructure.

The MITRE ATT&CK framework is used in this work for detailed threat modeling. It is a comprehensive approach that includes all the relevant attacks, and the attack matrix can be easily integrated with other methods. This paper proposes an integration of the MITRE framework in the SAS-VAPT design due to several reasons:

1. MITRE ICS framework is the most comprehensive framework available for threat modeling.
2. The MITRE matrices give a good correlation between tactics, techniques, and mitigations.
3. It is comprehensive and analyzes security properties against each system component
4. It is a widely accepted framework for ICS threat mod- eling and vulnerability assessment.

B, MITRE ATT&CK Based Threat Modelling

The different attacker goals used in the MITRE framework are called tactics. The various tactics that are used in the SAS- CPS attack model are as follows:

1. Initial Access: The Initial access can be gained into the substation either from outside or through an internal device. This step is used to gain an initial foothold.
2. Execution: Once the attacker is inside the substation, he can start executing commands to disturb the actual system behavior.
3. Persistence: The attacker then modifies programs and configurations to continue being in the system and maintain access.
4. Privilege Escalation: An attacker may not have all the permissions required during initial access. Once inside, he can enter more secure and critical data and controls of the HMI and IEDs.
5. Evasion: The attackers can evade various detection and protection methods, such as firewalls, by spoofing communication and exploiting software vulnerabilities.
6. Discovery: Remote discovery can be used to understand the substation topology. This discovery can help the proper later movement to reach the desired target.

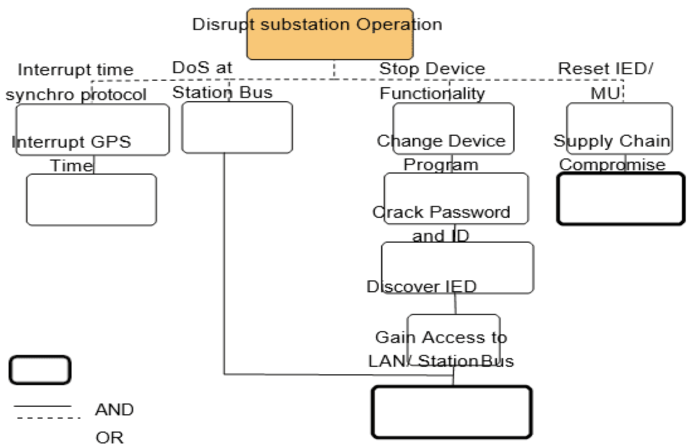

Fig. 2. MITRE ATT&CK matrix for Substation Automation System

7. Lateral Movement: Once the attacker has the complete substation data and topology, he can devise methods to move from the initial access points to the targets.
8. Collection: At each point of intrusion, the attacker collects data that can be further used to exploit the substation controls.

Initial Access	Execution	Persistence	Privilege Escalation	Evasion	Discovery	Lateral Movement	Collection	Command and Control	Inhibit Response Function	Impair Process Control
Exploit Public-Facing Application	Change Operating Mode	Modify Program	Exploitation for Privilege Escalation	Change Operating Mode	Network Connection Enumeration	Default Credentials	Automated Collection	Commonly Used Port	Activate Firmware Update Mode	Brute Force I/O
Exploitation of Remote Services	Command-Line Interface	Module Firmware		Exploitation for Evasion	Network Sniffing	Exploitation of Remote Services	Data from Information Repositories	Connection Proxy	Alarm Suppression	Modify Parameter
External Remote Services	Execution through API	Project File Infection		Indicator Removal on Host	Remote System Discovery	Lateral Tool Transfer	Detect Operating Mode	Standard Application Layer Protocol	Block Command Message	Module Firmware
Internet Accessible Device	Graphical User Interface	System Firmware		Masquerading	Remote System Information Discovery	Program Download	I/O Image		Block Reporting Message	Spoof Reporting Message
Remote Services	Modify Controller Tasking	Valid Accounts		Rootkit		Remote Services	Man in the Middle		Block Serial COM	Unauthorized Command Message
Replication Through Removable Media	Native API			Spoof Reporting Message		Valid Accounts	Monitor Process State		Data Destruction	
Rogue Master	Scripting						Point & Tag Identification		Denial of Service	
Spearphishing Attachment	User Execution						Program Upload		Device Restart/Shutdown	
Supply Chain Compromise	Modify Controller Tasking								Manipulate I/O Image	
Transient Cyber Asset									Modify Alarm Settings	
									Rootkit	
									Service Stop	
									System Firmware	

Fig-3

9. Command and Control: Using the data at hand, the attacker
10. finally implements control commands to alter the working of the substation controls.
11. Inhibit Response Function: Commands can also be introduced to inhibit safety controls and functions that respond during an emergency scenario.
12. Impair Process Control: Finally, the attacker can disable or even damage the substation's complete physical process, leading to an outage of the entire system.
13. Under each tactic, some subcategories are identified, and the final matrix chosen for the SAS is as shown in Fig.2

C. Mapping of Exploits to MITRE ATT&CK

Figure.3 gives a high-level flow of how the exploit is executed. More details of attack tree formation are presented in further sections. Each node in the high-level tree can be accomplished using a chain of events derived using the ATT&CK matrix. For example, to implement a Denial of Service (DoS) exploit at the station bus, the first step is to gain access to the station switch or LAN. This step can be mapped to the initial access steps as below:

(Exploit Remote Services) OR (Internet Accessible Device) OR (Replication through removable media) OR (Spear phishing Attachment)

Similarly, the next step can be further mapped to other cells of the matrix to obtain the detailed or lower-level attack flow.

V. ANALYZE THE LIKELIHOOD, IMPACT & RISK SCORES

Once attacks are mapped to the threat model to create a cyber kill chain, the next step is to analyze the likelihood and impact, leading to the final risk scores for each exploit. This process of risk assessment is carried out using the steps below:

1. Create Attack trees using the MITRE mapping (lower levels) and power system knowledge (upper levels).
2. Assign likelihood scores for each node using CVSS and NESCOR based scoring.
3. Calculate net likelihood of tree using probability theory.
4. Assign impact scores for the final nodes in each tree.
5. Combine the impact and likelihood scores to arrive at the final risk value using NIST-800 guidelines.

The most important step in the risk assessment is the designing or construction of attack trees.

A. Substation Attack Trees

Various attack trees are built to achieve attacker goals based on the tactics and techniques discussed in previous sections. Attack trees are an efficient way to represent the movement of attacks from their initial onset until the final attack impact. For example, Fig.3 shows a part of the attack tree that causes a substation disruption.

Attack tree in Fig.3 shows various paths through which the primary goal of disrupting substation can be achieved. Every node in the attack tree can be a part of multiple attack trees. To reach each node, there can be further sub-trees. Leaf nodes with further sub-branches are indicated with a bold outline as shown for the 'Gain Access to station bus.'

Each node can now be assigned likelihood values based on NESCOR guidelines. These individual scores can be used to determine the net likelihood. The determination of the net likelihood is discussed in detail in the following subsection.

B. Impact Scores

The impact score is assigned based on the final node of the attack tree that is reachable by a penetration testing module. The impact scores are assigned and the nodes in attack trees are colored based on the values in Table.II.

TABLE II: IMPACT SCORES

Final node	Impact score	Color
Tripping of critical assets like feeder, transformer	Very High	Red
Tripping of non-critical assets	High	Orange
Tripping of bay level devices	Moderate	Yellow
Tripping of ancillary services/ Data Collection	Low	Blue
No impact on physical layer	Very Low	Green

The system impact will be highest if the attack leads to the failure of critical devices in the substations, such as a breaker or transformer failure of critical feeders, due to which we assign the maximum impact score for these failures. Tripping of bay-level devices has a medium impact, and finally, tripping of ancillary services is given a low score. There can also be attacks on the system that do not impact the physical system but may impact the IT system to get data. Such attacks fall into the very low-impact category.

It is possible that due to implementation of security features in a substation, the penetration testing penetrates only until an intermediate leaf of the attack tree. Thus, the impact score of this leaf node will be considered for final risk calculation.

C. Likelihood scores

The likelihood scores are assigned in different steps. Firstly, likelihood scores are given for each leaf node. Then, probability theory calculates a net likelihood score for the entire attack tree. The net likelihood score is then designated as High, Low, and Medium based on the range in which the values fall.

The likelihood scores for each leaf node are decided using NESCOR Electric Sector Failure Scenarios and Impact Analyses [4]. CVSS scores are another means for assigning the scores. Comparing CVSS and [4] shows that all the parameters used are similar, with only name changes. The [4] document is used in this paper as it is more specific to the electric sector. The individual leaf likelihood scores are decided based on Table.III, which is derived from the NESCOR.

TABLE III: LIKELIHOOD SCORES

Criterion	**Sub-criterion**	**Scores**
Skill Required	Deep knowledge on domain and cyber attacks	0.3
	Insider knowledge required	0.5
	Basic domain and cyber skills	0.9
Accessibility	High expertise required to gain access	0.3
	Publicly accessible but not known commonly	0.5
	Common knowledge	0.9
Attack Vector	Attack knowledge available theoretically	0.3
	History of attack but with no attack scripts available	0.5
	Attack scripts/tools directly available in public domain	0.9
Common Vulnerability	Isolated occurrence	0.3
	More than one utility	0.5
	More than half of the utilities	0.9

The NESCOR document scores the likelihoods with discrete values (0,1,3, and 9). We combine specific categories and further divide the values by a factor of 10 to arrive at the values in Table.III. The division by ten is used to obtain probability- like values. This division helps calculate the net likelihood using the principles of probability theory. Net Likelihood Calculation: The overall likelihood scores are then generated based on probability theory. It is considered that each event or leaf node leading to the attack is independent of the other. Thus, the likelihoods of nodes combined using an OR are added together, and the likelihoods combined using AND are multiplied to arrive at the net probability for each high-level node. The net-likelihood is then divided into different categories using Table. IV.

TABLE IV: NET LIKELIHOOD SCORES

Final Net Likelihood	Likelihood score
≥0.7	Very High
0.5-0.7	High
0.3-0.5	Moderate
0.1-0.3	Low
≤0.1	Very Low

D. ***Risk Scores***

The risk scores are a combination of the likelihood and the impacts. This is obtained using the NIST Guide for Conducting Risk Assessments (NIST-SP-800-30) [1]. The likelihood and impact scores can be combined as shown in Table.V to obtain the risk scores.

TABLE V RISK: COMBINATION OF LIKELIHOOD & IMPACT

Likelihood Scores	Impact Scores				
	Very Low	Low	Moderate	High	Very High
Very High	Very Low	Low	Moderate	High	Very High
High	Very Low	Low	Moderate	High	Very High
Moderate	Very Low	Low	Moderate	Moderate	High
Low	Very Low	Low	Low	Low	Moderate
Very Low	Very Low	Very Low	Very Low	Low	Low

The final risk scores determine the security levels of the system. These scores will change as new security systems are introduced into the SAS. Thus, the VAPT is a continuous process.

SAMPLE CASE: DATA MANIPULATION ATTACK AT STATION SWITCH

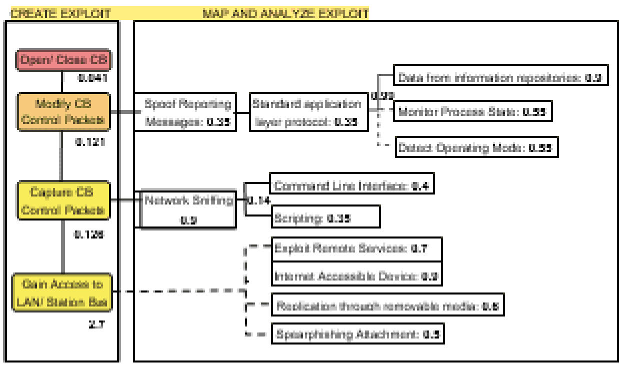

Fig. 4. VAPT for Case 1

In the example case considered here, the aim of the penetration testing is to Open/Close the circuit breaker. This is achieved using a data manipulation attack-based penetration testing. Fig.4 shows all the steps involved in the VAPT process.

We perform a network penetration testing at the station bus level. The exploit captures the packets, modifies them, and re-injects it into the network to give wrong commands for operation. The exploit is mapped to the MITRE ATT&CK to get the detailed attack tree as shown in Fig.4. The bold numbers in Fig.4 are the likelihood scores assigned to each leaf node.

A. Attack Penetrates to Final Node

Assuming that the circuit breaker is connected to a critical feeder line, the impact score assigned to the final event is 'Very High'

The final likelihood score of 0.041 is obtained using prob- ability theory as explained in previous sections and as shown in (1)

$$\text{Net Likelihood} = 2.7 * 0.128 * 0.121 = 0.041 \quad (1)$$

The final likelihood is thus ‘Very Low,’ and Impact is ‘Very High.’ Thus, the final risk is obtained from Table.V as ‘Low.’ The risk is low since it is a complicated attack.

B. Attack stops at Capture Packets

Let us assume that there are security features in the substation that prevent the spoofing of message packets. This could be achieved using Intrusion Detection Systems and Intrusion Protection Systems in the SAS. In this case, the attack is only able to reach until the second stage giving us a net likelihood value of 0.3456 as given in (2)

$$\text{Net Likelihood} = 2.7 \; \square \; 0.128 = 0.3456 \qquad (2)$$

The final likelihood is thus ‘Moderate’ and Impact is ‘Low.’ Thus, the final risk is obtained from Table.V as ‘Low.’ The risk is low since the attack does not impact any critical devices.

VII. CONCLUSIONS

This paper presents a detailed vulnerability assessment and penetration testing tool for substation automation systems. The tool is based on logical combination of various existing standards and guidelines developed by standard authorities such as NIST, IEC, and NESCOR. The exploits are created and applied to the system, it is then mapped to the MITRE framework, and finally the likelihood and impact scores are analyzed to get the risk associated with the created exploit.

The advantage of the tool is that it combines the reach of penetration testing along with risk assessment thus considering the security levels of the current system. The proposed tool can be used as a sample framework for penetration testers or substation operators to analyze the risk to substations due to cyber-attacks and devise suitable solutions to safeguard the SAS

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Solar Powered Smart Switching Multilevel Inverter for Smart Grid

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Abstract

In recent days, power electronics technology is becoming more popular and emerging as a practical solution to many issues. To be competitive in the power electronics industry, manufacturers have improved the converters performance, size, and cost, by using high-frequency modulation techniques. These techniques are useful in controlling the switching devices in inverters to generate a chain of positive and negative pulses in the output to produce desired sinusoidal voltage wave. The multilevel inverter acquires several advantages that include reduced switching stress, low harmonics and reduced current ripple. The harmonics of the inverter output voltage can be reduced by increasing the switching frequency using carrier-based modulation techniques. However, the increase in the switching frequency is associated with a tremendous increase in the switching losses. One of the useful strategies is to combine two different frequencies for the operation of the two different bridges associated with the inverter. This helps in the intensification of output power. This work focuses on a PV based smart switching multilevel inverter which receives the input DC power from a novel Switched Capacitor Cell boost converter. The complete converter unit is connected to the grid for voltage enhancement. It is a combination of an H-bridge configuration along with a symmetrical circuit made up of semiconductor switches with anti-parallel diodes. The neoteric approach can be used for Plug-in Electric Vehicles and is also used for reactive compensation in a smart grid system. The simulation studies of the proposed smart switching multilevel inverter are carried out using MATLAB/SIMULINK.

Keywords
Multilevel Inverter, Quadratic boost converter, Smart grid, EV

I. Introduction

The technological development in the power electronics sector has tremendous results. One such invention is the usage of multilevel converters for different applications like photovoltaic, grid tied systems, Flexible AC Transmission system etc., These converters possess many benefits which includes increased power capacity with low range power de- vices, enhanced quality, and fault tolerant capability [1-2]. The multilevel converters are also suitable for renewableresources. Among the renewable energies, the solar systems are preferred more by the industries and common peoples for low power applications even though it has some drawbacks [3-4]. In this competitive world, many industries on power electronics are trying to develop a new topology with some added advantages. In this aspect, they are working on the implementation of different converter configurations with improved capacity and reduced losses. Even researchers are working on the same either by developing a new circuit design or by modifying the switching techniques [5-6]. The most common topological classification of multilevel converters is cascaded H-bridge type, Neutral-clamped converter, Flying capacitor and modular multilevel converter

[7]. These conventional types have been widely used in the field of renewable energies and industrial power drive systems. Most of these are commercialized and earned lot of attention in the earlier stages.

Now-a-days, as the requirement of users is getting varied from person to person the conventional topologies are struggling to achieve it. For example, if we need better power quality converters, the harmonics should be low. In that case, certain modification should be done in these topologies [8-9]. The main advantage of these multilevel configurations when compared to two level converters is low THD and reduced switching stress. As the number of levels of the inverter is increasing, the number of switching devices also increased [10]. To overcome these drawbacks, several modified configurations are developed by the researchers and is shown in figure 1.

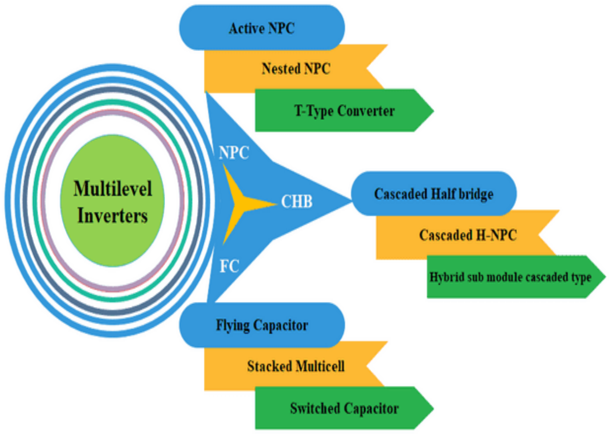

Fig. 1. Classifications of Multilevel Converter

Among all the types, T-type multilevel inverters have better efficiency and characteristics for switching frequencies at mediocre level. These converters are the modification of neutral point clamped (NPC) converter [11-12]. The T-type neutral clamped multilevel converters are considered as a promising configuration of converters in the industrial sector with very high power and voltage rating. The main reason behind this is the reduced number of switching devices incorporated in the system [13,14]. The paper is organized in the following manner: Initially, the configuration of the DC converter and its results are discussed followed by the concepts of multilevel inverter. The overall block diagram of the proposed work is shown in figure 2.

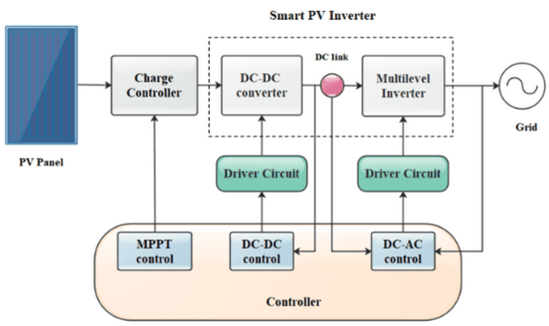

Fig 2. Overall block diagram of the proposed system

The output of the PV panel is controlled using an MPPT controller to retrieve the maximum power. It acts as the source for the novel DC-DC converter, which boost the voltage generated from the PV panel. The voltage of the boost converter is fed to the multilevel inverter via a DC link and it is synchronised with the AC grid.

II. Switched capacitor cell dc-dc boost converter

The proposed converter circuit comprises a switched capacitor cell with the combination of inductors L_1, diodes D_1, D_2, and D_3 along with a semiconducting switch 'S'. The circuit diagram of the proposed converter topology is displayed in Figure 3.

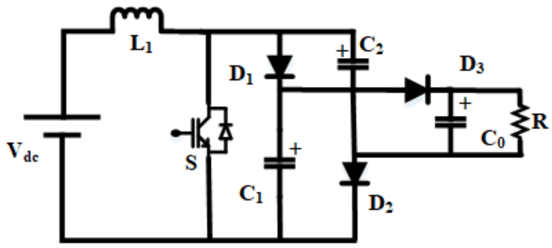

Fig 3. Circuit diagram of Switched Capacitor Cell boost Converter

During the switching interval, the switch 'S' is kept in ON-state, and the inductor L_1, capacitors C_1, C_2 and D_3 are also forward biased simultaneously, as presented in Figure 4.

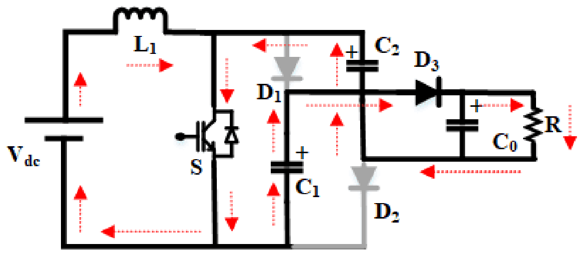

Fig 4. Equivalent Circuit for Mode – I

The voltage across the inductor L_1 becomes equal to Vdc. The capacitor C_1 and C_2 gets discharged, and it charges the capacitor C_0.

During the switching interval, the switch 'S' is kept in the OFF state, as shown in Figure 5.

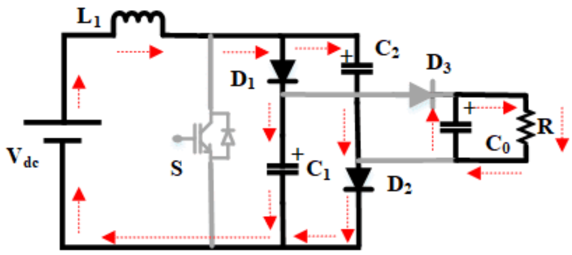

Fig 5. Equivalent Circuit for Mode – II

The inductor connected at the input side discharge and transfer energy to the capacitor C_1 and C_2. Meanwhile, the capacitor C_0 is discharged and supplies the load.

II. Proposed multilevel inverter

The proposed inverter is a combination of a cascaded H- bridge inverter and symmetrical semiconducting switches. The switches in the H-bridge topology operate with a frequency of 50 Hz and other switches operate with a frequency of 100 Hz. Two different frequencies have been used and the stepped voltage waveform is obtained across the resistive load of 250Ω. Thus, it can also be called a hybrid switching inverter. The voltage range is about 250V. The circuit configuration is shown in figure 6.

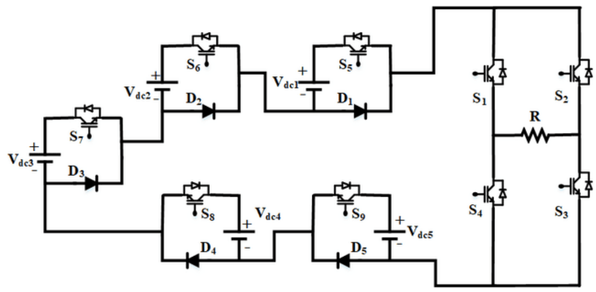

Fig 6. Circuit Configuration of Proposed Multilevel Inverter

The switching sequence for the proposed MLI is given in table I.

TABLE I: Switching Sequence for Proposed MLI

A. *Modes of Operation*

For Positive cycle, to obtain positive level Voltage (5Vdc), the switches S1and S3 of H-bridge is kept in ON state and the switches S5-S9 are also turned on for producing the positive level of the output voltage. The equivalent circuit for this mode is shown in Figure 7.

Voltage Levels	S1	S2	S3	S4	S5	S6	S7	S8	S9
5 Vdc	1	0	1	0	1	1	1	1	1
4 Vdc	1	0	1	0	1	1	1	1	0
3 Vdc	1	0	1	0	1	1	1	0	0
2 Vdc	1	0	1	0	1	1	0	0	0
Vdc	1	0	1	0	1	0	0	0	0
0	0	1	0	1	0	0	0	0	0
-Vdc	0	1	0	1	1	0	0	0	0
-2 Vdc	0	1	0	1	1	1	0	0	0
-3 Vdc	0	1	0	1	1	1	1	0	0
-4 Vdc	0	1	0	1	1	1	1	1	0
-5 Vdc	0	1	0	1	1	1	1	1	1

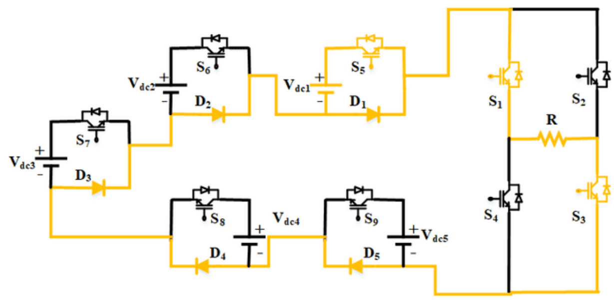

Fig 7. Equivalent Circuit for Mode-I

To obtain positive level Voltage (4Vdc), the switches S1 and S3 of H-bridge are kept in ON state and the switches S5-S8 are also turned on for producing the positive level of the output voltage. Here the diode connected in anti-parallel manner with S9 is forward biased and the current flow through it. The equivalent circuit for this mode is shown in Figure 8.

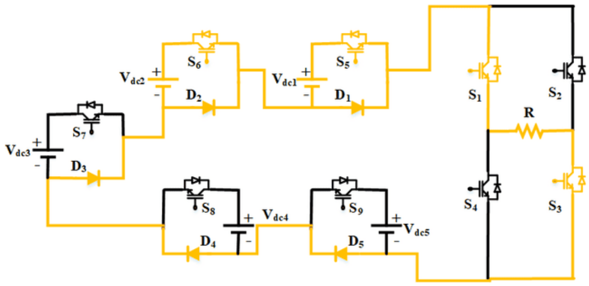

Fig 8. Equivalent Circuit for Mode-II

To obtain positive level Voltage (3Vdc), the switches S1 and S3 of H-bridge is kept in ON state and the switches S5-S7 are also turned ON for producing the positive level of the output voltage. The current flows through the diodes associated with S8 and S9 switches. The equivalent circuit for this mode is shown in Figure 9,

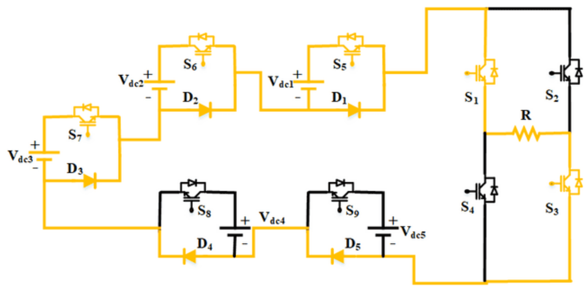

Fig 9. Equivalent Circuit for Mode-III

To obtain positive level Voltage (2Vdc), the switches S1 and S3 of H-bridge is in ON state and the bidirectional switches S5-S6 are also turned on for producing the positive level of the output voltage. The diodes connected in anti-parallel with S7, S8 and S9 gets forward biased due to the flow of current passing through it. The equivalent circuit for this mode is shown in Figure 10,

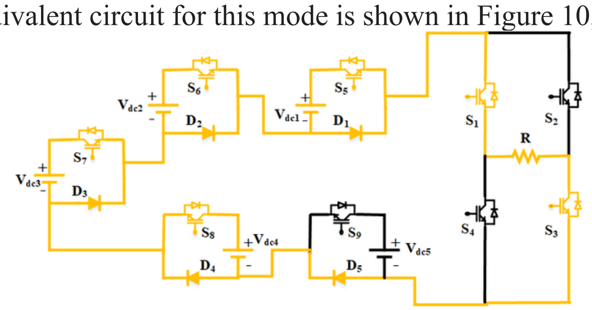

Fig 10. Equivalent Circuit for Mode-IV

To obtain positive level Voltage (Vdc), the switches S1 and S3 of H-bridge is in ON state and the bidirectional switch S5 is also turned on for producing the positive level of the output voltage. The diodes connected with the switches S6, S7, S8 and S9 are in conduction mode due to the flow of current through it. The equivalent circuit for this mode is shown in Figure 18,

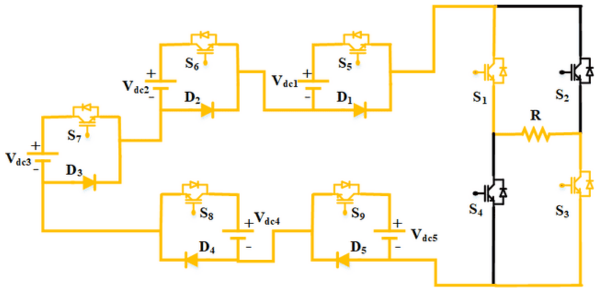

Fig 11. Equivalent Circuit for Mode-V

Similarly, the negative cycle operation takes place with S2 and S4 in ON condition. The pulse pattern waveform and the voltage waveform simulated in MATLAB/SIMULINK are given in figure 12.

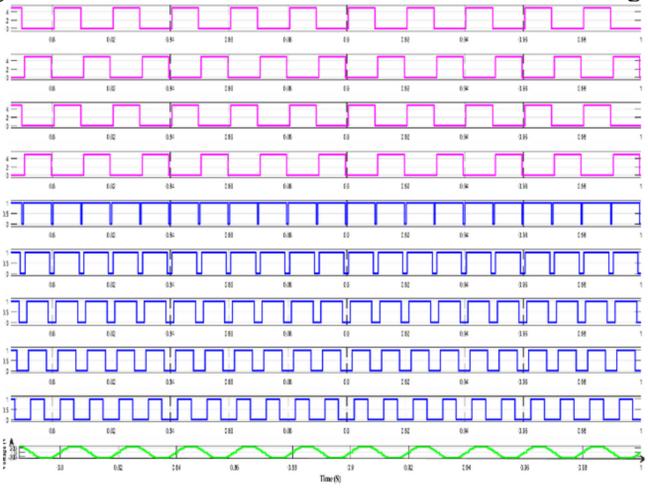

Fig 12. Pulse waveforms and output voltage waveform of the proposed inverter

The proposed topology is compared with other NPC and T-type topologies in terms of the number of devices, the number of levels, Voltage Total Harmonic Distortion, and it is given in Table II [15-21].

TABLE II. Comparison of proposed topology with conventional topologies

MLI Topologies	Number of Levels	Number of Semiconductor Switches	Number of Diodes	Number of Passive Components	Voltage THD (%)
[15]	5	8	10	3	41.27
[16]	3	16	6	2	29.44
[17]	3	3	0	3	95.02
[18]	3	16	6	2	-
[19]	3	6	0	2	-
[20]	4	8	0	4	-
[21]	3	9	0	2	>100
Proposed Topology	11	9	5	0	8.5

IV. Simulation results

The simulation of the proposed multilevel inverter is tested for a DC voltage of 250 V (50V per source) with Resistive load in the MATLAB/SIMULINK environment and the stepped voltage waveform under open loop is obtained as shown in figure 13.

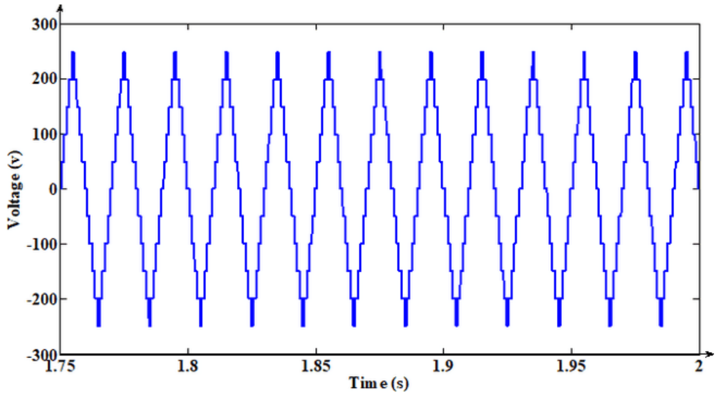

Fig 13. Voltage waveform of proposed inverter (For R-Load)

Figure 13 clearly shows that the voltage amplitude is around 248.25 V with 11 steps. The current value across the load is measured to be 2.5 A and the waveform is shown in figure 14.

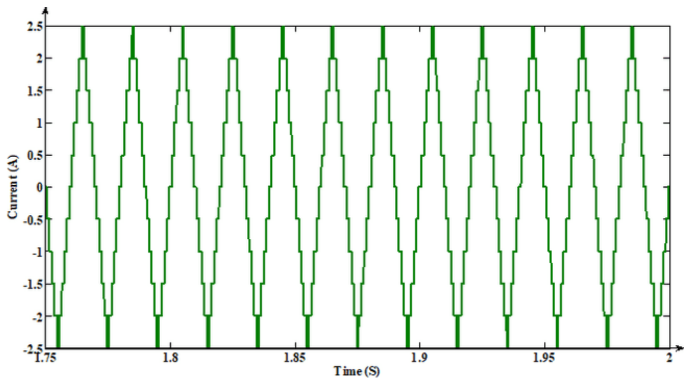

Fig 14. Current waveform of proposed T-type inverter (For R-Load)

The THD of the proposed MLI is found to be 14.65 % under open loop condition. The waveform is shown in figure 15.

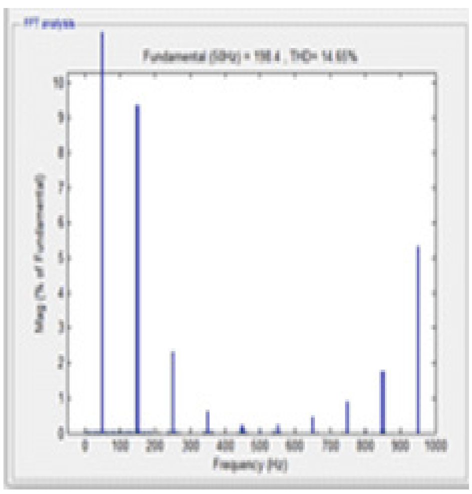

Fig 15. THD plot for proposed MLI (under open loop condition)

In the closed loop condition, the THD is found to be less in the range of 8.5-9.59 % for different switching frequencies. The THD plot for t-type topology for a switching frequency of 5 KHz is figure 16.

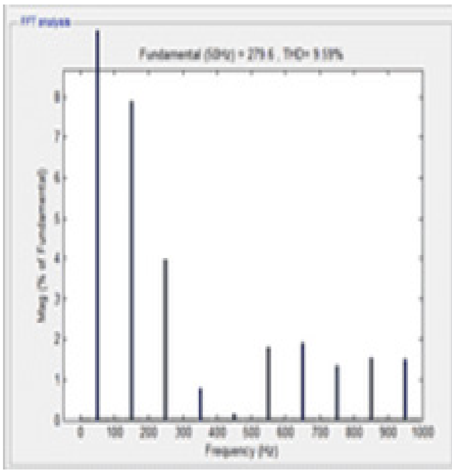

Fig 16. THD plot for proposed MLI (under closed loop condition)

The values of THD for different switching frequencies are tabulated and shown in Table III

TABLE III Switching frequency Vs THD %

Switching Frequency (KHz)	THD (%)
1.0	8.57
1.5	9.08
2.0	8.5
2.5	8.7
3.0	8.99
5.0	9.59

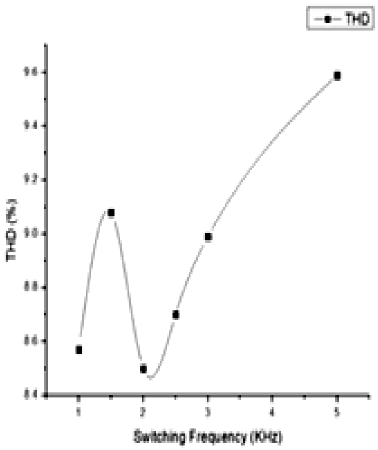

Fig.17. Switching frequency vs THD plot

Figure 17, shows the plot for rise and fall in THD value for different switching frequencies.

V. CONCLUSION

In this paper, a Novus multilevel T-type inverter along with a quadratic DC-DC boost converter is analyzed. The hybrid switching technique used in the system produces higher levels of output with fewer switches and it also helps to improve the voltage profile of the inverter. The topology is validated using MATLAB/SIMULINK tool and various electrical parameters were measured. Although only the new design and basic functionality of the proposed topology has been proposed in this paper, the grid connected mode of this topology for ancillary services will be an extension of this work. This paper will serve as a point of reference for those working in this domain.

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Situational Awareness of Grid using Wide Area Monitoring and Analytics Based on WAMS - GETCO Project

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Abstract

Modern day power systems face various challenges like the complex and ever-changing grid monitoring and control, faults or disturbances detection, constant variations in load and variability due to penetration of renewables sources of energy in modern power system. In order to overcome these challenges, the wide area monitoring system based on the synchro phasor technology and of Phasor Measurement units has enormous applications in detection of power system faults and in taking the necessary corrective measures before the failure of the power system.

In this paper, we shall discuss GETCO Project of WAMS phase 1 and phase 2 and some case studies of power system faults that occurred in the Gujarat grid on the state level basis of Gujarat in which the Phasor Measurement Unit was effective in the detection of faults. We will also discuss the use of WAMS based analytics presently in service and for future.

Keywords: Power systems, Synchro-phasor-technology, Phasor Measurement Units (PMUs), Wide Area Monitoring Systems (WAMS), Indian Grid, Fault detection, Grid monitoring, Analytics, System inertia, State Estimation, Small Scale oscillation.

Introduction:

Gujarat grid having installed capacity around 36 GW out of 37 % is renewable energy sources.

Due to intermittent nature of renewable energy and envisaging future growth of solar installation, real time situational awareness of grid for system operator is need of an hour.
To meet above need rising demand of consumers and climate change, electricity utilities are integrating renewable energy sources with conventional energy sources, present measuring system is not able to capture the dynamics of the system due to slow rate of capturing data.

Synchro-phasor technology is replacing the SCADA, which has high sample rates (25-50 samples per second). Which enhances the planning, designing and operation of the power system network also has the potential to improve significantly the operator's confidence to carry out real time grid operation, detect, and respond to possible disturbances.

Synchronized phasor measurements already recognized as one of the promising technologies for developing Smart Grid applications also expected to be the dominant source of insight predictions / forecasting.

Considering this, SLDC-GETCO had taken a pioneer step for installation of 113 PMUs at 25 Location including four RE rich location in Gujarat grid and installing 250 PMUs at 62 more location. Around 70 percent grid will be connected with Wide Area Monitoring System by December 2023. We are able to achieve performance of WAMS system with all function of SCADA during FAT.
The System architecture for WAMS Phase 2 is as below.

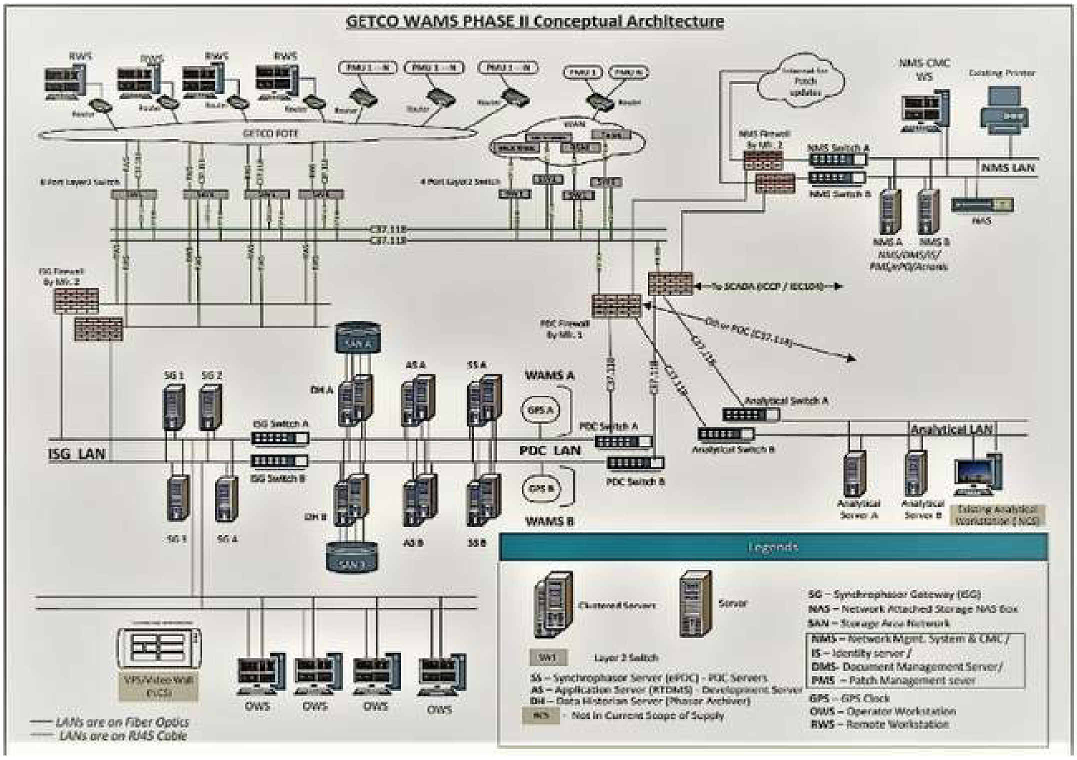


Fig: WAMS Architecture for GETCO Project

Description of WAMS

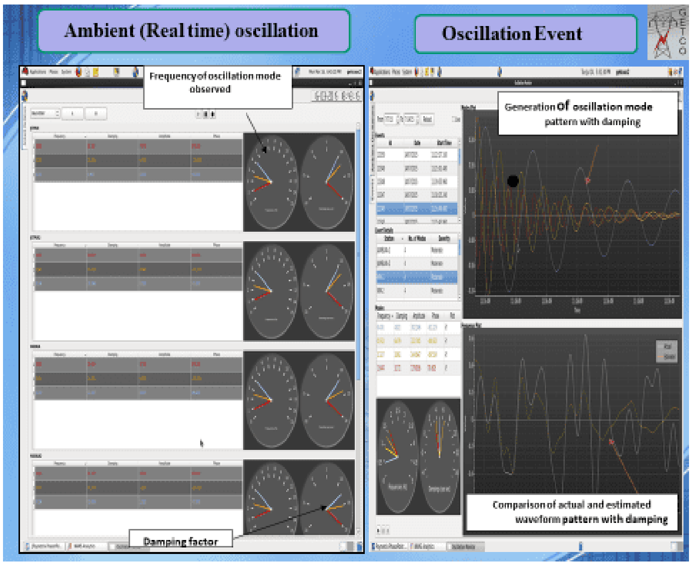
Wide Area Monitoring system comprises of the timing reference, PMU devices, Phasor Data Concentrator (PDC), communication layer, then higher level of the PDCs that are collecting data from the multiple substations, various Fire walls and routers, Historian Servers, visualization layer and finally at the top level the synchro-phasor-based applications.

In first stage, SLDC GETCO has developed three analytics based on WAMS with the help of IIT Mumbai.

1. Online Oscillation Mode identification
2. State Estimator
3. Voltage instability early warning scheme.

At present, the SLDC Gujarat is using WAMS and its analytics for

- Visualization of Magnitude, angle of all three voltage/ current phasor, Sequence components of voltage/ current phasor, Rate of change of frequency, Angular separation between pair of nodes, Voltage recovery post fault clearance.
- Analysis of Grid events within region, Type of fault viz. LG, LL, LLG, LLLG, Time of the fault and sequence of events, Fault clearance time, Summary of element on fault, Protection operation / mal-operation,1-phase auto reclosing in EHV transmission line, Performance of System Protection Scheme
- Detection of Ambient and Automatic Event Detection, Time, duration, amplitude, frequency of oscillations, Type of oscillation, Nature of oscillations viz. damped or un-damped, Modes present, their amplitude and damping factor.



Actual Screen Shot of Oscillation Detected in Gujarat Grid with good damping ratio.

In Wide Are Monitoring Phase 2, The work is under progress and Site Acceptance Test will start in January 2023 and project will be over by March 2023 will cover more than 70 percentage of GETCO stations of Gujarat Grid as below.

Total Substation under PMU Observation: 87 No (Only GETCO & Generating Stations.)

- Total Transmission Elements (Lines/BC/TBC/ICT/TR/GT): 1515 Nos
- Total Generating Station: 18 Nos
- In Phase II, PMU data sampling rate is 50 sample/Second.
- This reporting rate is first in Indian grid with one-year data storage facility at Control Center with @1000 TB Data storage provision.
- Control Center Designing capacity having 1650 PMUs & 3300 Feeder Data monitoring capacity.

Uniqueness of the Project

- This project is world's largest project as far as control center scaling is concerned as it has a capacity to handle 20 milliseconds data of 3000 PMUs.
- In this project, we are achieving all SCADA graphics and displays with performance so that in future we may think WAMS as a replacement of SCADA.
- GETCO is the only State utility doing such project.

Analytics based on WAMS

Looking to future, self-healing grid and WAMs based protection system; GETCO has planned for installing various analytics as under.

- Real time state estimation. -This analytics shows State of grid and generates alarm when state changes to system operator.
- Islanding detection and Resynchronization Application -These analytics detect islanding events in real-time and identify locations (PMUs) that are in the islanded region. The islanding detection algorithm uses a combination of frequency and phase angle difference signals to detect islands.
- Generation Trip and Load Trip Detection Application. These analytics automatically identify and detect generation trip and load trip events and indicate the location of the PMU closest to the generation/load trip. The automated event analyser picks key metrics (frequency, phase angle

differences, voltage, and Power Flows)

- Voltage/Angle Sensitivity, Voltage Stability Index Application -voltage and Angle Sensitivity algorithms are provided for use with PMU measurements to calculate sensitivities such as Power – Voltage (P-V), Reactive power – Voltage (Q-V) and power - angle sensitivity.
- Oscillation Source Location- This analytics includes Oscillation detection and source location.
- Real Time monitoring of System Inertia. –Due to, penetration of renewable it is utmost necessary to monitor System inertia. It is under development stage.
- Offline Advanced Study Tools / Report – This is useful for planning and post fault analysis

Advantage to System Operators and planners

- Time assessment of voltage/angle sensitivities to real power flows.
- Detect unknown forced oscillations in real time.
- Monitor inter area oscillations.
- Report on analytic results and alarm summary.
- System performance trends. Fast and accurate detection of islands.
- Detect Multiple islanding conditions and assist in system resynchronization after islanding
- Fast and accurate detection of generation trip/load trip
- Identification of first responding PMU location closet to generation trip location.
- Assess severity of event and system response.

Conclusion

WAMS and WAMS based analytics is a future of Grid Monitoring and Control.

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Monitoring of remote S/S through Robotics, Augmented Reality and Artificial Intelligence

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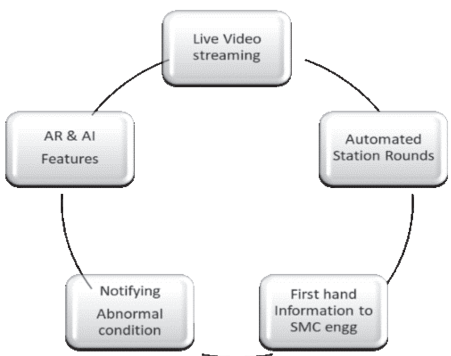
Introduction:

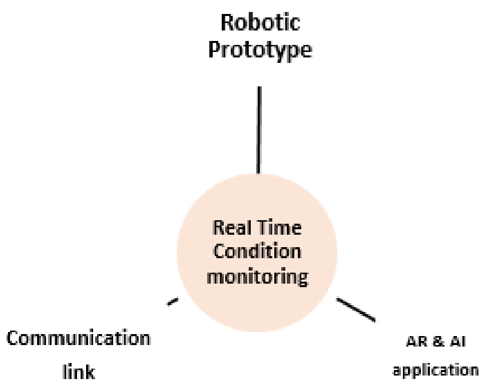
Remote RSS Overview

- Grant Road RSS is situated in premises of BEST Khetwadi RSS.
- Tata Power asset includes:
- 110kV GIS consists of: 110kV Carnac grant road & 110kV Parel Grant road line, 110kV Bus coupler.
- Relay room having CRP, RTU, Metering panels, UPS DB, Bus bar panel
- 110V & 48V Battery, chargers
- 415 V ACDB, 110V & 48V DCDB
- Trigger for Improvement:
- On duty SMC engineer in evening shift takes daily round of Grant Road R/S
- SMC engineer has to travel from Carnac R/S to Grant Road R/S
- Average traveling time is around 45 min,
- it may further increase subject to traffic situation
- SMC engineer fills checklist on GE-APM platform using Tab
- There are around 61 points included in condition monitoring
- This whole process takes around 2 hrs. for completion
- Time cycle for daily rounds needed to be reduced by eliminating personal visit
- Hence one automated mechanism was required for condition
- monitoring from remote location.

Solution:



System Overview:

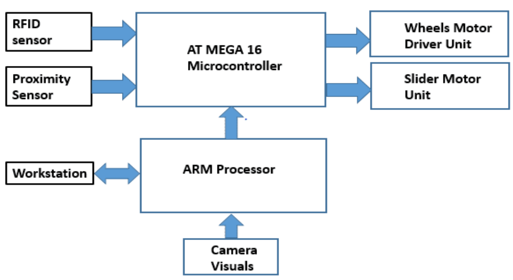


Idea Development:

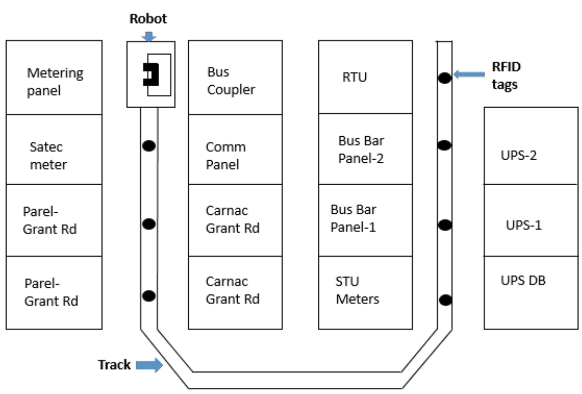
Robotic Prototype:

- Robot is a line follower, having line sensors for detection of path.
- It is having **Proximity sensor** for detection of obstruction
- Equipped with camera mounted on the slider for vertical movement
- Camera resolution is 12MP with 5X optical zoom
- **RFID** sensors are present for detection of RFID tags
- Remote command, Webserver development, relaying camera footage is done through **ARM** processor
- Motor controlling is done through **AT MEGA** microcontroller
- It is powered with **12V 7AH** battery enough for taking 3-4 rounds one with full charge

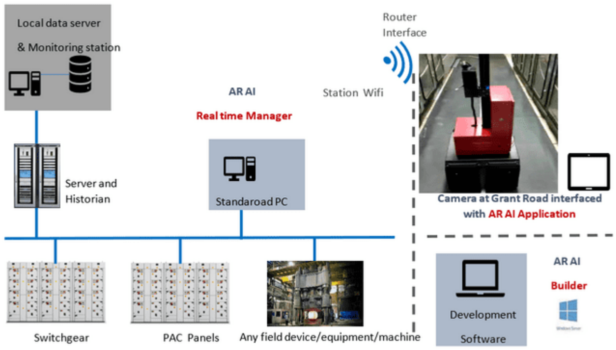
Block Diagram:



Schematic Arrangement at Remote SS Relay room:

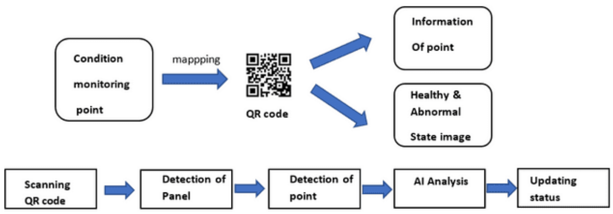


System Architecture:



Artificial Intelligence & Augmented Reality:

- Advanced Augmented Reality (AR) features were developed to superimpose real-time data & virtual objects on to the real system environment.
- AR application puts real-time information and relevant information at your fingertips, whenever and wherever it is needed.
- Digital application developed to guide real time operations and monitor the parameters of all Station Equipment.



Implementation Modalities:

1. All observations of O&M rounds are by using remote robot programmed to work automatically to take station observation round, using an AR platform on the workstation at Carnac RSS
2. The customized GUI display is designed to feed video feed from the Robot, real time AI based alarm display in a systematic way and without any manual interventions. The AR features will provide device selection, default status, data sheets, QR access, etc.
3. All AR features will be available on the Carnac workstation for the O&M engineer and information of the assets can be observed and synced with the central server

Challenges Faced:

- Space constraint in Relay room at Grant Road between two panels
- Camera movement in only vertical dimension
- RFID detection on uneven surface was difficult
- Camera with limited zooming capability
- Detection of QR code which were smaller in size
- Outages taken for fault simulation & cleared in minimum possible time

Benefits:

- Condition monitoring by O&M personals will have significant time saving and hence more stations can be added to the daily maintenance rounds
- **Easy of recording data** and abnormalities on-the-go
- Step by step procedures can be programed to restore the system faster while trouble shooting the devices / systems
- Complete station / system / equipment details will be available on the AR view, and hence carrying a physically all manuals, logs, logic data, data sheets will not be required. This will save significant time in maintenance operations
- Can serve as an effective tool for training new engineers on all different OEM makes and types of systems / equipment's

Future Prospects:

- Wireless charging for robot battery
- Historical server can be maintained for keeping records of round data, smoke detection, fire hazard detection, Thermal scanning, Gas detection using smart sensors can be incorporated in Robot design, Firefighting capability can be developed in system.

RDS- (Rural Digital Substation)

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Abstract

In present scenario, it is essential for any Power Distribution Utility to provide an uninterrupted supply to consumers. However, it is highly inevitable to prevent electrical network from fault. Hence, it is a big challenge for any utility to minimize the downtime whenever the fault occurs thereby increasing the reliability and customer satisfaction.

As a service provider, Utility has to ensure the reliability to all its consumers whether it is urban or rural. To assure the reliability to urban consumers most of the PSS (Primary Sub-station) are enabled with SAS (Substation Automation System) and can be monitored and controlled through SCADA system which helps in reduction of the power interruption time.

In case of rural the SAS was not implemented and there is no visibility of the network condition to PSCC (Power System Control Center). Due to lack of visibility of rural PSS to remote operator, there is increase in interruption time and decrease in consumer satisfaction. Additionally, revenue generated from the rural PSS is very less compared Solar Powered Smart Switching Multilevel Inverter for Smart Grid to Urban PSS. In order to make rural SAS cost effective some innovative solution was needed.

In view of the above, Rural Digital Sub-station (RDS) is a smart digital solution which helps to address the challenge. This RDS solution eliminates cost of CRP and provides complete SAS solution to have complete visibility to SCADA operator at almost 50% cost of conventional SAS solution. It facilitates distribution utility to minimize the revenue loss and increase the reliability index at very minimal cost

Keywords

PSS-Primary Sub-station, SAS-Substation Automation System, SCADA-Supervisory Control and Data Acquisition, PSCC-Power System Control Centre, RDS- Rural Digital Sub-station, CRP-Control relay panel, CT-Current Transformer, CB-Circuit Breaker, RTU-Remote Terminal Unit, HMI-Human Machine Interface,

WESCO- Western Electricity Supply Company of Odisha, PPP- Public-Private Partnership, TPCL-Tata Power Company Limited, TPWODL- Tata Power Western Odisha Distribution limited, AT&C- Aggregated technical and commercial, BCPU- Bay Control Protection Unit, ICE- International Electrotechnical Commission's, AC- Alternating Current, DC- Direct Current, DI/DO- Digital Input/ Digital Output.

1. INTRODUCTION

TPWODL (earlier WESCO) was incorporated in 1st Jan2021 as a JV of Tata Power (51%) and Odisha Government (49%) on the Public-Private Partnership (PPP) model. TPWODL took over the licensed area of operation of the Company is approx. 48,000 sq. km and covers nine revenue districts of Western Odisha. The TATA Power (TPCL) has made commitment to bring down AT&C Losses in TPWODL Utility to 9.08% in 10 years from the present losses of 27.56%. TPCL has committed to make the Capital Expenditure in the first five years to improve safety, technological and loss reduction. Besides, major improvements will affect in the reliability of network and consumer services.

For a power distribution utility, to improve reliability, it is very essential that the down time to its end consumers has to be minimal. It is, therefore, always the endeavor of the utility engineers to restore the interruption, if any, in the shortest possible time by isolating the faulty equipment and charging the healthy network. While this requires all the necessary information related to the fault should available at central control room to carry out the necessary operations. All PSS are automated to affect the operations from the remote-control room so as to reduce the interruption time of the consumers. This is arrangement is called as Substation Automation System (SAS). In conventional Substation Automation approach, control reply panels (CRP) used to be installed in control room and all control signals and CT connections connected in CRP. All

BCPU's then connected to RTU and finally communicating with SCADA system.

- For revamping of Rural PSS, following challenges where faced,
- Huge execution time for installation of CRP and RTU Panels
- Requirement of multiple outages
- New/ Refurbishment cables for status, control, and CT circuit
- Refurbishment of cable trench
- Refurbishment of control room/construction of control room

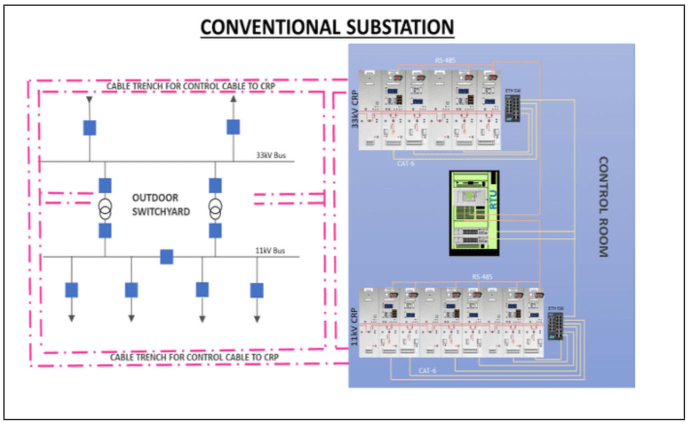

Fig. 1. Conventional Substation

2. RDS – Rural Digital substation

In order to avoid above challenges, it is proposed to have digital substation approach which in-turn, will help to reduce cost on big CRP's, control room, outages, and so on.

Rural Digital Sub-station (RDS) is a smart digital solution for refurbishment of PSS with digital communication. In RDS solution, every old CRP need to be replaced with small CRP which has complete CRP functionalities and the same will be installed near outdoor CT (Current Transformer) or outdoor CB (Circuit Breaker).

All these CRP's will be communicating over IEC61850 protocol and connected in ring/star topology to connect to RTU (Remote Terminal Unit) using CAT6 cable. Only RTU and local HMI (Human Machine Interface) will be installed in control room from where operator can monitor and control the PSS. This RTU will communicate with SCADA system over IEC104 protocol.

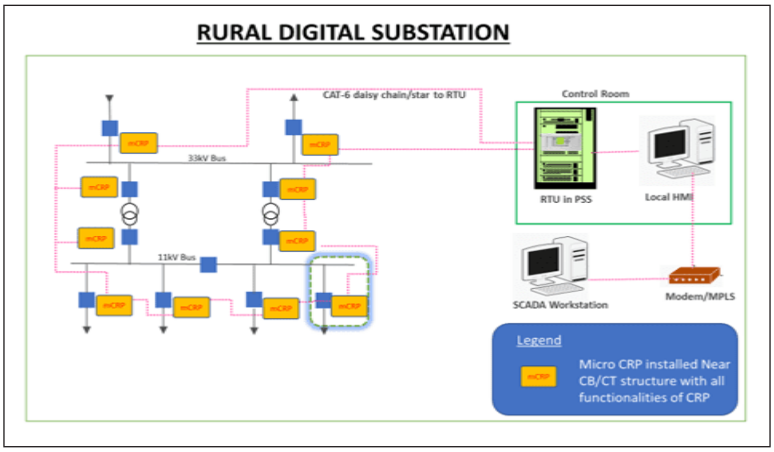

Fig. 2. Rural Digital Substation

3. Field Implementation

TPWODL has taken over WESCO to improve the reliability of power supply. If we go with conventional approach for implementation of SAS in conventional way there will multiple outages required and TPWODL might differ with their reliability goals which may leads dis-satisfactions in customer. Hence TPWODL developed innovative step to implement RDS for Rural PSS and successfully completed pilot installation of RDS at Attabira PSS.

Uniqueness and deployment at mass scale

RDS is a unique solution which gave tremendous benefits to its customer as well as TPWODL. Refer below table for comparison between conventional approach Vs RDS approach.
For calculation purpose, below parameter considered,

1. 33kV/11kV PSS
2. 2 Nos. 33kV line
3. 2 Nos. 33kV HT breakers, 2 Nos. 11kV Incomer breakers
4. 4 Nos. Outgoing feeders
5. 2 Nos. PTR

Attributes	Conventional Approach			RDS		
	Time in days	Approx. Cost (Lakhs)	Remarks	Time in days	Approx. Cost (Lakhs)	Remarks
Transportation of Panels from Store	3	1.5	Cost of transportation, services loading & unloading	2	1	Cost of transportation, services loading & unloading
ITC for 10 Panels	30	2.5	3 days per feeder and availability of outages	3	1	3 hours per feeder and availability of outages
Total Outages	3.3	4	4 hours per feeder	0.83	1	2 hours per feeder
CRP Feeder		21	CRP for 7 feeder protn.		10.5	CRP for 7 feeder protn.
CRP TRAFO.		10	CRP for 2 Trafo. protn.		6	CRP for 2 Trafo. protn.
Copper cables	5	14.4	60 meter distance from bay to CRP for CT, PT, Control, AC, DC cables	1	5.1	60 meter distance from bay to Control room for AC, DC cables 10 meter for control cable from CB, CT, PT to CRP
Size: Control room	90	30	3000 Sqft construction	30	10	1000 Sqft construction
Cable Trench	45	15	600 mt. per PSS	2	2	170 mt. HDPE Pipe/PSS
Vermin Proofing	2	0.05	For complete PSS	0	0	For complete PSS
Total (if control room is ready)	Max 30 days	98.45		Max 3 days	36.6	

* This data is calculated based on current conditions and skills of TPWODL, this may vary utility to utility

Table: Comparison between conventional approach Vs RDS approach

All over India, most of the utilities are facing similar type of challenges for grid modernization. RDS solution is a unique solution which can be deployed all over rural PSS in all utilities, which in-turn reduces copper consumption by almost 60%.

5. IMPLEMENTATIng RDS

RDS was successfully implemented in an already up and running. Following are the key modifications carried to implement the same,

Installtion of micro crp

Micro CRP is smaller version of CRP which have all functionalities like, control, protection, metering, remote communication, remote control and so on. This micro-CRP was installed below outdoor CB.

Before | After

Fig. 3. Installation of micro-CRP

Installtion of rtu

Indoor RTU along with RTU panel was installed in control room along with switches.

Before | After

Fig. 4. Installation of RTU

5.3 Laying of cables

- Only AC, DC and communication cable was laid from micro-CRP to control room.

- DI/DO signal were directly connected from CB to micro-CRP.
- CT and PT cable are also connected to micro-CRP

5.4 Use of hdpe pipe

As very few cables laying was involved, cable trench was replaced with HDEP pipe.

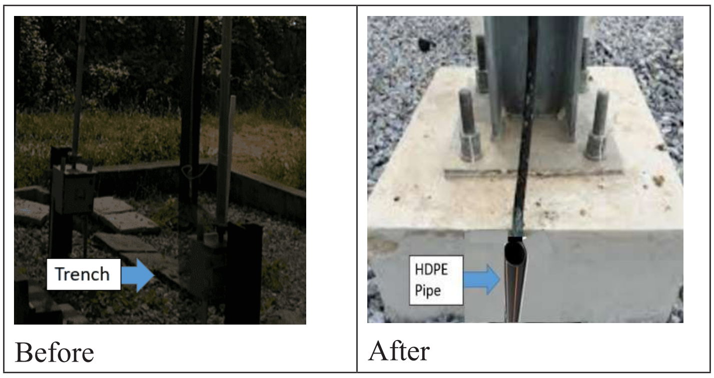

Fig. 5. Laying of HDPE Pipe

5.5 Local hmi

Local HMI installed in control room for local monitoring and control. Local operator can view all alarms, real-time condition of all the equipment's in PSS

Fig. 6. Local HMI

5.6 Use of plug type connectors

Pre-fabricated plug type connector will play plug and play role and reduced time in termination and wiring at site.

Fig. 7. Plug time connector

5.7 P2p through scada

RTU communicated with central SCADA over IEC104, point to point testing were conducted to verify all the DI/DO status on SCADA.

6. BENEFITS

6.1 To consumers:

Minimal Interruption Time: As RDS enables remote monitoring and control of PSS, quick response to various faults, results in reduction in interruption time.

6.2 To utility

- Improvement in the reliability indices
- Life of the transformers and associated equipment's will increase due to better monitoring and control of network through PSCC
- Pre-fabricated cables with plug type connection are reducing huge commissioning time and provide additional safety in isolating equipment's while taking outages, also helps to reduce fictitious alarms on account of oxidation and loose connections

6.3 To enviornment

Reduced use of transport vehicles for performing manual operations at remote PSS due to better visibility of complete network in PSCC Greater CO2 saving in kilograms, thereby reducing carbon footprint.

Conclusion

Distribution utilities can adopt an RDS approach to implement SAS in rural PSS to monitor and control the network for achieving the best restoration time for its consumers. Deployment of RDS for PSS helps in modernization of grids at almost 50% lesser cost than conventional approach with very minimal outages. Pilot implemented at TPWODL has been in operation for more than three months and with its satisfactory performance, it is intended to extend this to all Rural PSS in TPWODL and entire Odisha distribution

Innovative Smart Water Metering in a Multi-Utility Environment

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Abstract

The metering landscape of Abu Dhabi Distribution Company (ADDC) is very complex, consisting of about 70-meter models from numerous meter communication protocols such as DLMS, M-Bus, ModBus, Euridis, ST, Pulse etc. and includes about 700,000 electricity and water meters deployed in various scenarios such as buildings, villas, shops, bulk/interface points etc. A significant proportion of these meters are Point-to-Point (P2P) meters using cellular technology and it was a common practice to connect two different gateways, one each for electricity and water meter for the same premise. Subsequently, ADDC came up with a novel way of connecting both the electricity meter and the water meter in the same premise to the Head End System (HES) without the use of any external device such as gateway / data concentrator. In this innovative solution, the P2P electricity meter was used as a gateway for the water meter. It had an in-built cellular communication module to which the water meter was connected using a M-Bus cable. The design of electricity meters was changed to capture the registers from the water meter as well, store and send to the HES along with the registers of the electricity meter. This innovative solution helped ADDC to reduce the capex cost (no external device and reduced wiring), reduce operational and maintenance cost (reduced field visits owing to less complex architecture) and reduce the load on the telecom network as 2 different telecommunication channels were not required to be opened for a single premise. This solution is achieving the envisaged smart metering performance.

Keywords
smart water, head end system, point to point, innovative solution, multi-utility

1. Introduction

Abu Dhabi Distribution Company (ADDC) is responsible for the distribution and supply of water and electricity to consumers in Abu Dhabi. In line with the vision of ADDC to become a leading digital utility that delivers reliable and sustainable value to customers, smart electricity and water metering has been at the forefront of digital activities.

ADDC has a very complex metering landscape and comprises of over 70 electricity and water meter models having different types of data profiles and registers. In addition, numerous communication protocols such as DLMS, M-Bus, ModBus, Euridis, ST, Pulse etc. exist which further complicate the metering landscape. From the deployment perspective, numerous scenarios exist including villas, shops, buildings, etc. which are deployed in different configurations such as 1:1 (1 gateway connected to 1 meter), 1:2 (1 gateway connected to 2 meters), 1: Many (1 gateway connected to multiple meters) and Point-to-Point (P2P). A significant proportion of meters are P2P meters using cellular technology which is used in remote and scattered areas.

2. Issues in A Multi-Utility Environment

Apart from HES solution design complexity, arising from having different meter communication protocols and varied meter profiles and registers for both electricity and water measurements, powering the water gateway for remote communication is a major challenge. If a separate gateway is used for water meters, providing an AC power source for the water gateway is a challenge in most scenarios and the process is cumbersome. Alternatively, considering cellular communication modules (P2P configuration) for water meters was not viable owing to the power intensive nature of such meters.

3. Innovative Smart Water Metering

In order to avoid the cumbersome and expensive process of installing two different gateways (one each for the electricity and water meters), ADDC devised an innovative solution of connecting the water meter to the electricity meter using M-Bus cable, and by using the electricity meter as a gateway for the water meter. The solution required changes in the procurement, upgrading the design of meters, re-configuring the HES and field installation processes. The high-level solution architecture is mentioned in Fig. 1

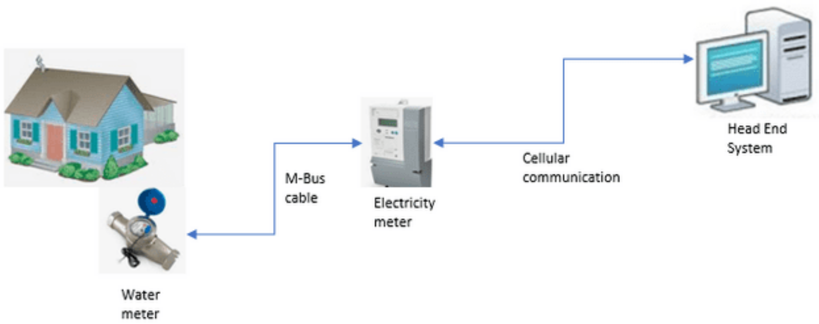

Fig. 1 Water meter registers sent over M-Bus to electricity meter

In order to capture the registers from the water meters, the design of electricity meters was changed to include an M-Bus port for connecting with the water meter. Also, the meter firmware was now able to capture 4 additional registers from the water meter, namely, 'battery life', 'error status', 'maximum flow' and 'total volume' which are read on an hourly basis (Fig. 2). These 4 registers were then appended to the registers related to the electricity meters and sent to HES. Electricity meter registers are mentioned in Fig. 3.

Another aspect of the updated electricity meter design is that upon receiving the pull request from HES, the electricity meter firmware is designed in a way to further request the water meter to send the water registers. This updated design for electricity meters was used for procuring new meters.
From the perspective of HES re-configuration, the updated datagram arriving at the data collection engine, comprising of the updated set of daily meter registers (from water meters and electricity meters), led to a

change in the data capture, data processing and storage mechanisms. In addition, with the additional load, the daily data gathering schedule was also enhanced.
Lastly, the field installation processes had to be re-drafted and required training to be provided to the field personnel and operations engineers for the updated installation work.

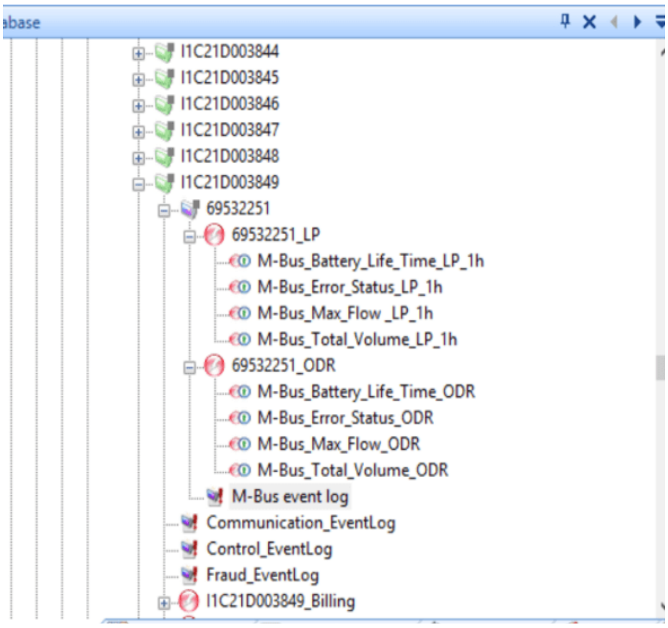

Fig. 2 Water meter registers sent over M-Bus to electricity meter

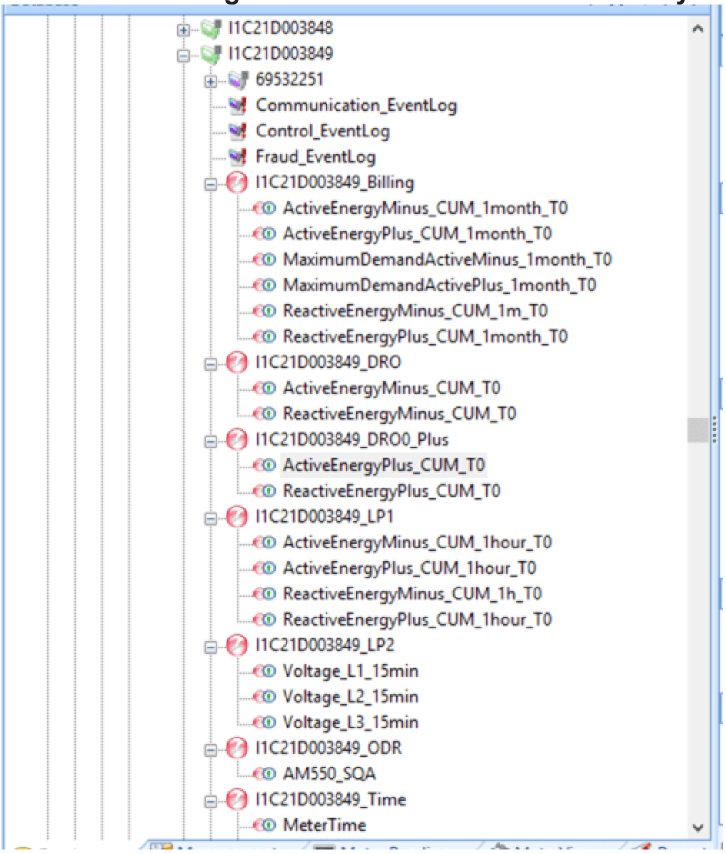

Fig. 3 Electricity meter registers sent to HES

4. Field Deployment of the Innovative Smart Meter Metering Solution

Fig. 4 depicts the field installation scenario in which the M-Bus port on the electricity meter is used to connect with the water meter using an M-Bus cable. Fig. 5 depicts the M-Bus cable connected to the water meter.

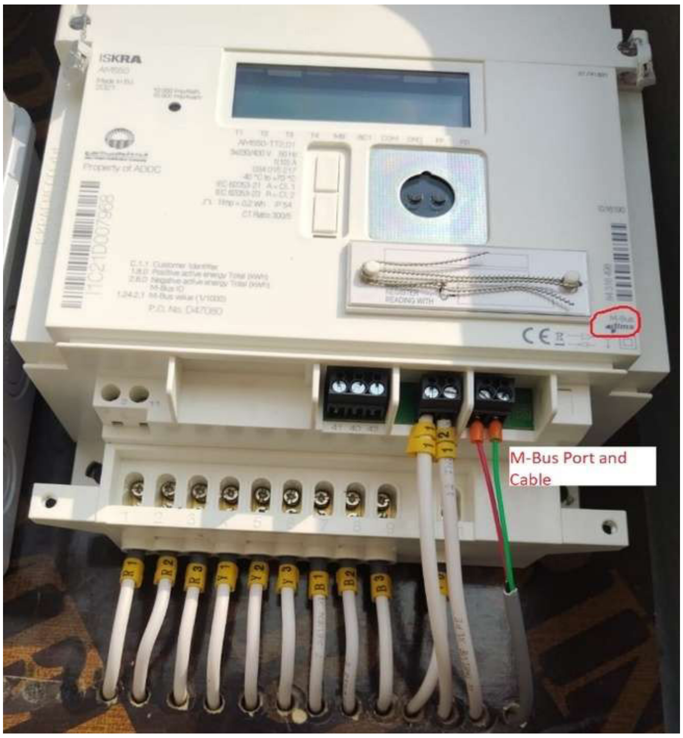

Fig. 4 M-Bus cable connected using M-Bus port of electricity water on the field

Fig. 5 M-Bus cable connected to water water on the field

HES receives the hourly/daily readings, and the cumulative volume recorded in HES is depicted in Fig. 6 and the cumulative active energy (import) is depicted in Fig. 7.

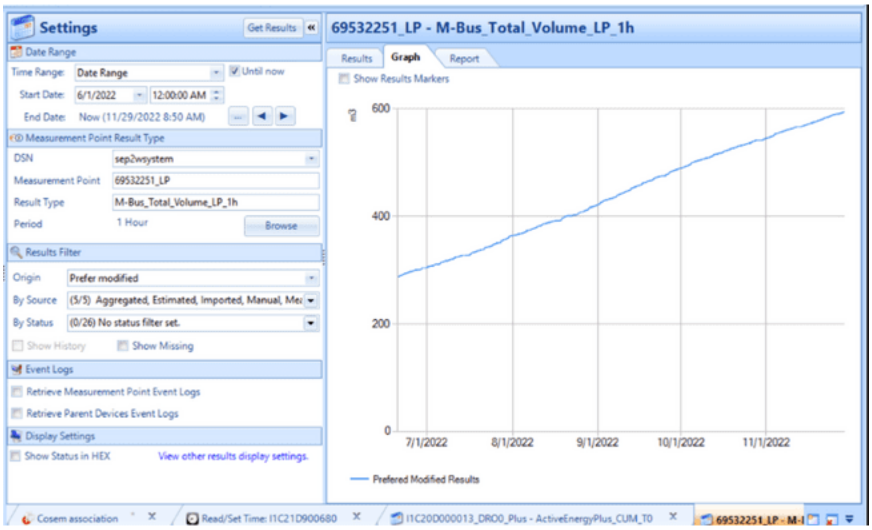

Fig. 6 Cumulative volume from water meter as captured in HES

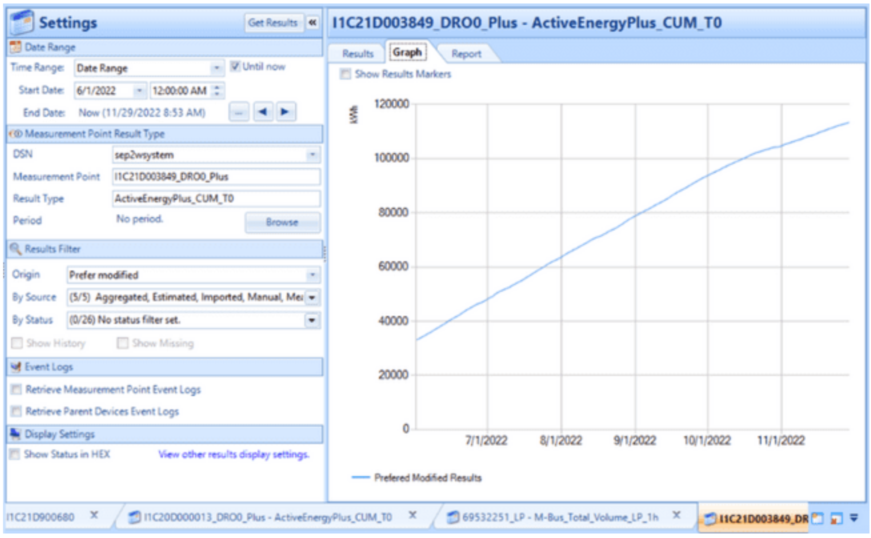

Fig. 7 Cumulative active energy (import) from electricity meter as captured in HES

5. Benefits of Multi-Utility Metering Using M-Bus

In a multi-utility metering scenario, M-Bus offers an innovative and scalable solution which avoids the use of installing data concentrators / gateways and reduces wiring to collect readings from water meters. This reduces the capital expenditure. As the solution architecture is less complex than regular smart metering, the operation and maintenance cost is also reduced.

Furthermore, as only the electricity meter is communicating with the HES, use of the second telecommunication channel is avoided in the same premise, thereby reducing the load on the telecommunication network. Lastly, with moderate changes in the design of existing smart meters, the envisaged objectives of both smart electricity and smart water were achieved.

6. Way Forward

The architecture depicted in this paper uses M-Bus and cellular technology to connect water meters with electricity meters using an innovative and scalable solution. However, to further improvise this solution, use of other technologies (apart from M-Bus) can be considered. On the telecommunication side, NB-IOT, 5G, narrow-band RF etc. can also be considered to be aligned with the technology evolution curve.

As only 4 water registers can be provisioned in the electricity meters, going forward, the meter firmware and memory can be updated, providing more water registers.

7. Conclusion

Multi-utility environments are intrinsically challenging in nature owing to the variety of meter communication protocols as well as powering the water meters for remote communication. Abu Dhabi Distribution Company devised a solution architecture using M-Bus technology to connect water meter with electricity meter thereby incurring huge savings in capital expenditure by avoiding use of additional data concentrators / gateways for water meters, reducing the operation and maintenance cost, and also reducing the load on the telecommunication network.

As only few water meter registers are needed on a daily-basis, this innovative and highly scalable solution works well in a practical scenario in a multi-utility environment. As shown in the snapshots of HES, this solution achieves the envisaged smart metering performance. Furthermore, this solution can be improvised and other meter communication protocols, telecommunication technologies and more water meter registers can be used.

Acknowledgment

We wish to thank the Department of Energy, TAQA, and Abu Dhabi Distribution Company for defining the vision to become a leading digital utility that delivers reliable and sustainable value to customers, and for providing the opportunity and guidance to implement one of the most complex smart metering programs. Furthermore, the constant motivation by our Management to be creative has been a driving factor for the team to achieve such innovations.

Regulatory Reforms Required to Enhance Distribution Level Flexibility in India

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Abstract

This paper argues that the operation of the existing regulatory framework is insufficient to deal with the evolution in discom functions. Discom organization and functions need an overhaul to enable the adoption of active network management that is critical for the energy transition. The paper identifies the shifts required in the regulatory practices and frameworks. Separating the different discom functions and apportioning costs to its users are the most critical elements of the regulatory transition, a process that has already begun in some states. Though these reforms have been advocated before, they have not yet been widely discussed in the context of the energy transition in India.

Keywords

regulation, distribution system operator, distributed generation, discom, functional separation, wires, and supply business

1. Managing Variability is Changing the Roles of Distribution Companies

Flexibility across the electricity value chain will be the cornerstone of the energy transition [1]. Indian states with high renewable energy (RE) concentrations already face grid integration challenges and require resources that can provide flexibility within seconds [2].

Expansion of distributed RE generation (DRE), distributed energy storage, and electric vehicle (EVs) charging increase variability in both demand and supply [3]–[8]. DRE disrupts the traditional business model of distribution companies (discoms) and may lead to what is known as 'utility death spiral'.1 Technical challenges include problems of reverse power flow, voltage and frequency regulation, forecasting generation, etc. [9].

Decentralizing Flexibility Management

Discoms must actively manage their networks to contain costs associated with variability and transition into a distribution system operator (DSO). Active network management (ANM) includes demand and supply forecasting, managing two-way power flow, regulating voltage and frequency, active demand response, utilizing short-term markets effectively, etc. [7], [10]–[15]metering and settlement of transactions in electricity (SAMAST.

New business models like virtual power plants, peer-to-peer (P2P) trading, etc. that can be implemented through intermediaries like aggregators can support the discoms in ANM [16].

1 Utility death spiral is the term used for the vicious circle of utilities losing their customer base to DRE and to make up for the loss must increase tariffs, driving even more customers to DRE.

Leveraging the available technology requires retail market transformation, a shift in the roles of existing players, and the entry of new players in the market [17], [18]. We limit the discussion here to enabling discom-related transformations.

Challenges with the Existing Regulatory Framework

Currently, the wheeling (or wires) and supply business of discoms are integrated without any functional separation [19]. ANM will change discoms' expenditure profile and ratio of capital and operating expenditures. ANM will increase operational costs [12] and DRE can defer capital investment in network upgrades [10], [13]. However, discoms will be disincentivized from incurring expenses on ANM since they will not form part of the rate base and generate no return on equity.

Power purchase costs make up the largest share of the expenses (up to 80-90 per cent) and do not leave sufficient financial space for other expenditures. Further, DRE decreases the discoms' consumer base from which it can recover expenses.

Hence, discoms also levy open access (OA) charges, wheeling charges, banking charges, cross subsidy surcharges (CSS), additional surcharge, etc. These charges are recovered as non-tariff income and, other than the CSS, are supposed to be recovered for specific expenditures on fixed costs or backing down conventional power. However, the calculations for these charges lack rigor leading to disputes (e.g., Petition Number 49/2021 before the Haryana Electricity Regulatory Commission). The Appellate Tribunal of Electricity (APTEL) has noted in Tamil Nadu Spinning Mills Association v. Tamil Nadu Electricity Regulatory Commission (TNERC) (Appeal Number 191/2018), in the context of banking charges, that charges must be calculated after "undertaking a study based on requisite data properly gathered and analyzed."

2. Required Regulatory Shifts

Fixed Cost Recovery Through Fees and Charges

The fixed costs component that we see on our retail bills do not translate to the discoms' actual fixed costs. OA consumers and DRE owners use the infrastructure but do not need the energy. Hence, discoms need to calculate, apportion, and impose fees based on who is using how much of the infrastructure [20], [21]. Maharashtra tried to adopt this approach by imposing grid support charges on rooftop solar consumers enjoying net-metering benefit. But without a policy and legislative backing the step faced litigation.

Fees means that only the incurred expenses are recovered and there is no profit. This aligns with the philosophy that network operation should be independent and hence revenue neutral [22].

Valuing Services

Electricity's value is dependent on when it is consumed and its purpose [23]. Utilities and regulators must formulate a methodology to quantify the savings due to distributed generation and storage systems and compare it with the cost of fresh investment in network infrastructure [24].[2] This framework can help in pricing the services more accurately and transitioning away from levelized cost based pricing. However, assessing the value and pricing the flexibility services will be a challenge since there is no baseline at present which reflects the value addition of these services to the system [14].

Customized for States

India's load profile is highly variable and specific to each region. Each discom will have a different structure and function [11]transmitted, distributed, or even consumed. It has opened new opportunities for the Indian power sector to redefine its existing operational and business models to cope with the unique challenges and follow an approach that maximizes social welfare across all energy supply chain

1 In the USA, many state regulators consider investments in DRE as 'non-wires alternative' to grid investments and accordingly regulate them as equivalent to capex [25]. In EU, Article 14/7 of the EU Electricity Directive requires DSOs to consider DRE as an alternative to network expansion.

segments. This journey will have significant impacts on the Distribution companies (DISCOMs since the costs and benefits of ANM vary depending on local load and network conditions [20].

Functional Separation of Wires and Supply

Discoms must segregate functions, calculate the network costs, and expand fees and charges regime. States like Delhi, Madhya Pradesh, Maharashtra, etc. already divide discom business plans into retail supply and wheeling business. This must become the normal practice for all states. The functional separation of wires and supply business has been advocated for many years [26], [27]. However, the perspective of its necessity in expanding renewable energy has been missing.

Policy Direction

Currently the state regulators follow the National Tariff Policy (NTP) to develop their tariff regulations. The NTP must incorporate these changes and provide the requisite policy direction. Without an overarching policy, discom transition will be ad-hoc. For example, the lack of express authority means that discoms cannot ask for data from market participants which is a sine qua non for ANM [28].

Key Considerations

Discom Capacity

The required shifts in regulatory practices and processes require capacity, resources, and will that have been lacking so far. For example, discoms in Rajasthan are required to prepare detailed asset registers but it has been stalled due to capacity constraints. These issues are viewed as 'legacy' discom issues even when there has been significant political will towards advancing RE deployment. Bringing in the RE lens to discom legacy issues can give them the required political and popular impetus.

Whether the DSO Should Be Profit Making or Revenue Neutral?

Existing literature on DSO envisages a revenue neutral and independent operator on the lines of the existing state and national system operators [29]. However, initially they will be housed in profit-seeking discoms and there is potential of conflicts of interest. The aim should be to have separate entities as DSOs. A new path to carriage and content separation hence emerges, where operations are segregated in substance prior to the organizations. Eventually, hiving off discoms will become easier with cleaner asset and cash registers.

Source of Discom Revenue

The proposed reforms clean up the operations of the discoms and make them more streamlined. As sales decrease and capital investment reduces, discom operations will be trimmed. They may not remain the behemoths they are now, and this is a major political economy factor to consider. Hence, these reforms must be undertaken step by step. Eventually, depending on the state context, discoms may remain as the provider of last resort for the underserved and as base load providers, etc.

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Exploring Virtual Power Purchase Agreements for increasing RE penetration in C&I segment of India

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Abstract

India has updated its Nationally Determined Contributions (NDCs) which includes a bold commitment to achieve 50% of the generation capacity from non-fossil fuels by 2030. To achieve this target, higher adoption of Renewable Energy (RE) by the Commercial and Industrial (C&I) segment is imperative as this consumer segment is responsible for nearly 50% of the total electricity consumption in the country.

Currently there are various procurement mechanisms available for C&I consumers in India to procure RE and green attributes. These include procurement through open access, green markets, renewable energy certificates, and green tariff. However, there are few challenges associated with each of the procurement mechanisms. An innovative model like Virtual Power Purchase Agreement (VPPA) could provide benefits like hedging the RE generator against market price volatility and at the same time pave way for corporates to meet their sustainability targets and internal green mandates. VPPA can also provide RE generators a firm revenue stream. Most importantly, VPPA can provide an additional means to reach the country's 2030 RE target.

The aim of the paper is to introduce the concept of VPPAs in India. The paper is segmented into four sections: (i) Introduction to VPPA – operating framework and payment mechanism (ii) Relevance of VPPA in Indian context (iii) International scenario (iv) Way forward for VPPA implementation in India.

Keywords

Virtual Power Purchase Agreement (VPPA), Commercial and Industrial (C&I) consumers, Green Tariff, Open Access, Renewable Energy Certificate, Green Markets.

INTRODUCTION TO VPPA

Operating framework of a VPPA

A Virtual Power Purchase Agreement (VPPA) is a bilateral contract between a Renewable Energy (RE) generator and a Commercial and Industrial (C&I) consumer under which the RE generator transfers only the green attributes to the consumer in the form of green certificates. There is no physical transaction of power between them under this arrangement – hence the name 'virtual.' The RE generator, after transferring the green attributes of the power generated to the consumer, is free to sell the physical power on the power exchange as brown power. The consumer (buyer) is also free to source its physical power requirement through other procurement mechanisms, which may be through a distribution company (DISCOM), power exchange, bilaterally, or in a captive mode. Figure 1 illustrates the operating framework under which a VPPA operates [1] [2].

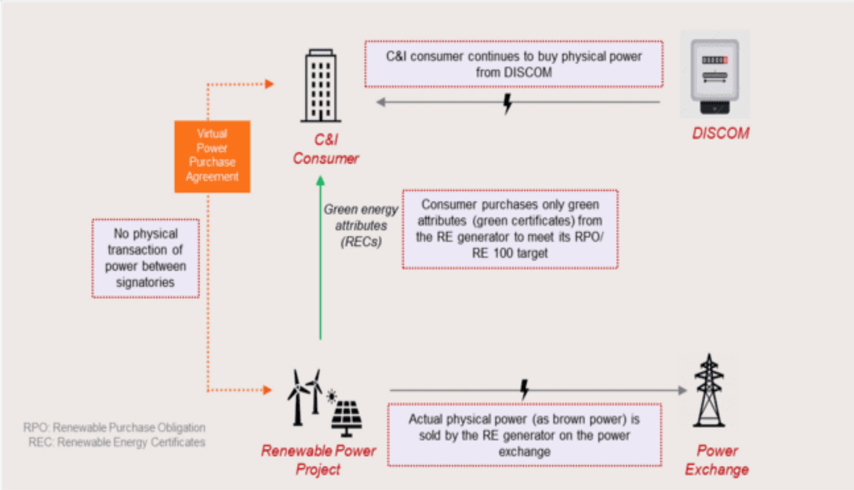

Fig 1: Operating framework of Virtual Power Purchase Agreement

The procurement of green attributes under a VPPA provide more flexibility and strategic advantage to the C&I consumer as compared to physical procurement of green power to achieve its sustainability targets. Physical green power is available for a limited period, thus making it difficult for the C&I consumer to replace its 100 percent of energy consumption with green energy. Further, aggregation of green attributes can prove to be beneficial for large consumers who have fragmented demand across various locations, which at times makes it difficult for them to attain their green and sustainability targets. Under VPPA, such consumers can aggregate the green demand and purchase corresponding green attributes without having to sign multiple power purchase agreements and complying with different rules and regulations of various states in India.

Payment mechanism under a VPPA

The underlying principle of price settlement between a C&I consumer and a RE generator in a VPPA contract is ‘Contract for Difference’ (CfD) which hedges both the entities from the market volatility.

While entering into a virtual power purchase agreement, the RE generator and the consumer sign the agreement at a pre-determined ‘strike price’ at which the green attributes will be exchanged between the two entities. The strike price is then compared with market clearing price on the power exchange where the generator sells the physical power as brown power. If the market price is higher than the strike price, then the generator is responsible for returning the price to the consumer. However, if the market price is lower than the strike price, then the consumer compensates the RE generator for the difference. This provides a desirable hedge on power price for both the entities involved. In the meantime, consumer continues to buy physical power from the DISCOM (or other procurement mechanism) to meet its energy requirement and pays accordingly as per its energy consumption.

For instance, if the VPPA is signed at a strike price of INR 4/kWh for the transaction of green attributes, and the RE generator sells its power on the power exchange at a market discovered price of INR 5/kWh, then the generator would compensate the consumer for the INR 1/kWh difference (outside the market). Similarly, if the power is traded at INR 3/kWh on the power exchange, then the consumer would pay INR 1/kWh to the generator (outside the market). Figure 2 illustrates the payment mechanism under a VPPA.

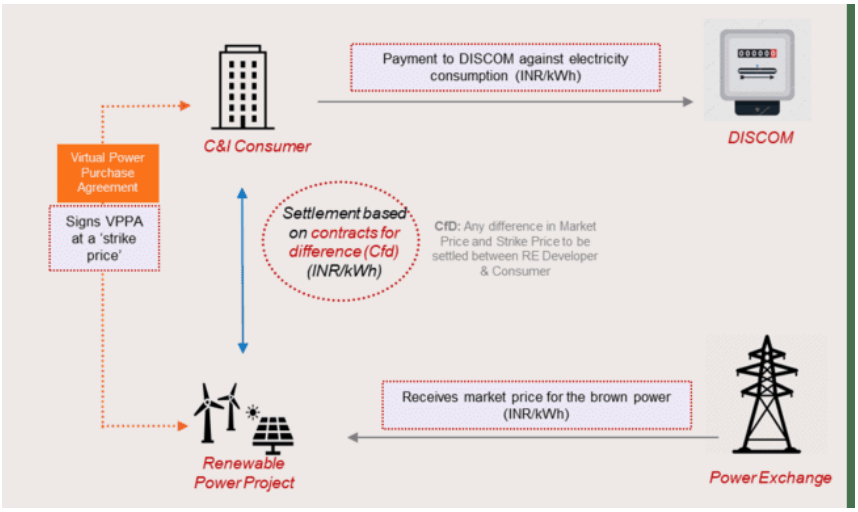

Fig 2: Payment mechanism under a Virtual Power Purchase Agreement

Advantages of a VPPA

VPPA is a win-win-win for all the entities involved in the transaction – C&I consumer, RE generator and distribution companies. Table I highlights the advantages that VPPA offers to different stakeholders across the value chain.

Table I Benefits of vppa across the value chain

C&I Consumer	RE Generator	DISCOMs
C&I consumer with fragmented demand across various locations can aggregate green energy attributes and meet their sustainability goals under one VPPA contract (multiple physical PPAs are not required)	VPPA provides a firm revenue (in the form of strike price) to the RE generator until the duration of VPPA contract. This would encourage addition of merchant RE plants as well.	Under VPPA, the DISCOM will not lose its heavy demand C&I consumers as the consumers will continue procuring physical power from DISCOMs.
Since there is no transaction of physical power, the C&I consumer is not impacted by different open access regulation and charges across various states.	While selling the green attributes to the consumer under VPPA, the RE generator is immune to the fluctuation in market prices, (Unlike the scenario if RE generator was selling the green attributes in the Renewable Energy Certificates (REC) market of India.)	
The consumers can meet their sustainability targets through purchase of green attributes from the RE generator and can assign the attribute to a particular project, thus supporting addition and financing of new RE projects.	Ease of operation – the RE generator need not comply to different regulations across different states	
The C&I consumer is hedged against the market volatility as it buys the green attributes from the RE generator directly at a pre-determined 'strike price' under VPPA.		

In addition to the advantages mentioned above, the VPPA framework will also help in meeting the 2030 RE target of India by enabling an additional contractual framework for RE, which can support the penetration of RE merchant plants and boost their financing.

RELEVANCE OF VPPA IN INDIAN CONTEXT

C&I consumer segment is the largest contributor in the total energy demand of India – contributing to around 50% of the total annual energy consumption of the country, as illustrated in Figure 3 [3]. As of June 2022, 23 Gigawatts (GW) of Corporate RE power purchase agreements (PPAs) have been signed in India [4], which correspond to only 7% of the total C&I consumption. Figure 4 illustrates the total C&I RE capacity installed in India as of June 2022.

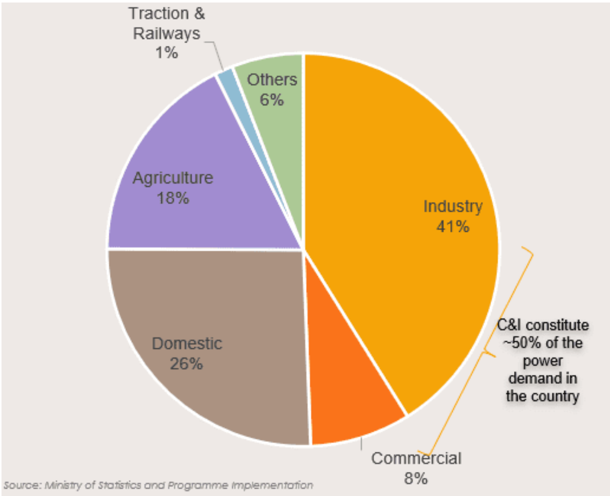

Figure 3: Consumption of Electricity (BU) by different sectors in India (2020-21)

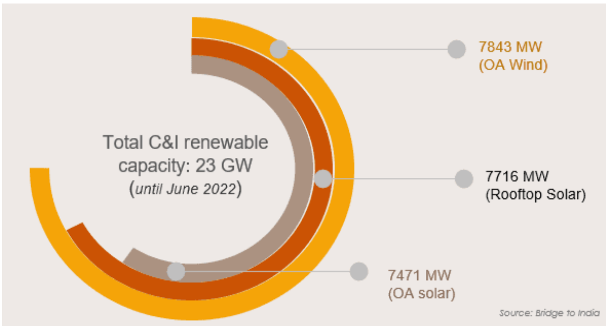

Figure 4: Total installed RE capacity for commercial and industrial segment (until June 2022)

The low penetration of RE amongst C&I segment could be attributed to various challenges associated with existing RE procurement mechanisms, which are discussed in this section. Currently, there are four RE procurement mechanisms available for C&I Consumers in India:

1 Green Energy Open Access (OA) through physical power purchase agreements: OA allows consumers with a connected load of more than 100 kW to procure green power directly from RE generator. To procure power through this mechanism, consumers need to follow open access regulations of various states and need to pay various charges (additional surcharge, cross subsidy surcharge, etc.) depending on the state regulations.

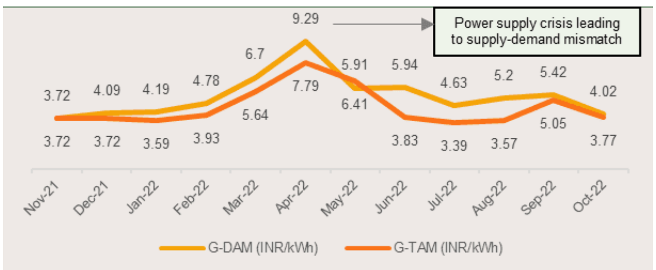

Figure 5: Existing Green Energy Tariffs in India

Green Tariff: Consumers can buy green power from the DISCOMs by paying an extra premium over and above the retail tariff. However, since green tariff is priced higher than the conventional retail tariff with premium ranging from INR 0.5-5.55/kWh, the uptake of green tariff has been low amongst the consumers. Other reasons like unavailability of surplus renewable power with the DISCOM (after meeting the DISCOM's renewable purchase obligation (RPO)) and retaining of green attributes by the DISCOMs (if the RE consumed by a consumer is more than its RPO obligation) also contribute to the limited uptake of green tariff in states. Figure 5 illustrates the existing green tariff in India.

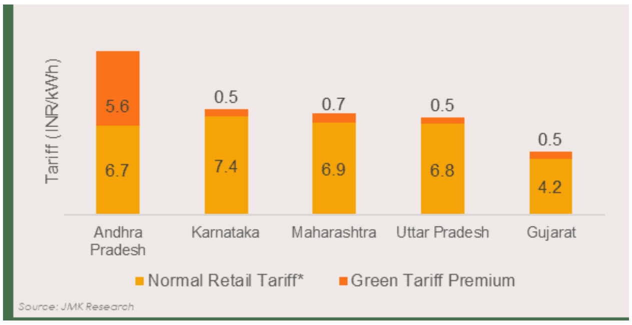

Figure 6: Clearing Price Trend of Renewable Energy Certificate Market in India

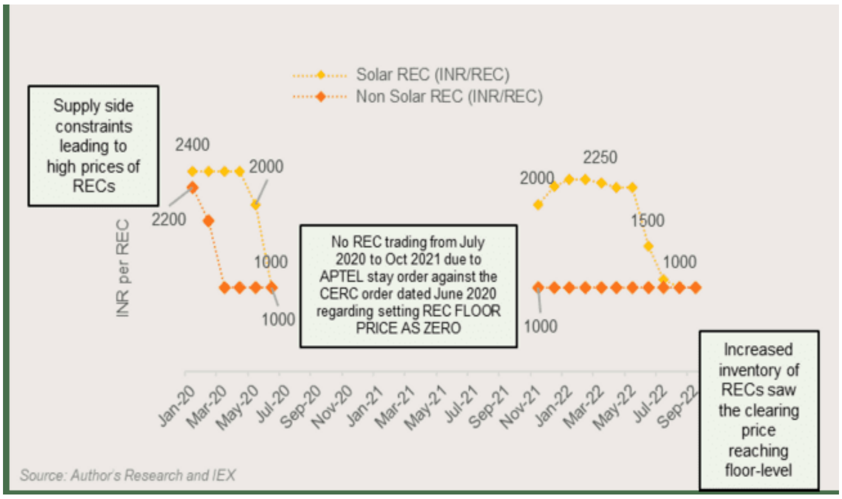

Figure 7: Price Trend of Green Day Ahead Market and Green Term Ahead Market in India

3. Renewable Energy Certificates: Consumers can buy green attributes/green certificates on the power exchange on Renewable Energy Certificate (REC) market. However, reasons like low liquidity of REC market and price volatility have led to limited participants on the REC market. Figure 6 illustrates the fluctuation in the clearing price of REC since 2020.

4. Green Markets on Power Exchange: Green Term Ahead Market (G-TAM) and Green Day Ahead Market (G-DAM) are the two market segments available on the power exchange where consumers can buy green power. Currently, G-TAM and G-DAM account for only 6% of the total transactions on the Indian Energy Exchange (as of September 2022). Volume of transactions on these two market segments is low since there is limited availability of merchant RE capacity or excess RE generation which can be sold in the market. This leads to mismatch in the demand and supply of green power on the power exchange which causes fluctuation in the market discovered prices. Figure 7 illustrates the volatility in discovered market price over the last one year.

From the above discussion, it is evident that there is a need for an additional RE procurement mechanism to increase the penetration of clean energy in the C&I segment of India. New procurement mechanism like VPPA can be explored and adopted as it provides a strategic advantage over physical PPAs, and hedge participants against market volatility. Ideally, this model suits large corporates with fragmented demand across different locations and states. VPPAs can also enable financing of new projects through firm revenue, thus supporting addition of new RE capacity in India.

VPPA: INTERNATIONAL SCENARIO

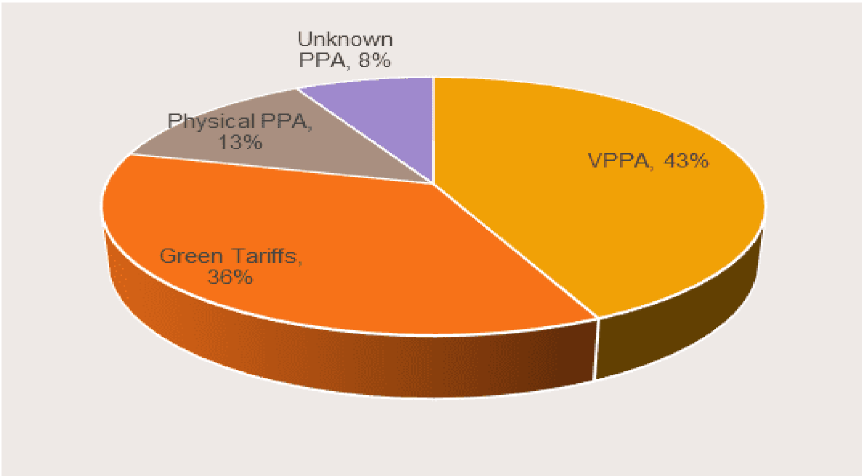

Figure 8: Corporate offsite solar power procurement in the United States of America

Globally, VPPAs have become a popular tool for corporates to increase the share of renewable power in their consumption. In the United States, VPPAs account for 43% of total corporate offsite solar power procurement. Figure 8 illustrate the share of various procurement mechanisms in procuring offsite solar power in the United States (U.S.).

Several companies have also recently signed VPPA in the U.S. to meet their RE100 goals. Table II highlights a few key VPPA deals signed by corporates in the U.S.

Table II Few recent VPPA contract signed by corporate companies in the united states

Corporate Name	Industry type	Contracted capacity	Type	Duration - Year	Provider
Huhtamaki	Food Packaging	42 MW	Wind	12	NextEra Energy Resources
AT&T	T&Ta	1,150,023,740 kWh/year	Wind	5	NextEra Energy Resources
AT&T	T&T	816,801,570 kWh/year	Wind	15	NextEra Energy Resources
Mars, Incorporated	Food & Beverage	726,633,050 kWh/year	Wind	20	Mesquite Creek Wind, LLC
Walmart Inc.	Retail	629,124,000 kWh/year	Wind	12	Geronimo Energy

Microsoft Corporation	T&T	222,812,000 kWh/year	Solar	15	Pleinmont Solar 2 LLC
The Clorox Company	Consumer Products	160,000,000 kWh/year	Solar	12	Enel Green Power North America
Apple	Electronics	111 MW	Wind	12	Geronimo IL Wind Project
Apple	Electronics	134 MW	Wind	12	power VA Solar Project

a Technology & Telecom

Other countries like Canada, the United Kingdom, and Australia have also now adopted the VPPA framework, though the mechanism is still at a nascent stage in these countries.

WAY FORWARD FOR VPPA IMPLEMENTATION IN INDIA

- To implement or even to bring this framework in India, it is important to sensitize and educate the stakeholders across the entire value chain (DISCOMs, RE developers, Corporate Consumers, Power Exchanges, Regulators) about VPPA.
- Extensive stakeholder consultations are required to establish a regulatory compliance and operating framework of the mechanism. The consultations should aim at:
- Developing operating mechanism of VPPA
- Establishing payment and settlement mechanism
- Identifying risk and mitigation strategies
- Establishing regulatory compliance requirements
- Developing stakeholder and regulatory responsibility matrix
- Based on the consultations, an action plan could be prepared for VPPA implementation in India.

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Smart Solutions for Strengthening Drinking Water Supply Value Chain

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Abstract
At the end of this decade (2030) the water demand is expected to outstrip supply by 40% [1]. Yet, 25-50% of all distributed water is globally lost [2] due to leakages, detoriating infrastructure, and other irregularities. This impending crisis can cost some regions up to 6% of their GDP, trigger migration and conflicts [3]. Beside such pressing problems, water utilities need to focus on process optimization for staying cost effective and align with energy reduction targets. This paper reviews practical solutions that can be adopted to strengthen the entire value chain of water supply system (treatment, transmission, and distribution) for sustainable growth.

Keywords

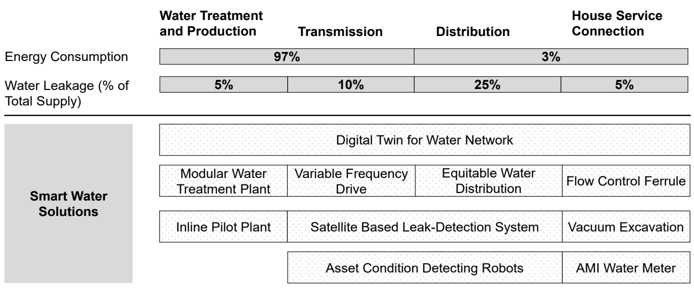
Leakage, utilities, process optimization, energy, water supply system, sustainable growth

1. Challenges in Delivering Safe Drinking Water

Water is essential for sustenance, yet 1/3rd of world population lack access to safe drinking water [4]. Three primary challenges delivering potable drinking water are contamination, leakages and rising energy cost for water treatment and transmission. As treatment methods of industrial and biological contaminants are standardized, this paper will focus on the latter challenges.

A. Water-Energy Nexus

Municipalities across globe spend 40-60 % [5] of their total energy consumption on pumping water from the source to the end user. Safeguarding natural resources like energy is of paramount importance while providing affordable drinking water to 8 billion people across the globe. Water-energy nexus is evident, and it is only wise to minimize energy consumption and extraction of water, beyond nature's capacity of regeneration.



B. Water Loss Due to Pipeline Leakage

Across the globe almost 335 billion liters [6] of water is lost every day due to leakage as ageing infrastructure and hydraulic conditions demand immediate attention. Utilities extract water and consume more energy to offset leakage loss. Leakages and water theft add on to Non-Revenue Water (NRW) which hits the profitability of water utilities (refer figure 1).

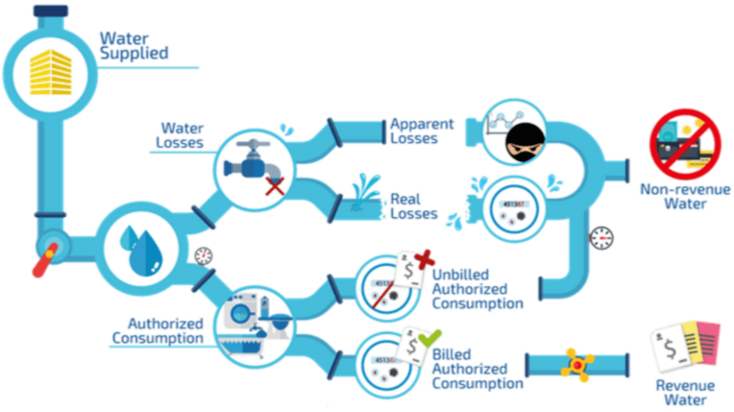


Fig 2 Downstream breakdown of supplied water [7]

Smart Solutions To Address Challenges Faced By Water Utilities

Utilities have options to select solutions based on industrial maturity in their respective geography and available funding. Figure 2 below, depicts potential smart solutions across water value chain. Further, Table 1 comprehensively enlist available contemporary smart water solutions and provides details such as relative investments, technology involved, application and impact of the solutions.

Table 1: Smart water solutions

Solutions	Functional Area	Application	Investments	Technology	Impact
Variable Frequency Drives	Transmission (Pumping Stations)	Refer II. A	$	Refer II. A	Refer II. A
Digital Twin for Water Network	Across Value Chain	Refer II. B	$$	Refer II. B	Refer II. B
Satellite based leak-detection system	Transmission, Distribution	Underground pipes can leak treated water for decades without having any visibility on the surface. Research on reflectivity of treated water has made it possible to detect leak locations accurately by capturing satellite images of area of concern.	$$$	Synthetic Aperture Radar (SAR)	Water network of a large city can be examined at once to start its journey towards leakage reduction. Utilities can then move on to traditional leakage detection techniques.
Leakage/ Asset Condition Detecting Robots	Transmission, Distribution	Self-propelling robots introduced inside pipe network capture photograph of pipeline and flags detected leakage, degraded material condition aided by AI/ ML	$$	AI/ML based Anomaly Detection	Considerable investments required for overhaul. Lack of objective condition assessment deters funding. Robots validate needs of asset replacement without any technical bias.
Equitable water distribution	Distribution	Distribution network is divided into District Metering Areas (DMA). Regulated supply at the entry point of each zone by using solenoid operated flow control valve (FCV). Apportioning water supply for each zone to the no. of customers served.	$	IoT, SCADA Programming	Addition of FCVs and regulating the daily/ hourly flow set points via SCADA avoids over-withdrawal of water at one zone at the cost of another fed by same pumping station.
Vacuum Excavators	Distribution	Utility strikes are the most common hazard while digging buried utilities. Vacuum excavation ensures safety of field engineers and minimize downtime due to sudden utility strike (electrocution/ leakage)	$	Vacuum Excavation	Safe working environment for field engineers and public keeps employees motivated and generates goodwill
AMI Water meters for Customer engagement	House Service Connection	Utilities have built customer engagement modules around AMI. Spike in hourly consumption triggers a message to the consumer which avoids surprise during monthly billing.	$$$	Radio Frequency Communication	Customer delight and retention follows customer engagement. AMI meters provide an opportunity for the utilities to leverage the live data and engage customer on consumption and leakages

It can be seen from figure 2 that the potential to save energy lies in the pumping stations as maximum energy is consumed upstream and *Variable Frequency Drives (VFD)* offers solution in this functional area, while *Digital Twin for Water* encompasses the entire value chain. In this section we discuss these two solutions which are effective to make water networks energy efficient and reduce the leakage.

A. Variable Frequency Drives

Motors attached to water pumps are designed for rated capacity (kw) commensurate to peak flow requirements. Such peak flow demand occurs for a very short duration over 24 hours of daily pumping cycle. A typical pump operates below rated capacity as pumps are operated at lower flow rate for most of the time. Such duty cycle in water network provides potential for application of VFD for substantial energy savings (refer figure 4).

Power consumption for pump-motors attached with VFDs reduce faster than the demand flow of the water network. Though VFDs are upfront capital expenditure, energy savings not only offset the cost liability but delivers continued long-term benefits for the system. Installation of VFDs ensures optimal pressure across water network, which enhances the longevity of pipes. Switching on/off pumps is associated with another phenomenon called water hammer. Sudden change in flow results in pressure surges when a pump is switched off or on.

Uncontrolled water hammer wears out inner lining of pipes and causes pipe burst in extreme cases. Vibrations due to water hammer also causes long term damage of valves and other appurtenances. VFDs with soft start addresses the problem and hence avoids leakage and operational downtime which in turn enhances overall resilience of water network.

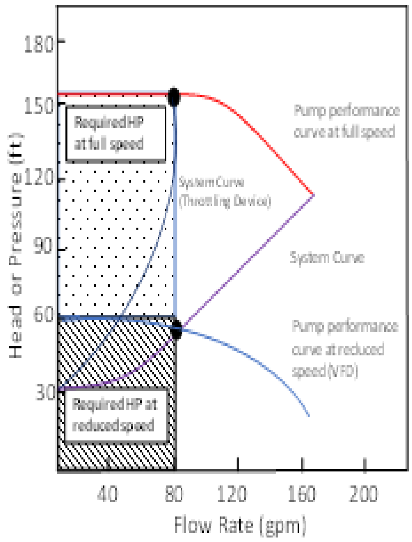


Fig. 3. Pump curves with VFD [8]

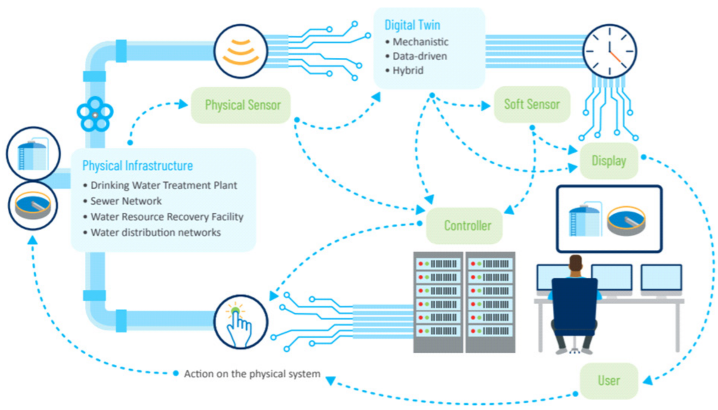


Fig. 4. Basic structure of digital twin for application in water systems [9]

B. Digital Twins

Digital twins enable utilities to compare health of present water network with past performance or simulations. Dynamic inflow of operational data relayed by flow and pressure meters via Supervisory Control and Data Acquisition (SCADA) systems help in identification of water demand pattern, potential leakages, and other network indicators such as water age or critical pressure zones.

Digital twin enables water utilities to visualize assets, perform simulations and check status on screen (refer figure 3). This helps to benchmark key performance indicators of the water network. Incorporating hydraulic model, digital twin allows simulation of events such as pipe failure, power outage, contamination, which in turn helps to calculate the resilience of the system and asses the risk. It leverages data from the existing water network to identify anomalies such as leakages promptly which result in lifecycle optimization of the assets. Conclusion

Globally drinking water supply costs $ 1.2/ m3 [10] on an average. Hence, a reduction in water loss by 20% from the current rate of 335 billion liters/ day [6] can ensure funds for serving additional 500 million people with safe potable drinking water. Also, adoption of energy efficient water treatment and transmission reduces operational expense and boosts return on investment.

Utilities can leverage latest innovations in water industry to improve their profitability and safeguard nature. They should prioritize their problems for adopting solutions and continuously reinvest to stay ahead of the competition.

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Design and Development of Grid-Tied Off-Board Intelligent Charging Station

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Abstract

The electric vehicle is the demand and necessity of the future generation as it is significantly helpful for the green environment. Electric vehicle batteries need to be properly charged so that the batteries can be used properly and optimally with smart charging infrastructure. Smart charging is directly linked to grid capacity. There are two chargers for charging the battery: an offboard charger and an onboard charger. In India, most EVs use onboard charging mechanisms, resulting in significantly higher EV costs, less power (kW) transfer, slow charging, supply voltage, the maximum current required by onboard BMS, and the phase setting of the charging station is causing problems. In the proposed model, an offboard charging mechanism is suggested for the EV charging station to solve the mentioned problems. The proposed model has a communication mechanism connected to the battery bank, which will read and receive all the parameters related to EV battery charging in real-time. The corresponding signal is sent to the charging station, which will calculate and transfer the parameters of the EV battery to be charged. There is high power transfer with an offboard charger, which helps with fast charging. It has been observed that the suggested smart offboard charging station can provide the best possible charging facilities for all EV segments, i.e., two-wheelers, light vehicles, multi-utility vehicles, and sport utility vehicles.

Keywords

Battery communication protocols, EV batteries Charging, Offboard charging, smart chargers

1. Introduction

By the year 2030, the demand for EVs is expected to grow at a CGAR of 94.4% [1]. Thus, the design and implementation of the EV charging station are a must on a large scale that can effectively charge EV batteries. By mentioning charging, an EV charger is vital in providing charging parameters by the battery. Nowadays, most companies use the onboard charger [2] to charge their vehicle batteries, which results in higher costs for EVs and takes up large space inside the battery section of an EV. Normally chargers like onboard do not provide the best possible charging utilities to charge an EV battery because there is a lack of proper communication between the charger and the battery [3, 4].

In the proposed model, an offboard intelligent charger is implemented, which can be directly attached to the charging infrastructure instead of attached within the EVs and can provide the best possible charging utilities by proper communication through sensors; the sensors will detect the voltage, battery capacity, and SOC level of the battery and calculate the charging current and charging voltage [5]. The proposed model has provided charging terminals at the end through which one can directly connect any battery, i.e., Lead acid, Li-ion, Ni-Cd, with different voltage and SOC levels. The intelligent charging station will automatically identify the type and status of the parameters associated with the EV battery and charge it through the best possible charging approach. The proposed model is expected to reduce the EV cost and manage the health of batteries by providing the best possible charging utilities and minimizing the chances of replacing the battery for a long period. It also provides space inside the vehicle that can be used to make EVs more comfortable. Also, the proposed model is not constrained to charge a single battery type; the user can connect the terminal port with the charging socket that identifies the battery so that process starts.

2 Design of Control Strategy

The electrical grid works as a pool system and is an allied network to supply electricity from generation to consumer [6]. In the proposed model, a grid-connected system is established with converters having controlled strategies to supply electrical quantities in a controlled manner. The essential components of the proposed model are mentioned below in Fig.1.

AC-DC Conversion – The 3-phase AC supply from the grid is converted to a variable DC supply through rectification. A 3-phase rectifier is designed to have six IGBTs, each with a connection port for the PWM pulse. The harmonics produced due to the AC supply by variation in load are maintained by inductive and capacitive filters clubbed in the circuit [7]. In AC-DC conversion, the DC voltage after conversion from AC has the same voltage as that of the AC supply.

*DC-DC Conversio*n -The DC-DC conversion is done by increaseing and decreasing the supply voltage level according to the need; for these operations, the buck and boost or buck-boost converters are used [8]. DC-DC converters can control the obtained voltage by managing the duty cycle [9]. The variable DC obtained after the conversion is inserted directly into the controlled DC-DC buck converter.

EV Battery bank – The battery bank is a storage device that chemically stores the charge from the source [10]. Different kinds of batteries have different chemical compositions, thus requiring different charging techniques/topologies, i.e., constant current – constant voltage, variable voltage, and charging through SOC estimation [11]. The proposed model-controlled strategy can charge any type of battery, i.e., Lead-acid, Li-ion, and Ni-Cd.

The converter stages designed are controlled by various parameter control techniques, i.e., Phase-lock-loop and PID control techniques [12][13]. The AC-DC conversion uses PLL to control voltage, while the DC-DC converters use the PID control method for controlling current and voltage. The flow diagram demonstrates the behavior of the proposed strategy is shown in Fig.2.

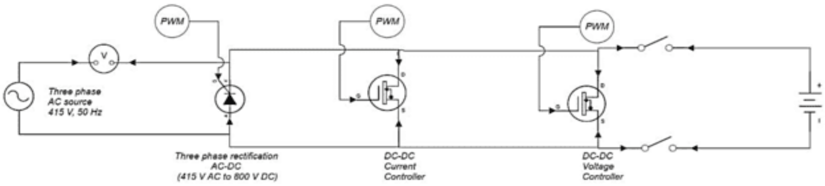


Fig.1 Grid-tied offboard charging station

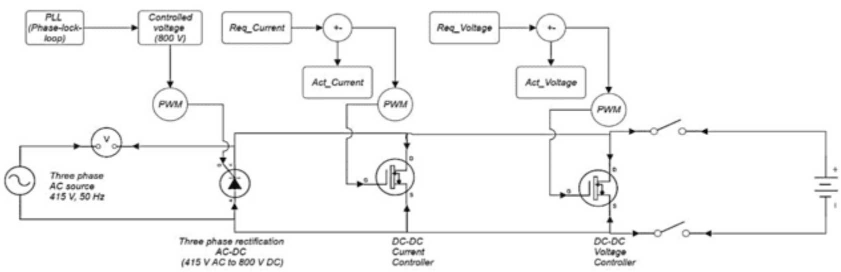


Fig.2 Charging station control diagram

3. Charging System Communication Strategy and Control Algorithm

A smart controller establishes communication between the charging station and the battery. In the process, the parameters, i.e., Nominal voltage (V), Battery type, and Rated capacity (Ah), are fetched from the mask parameter table of the battery model and transferred as input to the smart controller. These are the following parameters received by the controller:

- Nominal voltage = NomV
- Battery type = BatType
- Rated Ah capacity = NomQ

In the communication process, there is a delay of t = 0.2 sec in the charging station through which all the parameters mentioned above are sensed through the controller. All the above parameters, i.e., NomV, BatType, and NomQ, are fetched when the battery status is connected, as shown in Fig. 3.

The BatType defines the type of battery whenever a battery is attached to the charging station, and according to it, the charging controller selects strategies.

Case A: If BatType = 1

The battery is a lead-acid battery, and generally, the nominal voltages of batteries are multiple of 12, i.e., 12, 48, and 72 volts. Hence dividing the nominal voltage of the load battery by 12 gives the total number of batteries. Generally, a 12V lead-acid battery has N = 6 (Number of cells) having a voltage of 2.45 V/cell (C_vol). The number of cells inside the load battery (N_load) can be calculated by taking the product of the total number of batteries and the number of cells (N).

Battery Type	Battery Name
1	Lead-acid
2	Li-ion
3	Ni-Cd

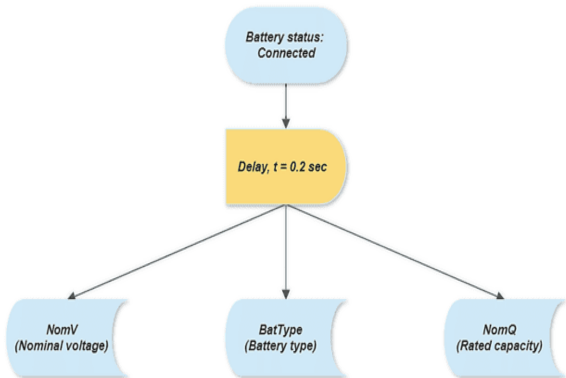


Fig.3 Battery connection stage

So, assuming the charging voltage (Ch_V) of the connected battery as V volts which is calculated by,

Total no. of batteries = Nominal voltage of the lead-acid battery / 12

*N_load = Total no. of batteries * N*

*Ch_V = C_vol * N_load*

Similarly, the charging current (Ch_I) can be calculated. The Ah capacity is fetched from the connected battery in the charging station. Generally, the charging current should be 25% of the battery-rated capacity for fast charging the lead-acid battery.

*Ch_I = 0.25 * NomQ (Capacity of lead-acid battery),* For medium and slow charging, the charging current should be 15% and 10% of the rated capacity of the connected battery,

*Ch_I = 0.15 * NomQ (Capacity of lead-acid battery),*

*Ch_I = 0.10 * NomQ (Capacity of lead-acid battery),*

In the proposed model, the charging time in hours (H) of the lead-acid battery is also calculated by,

H = NomQ / Ch_I,

According to the dynamics of charging (CC-CV) mentioned above, a lead-acid battery of any voltage, SOC level, and rated capacity can be charged effectively and appropriately.

Case B: If BatType = 2

The battery is the Li-ion battery, and generally, the nominal voltages of batteries are multiple of 12, i.e., 12, 48, and 72 volts. Hence dividing the nominal voltage of the load battery by 12 gives the total number of batteries. Generally, a 12V Li-ion battery has N = 4 (Number of cells) and a 3.7 V/cell (C_vol) voltage. The number of cells inside the load battery (N_load) can be calculated by taking the product of the total number of batteries and the number of cells (N). So, assuming the charging voltage (Ch_V) of the load battery as V volts which is calculated by,

Total no. of batteries = Nominal voltage of the Li-ion battery / 12
*N_load = Total no. of batteries * N*
*Ch_V = C_vol * N_load*

However, the charging current calculation for Li-ion batteries is complex. Li-ion batteries are subject to higher charge current as compared to other batteries. The maximum current given to the Li-ion battery can be 30% of the rated capacity [14]. In the proposed model, the charging current should be calculated as follows:

*Ch_I = 0.23 * NomQ (Capacity of Li-ion battery)*

The charging current should be 23% of its rated capacity for fast charging effectively so that battery health is not affected. In the proposed model, the charging time in hours (H) of the Li-ion battery is also calculated by,

*H = 1.5 * NomQ / Ch_I*

The dynamics used for charging the Li-ion battery is also CC-CV.

Case C: If BatType = 3

The battery is the Ni-Cd battery, and generally, the nominal voltages of batteries are multiple of 12, i.e., 12, 48, and 72 volts. Hence dividing the nominal voltage of the load battery by 12 gives the total number of batteries. Generally, a 12V Li-ion battery has N = 6 (Number of cells) having a voltage of 1.55 V/cell (C_vol). The number of cells inside the load battery (N_load) can be calculated by taking the product of the total number of batteries and the number of cells (N). So, assuming the charging voltage (Ch_V) of the load battery as V volts which is calculated by,

Total no. of batteries = Nominal voltage of the Ni-Cd battery / 12
*N_load = Total no. of batteries * N*
*Ch_V = C_vol * N_load*

Similarly, the charging current for the Ni-Cd battery is calculated as 10% of the battery-rated capacity.

*Ch_I = 0.10 * NomQ (Capacity of Ni-Cd battery)*

The Ni-Cd battery also uses CC-CV method dynamics for charging operation.

After the calculation of charging voltage and charging current through the controller, they are set to transfer to their respective DC-DC converters, where the PID technique is used to set compare the required voltage (Ch_V) and current (Ch_I) with their actual values obtained in the output side of converters. The designed algorithms for charging different types of batteries are mentioned in fig.4.

3. Test Results & Discussion

After the discussion above, some tests have been conducted on the proposed model built on Simulink-MATLAB, and a detailed discussion is done on behalf of the results obtained. A detailed explanation of the model is performed in this section

MATLAB/SIMULINK Modelling of the test system

The 3-phase AC source has 415 volts per phase, and a 50 Hz frequency is used as a primary generation source. The overall duration of the simulation is t = 0.5 sec, and the system is delayed for t = 0.2 sec to sense the battery terminal voltage and SOC at the instant load battery gets attached to the system. Assuming that the load battery has a nominal voltage of 48 V, 150 Ah battery capacity, and 60% for 1st case and 80% for 2nd case as SOC (State of Charge), the test results are obtained for different types of battery, i.e., Lead-acid, Li-ion, and Ni-Cd following the same parameter configuration mentioned above. The three-phase source and the load battery are taken from MATLAB, assuming the load is pure DC.

Simulation of Grid-tied offboard charging station

The proposed model has a 3-phase AC source (primary source) that maintains 16 kW power at the load end throughout the operation. The results showing voltage and current generated by the grid are shown in Fig 6. The phase-lock-loop method maintains the voltage at 800 volts DC after converting from a 3-phase AC supply of 415 V/phase. The LCL filters are implemented according to their standard values to reduce grid voltage and current harmonics. Also, a diode is connected in a forward biased to stop the back power flow due to variations in load.

The offboard station mainly consists of current-controlled and voltage-controlled DC-DC buck converters. The charging current and voltage are set whenever a battery is plugged-in the charging station. The converter becomes active, and the battery model delivers the essential parameter, i.e., Nominal voltage, Rated capacity, and battery type, to the controller. The converter decides the charging strategy according to the battery type defined by the battery model. After selecting the battery, the calculations were performed as described earlier to calculate the charging current and voltage that simulates the charging for the load battery effectively and appropriately. The algorithm would then allocate the charging parameters of the battery to the respective DC-DC converters, where the required voltage and current are compared with their actual values to deliver the expected output. Figure 5 shows the overall MATLAB Simulink model below.

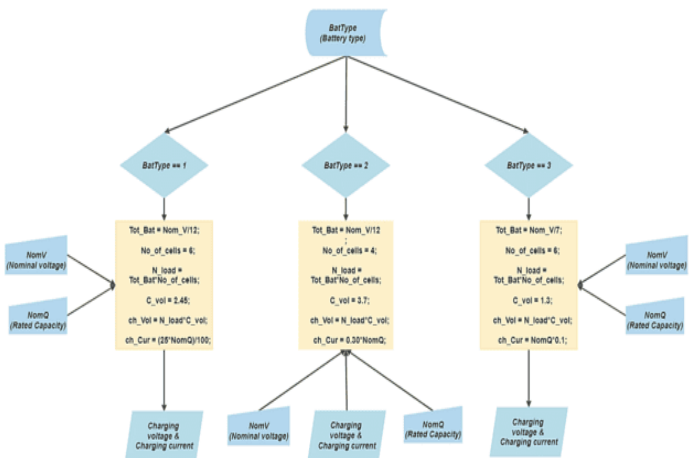


Fig 4. Algorithm for identification of Charger Control parameters

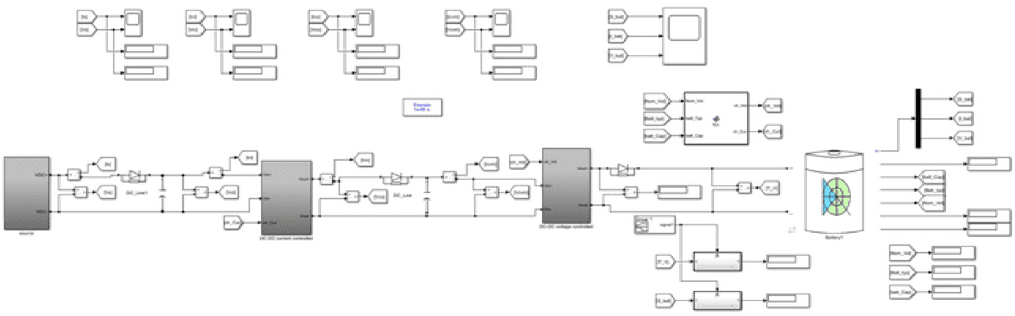


Fig 5. MATLAB/SIMULINK Model of Proposed Charging Station

Test results and observations

Observation 1: Grid profile of the test model

Fig 6 shows the three-phase voltage and three-phase current of the generation end. The voltage is controlled by the PLL method. The total harmonic distortion for the three-phase voltage profile is 1.41%, i.e., for a healthy system, the total harmonic distortion should be less than 5%.

The controlled DC voltage obtained after the conversion has a ripple content of 0.876%. The obtained voltage is controlled and provides 800 V DC as required by the system. Fig 7: shows the profile of voltage and current obtained after conversion of 3-phase AC supply to DC

Observation 2: Comparison of Charging Performance

In the following results, the li-ion battery would take less time to charge completely compared to lead-acid and NI-Cd. The increase in the percentage SOC of li-ion batteries in t = 0.5 sec duration is 0.40%, whereas for the lead-acid battery, it is 0.35%, and for the Ni-Cd battery, it is 0.25%. From the obtained results, the charging station provides optimal charging strategies for charging EV batteries of any type, i.e., lead-acid, li-ion, and Ni-Cd as shown in Fig. 8.

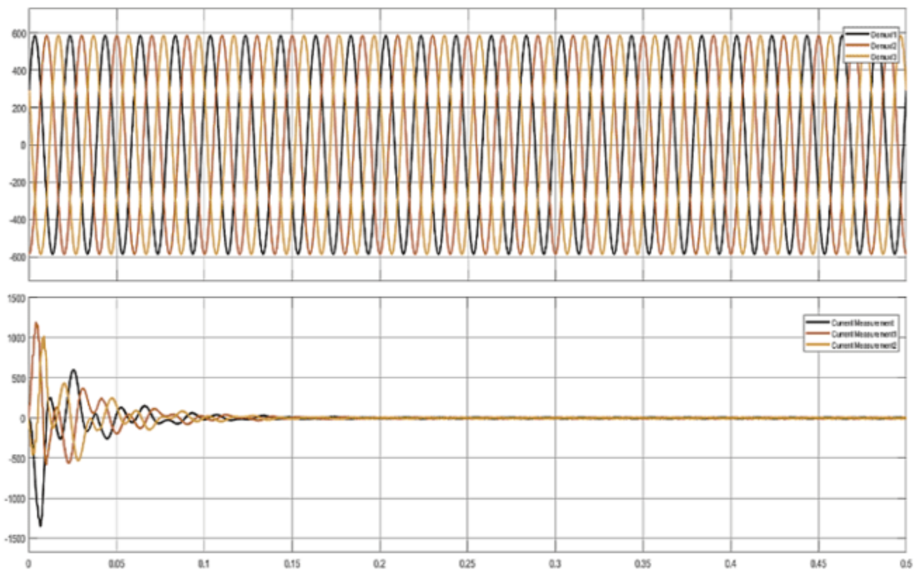


Fig 6. Grid voltage and current profile at charging

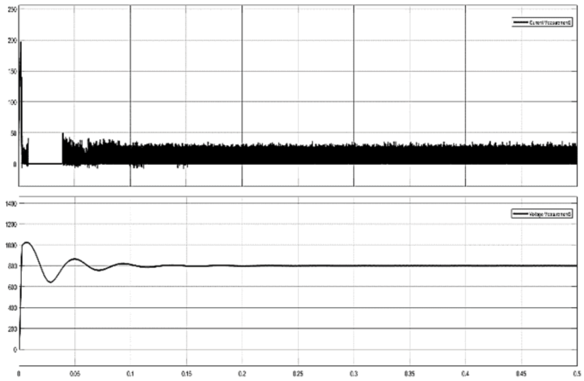


Fig 7. AC/DC converter output voltage and current profile at charging

IV. Conclusion

In the proposed work, the model describes various steps in the design of the offboard charger, which can retrieve battery parameters precisely through which it can accurately decides the battery type, i.e., Lead-acid, Li-ion, and Ni-Cd. An automated controller is designed to fetch the battery parameters by connecting it to the station and providing the best possible charging utilities for the designated battery. The identified batteries are charging appropriately and efficiently as defined by the used charging algorithms. The obtained results speculate that battery health, i.e., overcharging and heating, is maintained throughout the operation; the current stabilizes the battery quickly, resulting in low ripples. The overall model favours the use of the offboard charger as it reduces the cost of EV manufacturers by reducing the need for onboard chargers.

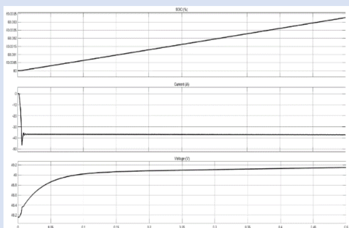
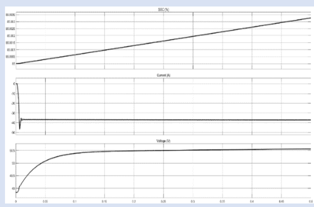
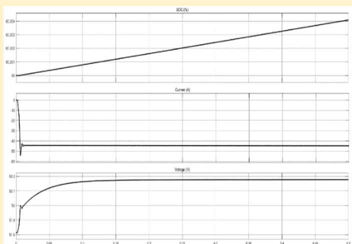
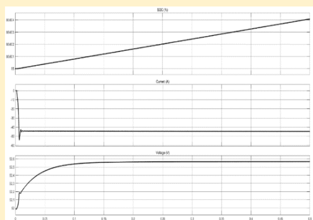
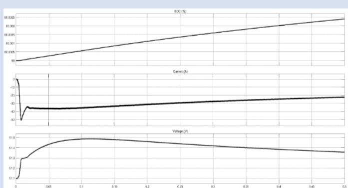
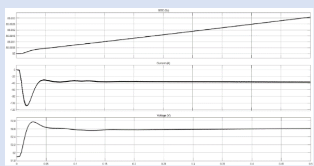
Battery Type	SOC Level 60% (1st case)	SOC Level 80% (2nd case)
Lead-acid battery		
Lithium-ion battery		
Nickel-Cadmium Battery (Ni-Cd)		

Fig 8. Charging profile of Lead-Acid, Li-ion, and Ni-Cd battery banks at 60% and 80% SOC levels

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The Need for a Framework and Govt. Policy to Encourage Retrofit Existing Petrol / Diesel Vehicles – A Case Study on ICE Two-Wheeler to Convert into Hybrid to Address Both Price and Pollution

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Abstract:

To reduce the carbon emissions produced by diesel and petrol combustion engines drastically, the Government of India is determined and promoting green technologies through MSME and has setup an ambitious target for electric vehicles. As a consequence, the nation is moving forward to deploy more electric vehicles on road. But still, the rate of this transition is not as expected and thus, may not be able to meet its dream of reducing carbon footprint and may leave people unhappy over petrol price. The country may concentrate on converting the existing petrol vehicles into 100% hybrid ones. Retrofitting in way would also not attract a new scrapping policy to be implemented.

The public transport buses on Indian roads expected to reach more than two million in another 8 years. In the same way, the number of other transports will also increase at a significant rate. As more and more electric vehicles getting added to the existing infra for want of reducing carbon footage, the roads of the main cities in the nation can get jammed. Therefore, one obvious choice is to retrofit the existing ones to hybrid variants so that the number count of vehicles will not rise and customers are also not under force to buy totally a new vehicle. In this paper, we put forth the experimental data of one such retrofit pilot project done using a two-wheeler and show how the existing infra is put to use in proper manner to address price and pollution problems.

1. Introduction

The Government of India is determined and promoting pollution free green technologies and has set up an ambitious target for converting at least 80% of two-wheeler vehicles by 2030. As per the statement made by the Transport and Highways minister Shri Nitin Gadkari on the floor of the parliament in the first week of August 2022, the total existing two-wheelers as of date are more than 21 crores. Though, in line with the Government policy to deploy more electric vehicles on road, with the current rate of transition, India may not be able to meet its dream of reducing its carbon footprint. One of the main reasons for this shortfall is the life of the existing conventional vehicles. The owners of these 21 crore two-wheeler vehicles, which may be on the roads for at least another 10 years, would neither find it convincing nor financially affordable to purchase a new electric two-wheeler, as most of the electric two-wheeler users are middle-class or lower-middle-class people. In view of the same, a case finds favor in concentrating on converting the existing petrol vehicles into 100% hybrid ones, through retrofitting the existing two-wheelers. We know that the Government of India has come out with a vehicle scrapping policy, which requires a lot of fresh space, effort, and financials. Retrofitting in a way would avoid scrapping of the vehicles to a large extent and the incentives being given for scrapping the two-wheeler vehicles may be extended to the vehicles going for retrofitting.

Further, according to various reports, despite several incentive-based policy frameworks and a ramp-up of domestic manufacturing India is projected to have only 50 million electric vehicles on road by 2030. This represents a shortfall of at least 40%, behind the cumulative sales projection of the NITI Aayog. Moreover, according to the Indian Auto LPG coalition, an estimated 300 million vehicles are currently running on polluting liquid fuels, contributing towards the unwanted status of India being home to 22 of the world's 30 most polluted cities, and thus highlighting an urgent need to convert this fleet to using alternative fuels.

Retrofitting the existing fleet of vehicles has the potential to address both these issues, while also ensuring that customers are not under force to purchase a completely new vehicle. In this paper, we put forth the experimental data of one such retrofit pilot project done using a two-wheeler and show how the existing infra is put to use in a proper manner to address price and pollution problems.

In order to drive substantial business and societal neighborhood impact, we need to embrace a holistic approach though appropriate Government policies and relevant motor acts. The policies and Acts that would attract in this endeavor are explained below. And also, we need to continuously work on new solutions that can provide meaningful opportunities for our policies and Acts as our observations, data and intelligence put to use. And there by our nation can make a positive impact on the world's energy sustainability efforts.

Impact of emissions from Indian Perspective: The recent findings from a study on vehicle and power sector emissions, air quality, premature mortality, to avoid health damages in India, the new electric vehicle policy estimated to have an ambitious electric vehicle (EV) sales scenario between 2020 and 2040, with and without robust power sector emission control and decarbonization strategies. The study was conducted by researchers from the International Council on Clean Transport (ICCT) and the Indian Institute of Technology Kanpur (IITKanpur) [1], and national and state level air quality values were generated using the WRF-Chem model, mainly focusing on fine particulate matter (PM2.5) concentration. The work is giving deep insight not only to policymakers but for all whosoever working in other technical areas and considering implementing large-scale vehicle electrification where electricity grids get the energy supplied by coal combustion. The study outcome infers that widespread adoption to EVs with robust power plant emission controls and power sector decarbonization policies would result in improvement in net air quality and will yield health benefits in every state in India by 2040, even under the very pessimistic assumption that all the additional power demand from EVs is met entirely by fossil fuel power plants. Power multipliers, renewable energy sources and lithium energy storage and swapping techniques can address these issues and enable EV deployment in much cleaner environment.

Indian policy and its commitment: India's commitment to the EV30@30 is a global initiative, which aims nearly thirty percent new electric vehicles share on roads in ten-year time period, which can add of about nearly twenty-four million two-wheelers, three million three-wheelers, and 5.4 million four-wheelers to the fleet in the same time period. After having put all those efforts, still India is heavily depending on the international market for EV modules and accessories, especially lithium battery cells [2]. The government is at present increasingly focusing on promoting Lithium-Ion battery manufacturing domestically through MSME programs and incentives and recently announced a five-year, twenty US billion-dollar production linked incentive scheme for ten key sectors that includes US$2.4 billion for advanced chemistry cell (ACC) batteries. The projections of battery capacity up to 2035 show in the table shown below as per ICCT

Table showing total battery capacity required as per 30@30, ambitious scenario in Gwh, 2020 – 2035

Year	30@30 scenario		Ambitious scenario	
	Annual addition	Cumulative requirement	Annual addition	Cumulative requirement
2020	2.2	2.2	2.6	2.6
2021	8.6	10.8	8.5	11.1
2022	12.7	23.5	13.2	24.3
2023	18.9	42.5	20.7	45.0
2024	28.2	70.7	32.8	77.8
2025	42.0	112.7	52.1	129.9
2026	62.2	174.9	81.9	211.8
2027	91.6	266.5	125.7	337.5
2028	130.3	396.8	183.6	521.2
2029	181.0	577.8	254.7	775.9
2030	246.9	824.7	338.2	1,114.1
2031	327.0	1,151.6	427.2	1,541.3
2032	416.6	1,568.2	513.9	2,055.2
2033	515.3	2,083.5	603.5	2,658.7
2034	618.1	2,701.6	693.7	3,352.4
2035	723.4	3,425.0	785.2	4,137.6

On experimental basis, two 2-wheeler vehicles have been converted to EV to assess the workings of financials, compliant to framework of Motor Acts and Govt. Policy

Retrofit idea is conceived from the policy and frame work explained below, and suggested few recommendations to meet Indian scenario scrapping rules, act, and policies etc.

For the existing petrol-based ICE vehicles, which are older than 10 year and ready are retrofitted with hub motor and thereby enabled to work with electric current too.

These vehicles are rated at 125 cc, and the mileage is nearly 40 km per liter. An EV motor of 1.8 KW is fitted to the wheel, and tested with the DC power source of 30 Amps and 60-volt battery.

Commercial viability and ROI to the customer as per the present gas price is estimated as follows: The running cost of the above-mentioned vehicles i.e., Suzuki Access 125, and LML Vespa are capable of giving 40 km for 1 liter petrol. The price of 1 liter petrol is taken as Rs. 100/-

On average the fuel consumption is five-liter petrol for seven days, and the total running cost per week is Rs. 500/-, and the monthly expense is Rs 2000/-. At this rate the yearly budget expected is Rs 24,000.00.

In case of Retrofit, the same vehicles in EV mode can give same range of 40 km for one time charge, and the cost of charge is being Rs 10/-. At this price, one week running cost is 10*5 = Rs. 50/-, per month cost is 50*4 = Rs. 200/-, and yearly cost is 200*12 = Rs. 2400/- Estimation of ROI in two-year term as per the present fuel price in India (approximately Rs. 100)

Cost of running expense for two years, if petrol is used as fuel is 24.000 * 2 = Rs. 48,000 Charging cost for two years for the EV projected is 2400*2 = Rs. 4,800. Total gain (or ROI) by switching over to EV in 2-year time period is: 48,000-4,800: Rs 43,200 Proposed Financial workings: Retrofit system integration cost with all accessories including battery is around:

Rs. 80, 000/- State & center government subsidy (if extended for retrofit vehicles as in the case of purchase of new vehicles). Rs. 20, 000/- Bank EV loans (Clean Energy, Environment protection promotion) say Rs. 40, 000/-
The total upfront, a customer supposed to pay in support of turning green is: Rs. 20,000/-.

If the battery is provided under the option of Battery as a Service (BaaS), Then the retrofit system integration cost may further be comedown and encourage middle class and lower middle-class buyers to move forward quickly to switch over to EV adaptation, particularly as the user need not pay for the battery upfront cost which is very high at present at a price of around Rs. 30,000.

Motor Vehicle Act: There is a need to bring retrofit vehicles under special category for exemptions. The incentives given under the Scrapping policy, may be extended to the retrofit vehicles. Battery swapping policy and considering the benefits on par with new vehicles will further help to achieve the goal by 2030 as mentioned above [3].

Policies are broadly aims to give subsidies/incentives to the manufacturers, who subsequently offer the consumers with certain incentives.

Private customers / riders too need some benefits. Encouraging retrofit vehicles with some incentives can give two-fold benefit, 1) Customers can get upfront payment relief, 2) Nation can achieve clean energy goals earlier than 2030.

Three major stakeholders have bearing on this 2-wheeler and 3-wheeler industry:

1. Manufacturers, 2. Financial institutions and the 3. Regulators (Ministry of Environmental Regulations and civil society groups).

India is a federal state, which means that the total powers on various policy matters are shared between the Central or National government and the State Governments. Generally, policies on various issues are developed by the Central Government, but implemented by the State Governments. Regulating a particular mode of transport by specifying limits in a city, such as implementing helmet laws or regulating emissions, are in the hands of the State Government, resulting in varying policies from state to state.

The transport sector policies in India are made by two ministries of the government: 1. Ministry of Shipping, Road Transport & Highways (MoSRT&H) 2. Ministry of Urban Development and Poverty Alleviation (under which Urban transport is a subdivision) In the various policies of these ministries, no specific guidelines for two and three wheelers are mentioned. Rather, the policy measures are aimed at increasing mobility on high ways by encouraging public transport and not enough attention paid on town / city planning to encourage the use of private modes of transport (NUTP, 2005) [4].

Since two wheelers come under the category of privately owned vehicles, the policies are indirectly designed to discourage two-wheeler usage. Among private transport rules, no specific preference for a two-wheeler is mentioned.

Two wheelers have benefits in terms of road space, cost, mobility, and release of greenhouse gases. However, safety, emissions and equality of the problems associated with two and three wheelers need to be addressed. Three wheelers in India act as intermediate public transport (IPT), a feeder system to public transport in large cities. They are the only available transport for people in places where public transport is unavailable. In India most of the middle-class people and people below the middle-class category are the main users of the two and three wheelers, for their transportation needs.

A successful public transport system with high ridership requires a good network of three wheelers. However, the policy guidelines of the ministry of urban development (as given in the National Urban Transport Policy (NUTP), 2005) encourage public transport while ignoring any mention of three wheelers. The policies of other ministries such as issuing low interest loans to the poor are encouraging people to buy more three wheelers as employment opportunities.

Varied incentives are provided by various state governments and the varied tax policies toward two and three wheelers needs to be revisited and a new uniform policy to be adopted by the Central Government to promote the common man`s vehicles (Both 2 & 3 wheelers).

In India the scheduled commercial banks are already extending the loan facilities for purchase of two wheelers, three wheelers and four-wheeler vehicles at a cheaper interest rate than the private financiers. The same facilities may be extended to retrofit vehicles also to promote the clean energy and also to protect the environment. This will further reduce the fuel and other maintenance charges of the 2 & 3-wheeler users.

As two-wheeler owners also earning through agencies like UBER, OLA, RAPIDO etc., as a measure of poverty alleviation and employment generation, the government should wave of the requirement of security deposits for the unemployed poor, if they provide the appropriate income certificate.

Swapping Policy:

Swapping Policy advocates bringing Battery Charging Systems (BCSs) under existing or future Time-of-Day (ToD) tariff as stipulated by the appropriate Commission so that the swappable batteries can be charged during the regimes off-peak periods when the electricity tariffs are low. This may also help the serving DISCOMs flatten their respective power demand curves and better manage the load emanating from battery charging at BCSs. To participate in a ToD tariff regime, a BCS should have a dedicated electricity connection. All retrofit agencies / entities should be permitted to install the Battery Swapping stations at suitable places to cater services to their clients. RE systems & power Multiplier may be used to charge the batteries to avoid dependence on DISCOMs.

Vehicle Scrapping policy:

As we are all aware that Road and Transport Ministry announced the Vehicle Scrapping Policy in the Lok Sabha. It was first announced in the Union Budget for 2021-22. The policy is estimated to cover 51 lakh Light Motor Vehicles (LMVs) that are above 20 years of age and another 34 lakh LMVs above 15 years of age [7]. Many incentives announced for scrapping that includes nearly 6% of previous show room price which is good for new vehicle buyers. In case the vehicle user thinks that his old vehicle can retrofitted and convert to pure EV or Hybrid vehicle and the benefit is much higher than 6% of previous purchase cost, the scrapping policy should consider road tax benefit for retrofit vehicles on par with new EV vehicles. This helps many middle-class commuters in a way, by reducing their upfront payment burden to buy a new vehicle. The price difference could be in the order like Rs 40,000, which is sizable amount for common people in India.

Encouraging retrofit vehicles has 2-fold benefits. One is to manage the scrap space, and the other is in extending promotional schemes to buyers at low interest price. Since the amount involved for retrofitting is lesser and is nearly by 30%.

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Drone based Surveillance of Overhead LT Network

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Abstract
Overhead network is the part of the LT distribution network that is most vulnerable to natural calamities like Nor'westers and cyclones. For a distribution utility like CESC that caters to a metropolitan city through a considerable length of overhead LT network (in tune of 5700 circuit km.), identification of weak points and proper monitoring of the overhead network for effective vegetation management are of paramount importance in order to ensure consumer safety and avoid prolonged outages in the wake of disasters.

Unmanned aerial vehicles (UAVs) or drones are rapidly gaining popularity in the field of remote sensing for capturing images with ultra-high spatial resolution while flying at low altitudes. Development of highly efficient miniaturized sensors and the use of geospatial image processing techniques have been immensely helpful in growing this technology as the most sought-after and reliable remote sensing technique at a relatively low cost.

This paper summarizes the adaptation of drone-based surveillance technology in the priority based proactive maintenance of LT overhead network with an emphasis on ensuring public safety and strengthening the network against outages during abnormal weather conditions for sustainable management in the long run.

Keywords: Overhead network, Drone-based surveillance, natural calamities, public safety, outages, sustainable management

1. Introduction

The main challenge for a distribution utility in today's uber-competitive energy sector is ensuring the reliability and quality of supply to a highly vigilant consumer base with ever growing expectations. The city of Kolkata has been struck with repeated natural disasters in the form of cyclones and deluge like Amphan and Yaas in the last few years. These cyclones have exposed the burning deficiency in the reliability of the LT overhead network. The prolonged supply interruption to the consumers in the wake of these disasters have had a hugely negative impact on the company's brand image and public perception. Recovering from the substantial damage done during these disasters had a huge bearing on the financial health of the organization as well. Notwithstanding the staggered cases of major natural calamities, the city of Kolkata is repeatedly hit by Nor' westers and torrential rainfall which significantly affect the highly susceptible overhead conductors in the network. In view of the above, it is clear that the only way to tackle these hurdles in the system is through smart monitoring and maintenance of the network to optimize manpower and budget usage to identify the weakest points in the network for carrying out network maintenance.

2. NEED FOR DRONE BASED SURVEILLANCE

The existing philosophy of overhead maintenance followed by CESC is the routine maintenance of overhead networks based on a fixed annual programme with expedited operation prior to Nor 'wester and monsoon season.

- The fundamental flaw with this philosophy lies in that this philosophy of maintenance does not dictate need-based maintenance of the most worn-out parts of the network.
- The only existing procedure of attending the vulnerable parts of the network is through human surveillance based on consumer complains when the damage to the network has already been partially or completely

done.

- The extent of these damages during storms or deluge makes it extremely difficult to effect supply restoration to the consumers within reasonable time frames.
- The chief contributor to overhead conductor snapping is the stress created on the conductors through falling of trees on overhead conductors or poles. Manual inspection of vegetation cover on LT overhead network is not always adequate due to the sheer length of the LT overhead network. Further, superimposing the Google satellite images of vegetation cover on the layer of LT overhead network is often misguiding in that the superimposed image only serves to indicate the overlap between the two layers on the land-base but is not indicative of whether the vegetation cover lies above or below the Overhead conductors, without which key piece of information maintenance schedule cannot be programmed without further manual inspection.

Furthermore, there are some aspects of the network like localized abnormally high conductor temperatures that are not visible to the human eye, but are extremely detrimental to the system and are bound to cause faults through conductor snapping or joint failures.

Therefore, drone-based surveillance is of supreme importance for proactive need-based maintenance in fault prone LT overhead network where manual inspection from ground level is unreliable or ineffective.

III. SELECTION OF PARAMETERS

The key parameters contributing to OH network breakdown that have been selected for remote monitoring are as follows:

- Hotspot in Jumpers and conductor joints
- Vegetation cover above overhead conductors
- Sag in conductor
- Non-optimal condition of overhead poles
- Physical wear and tear in conductors

IV. IMPLEMENTATION

The following steps were followed during the successful implementation of this technology:

a. Selection of Route Map:

The overhead network points that have been historically prone to faults during storms and peak summer load have been identified based on sensitivity of the customer base and network redundancy factors. Post chalking out of the breakdown aspects of the network, transformer loading data has been extensively analyzed to identify the electrically stressed overhead conductors. Data and human experience have been optimally blended to identify the network portion which are highly susceptible to breakdown during monsoon season. The existing constraints of DGCA prohibited areas have been considered while selection of the drone route.

Fig. 1: Selection of Route Map

b. Data Capture, Transmission and Storage

Aerial Drone Based Surveillance has been carried out for the entire LT Network emanating from individual Distribution Transformers in CESC. The surveillance comprised of all LT Poles, LT Conductors, Jumpers, Insulators, transformers, cables, service connections from the overhead lines. It further included the Vegetation layer covering the overhead network at certain points to be covered in 3D mode (X-Y-Z plane).

1. Aerial photography using cameras with resolution greater than 40 Mega Pixel have been used for collecting minute details of the Network & equipment.
2. Thermal Imagery of all the Assets referred to above have been covered during the surveillance.
3. The drones capture and store the surveillance videos of the overhead network in both RGB and Thermal modes.
4. The drones have been provided with in-built memory cards that store the captured data and are later used to upload said data to the processing software platform.

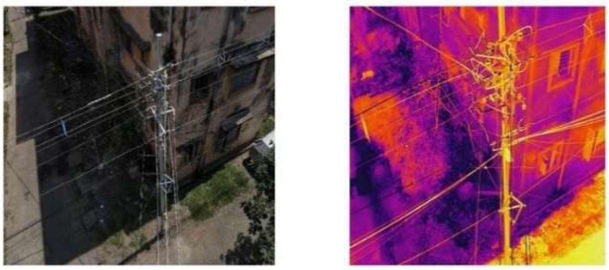

Fig. 2: 4K RGB and Thermal image captured by drone

c. Data Representation and Analysis

- ARU Software by KESOWA has been used as the platform to represent and host all the data for a period of 30 days, prior to which the said data is archived in AWS cloud platform.
- Exception Reports of both Ordinary Images and Thermal
- Image have been generated.

The chief features of the platform of data representation are as

- follows.

- Orth mosaic Map
- Digital Elevation Model
- Vector Layer of GIS Data superimposed on the Map

RGB and Thermal Videos and Images against each pole

List of Findings

a. Maximum Temperature
b. Tree Cover
c. Other Actionable areas (e.g., presence of Hotspots)
d. Sag Line
e. Conductor joints

- Vector Layer of GIS Data overlay on the Map has been created by mapping the field as a Vector Layer, which can be seen superimposed on the Raster Layer (Orth mosaic Layer) for better visualization.
- Hotspot identification is done using Thermal data. Thermal, or infrared, sensors enable drone operators to see invisible temperature data. Deployed on drones, thermographic sensors make it possible to collect radiometric data over wide areas.

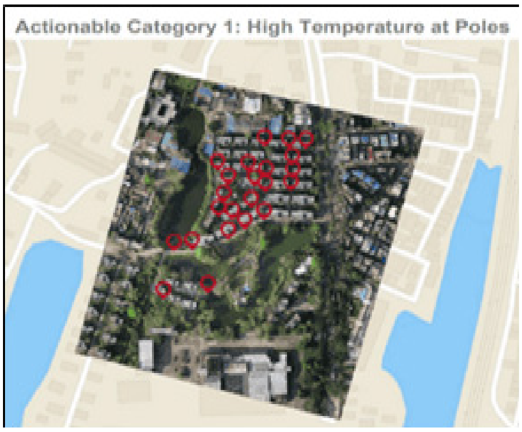

Fig. 3: Plot of poles with high temperature

Fig. 4: Plot of overhead conductors with significant amount of Sag

Fig. 5: Overhead network with significant tree cover

V. INTELLIGENT PREVENTIVE MAINTENANCE

- The exception reports generated through the remote surveillance provide an action plan to the utility to attend the vulnerable areas of the overhead network on a priority basis. The direct effect of this technology infusion in the mundane maintenance procedure has proved to be incredibly successful in curtailment of overhead faults in the LT network using drones in the field of LT distribution network has proven to be highly beneficial in the practical scenario. Proper actions taken against the exception cases reported with the help of Drone-based monitoring will lead to sustainable management of the distribution system in the long run.
- The surveillance videos give an essence of real time physical monitoring which helps us to analyses every point on the network through skilled technical eyes.
- Pre-emptive action in the form of attending vulnerable conductor joints, hotspots and vegetation management has resulted in a 37% reduction in overhead faults in the first quarter of FY’22-23 w.r.t FY’21-22.

VI. PATH FORWARD

- The logical next step in the utilization of this powerful technology lies in the remote monitoring of the otherwise inaccessible HT and EHT overhead Transmission lines that function as the backbone of the downstream distribution system.
- This technology can function as a crucial part in the process of raising alerts to effect supply disconnection in water-logged areas during deluge to ensure public safety from electrical hazards
- In the long term, machine learning algorithms can be embedded in the processing units of the drones in order to carry out daily monitoring of vital distribution system assets, so that real-time alarms can be generated by the processing software based on the network exceptions captured by the drones.

VII. CONCLUSION

This novel approach of introducing the technology of surveillance to carry out daily monitoring of vital distribution system assets, so that real-time alarms can be generated by the processing software based on the network exceptions captured by the drones.

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AI-based Predictive Maintenance Implementation in Wind Turbine Based on SCADA Data

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Abstract

The cost of maintenance on Wind Turbines (WTs) has increased over the years, and that's why system availability must be monitored and managed at all times. This paper presents an Artificial Intelligence (AI) based Predictive Maintenance (PdM) model that can provide valuable information for proactive actions such as the current health state and the Remaining Useful Life (RUL) in the WTs. The developed PdM model used Long Short-Term Memory (LSTM) to build characteristics and behavior of critical WTs components, such as gearbox and generator. Then, we used it to predict failures in future cycles in order to cut maintenance costs, minimize downtime, and optimize energy production through early warning signs. The proposed approach is based on historical Supervisory Control and Data Acquisition (SCADA) system data that is common in most wind farms. The experimental results show that developed PdM model is able to effectively and efficiently predict failures in future cycles of critical WT components, where the average accuracy is more than 94%.

Keywords

maintenance, wind turbines, artificial intelligence, SCADA, LSTM

1. Introduction

The rapid expansion of the energy transition towards renewable energy, especially wind energy, has been encountering many challenges [1, 2, 3]. The major challenges that limited the development of the wind industry are the high Operation and Maintenance (O&M) cost and poor reliability [4].

According to the International Electrotechnical Commission (IEC) standard [5], the design lifetime of a normal WT should be at least 20 years. Over the 20-year operating life of a WT, the maintenance cost is estimated to be 10%–15% of total income for an onshore WT, and 20–25% for an offshore WT, where the unexpected failures in the different WT components increase the O&M cost [6, 7, 8]. Fig. 1 illustrates the percentage of downtime and the cost of failures of the components of a standard WT [9, 10], where gearbox, generator, rotor, and main bearing comprise around 70% of downtime per failure [9].

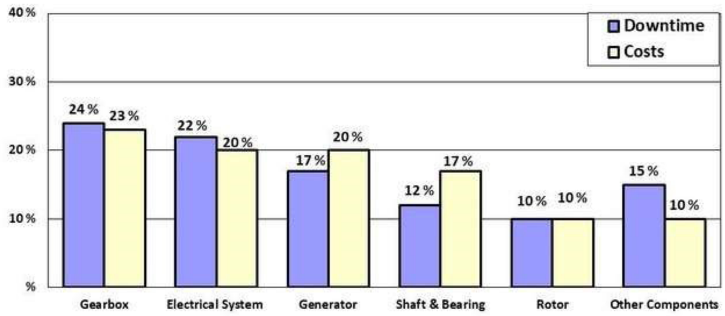

Fig 1: Failure rate of wind turbine components.

Predictive Maintenance (PdM) has been shown to be one of the best solutions for maintenance of wind farms, where it identifies the faults in the earlier stages before it turns to damage to other components of WTs [1, 11]. Among a series of strategies that have been proposed to deal with PdM models, the usage of Machine Learning (ML) is found to be an effective tool in PdM applications for smart manufacturing in Industry 4.0 [11]. Within ML techniques, Long Short-Term Memory (LSTM) is a well-known and important tool to make a forecast concerning the future trend of data because it is able to capture features in the time series data and simply recall past data in memory [12].

Hence, this work proposes to develop a PdM model using the LSTM method to predict failures in future cycles for critical WTs components based on the Supervisory Control and Data Acquisition (SCADA) system dataset. The objective of the developed model is to cut maintenance costs, minimize downtime, and optimize energy production in WTs through early warning signs.

The paper is organized as follows. Section II presents a literature review of ML models used in PdM techniques. In Section III, the descriptive analysis of the developed PdM model and covers the steps that are taken for processing the dataset. Then, in order to evaluate the developed PdM Model and to analyze the potential benefits of it in different scenarios, a set of metrics are shown and discussed in Section IV and, finally, conclusions and future work are drawn in Section V.

II. Literature Review

In recent years, several studies have been performed to build inductive ML models that predict incipient faults and anomalies by learning the underlying set of structures in SCADA data [1]. The LSTM is a well-known ML technique, an advanced Recurrent Neural Network (RNN), that demonstrates better efficiency in feature sequence extraction and data classification in many applications.

Z. Hameed et al. [13] studied different algorithms developed to monitor the performance of wind turbines to show the use of fault detection systems in maintaining wind turbine health [14].

O. Aydin et al. [15] described the implementation of the Keras library on the distributed clustering platform. The study also implemented an LSTM model with the purpose of predicting engine conditions. The model could achieve an accuracy of 85%, where the time frame in this study was set to 200 epochs [16].

In order to reduce the input variables fed into the LSTM prediction model, P. Qian et al. [17] applied the Mahalanobis distance method for feature selection. Compared to traditional backpropagation neural networks, the model yielded more accurate results and lowered the root-mean-square error by 4% [18].

III. The State Of The Art

This study aims to develop a PdM model for failure prediction of critical WTs components based on the SCADA dataset using LSTM method, which is a type of RNN. Fig. 2 illustrates the general framework of the experimental methodology for implementation of the developed PdM model in the SCADA system [19]. The main steps of the used methodology are:

- The SCADA data is collected from wind farms.
- The data is processed before further analysis.
- The useful features are extracted for analysis.
- A comparison of different ML models to select the best model.
- The faulty turbine data is given as input to detect the fault in the WT.
- Predict failures in the future cycles for critical WT components.

A. Wind turbine SCADA data collection

Modern wind farms use the SCADA system to control and monitor different parameters of WTs. In order to reduce the bandwidth of data, the SCADA system usually collects the data from the WTs in a 10-minute interval [4].

B. Data processing

In ML algorithms, the data needs to be processed before feeding it into the model. The SCADA data used for this study have an extensive number of WTs parameters. The parameters are normalized in the range of 0 to 1 using the MinMaxScaler class from Scikit-learn Python. Equation (1) shows the calculation to get the rescaled values, where W′ is the rescaled value and w is the original value, min (w) is the minimum, and max (w) is the maximum value in features [4].

In order to reduce the bias in the predictions and increase the accuracy of the model, the Python SciKit Learn libraries are used to remove the missing value from the dataset.

$$W' = \frac{w - min(w)}{max(w) - min(w)} \qquad (1)$$

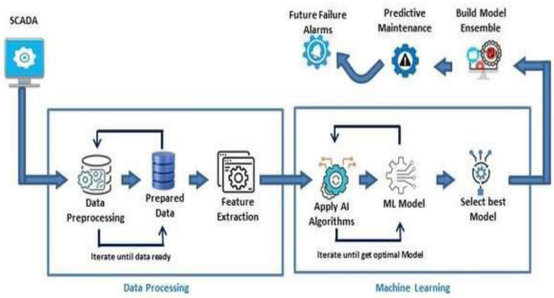

Fig 2: General framework of the experimental methodology

C. Sequence-to-Sequence LSTM Method

The LSTM Encoder-Decoder is a special class of RNN architecture designed to address sequence-to-sequence problems [12, 20]. The main advantage to choosing this model is that it can handle sequences of data, where a long pattern of multidimensional features is modeled to map the full sequence into a predicted scalar in regression problems [12].

The LSTM encoder-decoder consists of two LSTMs such that the encoder processes an input sequence and generates an encoded state and the decoder uses the encoded state to generate an output sequence. Fig. 3 demonstrates the Encoder-Decoder LSTM model [21]. The model produces an output y as close as possible to the target d by minimizing the loss function E for the given model, given the loss value and the accuracy which determines to what degree the output y and the target d agree (or disagree) with the given dataset (see Fig. 4).

D. The developed PdM model

The collected SCADA dataset for this research has been created by simulating random SCADA data from a virtual WT, which contains cycles as the unit of time expressed in machine cycles together with 2 sensor readings for each cycle.

The template takes three datasets as inputs to data:

- *Training data:* It is the WT Gearbox run-to-failure data.
- *Testing data:* It is the WT Gearbox operating data without failure events recorded.
- *Ground truth data:* It contains the information of true remaining cycles for each Gearbox in the testing data.

Here we need to generate labels for the values that we are going to predict with the developed PdM model, such as Remaining Useful Life (RUL), the length of time or number of cycles that a WT gearbox is likely to operate before it requires repair or replacement and is about to fail.
Next, we normalize the test data using the parameters from the MinMaxScaler normalization applied to the training data.

Finally, we build a deep network such that the first layer is a LSTM layer with 100 units followed by another LSTM layer with 50 units, where Dropout is applied to each LSTM layer to control over fitting. Because this is a binary classification problem, the final layer is a Dense output layer with a single unit and sigmoid activation. The LSTM model uses the sequence length, which is window size = 5 for LSTMs to look back on. The experiment has been performed in 20 epochs.

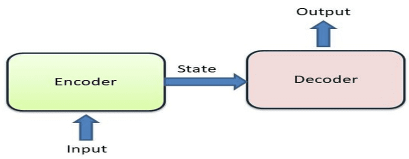

Fig 3: Encoder-Decoder LSTM model [19]

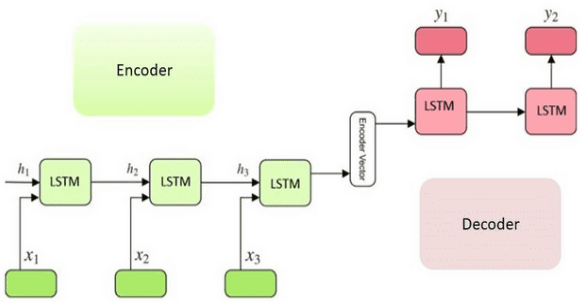

Fig 4: Encoder-Decoder LSTM model [19].

IV. Empirical Analysis

Finally, in this section, numerical simulation results are presented to measure how well the developed PdM model performs. In order to describe the performance of the model, Table I demonstrates the classification performance metrics of the confusion matrix for the Seq2Seq LSTM network applied to the developed PdM model, where:

- *True Positive (TP):* The number of times that the model correctly predicts a positive class.
- *True Negative (TN):* The number of times that the model correctly classifies a negative class.
- *False Positive (FP):* This is a result in which the model incorrectly predicts the positive class.
- *False Negative (FN):* This is a result in which the model incorrectly predicts the negative class.

Table: 1 Confusion Matrix Of Applied LSTM Model

TP	FN	FP	TN
58.92%	33.64%	2.15%	5.26%

In this study, four metrics were used to effectively evaluate the discussed PdM Model.

1. Precision (1) is the ratio of system-generated results that correctly predicted positive observations to the total predicted positive observations [4].

2. Recall (2) is the ratio of system-generated results that correctly predicted positive observations to all observations in the actual malignant class [4].
3. Accuracy (3) is simply a ratio of the correctly predicted classifications to the total Test Dataset [4].
4. F1 Score (4) is the weighted average of Precision and Recall [4].

The experiment results show that the developed PdM model could achieve the precision, recall, accuracy, and F1 Score, of 0.95, 0.85, 0.94 and 0.84, respectively. Table II shows the summary validation performance result of the best-performing architecture.

Table 2: Summary Validation Performance Result

Precision	Recall	Accuracy	F1 Score
0.95738	0.8514	0.94875	0.8425

As shown in Fig. 5, the initial validation accuracy is below 0.75 and after an epoch the validation accuracy increases to nearly 0.85. Also, the validation accuracy was low at first, but gradually improved to 94.85%.

Fig. 6 represents the model loss on the training and validation sets, where the initial validation loss is above 0.8, but the loss drops below 0.3 after an epoch.

The overall results of this experiment show that the developed PdM model has good performance, where there is a positive trend toward improving accuracy and reducing loss.

$$Precision = \frac{TP}{TP + FP} \quad (2)$$

$$Recall = \frac{TP}{TP + FN} \quad (3)$$

$$Accuracy = \frac{TP + TN}{All\ Samples} \quad (4)$$

$$F1\ Score = \frac{2 \times (Precision \times Recall)}{(Precision + Recall)} \quad (5)$$

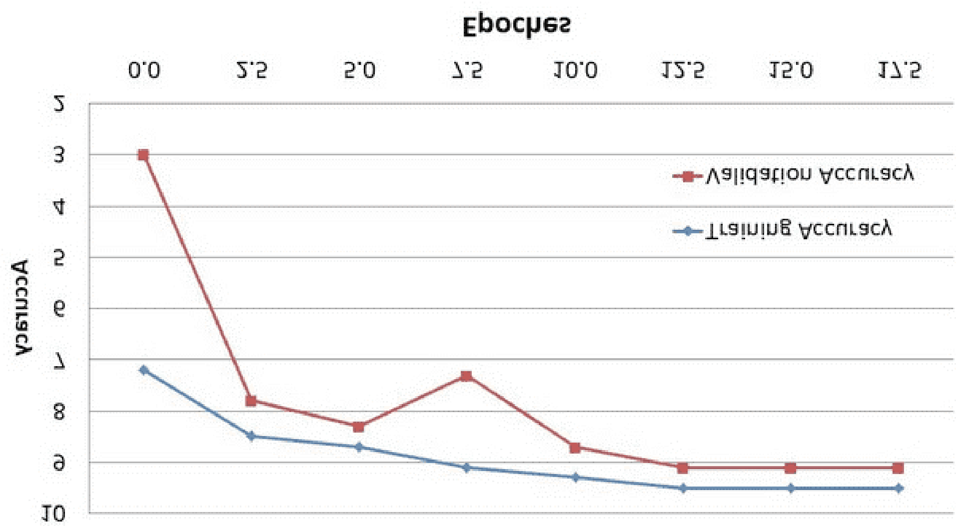

Fig 5: Graph representing model accuracy for training and validation set.

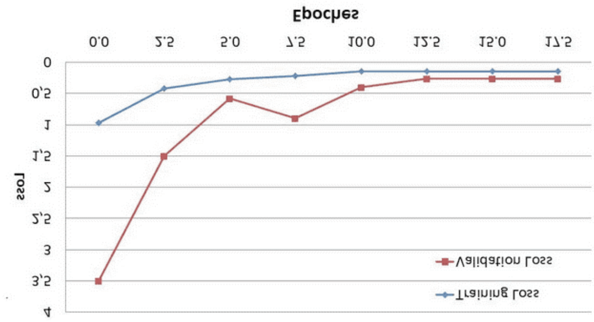

Fig 6: Graph representing model loss for training and validation set.

V. Conclusions and future work

This study presents a developed PdM model using an artificial neural network model called the sequence-to-sequence LSTM to predict future failure events for WTs components based on SCADA dataset, which can help in improving WTs reliability, availability, and reduction in O&M cost.

According to the achieved results, based on the metric measures, namely confusion matrix, precision, recall, accuracy, and F1 Score, the developed PdM model presented in this paper shows to be a possible solution for predictive maintenance problems.

Consequently, there are several possible future works to be done, such as implementations of the PdM model based on cloud and real-time applications for different WTs components. Moreover, it would be interesting to implement combination of ML models to study if it can provide better prediction compared to using one specific model.

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Demand Forecasting for Power Utilities Using Machine Learning

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Abstract

Optimized demand response (DR) has been an important area of focus for utility drivers on a transforming power grid. In reference, it is necessary to forecast the load ahead of time to regulate demand-supply ratios and set power pricings for potential customers. An accurate ahead of time forecast of demand helps a utility service provider to manage distributed power sources and allow a smoother operation. Further, in case of deficiency of generation sources, load side management would be a necessity. Thus, an accurate demand forecasting has been the need of the day along with precise generation forecasting to keep demand-supply in unison. In this work, the authors focus mainly on demand forecasting to enable utility service providers to schedule sources and provide an effective DR strategy whilst regulating real-time power pricing. Authors mainly contribute towards an easy to configure implementation of demand forecasting using a standard computing architecture and extend the scalability of the tool.

Keywords

Demand Forecasting, Demand Response, Machine Learning, Ensemble Learning.

Introduction

In the modern-day world, power systems have evolved from being in a conventional generating-supplying architecture to a distributed sharing framework. With ever increasing power demands, an always deficient power grid tries to ensure that all the consumers are provided in harmony and there are minimum number of outages. Although, it has always been difficult for the utilities to manage demand-supply ratios due to deficiency of the power generating sources. In which case, power utility companies try to provide the high-end customers due to ever increasing consumption levels and manage low end consumers accordingly. This is to primarily account for providing to consumers that can create opportunities of the market and complete the loop by engrossing low end consumers into it. Thus, to ensure the overall power flow is managed, power utility companies incorporate distributed energy sources and fragmented loads. And hence, they require to know demand and consumption requirements ahead of time to manage both generation and loads in real-time. The overall (demand/supply) power forecast can certainly help utility service providers to take necessary decisions beforehand and manage power channelization in case of an event.

In this work, authors try to understand the implemented demand forecast algorithms [1] in the literature to map real-time user requirements and highlight the contributions. An accurate demand forecast has lots of benefits as discussed in the literature [3, 4]. A complete statistical analysis on the subject has been conducted in [5]. Majorly, demand forecasting techniques can be clustered into three classes, namely correlation, trend analysis, and a combination. Correlation techniques are more specific to understanding the interrelation between different sets of parameters using which forecast can be made. Further, trend analysis technique involves fitting regression curves to historical data of electrical energy demand and use the same for extrapolation for the futuristic datapoints [5, 6]. These techniques are simple to implement, easy to understand and practically deployable; not to mention fairly accurate [6].

Additionally, there are end-use models that perform correlation analysis relating the system load to economic and demographic factors [5, 6]. A correlation is built between the two to understand the weightage of impact and then train the model to perform predictions. One of the biggest challenges involved are those related to forecasting accurate demographic parameters like population, heating, ventilation, weather data, building structure, and business are used in correlation techniques [5–7]. Of which, one of the most important parameters to be understood and forecasted are those related to weather. For which, these models depend on third party weather solutions that have accurate forecast to predict credible demands. These models are complex and development of the same requires in-depth understanding of data or physics behind which is out of scope of this work.

Another classification is based on interval-based demand forecasting, that can be categorized into very short-term load forecasting (VSTLF, forecast period between 0-60mins ahead), short-term load forecasting (STLF, forecast period between 1-168 hours (about 1 week) ahead), medium-term load forecasting (MTLF, forecast period between 1-52/53weeks (about 1 year) ahead), and long-term load forecasting (LTLF, forecast period between 1-20years ahead) [6, 7, 10]. These types of forecasting intervals are better suited for real-time control, day-to-day operations of the utility industry (such as scheduling the generation and transmission of electric energy), forecasting of fuel purchase, maintenance, utility assessments, forecasting the construction of new generations, strategic planning, and changes in the electric energy supply and delivery system, etc. [8].

Even with the above-mentioned techniques and approaches available, demand forecasting is seen to be complicated and cannot easily be solved with simple mathematical formulas [2]. According to research in [9], electric load forecasting has been a primary problem for the electric power industries for a very substantial amount of time. Even in case when electric load forecasting is a challenging task, researchers are working towards an optimal and proficient economic set-up of electric power systems and has continually occupied a vital position in the electric power industries [10]. Unplanned power flow leads to imbalance in demand-supply ratios thereby affecting and increasing outages as discussed in [9, 11]. Thus, the overall power flow must be managed to provide low-end consumers as discussed before. Besides, robust demand forecasting is essential in developing countries having a low rate of electrification and incorporate a full-fledged power system to the infrastructure [12].

A comprehensive study/systematic review has been conducted in [8, 9, 13, 14-18, 19] concerning the methods, models, and various algorithms used in demand forecasting based on inputs, outputs, time frame, scale, and value. One of the major highlights in [8] was the observation that despite the simplicity of regression models, they are mostly useful for long-term load forecasting whereas AI-based models such as artificial neural networks (ANNs), Fuzzy logic, and support vector machine (SVM) are appropriate for short-term forecasting. [9] focusses on demand forecasting methodologies, special techniques, common misunderstandings, and evaluation methods. Out of all, the most common evaluation metrics happen to be mean absolute error (MAE), mean absolute percentage error (MAPE), and root mean square error (RMSE). These can be used to evaluate the accuracy of the applied algorithms/techniques and understand the usage of the best machine learning algorithm. [14] presents a review of demand forecasting in smart grid environment focused on commonly used clustering techniques. [17] presents an overview of the basic machine learning techniques used to understand short-term demand forecasting. [15] examines the critical machine learning models for demand forecasting using a 1-year dataset of a commercial store. [20] presents a comprehensive review on LTLF relating various approaches in the method.

Authors in this work, leverage the capability of simplistic regression model i.e., gradient boosting to implement demand forecasting and understand its capabilities against already deployed algorithm at the utility (Telangana state northern power distribution (TSNPDCL)). The data was gathered via an application programming interface (API), features built on top and results compared with previous algorithms. The features extracted for model development were maintenance schedules, consumer profiles, consumer counts, holidays, and weather data. It was observed that the overall MAPE reduced by ~50% with an expected effective improvement of ~7%, ~10%, and ~14% respectively in weekly, monthly, and yearly timespans. Such framework deployed via an API can be easily deployed by various companies for an accurate short-term demand forecast for more efficient power purchasing and long-term demand forecast for optimal network planning.

The overall paper has been structured as follows. In the next section (I.e., PROBLEM FORMULATION), authors formulate the problem whereby authors put down the set of prerequisites of a problem and put down the requirements stated by the user. Here, authors also discuss the implementation framework and related nomenclature. Next, MAIN RESULTS discuss the availability of the data and implementation related information. In the same section, authors provide simulation results and related statistics to explain the effectiveness of the proposed idea. Finally, authors conclude the work by stating the outcomes and proposing future work ahead.

Problem Formulation

To implement demand forecasting algorithm using machine learning techniques, authors received the data samples from Telangana state northern power distribution (TSNPDCL) (one of the government owned utilities in India). The data made available by the utility was for 5 years on actual demand and incremental daily demand accessed via an API. The features extracted for model development are time stamp, maintenance schedules, consumer profiles, consumer counts, holidays, and weather data. Authors choose basic gradient boosting algorithm over neural networks to implement a simpler regression architecture which implies less computational complexity. A simpler model like gradient boosting allows definition of a faster and efficient articulation which is required for a demand forecasting type application. On the basis, an extreme gradient boosting (XGBOOST) algorithm is implemented as follows.

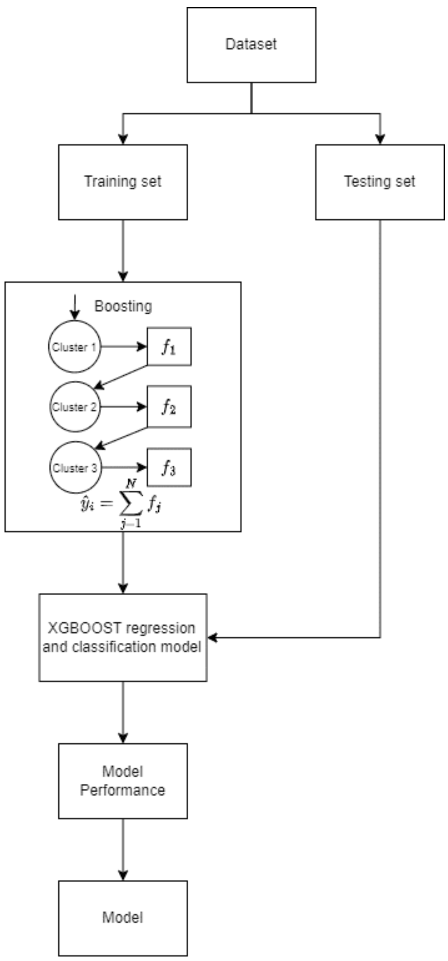

Fig. 1. Basic structure of XGBOOST model deployment.

The dataset so obtained is gathered via an API which is then analyzed for feature identification. The dataset is then divided into training and testing sets and the model is trained using the data. Then the XGBOOST model is implemented to be trained via the training dataset and the classifications are made. The model so obtained is then used for predictions, the results are analyzed and compared against the test data set for which the discussions are provided in the next section.

Main Results

The implementation of XGBOOST on the provided data can be visualized as below. Authors compare the actual load, forecast load, and scheduled load against one another. To further navigate, actual load of the previous year and temperature profile has been plotted too. The figures have been created using Microsoft Power BI tool by integrating the databases used in the entire development.

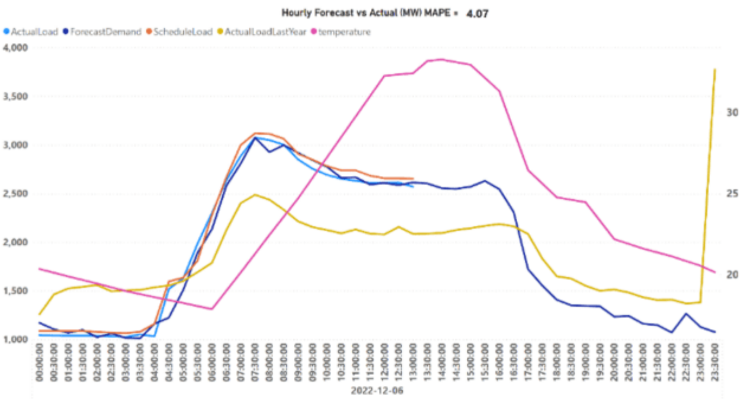

Fig. 2. Load forecast vs actual (Hourly data).

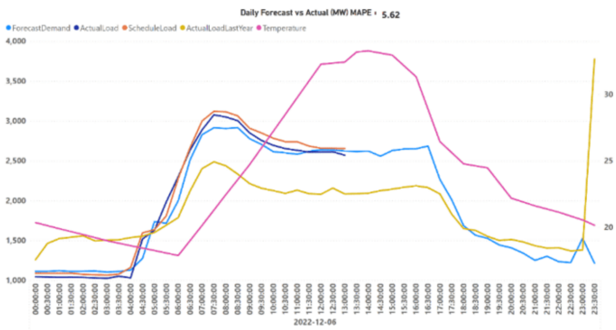

Fig. 3. Load forecast vs actual (Daily data).

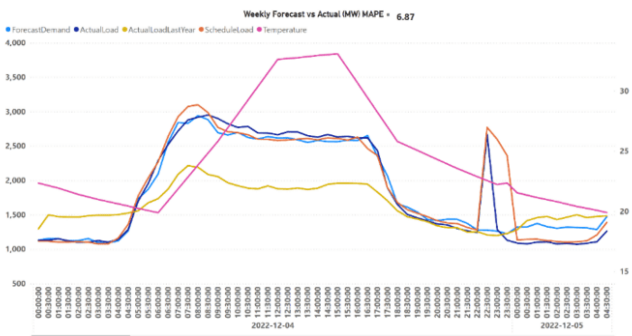

Fig. 4. Load forecast vs actual (Weekly data).

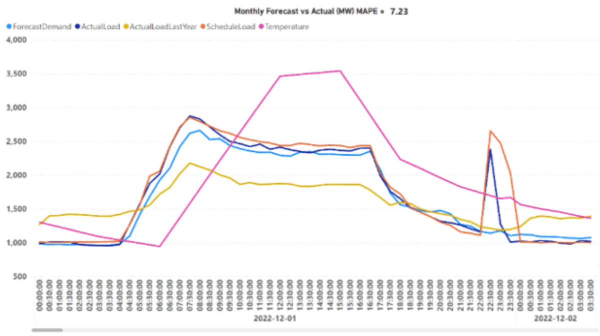

Fig. 5. Load forecast vs actual (Monthly data).

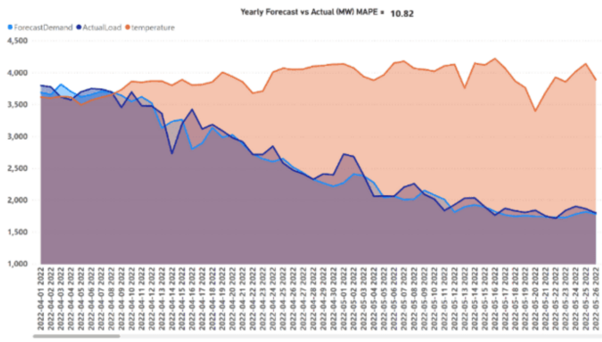

Fig. 6. Load forecast vs actual (Yearly data).

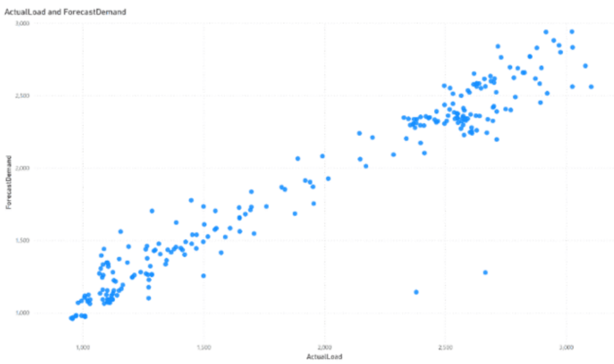

Fig. 7. Load forecast vs actual (Monthly data).

Fig. 8. Load forecast vs actual (Yearly data).

Authors highlight effectiveness of the model for hourly, daily, weekly, monthly, and yearly intervals as shown in the figures above. It can be observed that the mapping of data is accurate with an overall MAPE of ~7%, ~10% for monthly and yearly data, respectively. The scatter plot so shows that the overall predictions are fairly accurate and that the model can provide credible outcomes used for demand forecasting like application.

Conclusion

In this work, the authors showcase load forecasting in power systems by using the capabilities of simplistic models like XGBOOST on real-time data of an existing utility. The overall development shows an increase of almost 50% in MAPE and expected effectiveness of ~7%, ~10% in monthly and yearly data, respectively. The authors created a rapid deployment process via a standard infrastructure i.e., through an API. Results showing a competitive mapping between the actual and forecasted values and effectiveness have been concluded. The results indicate a futuristic platform using a rapidly deployable and infrastructure lite model for many power utility companies for their forecasting requirements. As a scope of improvement, the model can further be upgraded to increase accuracies by incorporating more complex algorithms and perform a competitive benchmark against one another.

Acknowledgments

Authors would like to acknowledge Telangana state northern power distribution (TSNPDCL) for providing real-time data for analysis. The data made available could make real-time scenarios easily accessible and implementation more realistic.

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Digital Technologies Transforming the City Gas Distribution Value Chain From Source to Consumer

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Abstract
In India, much like the rest of the world, introduction of CGD (City Gas Distribution) has led to a wide range of advantages as compared to traditional LPG (Liquified Petroleum Gas) distribution models: citizen satisfaction, increased adoption of clean fuels, better health, and increased affordability. Now, the focus is on making CGD smart, more accessible, and affordable. For this, the answer lies in building a comprehensive digital framework across the network, making the entire process safe and easily manageable. This paper will describe the overall CGD infrastructure, challenges and integrated digital technology enabled solutions for smart CGD.

Keywords

city gas, distribution, digitalization, SCADA (Supervisory Control and Data Acquisition), Artificial intelligence

BACKGROUND

As the global community accelerates it effort on climate change control, India's role is becoming increasingly crucial. CGD – piped networks delivering natural gas from source to consumer doorstep – is playing an important role in this effort. Pilot CGD implementations in urban Indian centers have provided early insights into establishing a robust, secure, and stable distribution network. However, scaling the network for broader coverage is only possible by addressing the challenges of managing diverse aspects around supply continuity, safe and efficient transmission, and commercial controls.

Integrating digital technologies with the CGD network can make a major impact in this context. Contemporary digital resources are proving to be highly effective globally, combining software, platforms, and modern data techniques (Artificial Intelligence, Machine Learning, etc.) with smart sensing systems, intelligent remote monitoring, digital measurement devices and others.

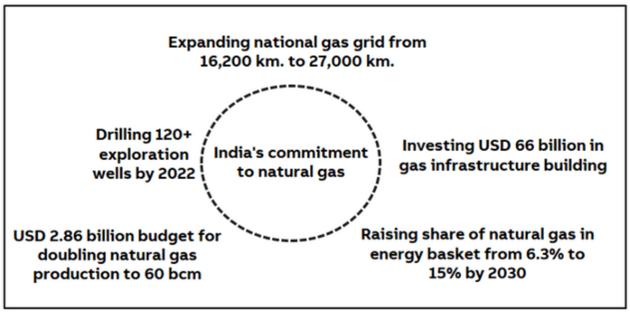

Figure-1: India's Gas Market

CGD network expansion is an important step in the journey towards clean fuel adoption across India. India is an energy-hungry market given its fast-growing population.

Analysts predict that current and planned initiatives on CGD will help extend its coverage to 70% of India's population. Also, the share of natural gas will be over 20% of the primary energy mix by 2030.

Current natural gas pricing trends make the sector commercially

challenging for operators. Well-structured policy will help address this. However, the most important transformation agent will be technology – which has several answers across the entire value chain from import / production to consumption for the pipeline, control, monitoring, leak detection and safety.

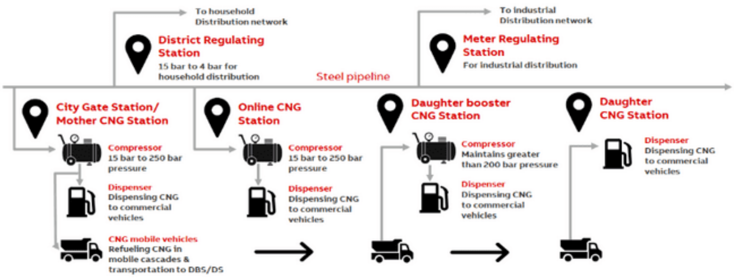

Figure-2: CGD Infrastructure

2. DIGITAL TECHNOLOGIES FOR SMART CGD

Challenges

CGD networks need to address a wide variety of challenges before they turn into major risks or areas of concern. A proactive approach is essential in this regard.

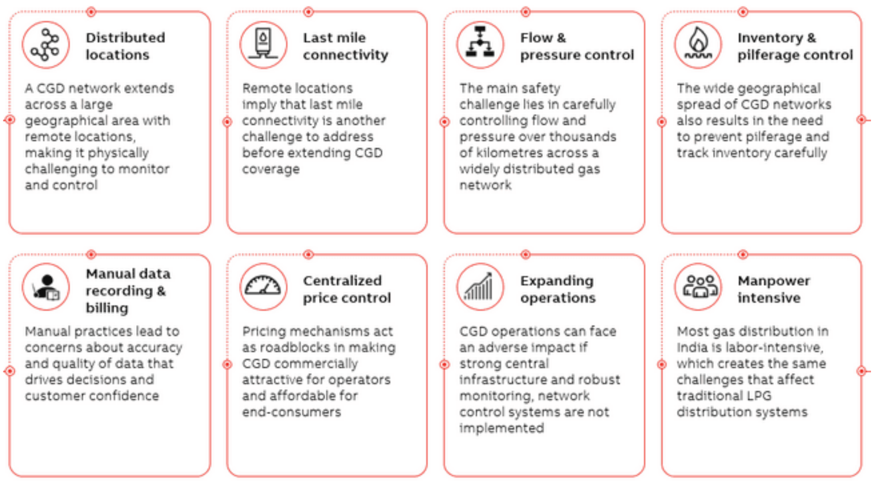

Figure-3: Major Challenges

II. Why Technology has the answers

Digitalization, driven by smart sensors, are transforming operations across sectors and geographies. Technologies which were once considered niche, such as digital measurement & analytics tools, advanced analytics, Technologies related to Artificial Intelligence, Machine Learning, and real-time reporting when they were in their nascent stages. These are now increasingly accessible and affordable and such Industry 4.0 enablers are having a major impact on diverse manufacturing sectors.

The combination of general digital automation technologies and those specific to the gas sector, are helping to address key issues associated with CGD. These include asset management, inaccurate metering, pilferage-related losses, and overall energy value chain management. Left unaddressed, these issues can have a detrimental impact on use of natural gas for domestic, industrial, and automotive use.

a. Scale of networks

CGD is a long distribution network, given typical distances between source and consumer, especially in a large geography like India and because of network opaqueness require remote monitoring capabilities are required.

b. Risk management and Security

b. Implementing systems for predictive fault identification & redressal is imperative for ensuring uninterrupted operations. This also mitigates risks related to leak detection, safety, exposure to vandalism and equipment performance, etc.

c. Multi-stage compliance

CGD networks demand a high degree of compliance to ensure that they stay true to their original objectives of
providing clean fuel while being efficient and safe. The complexity of compliance at various stages makes it essential for it to be tracked and addressed rapidly.

d. System enhancement

The true success of CGD networks lie in their ability to
quickly adapt to changing customer needs, increase in geographical coverage and demand levels. It is essential that the CGD infrastructure continually incorporates new technologies that will help it enhance efficiency and impact.

III. Digitalization: CGD

It is critical to implement a robust infrastructure layer, which lies at the heart of the CGD network. A strong backbone makes the network unerring in terms of supply, transmission, distribution and last-mile connectivity. This requires the coming together of technologies and equipment for measurement, control, remote telemetry, and communications in a seamless manner to ensure high efficiency and safety standards.

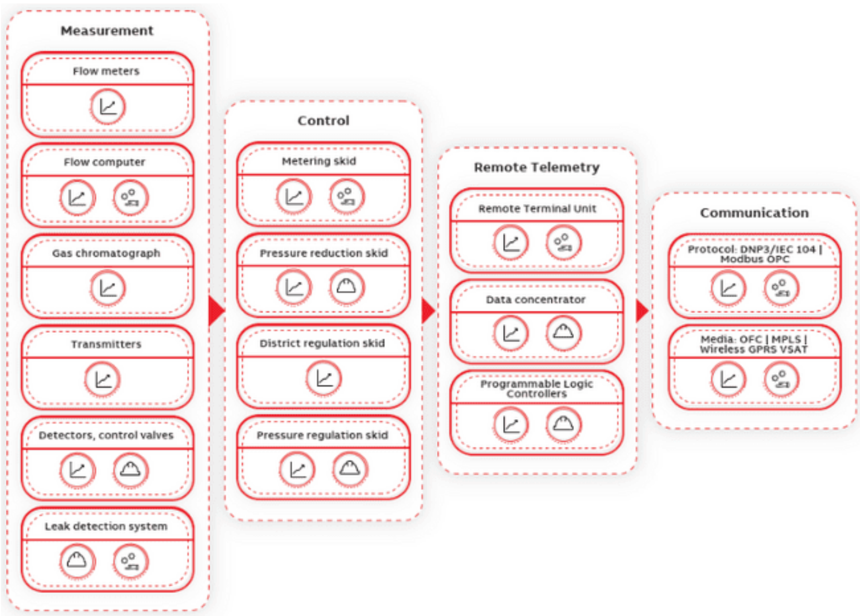

Figure-4: Buidling Blocks of CGD Digitalization

IV. Technologies that transform

A wide range of technology options that exist today can be harnessed to enhance the CGD effort across India.

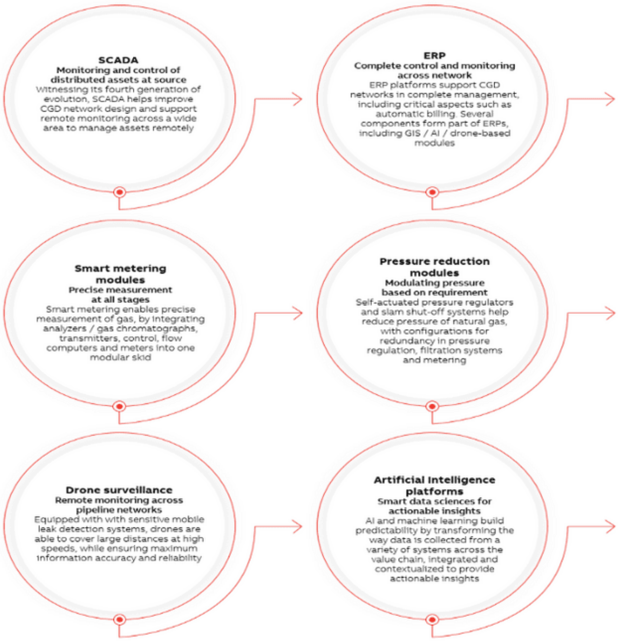

Figure-5: CGD-Operation Layer

3. IMPACT: SOURCE TO CONSUMER

Digital technologies have the potential to transform the entire chain for CGD from source to the customer's doorstep. It helps make the CGD network safer through monitoring critical, high-risk assets, as well as environmentally sustainable and strong commercial performance.

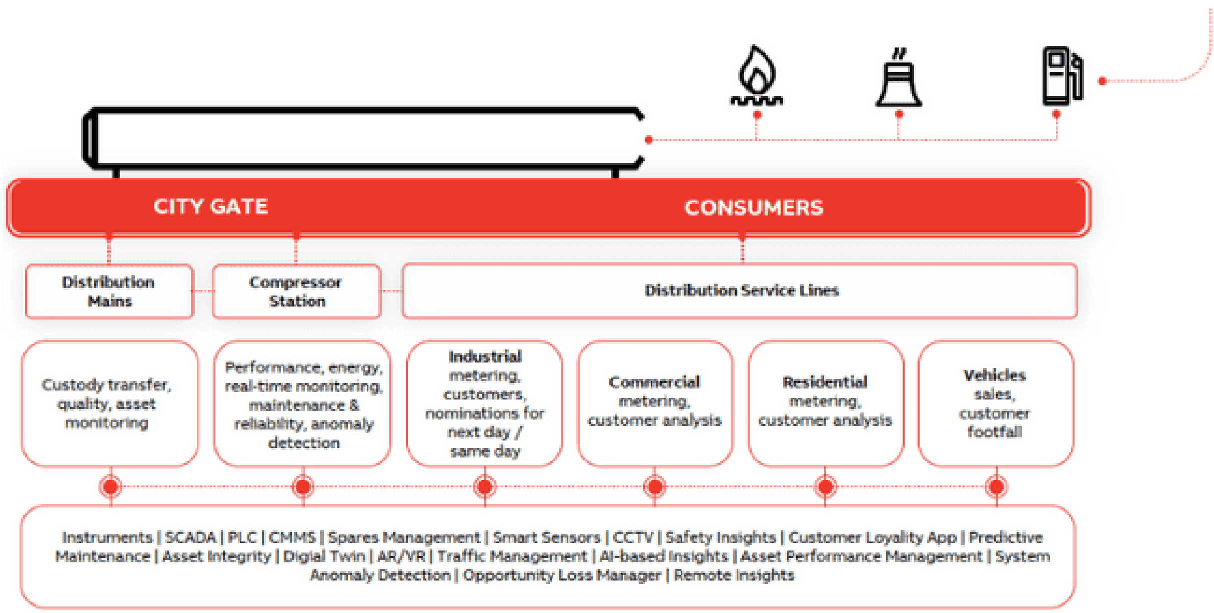

Figure-6: Integrated Digital solutions

IV. SYNOPSIS OF SELECT DIGITAL TOOLS

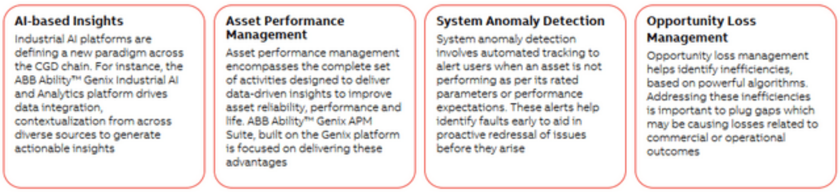

Figure-7: Synopsis

5. KEY SUCCESS FACTORS

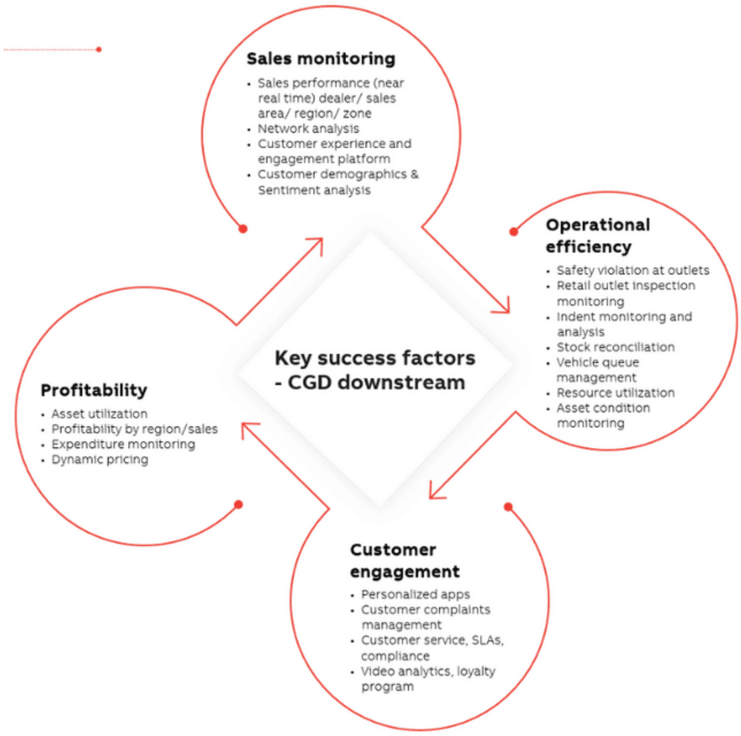

Figure-8: Key Success Factors

6. TRANSFORMATION BLUEPRINT

Today's digital technologies bring to the fore advantages of real-time collection, storage, analytics and reporting of data. A comprehensive architecture that combines all these elements helps CGD networks harness the full power of

digital technologies. One example of digital impact can be seen in SCADA applications. Thanks to web interfacing,

SCADA now integrates with diverse IT, OT, and communication systems, using ubiquitous wireless connectivity and fortified with cyber security.

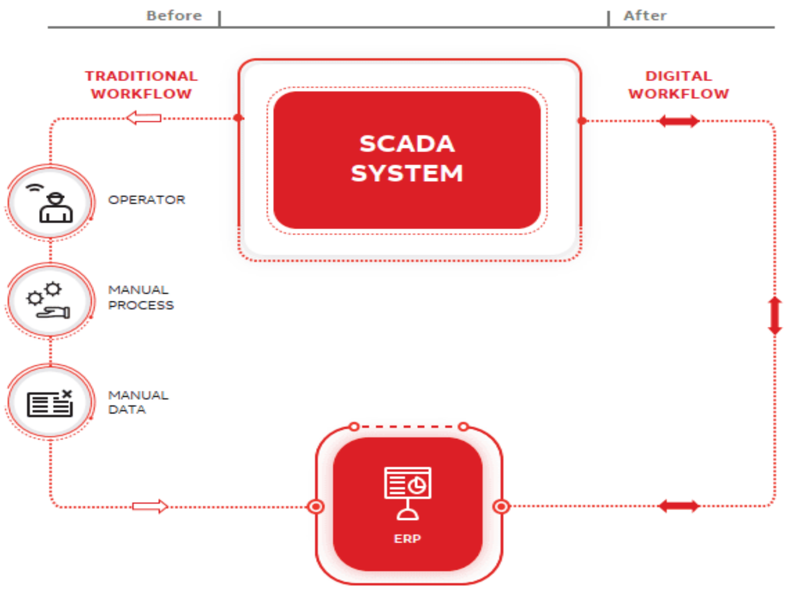

Figure-9: Integrated SCADA & ERP

VII. CONCLUSION

As outlined earlier, CGD is a key enabler of the clean fuel initiative and drive for sustainability. Revised regulations, which encourage higher participation from public & private sectors in the CGD market, are aiding in the expansion of the CGD network to 228 cities. In the process, this will also create opportunities for employment and equitable social growth.

A safe and effective CGD network depends on an array of factors - unerring design, high quality implementation, commissioning, operational controls, all seamlessly integrated with contemporary, future-proof digital technologies. In addition to the digital tools outlined earlier, a wide range of traditional and new-age practices come into play to build a CGD infrastructure that delivers value in a commercially viable manner.

For instance, when conceptualizing SCADA for CGD, it is essential to design the backbone architecture in a manner that is capable of analyzing data, generating insights, and sending real-time alerts.

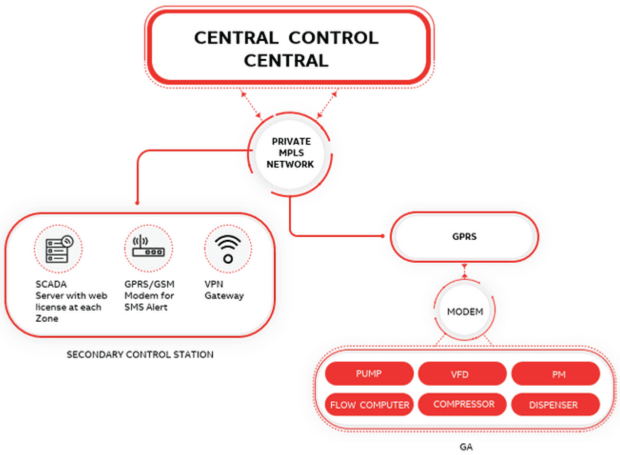

Figure-10: Typical Architecture

Aligning with all key characteristics of a smart city

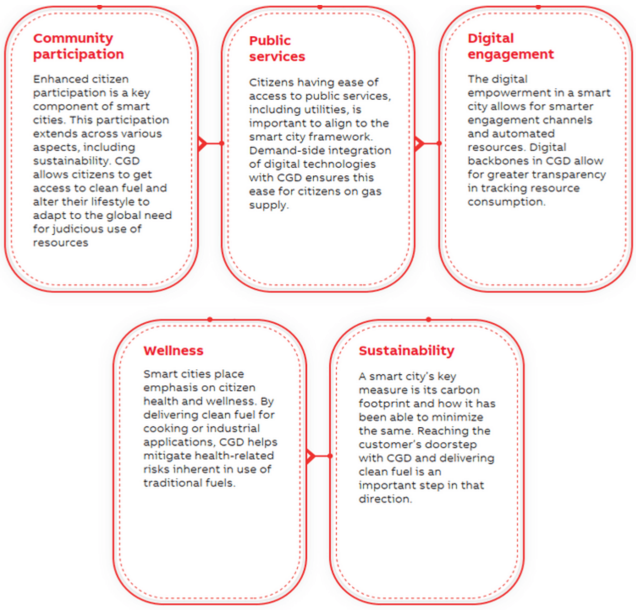

Figure-11: Full proof CGD operation

VIII. ACKNOWLEDGMENT

We wish to acknowledge the push and vision of Government of India, MoPNG and PNGRB towards a cleaner and sustainable fuel and use of digital solutions for smart CGD implementation & operation.

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Wearable Devices

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Abstract

Wearable technology a 'diffusion of innovation' or 'disruption of innovations,' and majority Thinktank concede with later one. Amidst the entire fanaticism around innovating, developing, and adapting new technologies, Healthcare wearable devices, mobile device (Apple's iPhone & 's Android Smartphone) have already flooded the market. In Energy industry, it is vital to recognize and leverage the operational workforce to educate, train and equipped with disruptive wearable devices.

Wearable devices leverage a digital transformation of O/H Lines maintenance inclusive preventive & predictive, make workforce freehand & enhance motive power, health caring lone worker, extend communication beyond Team In-charge to control / emergency center, digital data communication of work pre & post performed and control center advisory thereby enhancing utility efficiency, supply continuity, work safety, quick decision making.

Disruptors rapidly evolving Sensor technology making them lighter and less cumbersome, thereby leveraging **Embedment of sensors** conforming to work environment in **wearable devices/clothing** for utility workforce **always engaged in stressful jobs** throughout their career. In ever-changing world of technological innovations, gadget, sensor, or electronics exists to measure, report, and analyze almost any type of data.

The paper predominantly discuss Utility Workforce **Disruptive Wearable Devices viz**. Augmented Reality Non-Immersive Head Devices ; Google Glass (Google); AIQ Smart Shirt for assessing lone worker work capability; E-Textiles integrating electronics into textiles with fire arc flash capability ; GPS Tracking Band; **New Rubber Protection Blanket,** ozone / corona resistance elastomer, accidental brush contact with energized component; Robotic Power arm; **Line man communication device immediately extendable** to 'Radio Network Coverage', etc.
The paper also discusses Graphene disruptions viz 'See thru Screens, smart clothing, and sensors suitable to perform augmented capabilities of modern sensors. Technology is available but cost prohibitive.

Key Words
Diffusion, disruption, Innovation, Wearable, Sensors, Augmented Reality, Immersive, Graphene. Robotic Power Arm

1.Introduction

The Power Sector is already witnessing major shift from scale-driven, centralized, and standardized model, to a digital, distributed, and personalized one. It is imperative to embrace innovations at all levels in the grid.

However, making faster developments and technology affordable, low-cost Cloud based computing facilities viz. Software-as-a-Service (SaaS), Infrastructure-as-a-Service (IaaS), and Platform-as-a-Service

(PaaS) are now available on-demand platforms which have revolutionized the IT world. These services are now made use of by starters / disruptors at affordable cost. Further, AI technology is infiltrating in every sector and transforming the tasks that computers perform, lot of hype.

Wearables, at present, are defined as independent electronic items incorporated into various devices that can be comfortably worn on living human body. These wearables are used for tracking information on real time basis. They have motion sensors that take the snapshot of day-to-day activity and sync them with mobile devices or laptop computers. Wearable Tech [1] listing out of 10 Innovative Wearable IoT devices, item viii) Smart Clothing reads as “A recent survey by the WEF revealed that 92.1% of corporate leaders believe that by 2025, 10% of people will wear clothes that be connected to the internet. Primary Smart Cloth monitors important health -related information (heart rate, respiration rate, temperature, etc.). Smart Clothes are also used in military operations to get information of a wounded incumbent as it detects the impact of the bullet and sends a radio signal to the control room.” This is an advancing trend in Wearable Technology. 5G/6G communication would enhance the range of protective wears for utility workforce. Ladder safety app that used visual and audio signals to check safe ladder angles.

2.Wearable in Power Sector

The Power Sector has undergone operational change wherein ‘Consumer’ has become ‘Prosumer’ & gets in sync with the grid thereby contributes to improve stability, reliability, improve revenue. The Power Utilities have undertaken hardening of their supply resources against Climate changes causing storms, floods, tornadoes, natural calamities etc. Accordingly, the power system has been made smart and self-healing thru Smart Grids & reclosures, adopted automation, distribution and location of spares & tools, maintenance staff intelligently provided with effective communication etc.

2.1 Wearables for Linemen (Transmission)

The Wearables worn on body of workforce are presently designated as ‘Wearables.’ The apparels / wearables have been adopted by engineering / technical workforce from the inception. Out of their tools (General tools and SMTs), those at present designated as ‘Wearables’ are those which afford protection against arc flash, electric shock, electrostatic field, radio frequency exposure, etc. The Utility workforce wearables need to be revised / upgraded considering the digitization and smart wearables.

Lineman is also provided with Pole Climbing Gear comprising Climbing spikes (hooks, gaffs, climbers, spikes); Lineman boots, lineman belts, Fall protection equipment (Personal fall arrest system). Work positioning system, Fall restraint system)

2.1.1 Protective Wearables (PPE) [2]

Wearables PPEs for Lineman be of Requisite Fire Category and comprise of an ‘Overall/ shirt & pant, gloves, shoes, safety goggles, hard hat, face cover, ear protection, Dust masks and respirators etc.

Lineman PPE needs to meet the National Standards, American Society for Testing and Materials (ASTM) F15016: Standard Performance Specification for Flame Resistant and Arc Rated

Textile Materials for Wearing Apparel for use by Electrical Workers Exposed to Momentary Electric Arc and related Thermal Hazards and has an Arc Thermal Performance Value (ATPV) of 9 cal/cm². It is also compliant to the HRC 2 as defined by NFPA, and meets standards put in place by OSHA and National Electrical Safety Code (NESC).

A. The simplified PPE list based on NFPA 70E Table 130.5(G) [2] on category arc rating 12 cal /cm² (incident energy exposure equal to 1.2 to12 cal/cm²) and category 40cal/cm² (incident energy exposure equal to 12 to 40 cal/cm²).

2.1.2 Electrostatic Field Protections

i) Harmful AC electric field, Electric discharge during live work, Current shock from induced voltages and Thermal protection from electric arc,
ii) Meets and Exceeds IEC 60895-2020 with less than:
1-ohm overall garment resistance, 30-ohm glove resistance and 70dB shielding factor at 60Hz
iii) Meets and Exceeds IEC 61482 with a ATPV of 10cal/cm2
(The above specification may preferably comply Country National Standard and/or General Insurance Companies)

Lineman Apparel material [4]

Fabric system consist of three elements
i) A unique double sided conductive fabric – the highest level of shielding factor(70dB), ATPV level of 10Cal/cm2, oil & water resistance, isolation of its conductive side from human body
ii) A highly conductive tape- Low level of electric resistance
iii) Nomex reinforcing pads- protection of highly conductive tape from mech. damage, addl. mech strength of the elbows, knees and other parts of the suit that are highly subject to abrasion

The whole fabric system is resistant to human sweat and multiple washings.

A face mesh protecting the face, eyes and brain from harmful electric fields and dangerous radio frequencies need to be incorporated.

The electrostatic design protects the worker from 'Harmful AC electric field, Electric discharge during live work, Current shock from induced voltages and Thermal protection from electric arc Meets and Exceeds IEC 60895-2020 with less than 1-ohm overall garment resistance, 30-ohm glove resistance and 70dB shielding factor at 60Hz. Meets and Exceeds IEC 61482 with a ATPV of 10cal/cm2

3. Live Line Maintenance [5]

The special methods of breakdown restoration/ emergency restoration of breakdown without taking shut down are 'Hot Stick method' and 'Bare Hand method' and are deployed with specially trained Linemen and special tools / wearable [Chapter 7. CBIP 293].

3.1 Hot Stick Method

The linemen wear Fire Protective wearable / Apparel and hot stick tools comprising hot stick and metallic tools suitable for performing the requisite function. The tools required for hot line working comply with IEC 60832, 60895 and 61478.

3.2 Bare Hand Method [5]

The lineman wears Conductive suit as a wearable (acting as Faraday Cage) at the level of live line and bond himself with live line before making direct contact with an energized line. The methodology of working conforms to IEC 60832, 60895 and 61478.

The Wearables comprise Conductive suit, hand gloves, socks, boots, and static belts manufactured from thin stainless-steel wires and special type of fibers.

4. Arc Flash Personal Protective Equipment (PPE) [2,3,4]

The PPE is essential necessity when an electrician faces danger of being harmed by an arc flash. This flash can occur any time an electric arc is provided with enough electricity to cause injury, harm, or fire.

The temperature on arc flashes can reach, and in some cases surpass 35000°F (20000°C) at the arc terminals.

Few approaches to secure oneself from an arc flash risk, include wearing approved arc flash PPE or changing the outline and configuration of the electrical equipment working with.

Modacrylic-cotton blends are among the best fabrics to protect against arc flash risks. It is important to use the right PPE conforming to NFPA 70E under specific hazard classification (Energy Exposure; **40 cal/cm2)**

Shock Protection Blankets [6]

Shock-protection blankets (22x22 in) cover energized components to protect workers from electrical hazards. They provide a barrier for electrical equipment situated in cubicles, switchboards, and S/Ss. These blankets have eyelets so they can be secured in place with blanket pins, buttons, or straps.

It meets ASTM Standard Specification D1048, Class 4 type II (Ozone Resistance), protection from accidental brush contact with energized component during maintenance, made of ozone/ corona resistant elastomer, special formulation exhibits superior resistance to long term aging.

5. Modern Wearables [7]

The modern wearables cover Augmented Reality (Non-Immersive) and Virtual Reality (Immersive) devices. Virtual reality replaces individual vision and augment reality adds to it. The Difference Between AR and VR is that they accomplish the job in two very different ways, despite their devices' similar designs. VR replaces reality taking one somewhere else. AR adds to reality, projecting information on top of what is being already seen.

The Augmented Reality has made an impressive development in health sector, retail sector, sports training, industries, User -centric technology to enhance experience & knowledge, product selection in e-commerce whereas Virtual reality beyond gaming and entertainment, offers' Risk -Oriented Training', 'Flight and Car driving Practice', 'Designing by architects as using virtuality reality based applications', 'Convenient for next generation educational institutions and virtual leveraging AI, VR and virtual learning', etc.

5.1 The four New and potentially disruptive are as under:

i) Voice -driven interference

A novel method to improve the voice recognition performance by suppressing acoustic interferences that add nonlinear distortion to a target recording signal when received by the recognition device. The proposed method is expected to provide the best performance in smart TV environments, where a remote control collects command speech by the internal microphone and performs automatic voice recognition, and the secondary microphone equipped in a TV set provides the reference signal for the background noise source

ii) Augmented Reality & Virtual Reality

Augmented Reality	Virtual Reality
Non-Immersive	Immersive
Compatible with Other Tasks Talking/ Listening Taking picture/Messaging/ Receiving basic graphic information	Attention absorbing video games / video-based news and entertainment

iii) Heads-Up Computing [Head Up Computing]

Heads-Up Computing is ambitious vision to fundamentally change the way interaction is made with technology and to shift into a more 'human-centered' approach.

Heads-Up Computing is characterized by 3 main components viz 'Body-compatible hardware components', 'Multimodal voice and gesture interaction' and 'Resource-aware interaction model and the Model - a soft ware framework which completely exchanges information between head and hand'.

The Disruption potential in the mobile media ecosystem seems to be a recognizable disruption in wearables, specifically in glasses and some kinds of head gear, as they go beyond the immersive experience of the opaque-screen-driven interfaces.

5.2) Smart Shirts, Tracking Bands

i) AIQ Smart Shirt for assessing Lone Worker work capability [8]

Cardioid Smart Monitoring (CISM) is a solution for Lone Worker monitoring based on AIQ Smart Shirt. It acquires the Electrocardiogram (ECG), together with inertial information of the user and determines the user state providing man-down, vital signs, and fatigue indicators to the backend. Cardioid has been developing a technology for a non-intrusive acquisition of the heart signals that enables pervasive health monitoring, emotional state assessment, drowsiness detection, and identity recognition.

ii) E-Textiles integrating electronics into textiles [9]

Bioman+ is a base upper body garment solution for a wide range of smart clothing. It consists of conductive fiber-based textile electrodes for the acquisition of the electric activity of human body as well as conductive thread to carry the electric signals to the processing & transmission module that is snapped onto the garment.

AIQ-Synertial (25years Experience)

The capability to digitize human motion is significant in a wide range of application scenarios – Sports Coaching, Physiotherapy Management, Entertainment, and Industrial applications to name the most popular ones.

iii) GPS Tracking Band & NFC Smart Ring [10]

GPS Tracking Band along with Smart phone facilitate tracking of 'on walk' and 'run more' accurately in addition to heart rate monitoring. It also affords safety, security, and location of an un-accompanied individual/ group against kidnapping/ physical threats when on isolated assignments.

The different frequency bands of GPS are GPS L1 Band: 1575.42 MHz with a bandwidth of 15.345 MHz, GPS L2 Band: 1227.6 MHz with a bandwidth of 11 MHz, GPS L5 Band: 1176.45 MHz with a bandwidth of 12.5 MHz

6. Graphene and its deployment in Wearables, Energy Storage, Automobiles body parts, etc. [11]

Graphene is incredibly thin lattice of carbon, incredibly tough yet incredibly light, just one atom thick but seen with naked eye, 200 times stronger than steel and more flexible than an Olympic gymnast, fire resistant but a superb conductor of heat. *Used as structural components for cars, aircraft, ships, etc.*

Flexible wearable graphene sensors embedded in wearables attribute durability, light weight and used in Fitness bands, medical monitors, and Smart clothing (Bonbouton, USA). Tee shirt (Bonbouton) are for passively monitoring the skin's physiological signals to predict injury, detect infection and monitor muscular activity.

In Power sector, Graphene is at presently used in modern Power Grids; energy-efficient light sources; semiconductors used in spintronic devices; more effective anti-corrosion coatings; water filtration for purification and desalination; optoelectronic communication systems.

7. Robotic Power Arm & Supernumerary Robotic Limbs (SRLs) [12]

Robotic Power Arm / SRLs, an extended arm / limb to act as an extension of the Wearer own body, light weight and be worn on shoulder or waist to lift heavy objects or free up their own hands for another task. Massachusetts Institute of Technology (MIT) have created robotic arms that can lift heavy objects and things that are not possible. The arms are designed to streamline tasks, give humans an extra pair of hands and become an extension of the own body.

MIT presented their latest SRL prototypes, with one model featuring a pair of limbs that spring from the shoulders and another with limbs that extend from the waist. In addition to these extra shoulder arms, other researchers at the d'Arbeloff Lab are constructing waist arms that can be used for holding objects as well as for bracing the user, much like an extra pair of legs
The Robotic Power Arm / SRL, if provided, facilitates Utility workforce to lift heavy load on their own at isolated/ unapproachable locations

8. Communication Capabilities [13]

Lineman communication devices generally range to 30m. In case of emergency, windstorm, landslides, etc. and due to limited communication, induvial or group may get isolated and experience health hazard, etc. and as such, Line men shall be provided with reliable communication. The Linemen shall be provided communication facilities mentioned as under:

Table1: Proposed Communication for Linemen [12]

Immediately Extend LM Radio Network Coverage —› Work beyond	**Bring Anyone into the Conversation Affordably**	**Instantly Broadband enabling existing LM Radio**
The radio network edge and in the challenging areas like building interiors, automatic switching communications to a broad band network.	Invite workers outside your LMR network into radio conversations with a wearable broadband and without the expenses of a dedicated radio.	Provide broadband speech narrowband portable radio apps like Tait Geo Fencing using rapid location polling to monitor workers in hazardous zones

Tracking the emergency and rescue team becomes easy thus making the workplace more efficient and safer.

The above arrangement enables extending communication beyond Team In-charge to control / emergency center, digital data communication of work pre & post performed and control center advisory thereby enhancing utility efficiency, supply continuity, work safety, quick decision making, etc.

Conclusion

1.Wearables, defined as independent electronic items/devices incorporated into various items (e-Clothing, GPS bands, Monitors (health science, Sport training), are comfortably worn on living human body. These wearables are used for back tracking information on real time basis. They have motion sensors that take the snapshot of day-to-day activity and sync them with mobile devices or laptop computers. Hands -free nature of the wearable devices and Hands -free access to important data and information thru smart glasses and smart watches help workforce to be more efficient at the worksite. Incorporating /Amalgamating and improving the existing work tools/ wearable with the facilities provided under Modern Wearables would be desirable.

2. Out of outgoing modern disruptive, the 'Augmented Actual Reality' which is Non-immersive and Compatible with Other Tasks- Talking/ Listening, taking picture/Messaging/ Receiving basic graphic information. A small number of AR models run a mobile operating system and function as portable media players to send audio and video files to the user via a Bluetooth or Wi-Fi headset. Some smart glasses models also feature full and activity tracker capability as also have features found on a smartphone. Some have activity tracker functionality features (also known as «fitness tracker») as seen in some GPS watches.

3. The apparels / wearables adopted by Utility workforce afford protection against arc flash, electric shock, electrostatic field, radio frequency exposure, etc., but by providing additional facilities offered by Wearables viz.

e-Clothing, GPS bands, Monitors, Lone protection, etc., they are better secured, more efficient and better protection.

Wearable PPE (Conductive suit, hand gloves, socks, boots, and static belts consist of fabric system (thin stainless-steel wires and special type of fibers) with addl. mech strength of the elbows, knees and other parts of the suit that are highly subject to abrasion.' The components to meet and exceeds IEC 60895-2020 with less than 1-ohm overall garment resistance, 30-ohm glove resistance and 70dB shielding factor at 60Hz.

4. 'Immediately Extending Radio Network Coverage', 'Bringing Anyone into the Conversation -Affordably' and Instantly Broadband -Enable Existing LMR Radio' facilitate reliable communication, tracking of the emergency and rescue team making easy under emergencies (floods, tornadoes, landslides, etc.) thereby making the workplace more efficient and safer.

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Centralized & Decentralized Approach for Safe, Reliable Power Supply using IT-OT

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Abstract

Conventionally it has been observed in the Country that OT systems such as SCADA, DMS, OMS, and GIS etc. are largely implemented in Urban areas of the Distribution Utility. By virtue of the same a better visibility and control is achieved on the urban network distribution network. Although better operational control is achieved, however an effective system of operational, safety, outage & reporting management is far from reality. Add to this fact that we gain control only on a part of the discom under the OT system while the balance (mostly larger part) of the system continues to operate as per the historical approach creating a disparity both for the consumers and the discom. This would become more of a reality when Tata Power took over the Central Odisha Discom. We went ahead with developing a kind of Prototype for network management of Automated –Non-Automated and Urban –Rural setup which can be replicated elsewhere in the country. The significance of this approach is that that this probably the only example in the country for a Distribution Utility of this expanse for having managed its network operations with a composite Centralized and Decentralized approach. This approach has brought about a paradigm shift in the way large Distribution Utilities with an Urban and Rural footprint are operated.

Keywords

Power System Control Centre (PSCC) , Area Power System Control Centre (APSCC) , Permit To Work (PTW) ,Suraksha ,SCADA,Information Technology (IT) ,Operations Technolohy (OT)

Introduction

TP Central Odisha Distribution Ltd (TPCODL) came into inception on 1.6.2020 on taking over the operations of Odisha State's Central Electricity Supply Utility (CESU) as a JV between Tata Power and Govt. of Odisha. One of the foremost tasks of the organization in the area of Operations was to quickly make operational a Centralized Mechanism for Reporting, Monitoring of Critical operational parameters daily to the Management so that better visibility was available for decision making. This would at the same time build a data repository for reference and analysis as we mature into the journey. Getting the visibility of Power Distribution Network and Control for ensuring Safe Operations and ensure Safe Maintenance practices was the next objective in the journey of Operations Excellence. The core at all this was to adopt and implement automated processes for Support functions with minimal or no manual intervention.

TPCODL has managed to achieve this by leveraging power of Information Technology (IT) & Operations Technology (OT) integration by deployment of critical in-house developed tool "Suraksha Kavach "on the IT side and SCADA on the OT side With Suraksha Kavach tool, a plethora of modules have been developed for catering to the customized needs of all connected stakeholders. This has brought about remarkable change in

Delivering promising results towards ensuring safety Achieving operational excellence Managing events database for effective reporting Systematic planning of maintenance activities Information delivery to consumers regarding supply restoration Live feed of power status to Customer Care/Call Center Conducting Energy Audits. This was made possible by a systematic module-based training, monitoring, and retraining around 4400 in-house employees and more than 22,000 business associates' Crucial data points were now available in livestream to our Call Center and could also be shared to immediately with Customers via SMS, WhatsApp etc. The huge amount of data gathered could now be used for analytics and systematic deduction and works as a trigger for planning maintenance or infrastructure development accordingly.

II. Establishment of Power System Control Centre (PSCC)

Earlier all network operations were carried out in a decentralized manner locally by Substation Operators or Line staff as required for each of the Divisions/Sub Divisions/Sections of the Discom. With this approach an overall monitoring and status of the network would therefore be difficult Further though there existed a process of Permit to Work (PTW), the practices followed across Divisions were not uniform. Monitoring of Operational parameters at a centralized level was not possible.

Normally the concept of a Centralized Control Centre for Control. Monitoring and Reporting on a daily basis would be the panacea to begin with, as is the case with most of the progressive discoms in the country and elsewhere in the world as a Distribution System Operator (DSO) with the only difference being that it has a full-scale deployment of SCADA for complete visibility and control.

To begin with a 24 x 7 Control Centre or Power System Control Centre (PSCC) was institutionalized with manning round the clock and to begin with only reporting in the Form of a Daily Flash Report which would have reporting of critical network parameters.

III. Expanse of the Geographical area & Network Demographics

The essential point to be noted and which reinforces the requirement of a Central Network Control Centre is the sheer expanse of the proposition in the sense that we are talking of an area of 30, 000 Sq. Kms, consumer base of about 27,000,00 consumers catered by 220,33 kV Feeders ,370 ,33 /11 kV Primary Substations (PSS), 1200 ,11 kV Feeders and about 71000 Distribution Transformers which are spread across twenty Divisions in urban, semi urban, and rural areas of the discom.

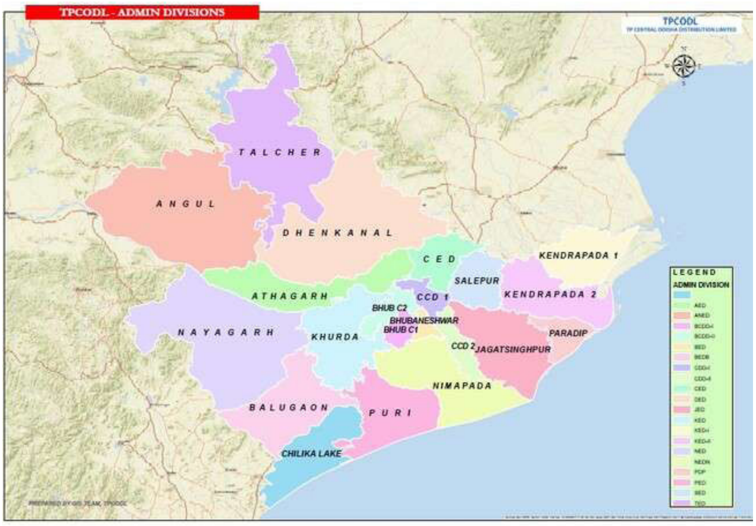


Fig 1 Geographical Spread

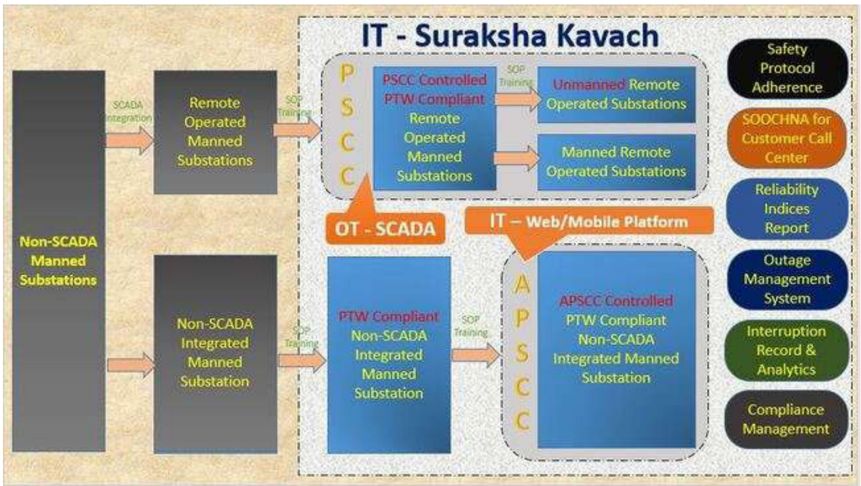


Fig 2 Centralized & Decentralized control with OT on one side and IT on the other side

This becomes more complex when we consider the fact that the PSS are mixed of Automated and Non-Automated or integrated to SCADA & remotely controlled or not.

IV. Approach

The consolidated approach for taking control of the distribution network across the discom has been exemplified in Fig 2. The OT system in terms of SCADA was to be made operational and functional. While the SCADA system is made Go Live, its sustenance, operations and scale up is a challenge in most of the geographically spread discoms.

Start of the journey was in a similar fashion wherein the SCADA system was to be made functional. In terms philosophy of operations, a shift from totally manually operated PSS to automated PSS by integrating to SCADA for remote operations was the first phase. This phase involved a lot of ground work in terms of change management in terms of people and processes. Detailed Standard Operating Procedures (SOP) were developed, extensive training was imparted to the PSCC Desk Engineer`s, Line staff and Engineers in the field with respect to Operations and Safety.
As these PSS matured in terms of the changed philosophy of operations, they were then taken to the next level in terms of Unmanning of the remotely operated PSS. This was affected by clubbing 3 to 4 PSS and operating them through a Mobile Operations Crew (MOC) normally stationed at any one of the PSS.

Considering the expanse of the network, it was not possible to cover all the PSS under automated operations and therefore we have now landed up into a situation where we had one set of PSS which were centrally monitored and controlled and other set of PSS which were not monitored or controlled at all and were on a standalone basis. This is the situation which we needed to alleviate and see that even though PSS were not SCADA integrated we needed to have a near real time view of network through some IT intervention that could be common to both remote Operated and manually operated stations or in effect an approach of Centralized & Decentralized control with OT on one side and IT on the other side.

This is kind of framework was needed to be developed for adopting a mix of Centralized and Decentralized control for these PSS. Also, as we moved ahead in the journey need was also felt to Unman PSS and actually reap the benefits of Automation. Arising out of this, various combinations of control were required to be established:

1. Centralized Automated Remotely operated manned PSS
2. Centralized Automated Remotely operated unmanned PSS

3. Decentralized Non-Automated Locally operated manned PSS
4. All the above was to be ensured to be done safely and through authorized and competent field personnel too.

Basis the above another layer of control center in addition to centralized **PSCC** was introduced as decentralized Area Power System Control Centre (**APSCC**) which was will essentially take care of the Non-Automated Locally Operated manned PSS. One APSCC was established for each division which would in turn have about 10 PSS under its umbrella. In this fashion all the non-OT operated PSS were brought on a common platform. This has been explained in Fig 2 above.

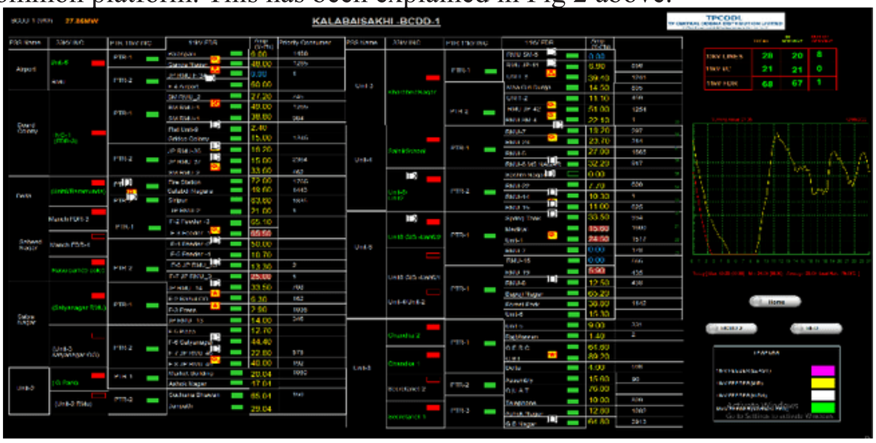


Fig 3 Power Monitoring Dashboard during Thunderstorms

While the normal SCADA functionalities were being reaped from the OT System, certain Niche requirements were also developed for efficient control and monitoring of the distribution network.

As seen above, a dedicated overview dashboard for monitoring and control of particular divisional area is seen. This is especially useful during the peculiar Kal Baisakhi or Nor'westers.

Both the OT and Non-OT controlled stations were brought under one IT tool as elaborated in the subsequent sections of IT.

V. IT Intervention

During the inception PTW `s were being managed through a manual Excel based system. This involved a lot of procedural work; it is a humongous task to manage and record such huge amount of entries for issuing and clearing PTW`s manually.

In order to overcome this, PSCC with inhouse IT team has developed a complete web based PTW Management system **"Suraksha Kavach"**

Fig 4 IT Application Suraksha Kavach

Through Suraksha Kavach, PSCC manages it is Permit to Work system efficiently. The following key aspects are addressed through this
Only pre-authorized personnel are eligible for working on lines/equipment's

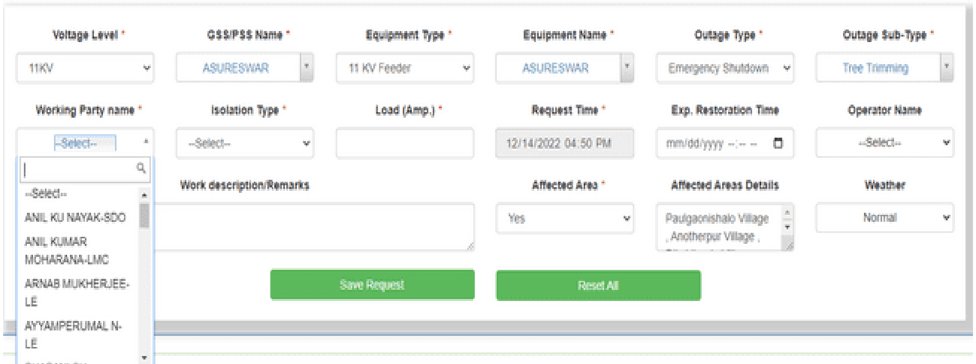


Fig 5 Authorized Personnel Selection for PTW

1. Every work is identified by a unique code number. This is only shared with working personnel so that only they can clear the line/equipment by charging.
2. The unique code is auto generated by Suraksha Kavach and SMS /WhatsApp is sent directly to registered number

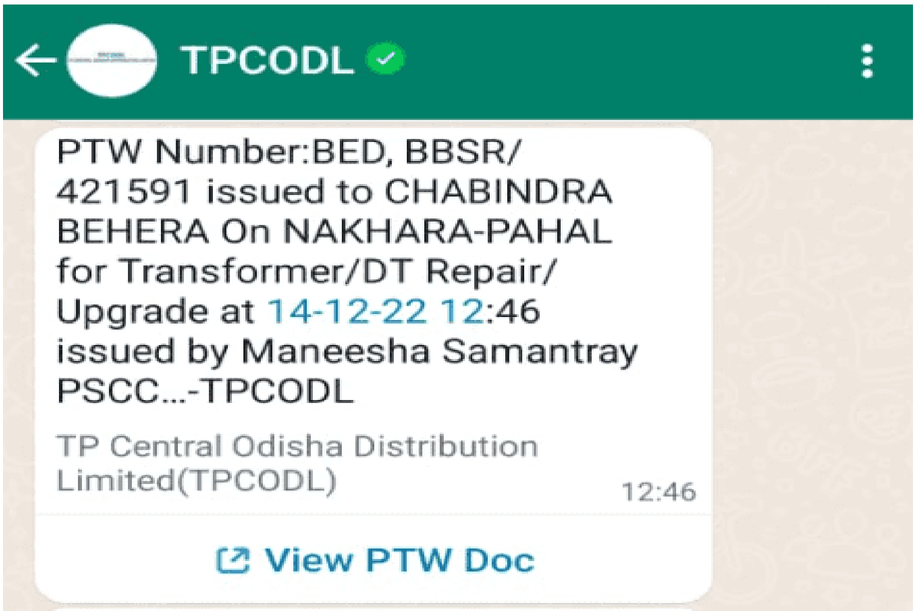


Fig 6 PTW through WhatsApp.

3. Division, Substation and Feeders are pre-mapped into the system. It automatically detects the number of consumers affected for any shutdown
4. One of the other important features in the application is ensuring that the field personnel availing the shutdown are aware of all the Hazards, use the right Personnel Protective Equipment and create a proper Safety Zone as seen in Fig 7

Fig 9. Scheduling of Planned Outages

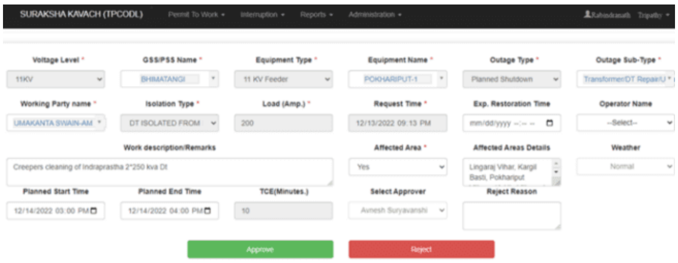
Fig 9. Scheduling of Planned Outages

With these prime aspects addressed, PSCC desk engineer focuses on ensuring safety adherence and minimal supply interruption time to consumer.

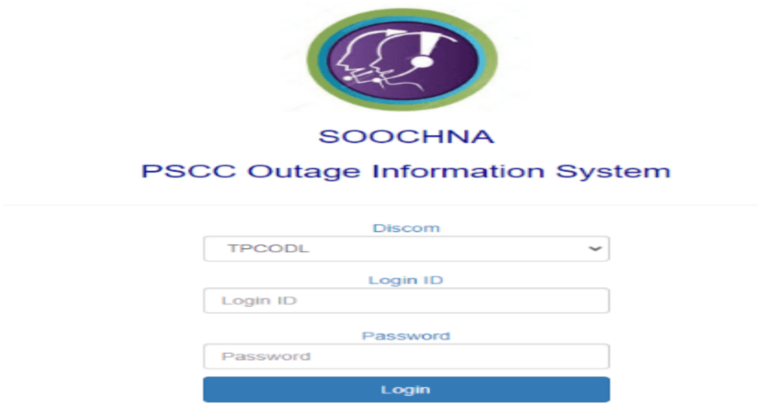
Additionally, Suraksha Kavach helps in data management and aids analysis by generating

Customized reports for monitoring operational efficiency.

Since all the network database in the correct hierarchy has already been mapped in Suraksha Kavach, this is also extended to function for the Outage Management Function wherein day ahead outages can be planned and approved at appropriate level for execution.



Further since all the discom real time and near time data in terms of outages, tripping was getting punched in Suraksha Kavach this had a near real time visibility of the power situation across the discom. It was only logical to extend this information to Call Centre so that the consumers are well informed. This was done by developing an application “SOOCHNA.”



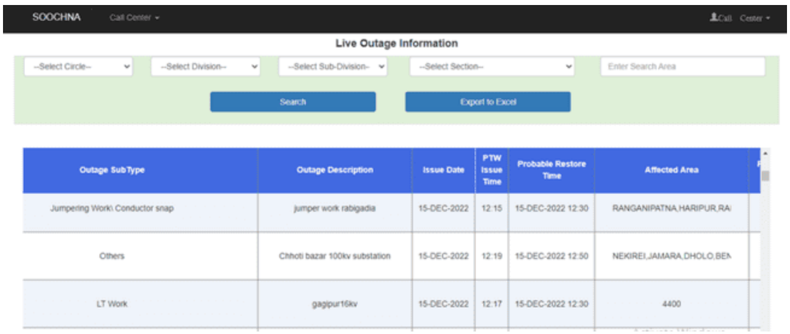


Fig 10. Live Outage Information

Various Reliability reports on a daily, monthly, yearly frequency for the whole of the discom area or any particular area is also published

VI. Value Creation

Arising out of the functions enlisted above, various benefits will be accrued leading to Operational Excellence:

1. Ensure efficient & coordinated operations across the license area as envisaged by the Grid Code.

2. Will facilitate faster restoration in the event of a shutdown /breakdown with the help of remote operations through SCADA. As a result of this reliable and uninterrupted supply to the consumers at large is ensured.
3. Will ensure optimal loading, utilization of the network by effecting real time positions of switches in the network so as to ensure the minimal possible losses in the network.
4. Facility of contingency analysis on the network with real time network parameters and under various scenario for initiating corrective action in terms of network improvement schemes.
5. Institutionalization of uniform safety procedures across the license area for planned /unplanned outages including preventive and breakdown maintenance activities by developing Standard Operating Procedures, Operating Instructions, Permit to Work and Safety Tagging procedures. This will result in ensuring safety of personnel and equipment and consequently avoid any accidents to utility personnel and outsiders alike.
6. Will ensure optimal outage management for preventive and breakdown maintenance of the network equipment's for ensuring maximum system availability.
7. PSCC will be a central data repository for network parameters and will carry out reliability analysis across various zones /voltage levels and across the license area. It will compute and report various reliability indices for the utility that would be required for benchmarking, improving performance parameters and further as a regulatory compliance for reporting.

VII. Conclusion

With this unique approach of Centralized and Decentralized Operations through PSCC and APSCC using the benefits of IT –OT integration, TPCODL has been able to develop and implement a model Distribution Network Operations methodology for a composite automated-non automated, urban-rural network ensuring & enhancing Safety manifold, ensuring Operational Excellence and improving Reliability.

This methodology has laid the foundation stone in terms of operating any discom with a vast geography, consumers, and network efficiently and can be adopted for replication elsewhere.

IElectrix Project – Results and Lessons Learned from the Indian Demonstration in Delhi

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Abstract

IElectrix is a response to the Horizon 2020 Call of the European Commission: “Integrated local energy systems”, which experiments 1 demonstration in India and 4 demonstrations in Europe. “Local energy systems” is a mix of locally generated power and consumption, thereby addressing the challenges of Renewable Energy Sources penetration and network associated challenges in case of reverse power flow back to the grid.

The Indian demonstration is the first pilot project co-financed by the European Commission to physically implement an urban Low Voltage (LV) Microgrid in Delhi.

Most of the equipment and software have been designed and manufactured in Europe. Therefore, after having shipped the configuration to Delhi, all the different equipment and systems have been installed and commissioned in March 2022 at the demonstration site, which is the St. Xavier Sr. Secondary School substation in Delhi operated by Tata Power-DDL.

After resolving several technical issues encountered during the summer period, the experimental phase of the Indian demonstration was carried out in the second half of 2022. The objective of this phase was to test the microgrid with its islanding capability in order to assess the potential improvements in terms of quality and continuity of the LV distribution power supply at the secondary substation of St. Xavier School.

The paper presents a technical description of the results obtained as well as the lessons learnt from this smart grid project.

1. Introduction

The Shakti demonstration, located in Delhi, implements a microgrid solution being deployed in the St. Xavier secondary substation and its associated low voltage (LV) grid.

This document begins with a brief presentation of the final configuration of the microgrid installed on the site.

Then, the main results obtained during the experimentation period are presented in the following domains:

- Local monitoring
- Improvement of the resilience of the local energy system
- Frequency management
- Voltage management

Eventually, the main challenges met during the testing phase of the demonstrator are presented along with the associated lessons learnt.

2. Microgrid final configuration

Shakti Microgrid demonstration is connected to a Tata Power-DDL distribution network through 3 LV feeders, with existing 3 PhotoVoltaic (PV) fields. A set of equipment including a smart MV/LV transformer with on load tap changer to enhance the community's electricity quality and renewable hosting capacity, an Energy Control Center which enables electrical safety and cybersecurity, a Battery Energy Storage System (BESS) allowing the electrical back-up in case of a Medium Voltage (MV) grid loss, were installed in order to transform the classical secondary substation into a smart and more resilient one, as represented in Fig. 1. This configuration is managed by a Supervisory Control and Data Acquisition System (SCADA) and an Energy Management system (EMS).

Fig.1 Shakti on site final set-up

3. Main results of the demonstration

A. Local monitoring

A.1. Local monitoring through the SCADA system

The system that has been deployed includes a detailed logging of the status of the main components of the demonstrator, as well as the value of the main electrical parameters of the LV distribution grid. Hundreds of signals have been configured to be continuously monitored and sent to the SCADA system, so the operators could know at every moment the status of the installation and have the right information to operate it in a proper way. Those signals are also stored in the SCADA database, to show a greater insight about past events on the installation.

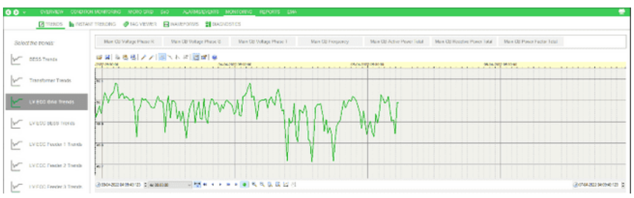

Fig. 2 Trend of the frequency of the electric grid as collected in the SCADA.

Besides the usual electric parameters (voltage, currents, power, frequency), and the status of the breakers (open/close), other parameters like temperature and humidity are also collected, to be used for condition monitoring purposes and to anticipate the need for maintenance of the monitored installation.

Finally, and to support the local monitoring of the installation, detailed system and alarm logs are available to shed light about specific situations affecting the demonstrator. For instance, they are useful to identify communication instability, availability of power on the main grid, status of the battery energy storage system, and so on.

A.2. Local monitoring through the Odit-e software

A LV Grid Observability software developed by Odit-e within the IElectrix project allows Tata Power-DDL to monitor its LV grid.

The analysis has been built based only on the data coming from the smart meters connected to the St. Xavier secondary substation.

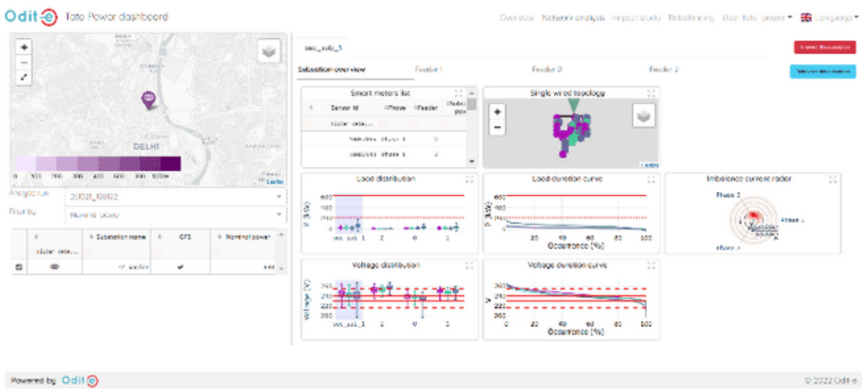

Fig.3 Network Analysis through the Odit-e software

It displays to the user different widgets that have different applications for the Distribution System Operator (DSO).

The two first widgets show the retrieved topology of the LV grid, meaning that only with smart meters data and Machine Learning the meter-to-feeder associations. This information was crucial for Tata Power-DDL in order to confirm or correct Geographic Information System (GIS) data that is often unreliable.

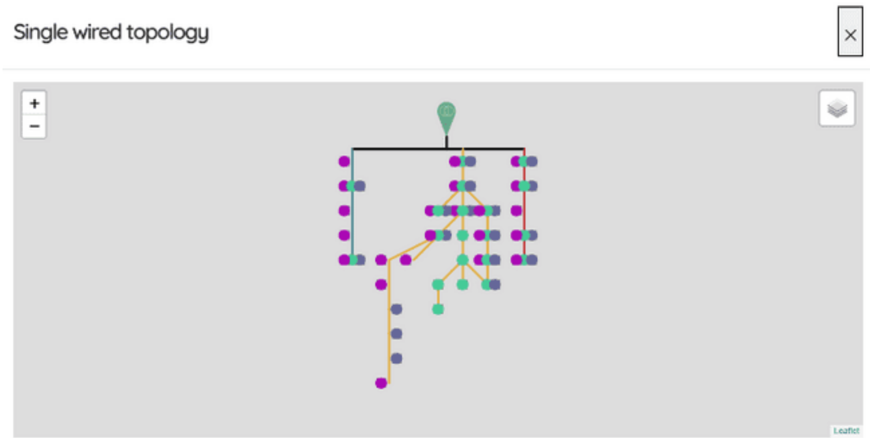

Fig.3 Graphical representation of the retrieved topology in the Odit-e software

The following widgets provide a statistical overview of the condition under which the St. Xavier secondary substation is operating, with views such as duration curves (voltage and load), distribution boxplots (voltage and load), and a radar of imbalance.

All these tools enable Tata Power-DDL to monitor the LV grid and take corrective actions if necessary. Concretely, such actions consist of rebalancing plans or changing the taps of a distribution transformer to mitigate voltage excursions and high neutral current issues.

This software tool showed overall that the substation studied during the IElectrix project was not overloaded and was not too imbalanced. However, many voltage excursions have been identified, mainly over voltages happening during the nights when consumption is low.

On one hand, voltage plan happens to be set at a high level to compensate the important drops during the day. PV production on another hand allows to mitigate voltage drops drop during the day, which occur mainly in the mornings and evenings (see Fig. 5).

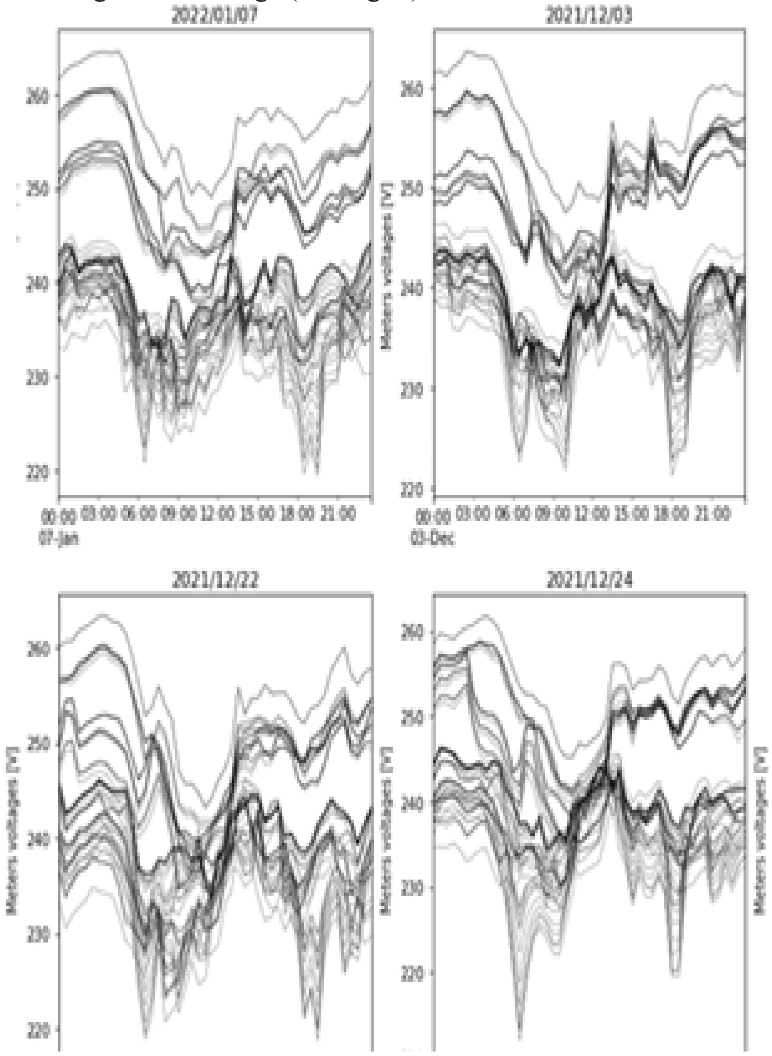

Fig.4 Voltage time series for all meters and all phases on 4 random days

Improvement of the resilience of the local energy system

For the India demonstrator, the type of customers obliges the DSO to maintain a high level of power continuity.

Firstly, feeder 1 of the switchboard is connected to St. Xavier's School which has over 4,000 students and many teachers and staff. A power cut during an examination period or simply during teaching days must be avoided. Secondly, feeder 2 supplies critical government establishments and associated area where Tata Power-DDL is committed to providing the highest quality of supply.

An issue on the grid, like under/over voltage and under/over frequency is detected by a MiCOM P923 relay acting on the under-voltage release coil of the main breaker.

For the Shakti demo, the conditions to switch to islanding mode have been set as unavailability of the main utility grid for a maintained number of seconds, and while the BESS is in good condition without presenting operating alarms.

In November 2022, an islanding test was performed with the St. Xavier School.

The goal was to simulate a loss of the grid and analyze the complete cycle:

- Sequence of operation from ON grid to OFF grid.
- Capability of the BESS to supply the customers.
- Sequence of Operation from OFF grid to ON grid mode.

During 30 minutes, Schneider Electric, Enedis and Tata Power-DDL teams monitored the state of the system through a remote session access to the SCADA system. As shown on the following figure, the main CB was opened and the BESS was power supplying the school.

Fig.5 Main screen of the SCADA system during the islanding test on November 2022.

The total consumption of the school was around 10 kW, having 5 kW supplied by the PV production and 5.5 kW by the BESS.

In parallel, the battery cells delivered 10 kW of power and only 5.5 kW were injected on the network. Indeed, the HVAC system to cool the container consumes in average 4 kW of power.

Fig. 7 highlights the islanding process from a voltage point of view.

The first drop corresponds to the loss of the grid and then, the feeder voltage is maintained at 230V during the test until the reconnection to the grid, marked in this case by a slight increase of the voltage.

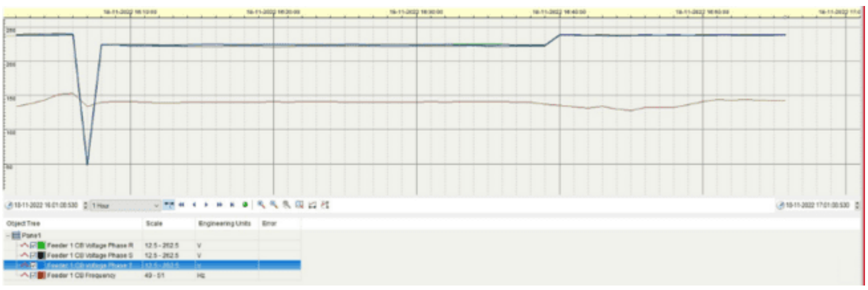

Fig.6 Trend of voltage during the islanding test on November 2022.

Frequency management

The deployed solution includes a feature for automatically regulating the frequency of the low voltage grid of the demonstrator. Thanks to the real-time monitoring of the frequency of the installation, and to the thresholds that have been defined, the system is able to automatically charge/discharge the BESS when any of the thresholds are crossed, in order to restore the frequency measurements to the desired values.

This feature was tested during March 2022, and it is displayed in Fig. 8. The figure shows in green the frequency measurements of the main circuit breaker of the substation, and in black the charging/discharging of the BESS. A positive slope in the black line means that the BESS would be charging, consuming energy from the grid. On the other hand, a negative slope would mean a discharging of the BESS.

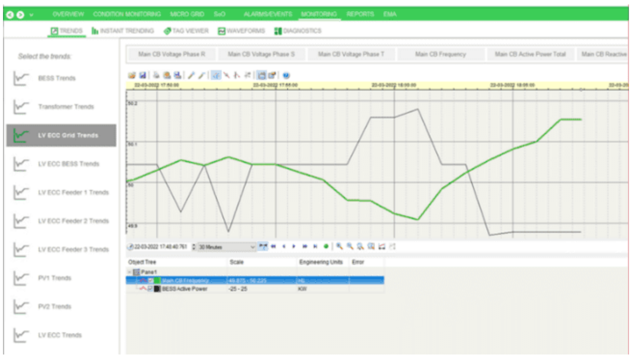

Fig.7 Frequency regulation test on March 2022

In the test illustrated in the figure, it is possible to observe that when the frequency went down beyond a specific threshold, a command was given to the BESS to inject energy to the grid, and as such, provoke an increase of its frequency.

Voltage management

As shown by the Odit-e LV Grid Observability software based on smart meters data (previously described in section III, A.2), the demonstration site faces network instabilities due to weak infrastructure, especially voltage drops and peaks which pose a challenge for stable and reliable grid operation.

Because of that, voltage management is another aspect addressed by the solution deployed in Shakti demonstrator. It relies on a Minera transformer able to be remotely regulated, on an Easergy T300 regulation algorithm implementation, and also on the optional inputs that may come from the LV Grid Observability software developed by Odit-e. The ambition is to regulate the voltage level of the energy community, to provide to the users of such community a stabilized voltage supply.

Minera transformer provides on-load tap changers that can be remotely commanded to adjust in real-time the voltage level of an electrical installation. That regulation is commanded by an algorithm embedded in Easergy T300 Remote Terminal Unit (RTU), and takes into account the voltage values in the Shakti secondary substation. Based on several thresholds that have been defined, the RTU is able to identify which is the right voltage setting for the mentioned on-load tap changers of the transformer.

Complementary to the regulation algorithm executed in the RTU, it is possible to combine the regulation with the outputs of the LV Grid Observability software, a digital twin of the LV grid based only on smart meters data. Odit-e grid observability software, as in [2], estimates and predicts voltage values for the LV side of the substation. The use case consists here in sending those voltage estimations to the RTU, as an input to regulate the On-Load Tap Changer positions which manage the voltage plan of the local grid.

The following graph sums up the voltage management process:

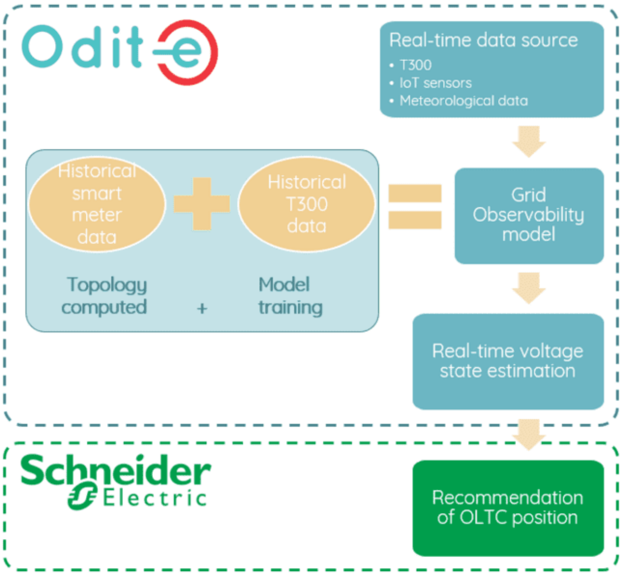

Fig.8 Summary of the voltage management by Odit-e with integration of historical smart meter data and real-time data from Easergy T300

This regulation by using inputs from the LV Grid Observability software is an optional one, as in the event that the communication with such a system was not available, the regulation of the MV/LV transformer could still be performed by using the local regulation algorithm implemented in the RTU.

4. Challenges and main lessons learnt

E. Impact of domestic electrical installations

As the Shakti demonstrator involves real customers, the amount of testing that could be performed on site is rather limited. Because of that, once the system was deployed, just one of the 3 feeders was connected, and the remaining two ones were fed by a nearby substation, in order to minimize the level of disruption for the customers.

Although the microgrid was tested in a real MV/LV network platform in France before being shipped to India, it was impossible to test the protection scheme with the actual electrical installations of customers in Delhi. After the first feeder was connected to the system, it was found that the protection scheme was not well suited to the electrical installations at the demonstration site. Several protection relays had to be replaced at site with local devices supplied by Tata Power-DDL, as the supply of European equipment was difficult due to the post Covid global supply chain crisis.

Implementing an innovative demonstrator in India using equipment fully designed and supplied in Europe is a challenge, especially after the sanitary crisis. Therefore, it is highly recommended to use as much as possible local sourcing of equipment.

F. Impact of external environment on HVAC system

The Lithium-Ion battery cells required to be maintained at a temperature of around 24°C and in a clean environment.

The harsh environment of Delhi (very high temperatures and extreme air pollution) has impacted the operation of the 2 Heating Ventilation & Air Conditioning (HVAC) units of the Battery Energy Storage System (7 kW cooling capacity).

Indeed, the accumulation of fine particles and dust in the filter stifles airflow and forces the HVAC systems to compensate by increasing its outputs. This in turn results in higher energy consumption and a reduction of filtering capability. Increased air conditioner output means the unit runs at full throttle most of the time. This puts constant stress on the system, which can lead to frequent breakdowns and increase the risk of thermal runaway.

The compressor units of the 2 HVAC were replaced after several interventions of the supplier.

Finding a European HVAC supplier which meets both the thermal performance (50°C) and the sizing (2 units in a 10 ft container) requirements to operate in Delhi is not easy. Furthermore, it is necessary to clean the HVAC filters every month during the pollution period.

5. Conclusion

Implementing a microgrid solution on a LV network raises many technical challenges. Ensuring compliance with electrical protection standards in both grid connected and grid islanded modes, performing the use cases tests while minimizing the disturbances for the consumers or simply limiting the technical problems are complex tasks that need to be thoroughly studied before the implementation begins.

Being in India brings also additional challenges related to the environmental conditions and the lack of local support for the European technologies.

Even though site studies have been performed before designing the demonstrator, several modifications had to be made during the commissioning phase to adapt the system with the domestic electrical installation and the Indian environment. Following these modifications, the islanding test to increase the resilience of the local grid has been tested successfully. In parallel, the microgrid system put in place has provided real-time data and a better understanding of the LV network and of both the consumer consumption and behavior of PV panels.

At the time of writing this paper, the demonstrator is in operation, and it is expected that further testing and tuning activities are performed until the project finalization at the end of February 2023.

Besides the testing constraints faced during the project due to the installation of the demonstrator in a real-substation currently under operation, the results provided in this paper are promising, and are the outcome of the close collaboration between project partners Enedis, Tata Power-DDL, Schneider Electric and Odit-e.

6. Acknowledgment

The activities described in the paper are relevant for the SHAKTI demonstrator to be implemented in the IElectrix project. IElectrix project has received funding from the European Union’s Horizon 2020 research and innovation programmed under grant agreement No 824392.

This paper reflects only the authors’ view and the Agency and the Commission are not responsible for any use that may be made of the information it contains.

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Leveraging Data in Power Distribution

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Abstract

Indian power distribution ecosystem has evolved very slowly from electromechanical meters to electronic meters. However, through regulations and policy thrust, the Ministry of Power is planning to squeeze the evolution to prepaid smart metering over the next 4 years under Revamped Distribution Sector Scheme (RDSS). With the intent of the Ministry of Power to progressively have more than 250 million consumers on Smart Prepaid Meters and the corresponding commitments by States / DISCOMs under RDSS, it seems pertinent that the initiative would lead to the generation of huge troves of data. A single smart meter is expected to communicate 48 / 96 metering profile data points daily, in addition to various other generic metering parameters and additional parameters based on specific use cases of the DISCOMs. The installation of millions of smart meters along with feeder and distribution transformer meters can provide access to near real-time data of end-to-end electricity usage and the same may be capable of providing a variety of insights to enable DISCOMs. This paper explores the ways of leveraging the reliable data available to create a platform that will help DISCOM to better serve their consumers, reducing technical and commercial losses, improving operational efficiency, preventive asset maintenance, planning for network upgradation and power procurement requirements.

Keywords— smart pre-paid meter, analytics, RDSS

1. Introduction

Indian power distribution ecosystem has slowly evolved from electromechanical meters to electronic meters. However, through regulations and policy thrust, the Ministry of Power is planning to squeeze the shift to prepaid smart metering over the next 4 years.

In recent years, the power industry, outside India, has witnessed adoption of data analytics across a number of functional areas. Increasingly the utilities are realizing the benefits through analytical insights from smart meter data. The USA's National Science Foundation (NSF) provides grant for cross-disciplinary research on smart grid big data analytics [2]. The projects for smart meter data analytics supported by the CITIES Innovation Center in Denmark, investigates machine-learning techniques for smart meter data to improve forecasting and money-saving opportunities for customers [3]. The Bits to Energy Lab has launched several projects on smart meter data analytics for customer segmentation and scalable efficiency services [4]. In June 2017, SAS published the results from its industrial analytics survey [5]. This survey aims to reflect on the issues and trends shaping the deployment of analytics on the data, thereby enabling the utilities in achieving their business goals. 136 utilities from 24 countries have responded to the survey and the results indicate that data analytics application areas have generally included energy forecasting, smart meter analytics, asset management/analytics, grid operation, customer segmentation, energy trading, credit and collection, call center analytics, and energy efficiency and demand response program engagement and marketing [6].

The current status of 11 kV feeder metering is ~99.2%, while less than 70% are registered on NPP and of ~1.45 Crore DTs in the country, only ~33% are metered as per CEA [1]. However, the status of communication from these feeder and DT meters through automated means is even lesser. Further, the consumer indexing details across DISCOMs may be quite dated and as a consequence, the Energy Accounting reports across DISCOMs are largely based on the best guess estimates, depending upon the data available at various levels. With the current policy guidance to progressively have ~250 million consumers on Smart Prepaid Meters and the commitments by DISCOMs under RDSS, this shift should lead to the generation of vast troves of data. A single smart meter is expected to communicate 48/96 metering profile data points on day-to-day basis, in addition to various other metering parameters as per DISCOM requirements. The installation of millions of smart meters along with feeder and DT meters can provide access to near real-time data on end-to-end electricity usage and the same may be capable of providing a variety of insights to enable DISCOMs to better serve their consumers, reducing technical and commercial losses, improving operational efficiency, better asset maintenance, planning network upgradation, and power procurement planning. For that to happen, various DISCOM IT systems ought to operate in sync with Smart metering data to drive the next leg of technological upgrades at the DISCOMs. This paper deals with data analytics under the Indian Distribution sector context.

2. Problem Statement

10th Integrated Rating Report of power utilities for FY 2020-21, puts the cash-adjusted losses for the DISCOMs at ~Rs. 1.13 Lakh Crore for the year. The enormity of this number may be understood by comparing it with the gross fiscal deficit of all state governments for the year of ~Rs. 8.32 Lakh Crore (provisional accounts–RBI report) for FY 2020-21. Since, the losses of State DISCOMs are de-facto State Governments liabilities and so, in effect add ~14% to the state's fiscal deficit each year on account of power sector losses alone. Also, the State Governments are required to bear the burden of ~Rs 1.32 Lakh Crore on account of tariff subsidy during FY 2020-21. Further, under FRBM (Fiscal Responsibility and Budget Management Act of Government of India) relaxation scheme, several State Governments have committed to progressively take over the losses of State DISCOMs, these to de-jure state liabilities. Therefore, in the medium term itself, this would put pressure on State Government finances to either work with their DISCOM to ensure turnaround or else, privatize it. Now, there is enough literature available on the politicization of public service by DISCOMs, in terms of below-cost tariffs, unmet subsidy commitments, non-issuance of tariff orders, etc. leading to DISCOM losses. However, not many studies are available on the operational inefficiencies of DISCOMs beyond AT&C losses. One reason for the same is the unavailability of any reliable data except for Annual Accounts and haphazard adoption or under-utilization of available IT systems. Though, a number of these inefficiencies may be under DISCOM control but do not receive adequate attention, as there is no data to highlight those.

3. Emerging Requirement

Apart from the immediate operational requirement to increase efficiency, data obtained from meters can be used for other must do analytics of utilities.

A. Consumer Service Quality

To support consumer empowerment, the Government of India has promulgated "Consumer Rules," laying down the benchmark service metrics for DISCOMs and would enable consumers to demand better service delivery. While these rules are being implemented, the Regulators are also stipulating progressive improvement in supply metrics e.g., the Regulators of Bihar and Delhi have laid down penal provisions for DISCOMs coming short of the defined service qualify parameters.

B. Load Forecasting and Energy Transition

The majority of DISCOMs face the cash burden of deviation settlement charges and expensive short-term power procurement, due to improper demand forecasting and supply management. The issue is set to become more pronounced with an increase in RE generation in the mix.

C. Network Planning

There is a visible move towards electrification of energy requirements e.g., transportation (railways, metro, electric vehicles), cooking, heating needs, etc. and with an increase in rooftop solar/other decentralized generation sources, and EV charging loads (fast and slow chargers) integrated into the distribution grid, network planning on an ongoing basis may be needed, as per emerging local area grid requirements.

Also, with the impending adoption of mechanisms like Market-based Economic Dispatch, GNA, lowering tolerance band for deviation in schedule, need for ancillary services, etc., the DISCOMs thar are able to improve their power procurement planning and management can substantially reduce their operational expense.

The node-level availability of consumption details/supply metrics across the day, assessment of the load types, and consumption pattern can aid the DISCOMs in better managing increasing requirements of RE integration, accelerate the move towards adoption of Time-of-Day tariffs, and incentivize electricity demand response, including the adoption of technologies like Battery Energy Storage System (BESS), Green Hydrogen, etc. However, carrying out the system study, monitoring, and analysis, to bring out actionable insights on an ongoing basis and be able to respond appropriately, would require robustness of the base DISCOM IT systems.

4. Data Quality

The current mechanism of MIS reporting and dash boarding is limited in breadth as well as depth, as the same is based on numerous assumptions, is generally compiled manually, and is received from various divisions/subdivisions at the DISCOM headquarter level in their own formats, which gets altered to satisfy the perverse incentives at different levels. So, the current analysis is based on the adjusted/estimated data, rather than the raw system data. While most DISCOMs have technology products to support better data availability, however inadequate employee capacity, disparate planning for IT products, and reliance on parallel in-house applications, get in the way of the stabilization of these IT applications and limit their utility. To ensure the availability of quality data for any analysis, it is pertinent that the same is free from human intervention and is collated based on transparently defined systems and processes. The methodology proposed for smart metering implementation and associated data protocols would ensure concurrent data from across consumer meters, and system meters; thus, providing the snapshot of electrical parameters at variously defined timestamps. Such systems would limit the capability of system participants to tinker with data and its availability, in view of the defined Service Level Agreements (SLAs), tightly coupled with smart metering contractor payments.

5. Data Analytics

A. Analytics Approach

Once the base, raw data is available from various sensors, field equipment, and IT/other systems, then the same ought to be cleaned, on account of analytical adjustments and to ensure data completeness, etc. Thereafter, a number of standardized approaches are available, which may be relied upon to generate useful insights. Depending upon the type and availability of data, the analysis could generally involve the following broad approaches:

Descriptive analytics, involving thorough examination of data, to describe what has happened or is happening, that may be presented through appropriate visual means e.g., pie charts, bar charts, line graphs, etc. for ease of understanding,

- Predictive analytics, involves predicting future outcomes of the parameters of interest, using historical data combined with statistical modeling, data mining techniques, and machine learning algorithms,
- Prescriptive analytics, is a form of advanced analytics which examines data or content to answer the question “What should be done?” or “What can we do to make _______ happen?” and is characterized by techniques such as graph analysis, simulation, complex event processing, neural

networks, recommendation engines, heuristics, and machine learning. (Source: Gartner)

- Diagnostic analytics, is a form of advanced analytics that examines data or content to answer the question, "Why did it happen?" It is characterized by techniques such as drill-down, data discovery, data mining, and correlations. (Source: Gartner)
- The approach to be followed would depend upon the temporal data availability, data type, comparable datasets from peer organizations/industry, and any specific end purpose or use-case for such analysis.

B. Use Cases

In addition to supporting solutions to known issues, the availability of the right kind of data and analysis could bring out several benefits that would become apparent with an improved understanding of the data. Just like a doctor, who carries out various tests to establish enough data points, before attempting to prescribe a cure, the availability and integrated analysis of power system data should be able to highlight the right problems that need to be solved.

Some of the analytics approaches along with broad use cases may be as follows:

Descriptive analytics

- Understand category-wise consumption growth and consumer requirements, in terms of load patterns at different times during the day or seasons during the year, thus supporting category-wise demand planning. This should help in, the identification of consumer categories most contributing to the peak load and plan for their load shifting through suitable ToU tariff design
- Curing anomalies in Energy Accounting reports, e.g., reports for a few DISCOM feeders might show negative T&D losses but is generally due to prosumers inputting energy into the grid. Being able to showcase the actual consumption and production by various consumers/prosumers alongside the system meter report should provide much clarity.
- Auto-alerts to consumers and auto-logging of complaints with respective DISCOM O&M team, for the power loss in any area as noted through DT or a feeder meter or consumer meters, as may signify the probable fault at a consumer /DT /feeder level.
- Study of the growing generation participation by the prosumers, the areas it is getting set up, to understand the impact on the local distribution grid and the need for local level network upgradation or setting up energy storage systems
- Better targeting by State Governments of consumer subsidy, planning of incentive schemes for agricultural consumers to rationalize their consumption and reduce the negative impacts such as reduction in water table e.g., incentive scheme implemented in Punjab, for consumption by farmers below a benchmark
- Periodic metering profile and other usage parameter details (voltage, CAIFI, CAIDI etc.) can be proxies for regular consumer feedback and can help in addressing supply deficiencies and improving reliability
- Allows for the generation of suitable management reports highlighting the time taken at different levels for various planned/unplanned activities, thus promoting transparency and accountability across the value chain

Predictive analytics

- Correction of connection type: Indore DISCOM claims to have noted that several smart metered domestic consumers would not use electricity during the night-time and on further checking, could convert these connections from domestic to commercial category consumers, leading to higher revenue accrual.

- Forecasting of electricity demand, based on empirical consumption data across consumer categories, expected growth as well as likely weather patterns, etc. Details on existing tie-ups along with such analysis provide data for planning appropriate demand response mechanisms and optimizing power purchase requirements
- Optimize power procurement planning for a suitable mix of long / medium / short-term PPAs or real-time purchases, taking due care of the planned plant maintenance schedules and expected power availability from RE plants during the day and across seasons based on weather forecasts/ patterns
- Better planning for filing of tariffs and other petitions as are inherently based on projections
- Scheduling asset maintenance by O&M teams, based on predicted health of assets, based on their loading patterns, aging, repair history etc.
- Trading of electricity based on data insights, in terms of power requirements or price signals for term-ahead / day-ahead / real-time markets

Prescriptive analytics:

- A better understanding of the consumer load types can enable the planning for reactive compensation requirements at the low-voltage level through fixed / auto-capacitors
- The understanding of loading patterns of feeders/distribution transformers and availability of any distributed generation in respective areas due to large-scale deployment under KUSUM or otherwise, can help the DISCOM in reducing network capex requirements as well as technical losses, through optimized planning for local level energy storage systems, etc.
- Consumer education and oversight, through a mechanism similar to that followed by the Income Tax department e.g., through form 26AS, AIS, TIS, etc., by making the consumer aware of their transactions across the year. The same may also be able to promote the usage of energy-efficient appliances, lowering of peak load requirements and making the consumers conscious of moral behavior
- Auto-targeting of theft pockets / thieving consumers, thus prompting unbiased and data-led vigilance actions
- Planning for targeted incentive schemes to promote grid support by consumers e.g., V2G support or reducing avoidable consumption (acting like virtual power plants) along with other ancillary support during peak power requirements
- Allows for inbuilding of alerts to time-sensitive activities with defined responsibility-matrix-led compliances and suitable escalation matrices, to ensure accountability and timely action
- Diagnostic Analytics:
- Identifying the reasons for the failure of network assets e.g., overload, extreme weather, age of the asset, wear and tear, sabotage, etc.
- Identify the reasons for operational losses, e.g., whether on account of improper tariff mix, high working capital needs, lower capitalization claims, improper tariff filing/estimation, improvement needed in power procurement planning/trading, etc.

In addition to the above few apparent use cases, a better understanding of data would be able to bring to the fore other various benefits from having reliable data.

6. Road Blocks To Desired Outcomes

With the availability of the right type of data and approach, it is evident that several possibilities open up to address the areas of interest. There are numerous, readily available data analytics frameworks and artificial intelligence models which could aid in better operational and financial planning by the DISCOMs. While the electrical system components perform their envisaged disparate functions, a well-designed IT system could act on top of these, to provide an integrated view and actionable for the entire system. Based on such a comprehensive view, the user may plan to take requisite next steps, rely on system notifications/alarms or program the system to take automatic actions. However, the appraisal of existing utility systems as carried out for planning of RDSS works has brought out numerous roadblocks to achieving such levels of maturity and dependency with their systems, a few of which are as under

- IT Department in DISCOMs is still seen as a support function, due to the Projects/O&M Division traditionally being at the forefront.

However, the customer care centers are now shifting to the backend, and infrastructure development/ upgradation is largely on a turnkey basis with monitoring through physical and automated technology means, revenue collection would shift to prepaid mode through auto-disconnection / re-connection. So, more and more traditional functions are getting automatized and this shift is slowly getting recognized by the DISCOM management

- No separate IT cadre across many DISCOMs or even with a separate cadre, there is a lack of adequate primacy in the business operations and clear visibility of IT cadre to reach the top positions
- The DISCOMs are slowly and steadily becoming more and more technology-oriented, but this move is largely through reliance on third-party agencies, and the capability to manage and derive requisite value from either these applications or agencies remains limited.
- Inadequate IT understanding of DISCOM officials leads to most of the product's adoption becoming vendor-driven, without due focus on their contextual requirements
- Adopting World-class products, but customizing them to match the existing, legacy operating procedures, thus rendering these unusable, while major value driver of these products is the simplification of business processes that they provide

The government of India had also supported DISCOMs in the initial leg of their digital journey under Part-A of R-APDRP. While most of these adoptions may have failed to generate adequate value for DISCOM operations but have provided them with good exposure to technology applications and their implementation pitfalls. Inadequate capacity apart, the other major reason for failure was coverage of entire funding under GoI grant, with DISCOMs having no skin in the game. RDSS has accordingly placed due importance on digitalization, with the investment focus on actual digitization by favoring on-cloud implementation and stipulation to bring at least 40% of the investment.

7. Need For a Strategic Digital Plan

With the availability of the right type of data and approach, it is evident that several possibilities open up to address the areas of interest. There are numerous, readily available data analytics frameworks and artificial intelligence models which could aid in better operational and financial planning by the DISCOMs. While the electrical system components perform their envisaged disparate functions, a well-designed IT system could act on top of these, to provide an integrated view and actionable for the entire system. Based on such a comprehensive view, the user may plan to take requisite next steps, rely on system notifications/alarms or program the system to take automatic actions. However, the appraisal of existing utility systems as carried out for planning of RDSS works has brought out numerous roadblocks to achieving such levels of maturity and dependency with their systems, a few of which are as under

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8. Conclusion And Way Forward

In the end, it is very critical to ensure that the technology applications are actually put to use by the end-users, as it is only through such usage experience that these applications as well as DISCOM officials go through the maturity cycle and the system becomes dependable. And the integrated, dependable IT system with quality data that is becoming available, could play a paramount role in driving business value as well as efficiency. Plus, the same can be achieved at a much lesser cost with enhanced value delivery through an increase in process automation, thus freeing the DISCOM officials for higher value analysis of such data dashboards, alerts/notifications, and focus on the end-delivery as per their actionable use cases.

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Communication Solutions for Smart Grids and Smart Cities

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Abstract

Evolving smart cities require evolving advanced communication network as the main characterization of such grid is flow of two-way data. The various communication technology too has key metrics for performance as these play a major role in tying the smart entities like meters & devices together. This paper will be on comparison of the different technologies based on their parameters like cost, area of coverage, spectrum, security, topologies best suited for, efficiency, reliability etc. There is no one solution that fits all the purpose in smart grid applications, so utilities are deploying advanced edge-to-cloud solutions need options and combinations of features that can match their specific operating requirements.

Keywords

Communication protocols, management, distribution, AMI, smart meters, Radio Frequency, Cellular.

1. Introduction

There has been notable advancement in the communication technology field that is shaping the utilities to be more dynamic. As we know, there are two main communications medium available for communication technologies, that may be used for data transmission i.e., wired, and wireless. In some instances, wireless communications have some advantages over wired technologies, such as low cost and availability of connection. On the contrary, wired solutions do not have interference problems.

But, with the dawn of new edge-cutting communication technology, giving the liberty to Solution Providers for choosing their communication technology is a disadvantage. The solution may be cost-effective, but it may hamper the SLA performance. Given the choice of Communication Medium affect the cost and technology of the smart energy meters directly.

The bottom line for modern utilities is that they are no longer willing to be slowed by insufficient network capabilities and do not want their innovation programs inhibited by the limitations of traditional networks that lock them into single vendor solutions and act as a barrier to innovation.

The key to success for utilities is working with a technology partner who understands the needs of the industry and offers technologies, resources and services that are sustainable over the long run period.

2. Technology choices for smart grid solutions

Smart Grid is an ecosystem of people, processes and technologies empowered via the digital transformation to meet the varying demands of the customers, realized through deploying an integrated strategy of communication infrastructure that enables bi-directional flow of energy, information, knowledge and decision making support, controlled and monitored by sensors/NIC of smart systems to transparently, efficiently, reliably , sustainably , and securely serve all stakeholders through cost effective measures.

There are many issues related to network performance, suitability, interoperability, and security that need to be resolved. This paper will focus on identifying the technology for utilities and System Integrators to tailor communication protocols that have been designed to provide quality of service (QoS) to smart grid applications like SCADA, OMS, EMS, DERMS, ADMS etc.

Communication and control are a core smart grid application for these functionalities given below with comparison against the available communication technologies.

Parameters	Cellular (2G/3G/4G/5G)	RF	NB-IoT	LoRa	Optical Fibre	PLC
Topography	Scattered & Dense	Dense Population	Scattered & Dense	Dense population	Dense population	Dense population
Topology	Point to Point	Mesh	M2M	Star	Bus	Bus
Spectrum	500 MHz-2.5 GHz - 4G 28 GHz -36 GHz - 5G (licensed)	865-867 MHz (licensed)	3G - 4G spectrum (licensed)	867-896 MHz (unlicensed)	>100 MHz	50 to 500 kHz
Area Coverage (Urban)	2-2.5km	<500m	2-2.5km	5-10 km	Wherever cables are laid	
Cost of Implementation	Low	High	Low	Low	Cost depends on site feasibility	
Easy of implement	Very easy	Complex	Very easy	Very easy	Need to lay wires and establish connectivity at every location	
Interoperability	Plug and play	Complex integration	Plug and play	Plug and play	Not interoperable	
Technology obsolence	Low	Low	Medium	High	For larger deployment - Not used, Small Pilot Project - May be used for high success	
Data Speed	High for 5G	Medium	Medium	Low	Very high speed	
Latency	Low	Low	High	Medium	Very less Latency in the order of	
Application	Smart grid, Smart Cities, telecom	Smart grid, Smart Cities	Smart Grid	Home Automation, Smart Cities	Smart Grid, telecom	
Max. nodes covered	High	Medium	High	Low	No Limit	
Security	Very Secure	Very Secure	Very Secure	Less Secure	Very Secure	
Power Consumption	Medium	High	Low	Very Low	Transmission loss is higher	
SLA Performance	Medium	High	Medium	Low	80-85% (for large deployment), 90% (for small pilot deployment)	

Table 1: Comparison table of various communication technologies

Though not one solution is not fit for all situation and terrain. This paper has tried to summarize the most possible scenarios accordingly.

3. Technology choices for smart city solutions

Smart cities are examples of massive IoT use cases. For instance, connected traffic lights receive data from sensors and cars adjusting light cadence and timing to respond to real-time traffic, reducing road congestion. Connected cars communicating with parking meters and EVs charging docks and direct drivers to the nearest available spot. Home automation like temperature control for Air conditioner, home lighting as per time of the day, Smart garbage cans at consumer premises automatically send data to waste management companies and schedule pick-up as needed versus a pre-planned schedule. Smartphones storing digital credentials of consumers integrates with city and local government utilities and services for ease of access. Together, these smart city technologies are optimizing infrastructure, mobility, public services, and utilities.

Likewise, there is no one-size-fits-all, the evolving technologies NB-IoT, LoRa, Bluetooth are well suited to most smart city applications for their cost efficiency and ubiquity. The advent of 5G technology is expected to be a turning point event that propels smart city technology into the mainstream and accelerates new deployments. The Table 1 may be referred for these technologies.

4. Choosing the best-fit solution for both smart grid and smart cities

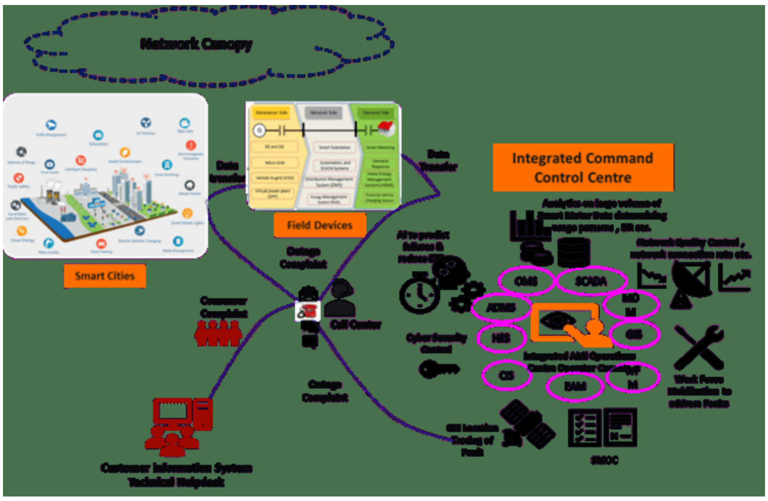

Fig 1: Network Canopy for Smart Grid and Smart Cities and ICCC formation

Combining the smart grids and smart cities is a vital combination as the future lies in decentralization with the right set of flow of data in the desired applications. Therefore, the establishment of communication network canopy truly demonstrates the power and potential of a high-performance, multi-application industrial IoT network. The communication canopy network platform based on RF mesh technology can support multiple Smart Grid applications like AMI, DA, Sub-station automation, and Smart city applications like Street light management, home automation etc. over a common single communication platform. The RF canopy should support multiple application data and all endpoints should be able to be connect to either the AMI Head End System (HES) and Smart Metering Control Centre (SMOC) which will form the Integrated

Command Control Centre (ICCC) for Smart cities. It shall have capability of communicating with large numbers of end points simultaneously over the same network at the same time maintaining prioritization as per requirement of the operational applications. Having the ability to support multiple communication protocols to provide flexibility to cover existing and future protocols. The canopy shall maintain the time synchronization to allow real-time monitoring which is a key aspect.

5.Comparative analysis for the identified kpi

To compare these technology solutions, this paper has assigned Key Performance Indicators (KPI) derived from the above Table 1 for measuring the value of the solution that demonstrates how effectively it can perform under these parameters as illustrated.

Based on the various projects and experiences we have assigned the weights to the parameters, which may differ according to the site survey of system integrators or as per preference of Utilities.

This study is just to give a reference of the parameters on which a communication technology should be chosen and analyse according to the system requirements.

This KPI has been based on a case study, where the following assumptions were made:

1. Topography: Hill terrain, scattered population
2. Network is available, but scarce.
3. DISCOM fund availability and preference
4. SLA requirement
5. Cyber-Security

Taking the example of Smart Metering installation in Ladakh and Jammu & Kashmir where the geographical terrain is mountainous, scarce network, scattered population, prone to cyber-attacks but requirement of high SLA performance.

J&K chose to RF communication as cellular communication requires special permission and requires more secured communication than cellular for dense population. Ladakh on the contrary chose cellular, as RF may be too costly for the scattered low-density population.

So, communication technology shall have to be chosen very precisely according to the site condition after survey as it is the backbone of every smart grid or smart city system.

Technology	Weights	Base	Norm	Target	Cellular		RF		NB-IoT		LoRa		Wired	
Key Performance Indicators (KPI)					Fact	Index KPI	Fact	Index KPI	Fact	Index KPI	Fact	Index KPI	Fact	Index KPI
Topography	10%	0	80%	100%	80%		80%		80%		80%		70%	
Topology	5%	0	80%	100%	80%		80%		80%		80%		80%	
Spectrum	2%	0	80%	100%	90%		90%		90%		70%		90%	
Area Coverage (Urban)	4%	0	80%	100%	100%		70%		100%		100%		70%	
Cost of Implementation	10%	0	80%	100%	90%		70%		90%		80%		60%	
Easy of implement	10%	0	80%	100%	90%		70%		90%		80%		60%	
Interoperability	5%	0	80%	100%	80%		80%		80%		70%		70%	
Technology obsolence	5%	0	80%	100%	80%	83%	90%	82%	80%	78%	70%	72%	60%	70%
Data Speed	5%	0	80%	100%	80%		80%		60%		60%		90%	
Latency	4%	0	80%	100%	80%		80%		70%		60%		90%	
Application	5%	0	80%	100%	80%		80%		70%		70%		70%	
Max. nodes covered	5%	0	80%	100%	80%		70%		70%		70%		80%	
Security	5%	0	80%	100%	70%		90%		70%		70%		90%	
Power Consumption	5%	0	80%	100%	80%		80%		80%		80%		80%	
SLA Performance	20%	0	80%	100%	80%		100%		70%		60%		60%	

Table 2: KPI for various communication technology

To give a global perspective, other than Indian Utilities, WAN which is the communications path between the control centre/HES and the DCU. Cellular technology is most commonly used. The NAN which is the path between the DCU and the meter. It is used mainly on PLC. A summary on global communication technology for Smart Grids are given below.

Region	WAN	NAN	HAN
North America	Cellular	G3-PLC, Wi-Fi	G3-PLC, Wi-Fi, ZigBee
Europe	Cellular	G3-PLC, Wi-Fi	G3-PLC, Wi-Fi, ZigBee
China	Cellular	G3-PLC, RS-485	G3-PLC, Wi-Fi, RS-485
Rest of the world	Cellular	G3-PLC, RS-486, Wi-Fi	G3-PLC, Wi-Fi, ZigBee, RS-485

Table 3: Global smart grid common communication technology used

6. Realization of benefits

From the perspective of application usage, cellular technology provides the flexibility of a unified, platform capable of communicating seamlessly across the universal set of assets and devices that are connecting to the utility network. This simplicity stands in contrast to the complexity utilities are already facing today in managing both RF mesh and NB-IoT communications— a challenge which could grow considerably as connectivity demands increase.

In this case, Utilities can ensure a primary mode of communication and at the same time prepare a backup or secondary mode of communication as well, which may have interoperability, profitability, SLA adherence etc.

Like a combination of RF and cellular is commonly used in smart metering projects, cost-effective combinations like RF and NB-IoT, LoRa and NB-IoT may be conducted in pilot cases for feasibility studies. Wired solutions like PLC and Optical Fiber (OFC) as primary with secondary backhaul communication like NB-IoT, LoRa may be explored by Utilities on case-to-case basis by deriving the KPI based approach demonstrated above for these groupings.

7. way forward

Cyber-Security Risk Management of communication technology is a major challenge for Smart Grid and smart cities it is the weakest link. With Smart Grid systems in place, the complexity, and the number of possible channels for cyber-attacks increases. Attacks targeting the distribution infrastructure do not necessarily aim only to cause power blackouts. They start from manipulating energy bills, blackmailing, power disruptions using Smart Meter-integrated switches, damage of distribution or customer equipment, up to effects on transmission grids with extensive consequences. So, a robust cyber-security implementation is necessary for these wire-less communication technologies.

And saying that, Communication is not a support technology but a driver for success of these initiatives. Though communication has been an integral part of globalization. Some challenges still to overcome in this field are:

1. Interoperability of the various communication technology
2. Monitoring towards optimal usage and applications
3. How can different communication conduit/channel connect for interdependence?

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In-house Robotic Process Automation

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Abstract

we are introducing in-house RPA. In-house RPA is like an AI-based python scripted bot for supporting NPCL in automating the process, saving man hours, and removing human error. This will also help in increasing customer satisfaction and is helpful in decreasing the processing time.

Keywords

Python, Thinker, SAP, JavaScript, Rest API, JSON, Shiny R, and MySQL.

1. Introduction (IN-House RPA)

In-house RPA is a python-based GUI-based scripting Bot that is used in NPCL for automating the SAP-related Process. This bot is helping in reducing the processing time and manage the workflow. The exceptional handling has been done in very point. There is a dashboard to see the bot's performance and no of cases that have been done by the Bot. As per the current run, we observe that 98% of real-time scenario has been covered. We also have a MySQL database for storing the data. We also have master data where we store the data of every run.

We also follow every cybersecurity major for successfully running the process. We create the .exe for every process.

2. Ease of Use

A. Schedule bot

In the Schedule bot, we have decided at which time frame the bot will run and do all the remaining tasks and trigger the mail about the all-successful result. We also store the information in our database in date and time-wise.

B. Click Bot

In Click Bot we provide the .exe file to the user where he can select the time frame and run the bot according to his need. In this case, we also provide a list of eligible cases. Where he also has the option to select/deselect the case that he will not run after that once he clicks ok all the cases will run automatically and provide him the result. Where he can verify whether the cases run is correct or not.

2. IMPLEMENTATION

The implementation has been done completely in-house and we have created two types of bots for making easy use of the bot. The two types of Both are: -

- Schedule Bot
- Click Bot

We have developed the two types of a bot as per the user need so that we can use the bot both ways time schedule and when needed. So that we can provide efficiency. We have also created a dashboard for monitoring it.

C. Schedule Bot

How the schedule bot is running we can show you by example. At first, we validate the system before running the process. We store the particular IP and Username in our system. Then it automatically runs on the current date and (current date -1) and will provide you about the successful running of Cases.

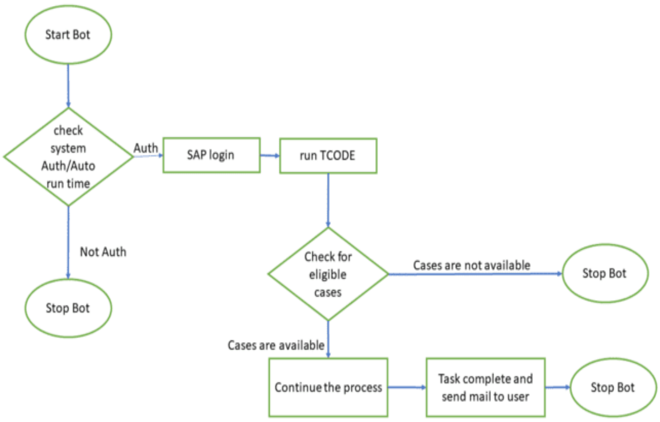

Figure 1. About the running of Schedule Bot

D. Click Bot

In Click Bot we provide users to run the process whenever they need. On selecting the date range, the process will run automatically. When the bot identifies the eligible cases, the mail is automatically triggered for the verification of the cases, User can also select/deselect the eligible cases to run the process. After the completion of the Process, automated generated mail is sent to the user with the list of all processed cases. He also tells about the pending cases where the payment is pending so that process becomes effective and fast.

We will show you in the image below how the process will run: -

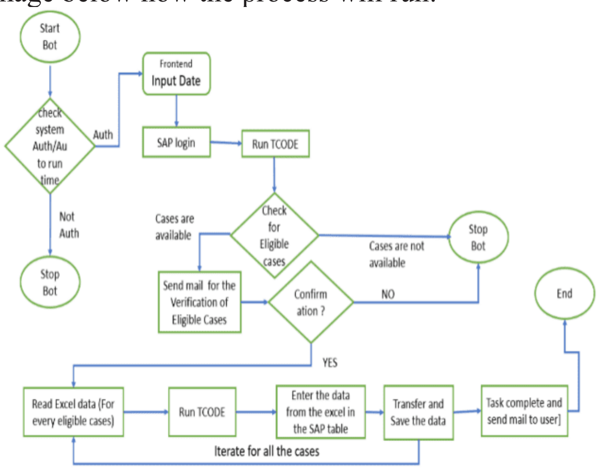

Figure 2. About the Running of Click Bot

E. Analytics Dashboard

We have also implemented the Dashboard where we see the performance of the Bot and also how can process has been run. List of the pending task. Cases that need to refer to other departments for verification. As you can see in the image below: -

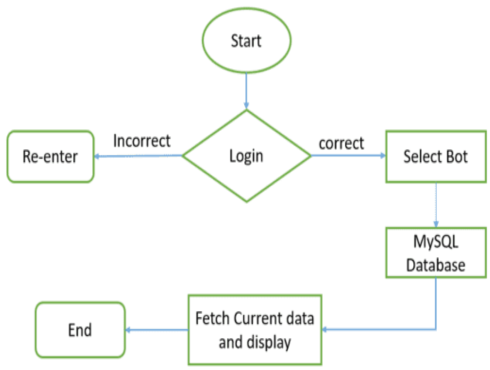

Figure 3. About the Analytics Dashboard

3. The architecture of the In-house RPA Bot

You can see the tools and methodology that have been used in the architecture of the In-house RPA Bot image below: -

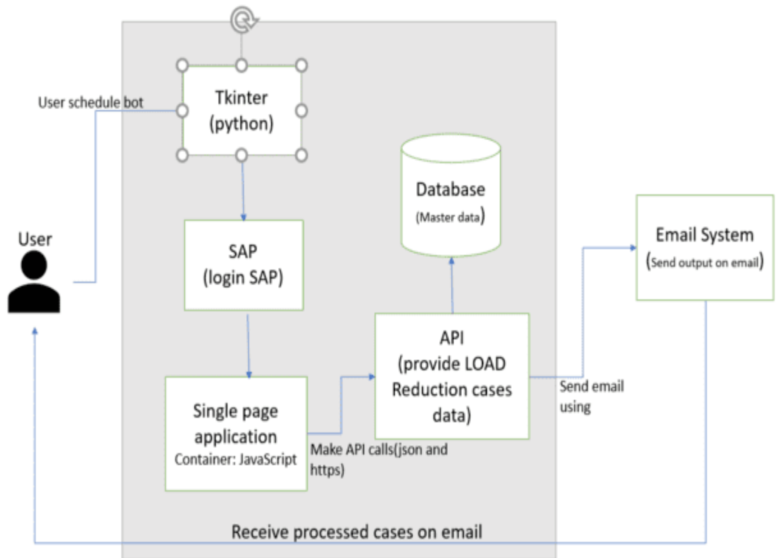

Figure 4. The architecture of the In-house RPA Bot

- We have used Python GUI Based Coding for the Backend code. The integration of the SAP and Rest API has been done in python. Python is the core tool that has been used in the development of In-house RPA
- For storing data, we have used MySQL Database. We are storing all kinds of information in MySQL data like Authorized users, system information, Exceptional handling data, log-in log, and master DB of processed cases.
- For Front-end we have used Tintern in Click Bot. Tkinter is a Python binding to the Tk GUI toolkit. It is the standard Python interface to the Tk GUI toolkit. Tkinter also included standard Linux, Microsoft Windows and macOS installs of Python. The name Tkinter comes from Tk interface. We

are using Thinter for running the backend code.

- We have used also used the SAP Rest API. We have used the SAP-based for the calculation of data at the backend. So that we can optimize the speed of the bot running.
- Analytics has been developed in shiny R.

4. Result

After the implementation has been completed now RPA Bot is running in the Production System for some of the Processes like Load Reduction, Category Change, Name Change, Name Mutation, etc. We are now also working on the other process for LCC Department where we are expanding our capabilities for this process.

Figure 5. RPA Bot Running

F. In-house RPA Bot Dashboard

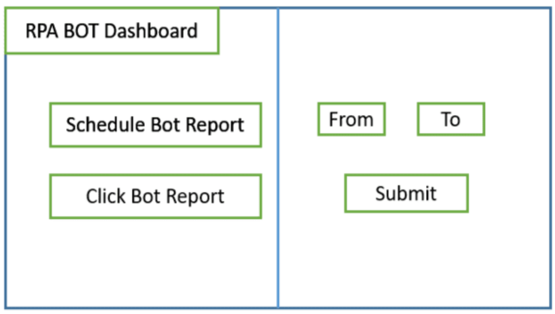

Figure 6. RPA Bot Dashboard

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Smart Energy Communities

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Introduction

The conventional sources of energy are fast depleting. Fossil fuels are not renewable; hence, countries are taking recourse to expand renewable energy (RE) sources, which are cleaner. Smart energy communities acknowledge the virtues of cleaner energy. Building smart communities has to begin with an individual household, a micro-enterprise and official units of government hierarchy. The people who are aware of energy conservation are the main drivers of building smart energy communities. This movement of positive impulses towards energy conservation at the ground level has to be combined with a strong mandate from the top.

Building Smart Energy Community

Energy conservation, energy efficiency and transition to net zero carbon emissions are the pillars to move along the path of cleaner air. While social acceptance is prevalent for environmentally friendly behaviour, practices are woefully inadequate to meet sustainable goals. The mandate for sustainable energy use is given by the UN 2030 agenda of Sustainable Development Goals (SDGs).

Existing organisations that have reached sustainable energy use levels are the platforms for building a grid of stakeholders. Reduction in energy costs follows sustainable practices. This itself is a strong incentive to save energy use. The official systems must include rewards for clean energy use. The subsidies in funds, lower interest rates on loans, assured government procurement shall facilitate clean energy users to continue this path.

The example of the India International Centre (IIC), an organisation that has saved 1.6 lakh units of energy per annum by green and sustainable measures, is worth citing. It is located close to an Indian heritage site surrounded by historical buildings amidst a green, salubrious environment of Delhi's Lodhi Gardens. These invaluable treasures of India have to be preserved. In this context, the IIC has done a remarkable job in helping preserve the physical environment by taking recourse to green energy.

The IIC conducted an energy audit of its buildings, plant, and machinery, through Tata Power and a green audit of its systems through Skill Council for Green Jobs. In 2019, this process began and the suggestions and solutions made available from these audits were implemented by the IIC. The following specific measures have been taken to protect its ecology:

- To have zero discharge of untreated solid/liquid waste;
- To do away with the dependency on underground water by using recycled water extensively;
- To upgrade the buildings to green standards and adopt best practices with tangible outcomes and defined cost savings.

The measures adopted by the IIC reduced CO2 emissions by 80 tons annually. An additional solar plant is to be installed, further saving 38,000 units of electricity per year. Replacing lights with LEDs, harvesting rainwater and bio-urja were the other significant steps taken. A substantial saving of 1.6 lakh units per year has been achieved by the IIC. Monitoring systems performance through Supervisory Control and Data Acquisition (SCADA) system helped improve energy efficiency. Further, converting organic waste into compost and recycling the entire garden waste into manure, reducing the use of plastic bottles, and using an electric vehicle are some of the best practices that help in conserving the physical environment.

The Delhi based Mohan Parrikar Institute of Defence Studies and Analysis (MP-IDSA) has teamed up with the cantonment authorities to contribute its sewage on its campus to a nearby Sewage Treatment Plant (STP) run by the cantonment authorities. MPIDSA, in return, receives treated water which it uses to water its gardens. The STP receives sewage water from several nearby localities. It also generates valuable manure which is used locally in the gardens. The institute also has a rooftop solar plant which is generating electricity for several of its buildings.

Several Resident Welfare Associations have also taken recourse to government subsidies for installing rooftop solar plants. For instance, in 2019, the IFS Cooperative Group Housing Society (IFSCGHS) in Delhi took advantage of the Delhi government's attractive subsidy scheme and a rational power purchase agreement to instal a rooftop solar plant in 2019 free of cost. The savings from solar energy generation have considerably improved the financial health of the RWA and delivered benefits to each flat owner. This is an example of a partnership between the government and a resident welfare society.

Ecological conservation can also offer substantial benefits not only to society but also in terms of energy savings. Professor CR Babu, Emeritus Professor at the University devised a natural, plant-based, system of cleaning sewage water from a village near Delhi's Vasant Kunj locality. The treated water was channelled into a natural depression where it has formed a medium sized lake. This natural sewage treatment plant does not use any electricity and also provides tremendous benefits to the neighbourhood by making it green and hosting flora and fauna.

Smart measures for clean energy system robustness

Blockchain technology enables tracking assets and data. By working through decentralised control, electricity grid security is ensured. Customers are investing in RE, clean energy and electric vehicles. For energy transition to net zero, blockchain technology is needed.

Energy trading and renewable energy certificates are facilitated in distributed energy systems by blockchain. Market records are encoded. Bitcoins provide new companies with a wallet for prepaid metering. Smart utility payments and meter data integrity flows with the use of bitcoin technology.

A smart energy community requires behavioural changes in citizens for energy efficiency, energy conservation and net zero carbon emissions. Behavioural energy efficiency programs are based on principles of proactive, personalised feedback and social norms comparisons. This is Demand Side Management (DSM). DSM includes improving energy efficiency and adjusting demand during peak load through demand response mechanisms. These steps free up available supplies to meet demand. India's first large-scale behavioural energy efficiency pilot program was conducted in New Delhi by the BSES Rajdhani Power Ltd with support from some stakeholders including Delhi Electricity Regulatory Commission. Its objectives were:

To demonstrate the benefits of Home Energy Reports (HER) to consumers; empower consumers to save money on their energy bills; promote domestic consumer energy literacy and energy efficiency;

To demonstrate the benefits to the grid; generate verifiable energy savings at scale; prove the potential for cost-effective and large-scale residential/domestic DSM in the form of aggregated grid load reduction, To prepare a model for ongoing utility-led, consumer-focussed behavioural energy efficiency programs in India; establish incentives/ cost recovery mechanisms for Delhi utilities running HER is, to save consumers energy and money. (Source: http:/www.aeee.in/wp-content/uploads/2019/02/Behavioural-Energy-Efficiency-Potential.pdf)

Conclusion

Covid 19 pandemic introduced many changes in social behaviour. People became aware of health security and social communities were formed to survive the pandemic. Likewise, societies may also mould their behaviour to use energy smartly. This is needed for survival.

Environmentally aware citizens, responsible governments, and strong communities can join hands to form smart energy communities. The use of modern technology, financial incentives, awareness campaigns and local initiatives can go a long way in forming such communities. These communities provide benefits not only to consumers but also to the power generation utilities, neighbourhoods and eventually to the nation. The need of the hour is to network individuals, households, local initiatives, power generation companies and governments into larger, aware, smart energy communities.

Foundational Blocks for Smart Grid ESS - Applications and Business Cases

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Abstract

Driven by global concerns about the climate and the environment, the world is opting for Renewable Energy Sources (RESs), such as Wind and Solar. However, RESs suffer from the discredit of intermittence in terms of power and frequency, for which Energy Storage Systems (ESSs) are gaining popularity worldwide. Surplus Energies obtained from RESs can be stored on Battery Based Energy Storage Systems (BESS) and later utilized during peak shaving and load levelling periods. The four main pillars of Grid-level Energy Storage Systems are: Frequency Regulation; Peak shaving; RES Integration; Power Management.

The foundational blocks for Smart Grids are Batteries because of their attractive features such as flexible installation, modularization, rapid response, high energy efficiency and density. This paper covers all core concepts of BESS applications and Business Cases, the current scenario, environmental impacts, policies, barriers and probable solutions and prospects. This elaborate discussion on energy storage systems will act as a reliable reference and a framework for future developments in this field. Any future progress regarding ESSs will find this paper a useful document wherein all necessary information has been provided

The choice of Battery Technologies and Integration will play a crucial role in any BESS Business Applications for energy storage systems.

Keywords

energy storage, renewable energy, applications, policies, barriers, Renewable Energy Sources (RESs)

1. Introduction

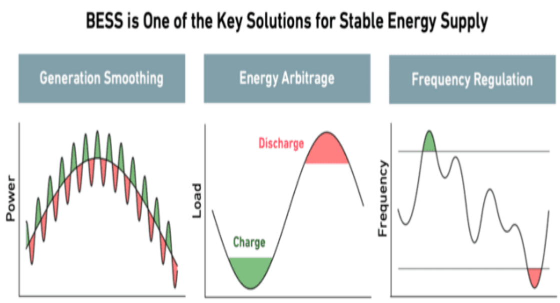

Fig. 1. Functions of BESS

Electrical Energy plays a dominant role in industrial development, urbanization and economic advancement, as well as in our daily life.

However, given that the demand for electricity is fluctuating, imbalance between power generation and utilization often occurs. Moreover, to reduce carbon emission, the associated climate change and the issues of energy supply shortage, electrical energy generation around the world, which is accompanied by the development of some renewable energy sources is undergoing significant changes.

Storing energy is becoming more important in order to integrate fluctuating renewable energy sources in the grid. Energy Storage Systems (ESS) are effective tools for decoupling the production of clean energy from its consumption, both in utility size and distribution.

The grid-level energy storage system converts (ESS) electricity from the electrical energy generation network into a storable form and converts it back into electrical energy on demand. The grid-level ESS have been deployed to support a wide range of applications from power generation to transmission and large-scale electronic devices. For stationary application, grid-level electrical ESS store the excess electrical energy during peak power generation periods and provide the vacant power during peak load periods to stabilize the electric power systems by load levelling and peak shaving.

In addition, ESS can balance the load and power of the grid network by charging and discharging to provide regulated power to the grid.
The Energy Storage System can also help to establish a sustainable and low-carbon electric pattern that is achieved using intermittent renewable energy efficiently and continuously.

2. Foundational Blocks for Smart Grid -Batteries

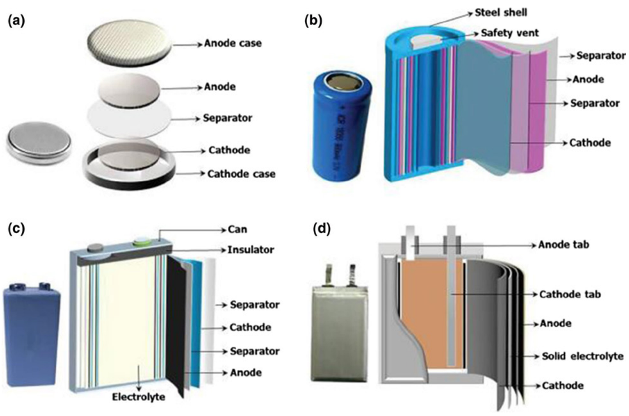

Fig. 2. Basic Cell Topologies/Form Factors

Among the Energy storage systems, electric batteries exhibit considerable potential for application to grid-level electrical energy storage because of their attractive features such as flexible installation, modularisation, rapid response.

Among various battery technologies, Lithium-ion Batteries (LIBs) have attracted significant interest as supporting devices in the grid because of their remarkable advantages, namely relatively high energy density (up to 200 Wh/Kg), high Energy efficiency (>95 %) and long cycle life (6000 cycles at deep discharge of 80 %).

Frequency regulation and peak shifting and integration with renewable energy sources and power management are the hallmarks of LIBs serving as promising energy storage technology for smart grids

Although LIBs dominate the market, they also encounter serious challenges in realizing their wide-scale use. The major limitation is their high cost, which can be attributed to the scarcity of lithium metal sources, specific packaging and internal protection circuits preventing overcharge.

3. Applications of Grid-Level ESS-RES Integration Systems

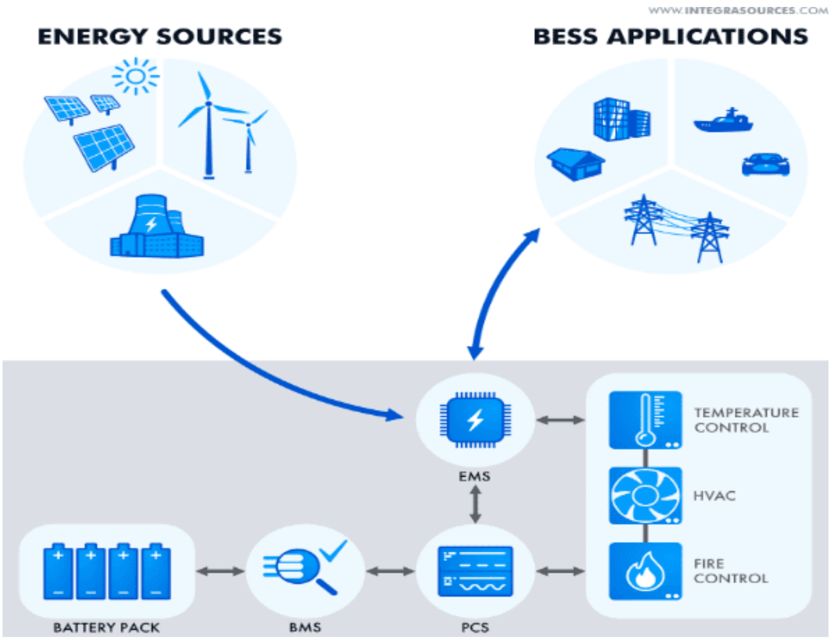

Fig. 3. BESS Structure

The grid-level energy storage system plays a critical role in the usage of electricity, providing electrical energy for large-scale deployment applications. The demand for electrical power varies daily, seasonally and even occasionally. Moreover, a large peak-to-valley difference between day and night can be observed. Therefore, storing the generated power and providing vacant power during peak load by peak shaving and load levelling are necessary.

The renewable energy sources are susceptible to geological, seasonal and temporal conditions. The intermittent nature leads to unpredictable fluctuations of output power, which cannot meet the demand for application to the electrical grid directly. The Power grid system needs to smooth the intermittent output power generated from renewable energy sources and reduce the fluctuations caused by renewable energy sources such as wind and solar energy by adjusting their output profiles.

4. Frequency Regulation and Peak Shaving

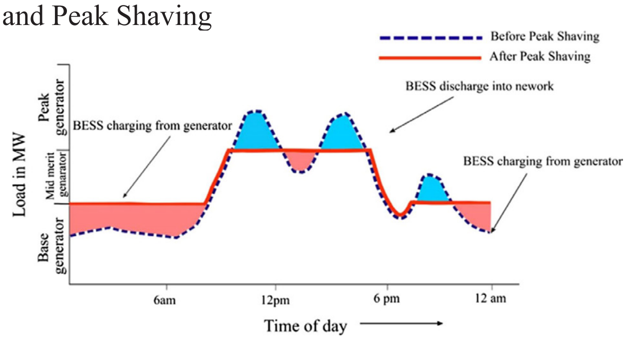

Fig. 4. Role of BESS

To provide stable and reliable power in large-scale deployment applications the stability of the voltage and frequency will be considered. When there is a mismatch between power generation and utilization ESS can maintain the stability of the voltage and frequency of power supply for short-term and long-term applications.

5. Renewable Energy Integration

Renewable sources have become one of the most cost-effective choices for power generation in power grids in many regions. The substantial growth of variable renewable sources promotes the development of electrical energy storage systems. BESS can effectively store the generated electricity of renewable sources, contributing to grid system stability and reliability, which in turn promote the use of renewable energy sources.

Wind Power generation represents one of the main renewable energy sources. However, given that it is strongly influenced by the season and geographical location, wind power generation considerably suffers from intermittence. Moreover, mismatch between peak power generation and demand is often observed. Storing the excess energy produced by wind farms to supply electrical energy when the power demand reaches its peak is an effective solution.

6. Power Management

The power management system is an essential contributor to the capability of the battery to satisfy the requirements of grid-level energy storage applications, which have a considerable effect on the operation of the overall battery stack and its safety and cost.
For effective operational safety of BESS

- Circuit balancing to prevent the voltage or current of any cell from exceeding the set limit
- Monitoring the temperature and prevent the thermal runaway.

7. BESS - BUSINESS CASE

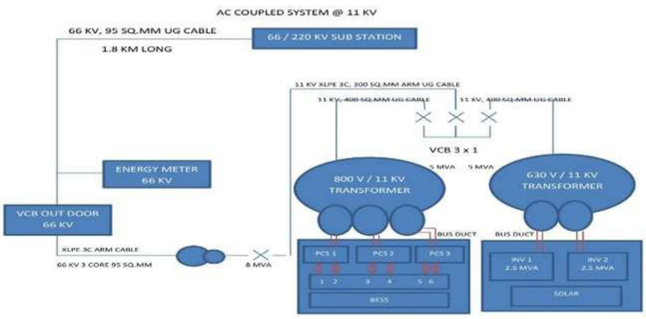

Fig. 5. Schematic of BESS

Cost Saving Mechanisms:

- Coupling at 11KV/33 KV
- Replacing Dual AC coupling Transformer with Single one
- Co-location proximity with sub-station
- Single Point Penalty @ Final contracted Electrical Units Injection
- BESS-Backward integration with promotion of locally available raw material (e.g., Sodium) Cell chemistries

8. Conclusion

In the twenty-first century, economic growth and social prosperity are more dependent on electrical energy than at any time before with a strong demand for a grid-level energy storage system.

77% of Electrical Power Storage Systems in the USA that operate to stabilize the grid primarily for regulating the frequency rely on LIBs indicating a high-value business case for LIBs

However higher cost and potential resource limitations of LIBs forces to explore high performance and novel battery systems based on Sodium-ion and Hydrogen Cells

SIBs Chemistry will reduce Total Cost of Ownership for BESS Apps in future

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Data Driven Cognitive Model for Enhancing Sustainability Footprint of Customer-base of Electricity Industry

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Abstract

Today, it is imperative for every enterprise, industry, business, service to track the activity-based environmental-emission footprint to comply with the regulatory mandates of reporting and disclosures, also keep the alignment with the strategic initiatives aiming to achieve sustainable development objective.

Achieving business-growth and transformation with a keen emphasis on sustainability aspect has become the most adopted approach across industry sectors. This paradigm shift has opened the potential market with greater demand of advisory consulting and solutions addressing the issues, challenges of industry-ecosystem around environmental-emission, along with exploring opportunities in decarbonization, circular economy, waste management, optimizing water and energy footprint etc. The need of the hour is a comprehensive solution which can provide a holistic and reliable view of the environmental impact (including Emissions) for organizations across their Product value chains.

This paper is a thought leader approach in educating the energy ecosystem about the data driven ability to get a clear picture of the presence of carbon in terms of global warming potential (GWP) measured in gCO2e as an impact of diverse customer base. The point of view presented in this paper would trigger the optimized power flow, along with identifying the locations/load centers that are carbon intense, that in turn would unlock decarbonization opportunity.

Keywords
Data Analytics, Global Warming Potential (GWP), Sustainability footprint, Electricity Industry

1. Introduction –Power Sector Net Zero Carbon Objectives

The entire energy eco-system today is sensitive towards contributing to net zero targets, reducing carbon emission, decarbonization, minimize loss, leakage, waste management and increased recyclability. Electricity Generation industry, Transmission and Distribution industry set their targets and get approved by science Based Target Initiative (SBTi) etc and also invest accordingly aiming to achieve those targets in the promised time window. While achieving the environment- friendly and sustainability focused targets, Power sector needs to actively involve customer-base to act sensibly towards carbon and emission footprint. Along with energy conservation, usage of smart and green energy products, participation in the green-initiative programs of electricity commission/ industry is imperative.

The consumer of electricity is keen in availing the options of the smart, energy efficient equipment, green gadgets, ensuring following up of green energy policies. Government policies incentivizing the customer to buy electric vehicles, install rooftop solar PV panels, act as a catalyst in increasing the momentum to the social adaptation towards green energy initiatives.

Today, the customer is interested in getting a clear visibility on their own energy consumption-patterns, energy generation -patterns and explore opportunities of managing energy consumption as well as trading the power under newer business models as a prosumer. Hence it is imperative to unlock the potential of big data to derive insights to recommend actions to empower customers in achieving their sustainability goals. Practice

Fig.1. Sustainable Development Goals and Electricity Sector

As mentioned in the Fig.1, out of 17 SDGs there is direct mapping of a couple of SDGs with power sector.

It is imperative for Utility industry to prioritize on the sustainability driven materiality aspects such as optimizing green power, affordable energy, bio-diversity ecological balance minimization of loss, pollution, water and land coverage, supply-chain management, active customer engagement etc.

This paper articulates the global challenge of utilities being able to quantify the carbon impact across diverse customer base. This input of carbon intense locations at the distribution side, would enable system operators in maintaining availability of renewable generation, in turn the optimizing the grid balance.

In the following paragraphs, representative four load-base types, the potential of carbon-contribution is detailed as an example. At network, when the load flow is run to identify the power flow in terms of active power, reactive power, one can get the idea of carbon emission as operational carbon. Unlike other industries, Electricity Utility industry is unique to compute the variable carbon, as an effect of variable power flow through the network, assets, line-losses, heating due to harmonics-nonlinear load etc.

Hence while achieving the net zero target, Utility industry needs to get a clear picture of landscape of carbon footprint across the value chain under portfolio, e.g., distribution utility.[1]

From the point of electricity utility's environment impact, there is carbon emission as embodied carbon in terms of material, process, transport impact, that can be treated a constant. The power flow in real time results into operational carbon that is a variable value.

With availability of data regarding type of loads, their patterns, the predictive models can be built and their behavior can be simulated. [2,3]
The simulations would provide the guidelines to the decision makers regarding the opportunities of decarbonization, with strong involvement of customer in the journey of achieving objective of supporting environment.

2. Emission Impact based on Type of Load

The transformation of utilities in adapting digitalization and deployment of SCADA, IOT, AMI, PMU etc. have enabled access to the real time DATA of grid, giving opportunity to be able to apply analytics to get the trend of behavior of grid, unlocking the potential solutions for techno-economical vulnerabilities.

Distribution utility do cater the power supply to customers at low voltage such as 11kv,22kV, three phase 415 V 50 Hz, Single phase 230 V, 50 Hz. The distribution transformers do have a mix of customer –base including domestic, industrial, commercial, hospitals, hotel-hospitality industry etc. The type of customer defines the peculiarity of energy consumption, carbon presence and footprint.[4]

As known to all, generation of electricity has significant carbon footprint, hence it is worthwhile to delve into a couple of details on type of generation as shown in Fig.1.

Fig.1 states the fact of the lower carbon emission of renewable power generation sources compared to fossil fuel-based sources. The corresponding values for renewable are less than 10% of the cleanest traditional source.

Following paragraphs provide details around four types of customer-bases, their carbon footprint and environmental impact;

1. Cement Industry
2. Steel Industry- Electric Arc Furness (EAF)
3. Commcerial Malls
4. Domestic Housing Society

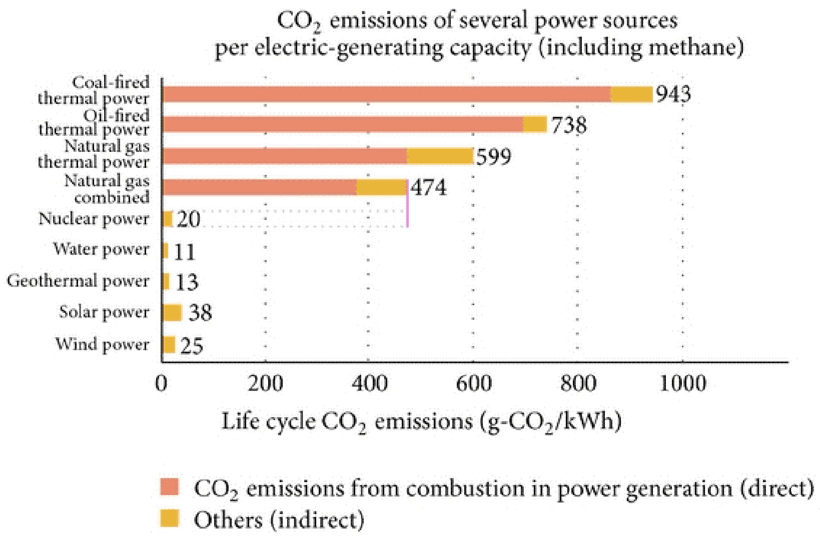


Fig.2.Per Unit generation of electricity and Life Cycle CO2 emission

Cement Industry

Cement industry is one of the most focused industries, in quantifying and also attempting to minimize the emission impact across value chain.

The direct emission intensity of cement production is envisioned to be within till 2030. [5]

The clinker production is the key contributor in emission as a part of process. It is reported that global thermal intensity and fuel consumption of clinker-production ranges very high. This becomes the baseline for taking up decisions in setting targets in net zero.

These attributes provide insights about the required initiatives to strengthen the grid by enabling green power in the cement production process which in turn provide prescriptive guidelines on providing opportunities of carbon capture storage and use.

Global Cement and Concrete Association (GCCA) European Cement Association, Portland cement Association are the associations across globe to set target for net zero emissions by 2050, with their member countries including UK India, Brazil USA. On 5th July 2022, 17 firms came together to create a market for net zero concrete committing to procure 30% low-emission concrete by 2025 and 50% by 2030 under Climate Group's Concrete Zero initiative. [4,5]

To report the cement industry in India, with energy efficiency programs, India's cement industry has a foot print of progress of reducing CO2 emission levels from 0.719t/t of cement produced between 1996 and 2017 to the target of 0.35t CO2/t of cement by 2050. [5]

The data regarding the life of the plant also decides to prioritize on investing towards green sustainable solutions through subsidized interest loans, proactive engagement with the leading research institutes and countries involved with green tech-related innovation in the cement industry, including supply chain, upstream and downstream activities.
Hence aggregating the data pertaining to high energy intense processes is a vital input to the distribution utility industry to build a localized green energy hybrid model, that are techno-commercially viable.

2. Steel Industry – Electric Arc furness

The steel industry is another high electric intense type of load, with the appreciable carbon presence along with harmonics too. The Electric Arc Furness over the conventional blast furnace has brought down the energy consumption to a large extent, however still the Steel industry is on high radar in terms of their SBTi target and sustainability driven KPIs.

The powders resulted during the technological operations of base material loading and steel melting, refining, alloying and evacuation which contain heavy metals (Cr, Ni, Zn, Pb, etc.) and can reach values of 15 kg/t steel. [4]

The gases resulted from melting and refining proceedings, which mainly contain CO, CO2, SOx, and NOx from the total polluting emissions, over 90% are generated during the technological operations of melting and refining. These emissions have a high content of iron, manganese, aluminum and silicium oxides, as well as heavy
metals oxides (Ni, Cr, Cd, Pb, Cu).

Thus, as a customer-type Steel industry is crucial being high energy intense as well as impacting many environmental categories. Identifying the location of such customer base across the distribution network is key driver to enable de-carbonization attempts, energy efficiency programs etc.

Domestic /Housing Societies – Smart home

The domestic or housing complex is another category of customer base drawing attention of distribution utility industry mainly due to enhanced digital interventions through smart meters, increased roof top solar PV generation systems, adaptation to electric vehicles.

Data drive classification could create a clear picture of different load centers to be catered on priority as well as nodes where concentration of prosumer-category is observed, with opportunity to decarbonizes green energy available at low voltage.

This specific category has introduced more dynamism in the load demand patterns, challenging the short-term planning phase.

Hence, today, Utility industry needs to aggregate the data and build data driven models to predict trend of consumption of their loads as well as generation of power through solar PV, including impact of seasonal, weather, festival variance along with factors such as time of day, type of day, type of month etc.

Means and measures to achieve net zero carbon target –

1.Integrating massively deployed sensors and smart meters, dozens of nodes to be controlled, such as appliances, heating/ventilation/air conditioning (HVAC), solar panels, electric vehicles, and so forth.

2.The information could be presented to consumers as numerically, graphically, or symbolically as alerts or alarms, including: current and historical energy use, equivalent emissions, instantaneous demand, current prices, and ambient temperature, humidity, and lighting levels, alarms are triggered by preset values to inform the consumer of pending price events or energy use thresholds.

3. Demand response is the key program resulting into active customer engagement in supporting grid balance load with encouraging green energy usage. The digital intervention enables Utility to provide direct feedback on electricity pricing throughout the day, especially during the peak interval, will make consumers adjust their usage in response to pricing.

4) Commercial shopping malls

Commercial complex, shopping malls are important to be discussed as they have very high HVAC, induction-motors, lifts/hoists etc. The usage of high electricity is the major reason for scope 2 emission, along with upstream as well as downstream activities and aligned environmental impact. In response to minimize the carbon emission contributions from commercial malls etc., Utility engages them with Electricity Efficiency program, Energy conservation program etc.

3. Data Analytics for Carbon Intense Area

It is proposed to build a data-driven cognitive model, to support utility to identify the areas and load centers across network that are high carbon intense, also to engage with customer to efficiently optimize the energy consumption as well as balance the energy generation at customer premise.

Test Power System and its Graph

As introduced in the previous section, the enablement of data is the success in getting clear visibility of data-types across network and initiate analytics to derive insights to enable tasks of decarbonization, reduce electricity consumption etc. The representative grid system is used for proof of concept in the paper, where the proposition can be scaled up to a lager grid.

The test system presented in Fig 3, consisting of diverse generation as well as load types. The concentration of loads as well as generation availability is modeled with reference to Maharashtra State Grid (In a miniature version with specific assumption)

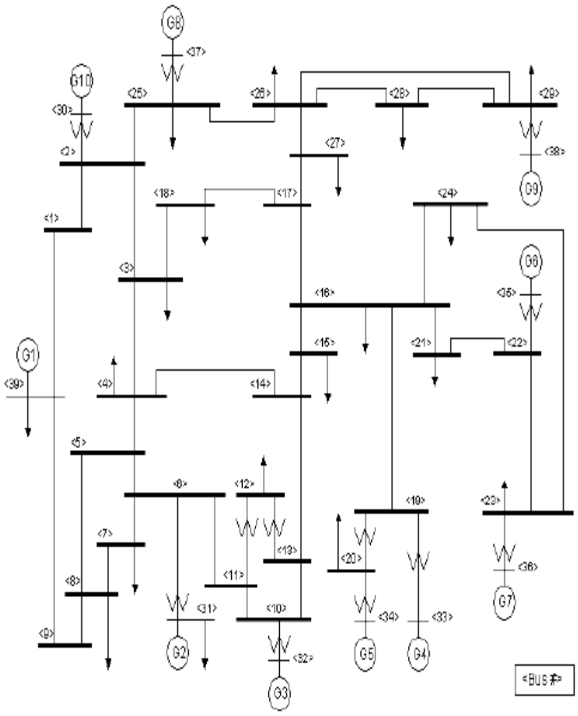


Fig.3. Representative Reference Grid

Graph theory is applied to represent the test system, more generally, a graph G = (V,E,WV ,WE) is considered with the weights WV as node weights, a nonnegative weight for each node, and WE as edge weights, a nonnegative weight for each edge. WVvi means the cost of job i, WEe(i,j) means amount of data that must be transferred from job i to job j. Partitioning G means dividing V into the union of n disjoint sets

V = V1 U V2 U ... U Vn (1.1)

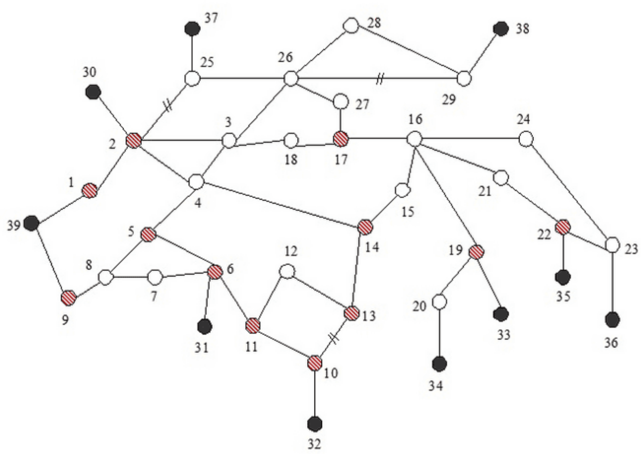
where the nodes (jobs) in Vi are assigned to be done by processor Pi and U stands for union.

For optimal grouping, some conditions should hold:

1. The sums of the weights WV of the nodes in each Vi should be approximately equal. This guarantees a load balance condition across processors.

2. The sum of the weights WE of edges connecting nodes in different Vi and Vj should be minimized. This minimizes the inter-processor communication.

Applying the basic rules, the Test system is reproduced as following in the graph network as shown in Fig. 4.



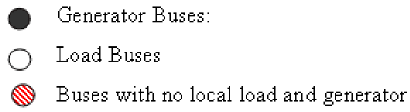


Fig.4. Graph –Representation of Reference Grid

Leveraging the smart meter data, the deep learning techniques would intelligently correlate the granular level energy consumption with the time of day, type of day and type of season etc. This would identify the likelihood of patterns embodied. The intelligence mapped could be leveraged in providing timely advice on the demand control and benchmarking the load demand, its impact of consumption bill and most importantly carbon footprint. Artificial Intelligent (AI) model would predict the surplus generation availability, that can be traded in market. The results of the predictive models are not presented in the paper.

Indicative Data:

1. Meter data with consumption details at certain time stamp (Structured data)
2. EV vehicle related details (Unstructured data)
3. Solar PV generation details (Structured data)
4. Customer details (Unstructured)

Schematics of Building Data Driven Solution

This paper aims to advice the possible solution capability to address this challenge of quantifying the global warming potential, in terms of carbon emission as kgCO2e across the business functions. Following are the indicative models to be explored while developing a contextualized solution.

Clustering Model

Applying K-NN technique or K-means technique, the gadget, season, and time centric consumption-data clustering would be useful in understanding the patterns and correlation with the logic of benchmarking the demand as well as scope of load prioritization as per heavy power consuming equipment, essential/ non-essential loads are concerned.

Predictive Model

With the clear understanding of functional correlation and dependencies of the weather-related data variables, AI-ML algorithms shall be developed to accurately predict green energy produced at customer-premise. This predicted value would become an input to the optimization model to take up decision on either utilizing or the trading of power, based on the demand scenario. The impact can be measured in terms of harnessing green energy generated by each prosumer and support provided for demand response program of supply-demand balancing etc.

Cognitive Engine and Advisory Sustainability Roadmap

Building a situation-aware system would ensure achieving efficiency while taking operational decisions on priority order of loads, high power electric vehicle charging etc. dynamically and optimally enabling supply-demand balancing in near real time. This would provide predictive inputs regarding the trading of surplus power generated at Solar PV to neutralize the carbon emission footprint at peers.

The logic ensuring the functional understanding of the impact of load-generation management on carbon footprint would be scaled up for what-if analysis and root cause analysis, providing ability to continuously monitor and provide decisions to enable customer to meet sustainable goal.

Carbon Profile of Network

Using free body diagram, the aggregated carbon at each node is calculated based on the network connectivity, showing one example in Fig. 5.

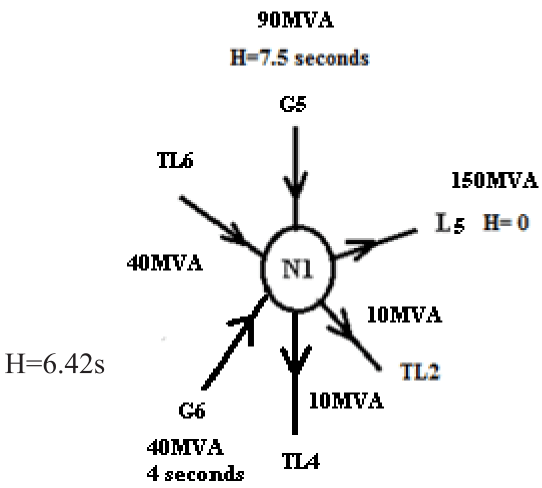


Fig. 5 Isolated Node Free Body Diagram

The carbon profile (kgCO2e) of the representative grid at nodes is shown in Fig. 6. Based on the type as well as capacity of load at various buses, the embodied as well as operational carbon footprint, in terms of global warming potential varies. This provides us understanding of the high GWP nodes.

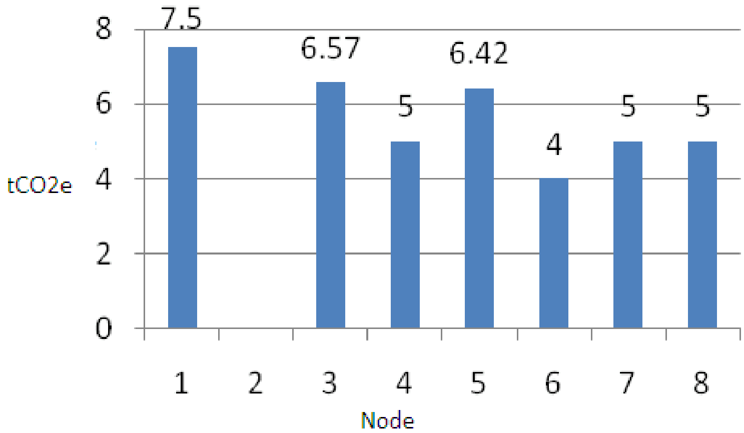


Fig. 6 Isolated Node Free Body Diagram

Mapping of Priority nodes to decarbonize

The embodied carbon is the characteristic value of any asset as per the technical speciation and entire life cycle assessment. The variable carbon is based on the operation of the asset, loading of the equipment, losses, leakage etc., hence exhibits the variable nature.

The load dynamics used to be the main governing factor, creating generation-load unbalance in the system, but today, in presence of generation from renewable sources, the dynamicity at the generation side is introduced. There is need for including generation intermittency as an additional factor while assessing the resiliency of grid.

It implies more complex operational challenge of handling load as well as generation volatility, while keeping the system balance.

Based on the data of load, generation at each load, predicting the trend of variation in these parameters, it is possible to identify those nodes, having opportunity to install roof top solar PV etc.

Based on this study, the nodes can be grouped together to result into improved environmental effect, with minimizing energy loss, optimize generation-load balance etc.

Fig. 7 and Fig 8 provides such results when load flow is conducted and the actual power flow is referred to build the reference grouping.

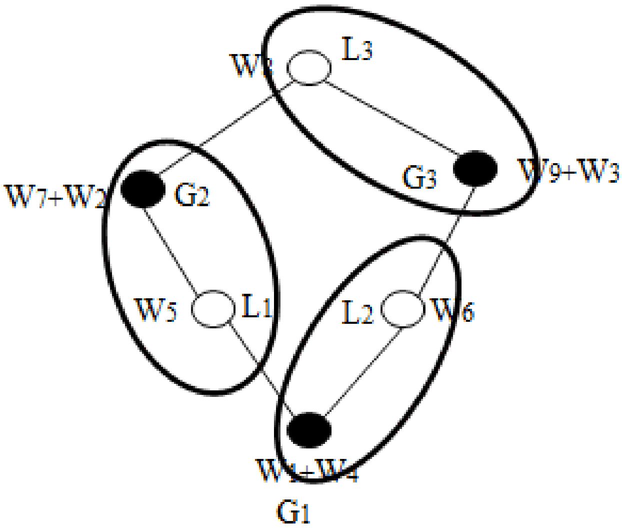


Fig. 7 Groping of carbon-balancing nodes

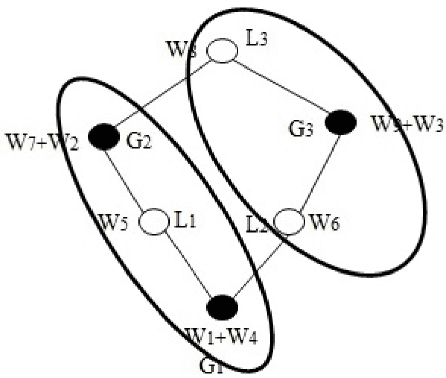


Fig. 8 Groping of carbon-balancing nodes

4. Outcomes- Carbon Assessment to Support Net Zero target

One of the important stakeholders in the energy ecosystem is Customer-base. The proposed idea guarantees customer to gain an appreciable increased operational insight for achieving net zero carbon target, while responding to Government and Policy makers' sustainability initiatives.

The cognitive feature of module would make it adaptive and scalable to the newly evolving business models. The AI algorithm would handle the uncertainty in demand as well as generation in case prosumer-category and would be adaptive towards incorporating the behavioral changes through self-learning.

This would ensure enhanced customer experience, through clarity on scope to conserve electricity consumption and trade the green energy generated, optimum resource-management, enhanced resiliency and stand out as a support to the climate change movement.

In short, the insights drawn out of quantitative analysis has enabled the customer to carve out the strategic action plan to reduce the carbon footprint, to make appropriate decisions of choice of energy-mix, choice of suppler, to optimize usage of gadgets as well as balancing of energy generation as well as energy consumption.

Following are the possible initiatives to achieve the required minimization of CO2 emission

Energy Simulation and Improve Energy efficiency

Simulating the scenarios on where and why energy is being used across the network is vital in knowing the carbon landscape, identifying areas to target your improvements, and cut carbon emissions. This energy audit would become a basis to drive tangible change.

It is also envisioned to use digital twin, accurate digital model of the building to be constructed, to determine the most efficient energy usage patterns.

Of course, when building with sustainability is in mind, all materials should be recycled or low impact if possible.

Decarbonise

The renewable energy technologies like solar panels and wind turbines, and organic waste towards biomass boilers, are the feasible options to explore.

Energy Management

The intelligent software can be built to monitor, record, learn and advice on the light usage based on occupancy, purpose of utilization etc. The best optimization tool would result into proper generation load balance prioritizing selection of green power and minimizing the conventional source.

Architectural Biodiversity

Towards bringing down the CO2 emission, one can incorporate live plants and green spaces into the advisable areas to maintain biodiversity and creating offset mechanism through architectural biodiversity.

Conclusion

While an industry segment is embarked on the journey of net zero carbon, it is empirical to quantify the presence of embodied carbon and operational carbon across the ecosystem and stakeholders. Obtaining the clear picture of emission landscape, the strategic action plan to be carved out.

This paper aimed to provide thought-leader view with examples on the approach of using customer-base data and enabling the decarbonization attempts.

The concept, methodology and indicative results are very value added and relevant to Utilities in achieving target sof reducing carbon emission, enhanced sustainability footprint and addressing environmental concern as a response towards climate change.

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Demand-side Flexibility as a Demand Response Mechanism – A Review

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Demand-side Flexibility as a Demand Response Mechanism – A ReviewAbstract—The load curve is constantly changing. Utilities worldwide are tirelessly working to meet supply and demand during peak hours. The daytime peak is a new challenge in addition to the conventionally accepted morning and evening peaks. According to NITI Aayog 2019, 24% of the electricity consumption is from the residential sector and 28% from the agricultural sector. Hence if the consumer engagement process is successful, applying demand response programs including shift and shed, can develop a virtual power bank in GW. For example, suppose 10% from an agricultural load of 60 GW is shifted towards peak solar hours. In that case, a 6 GW of flexible power bank is created. Hence demand-side flexibility is a source. This source can manage peak load without increasing the electricity price, improve the grid reliability and stability and curtail emissions. India can economically achieve its clean power targets if this flexibility potential is exploited successfully. In-depth research is needed to uncover the demand flexibility potential in a country and formulate energy policies. This paper reviews all the relevant work related to residential demand-side flexibility based on worldwide case studies. The work proposes a methodology for estimating the flexibility potential of the residential energy community. In addition, the constraints and concerns for demand-side flexibility and the major demand flexibility programs that can best contribute to flexibility potential are identified. The paper also assesses the capacity and constraints of EV batteries as the major source of demand flexibility.

Keywords

Demand flexibility, Demand response, Demand side management.

1. Introduction

World scenario: Energy consumption is ever-increasing. As per the IEA world energy outlook 2022, energy consumption has roughly doubled in the past 20 years. Global electricity demand reported a yearly increase of 6% and reached 24700 Terawatt hours (TWh) in 2021 [1]. This increase in consumption is primarily due to developing nations and other emerging economies. The share of electricity in total final energy consumption (TFEC) in 2021 stands at 20%. TFEC shall reach 22% in 2030 in a normal scenario. However, in the 'net zero emission' scenario (NZE), the share of electricity in TFEC is expected to reach 28% in 2030 and 52% in 2050.

In short, electricity is developing as a 'new oil' in terms of its dominance in TFEC [1]. Electricity in coming years plays a major role in all end-use sectors, including heating, cooling, transport, communication, finance and health care and improvement in overall energy system efficiency. This trend is pointing towards the need for strong electricity security measures. Hence it is placed high on the energy policy agenda. The demand for clean power, NZE and the high increase in the electricity demand point towards structural changes in electricity systems.

Utilizing the existing flexibility assets for demand response is becoming a policy priority with grid modernization. The increase in the use of distributed renewable sources, mainly solar and wind, the drastic increase in the use of electric vehicles, and Gigawatt scale battery energy storage aid the demand flexibility. The assessment of the flexibility potential of the assets is being carried out worldwide.

Indian scenario: A study conducted by Alliance for energy efficient economy on the energy demand scenario made projections for India in 2030. It is found that the peak demand in metro cities like Bengaluru, Hyderabad, Mumbai, and Kolkata is about to double by 2030 when compared to the peak demand in 2020. Hyderabad shall reach at a peak demand of 6000 MW by 2030. Other major cities like Kanpur, Agra, Varanasi and Nagpur, whose peak demand was between 600 - 800 MW, shall reach to 1000-1200MW [2]. This drastic increase in energy demand translates to capacity additions in the generation, transmission, and distribution, necessitating a need for huge investments.

The renewable portfolio of India, as of August 2021, the total installed capacity of renewables has reached 100 GW. The revised target for 2030 is 450 GW of installed renewable energy (RE) capacity. In tandem with achieving RE targets, the country has achieved its emission targets well ahead of time, leading to a revised emission target for 2030 [2]. Thus, decarbonization of the electricity sector is taking place in parallel. The efforts in the renewable energy sector have put India to the top 3 G20 performers in the Climate Change performance index (CCPI) of 2023 and ranked 8th among 56 countries and Europe [2]. Demand flexibility (DF) as a resource is yet to receive the attention of policymakers and utilities to meet the ever-increasing demand. DF allows the consumers to take up stakeholder responsibility in demand-side management by controlling the loads.

Definition of Demand Flexibility

Demand Flexibility is a process in which a portion of the demand is curtailed, shifted, or increased in a particular period. A detailed definition is given by the International renewable energy agency (IRENA). According to IRENA, 'demand-side flexibility' is defined as a portion of the demand arising from the electrification of energy sectors, such as heat or transport via sector coupling, that could be reduced, increased, or shifted in a specific period. DF helps to reduce the peak load, shape the load curve by integrating variable renewables to match the load demand and shift the load from a period of high per unit price to a period of low per unit price [3]. From a consumer point of view, demand-side flexibility (DSF) is the ability of customers to change their consumption and generation patterns based on external signals [4]. According to the IEA report on demand flexibility 2019, the estimated potential of flexible loads during each hour is 4000 TWh. By 2040, the demand flexibility potential is predicted to touch 7000 TWh. One of the major reasons for this huge potential is the forecasted penetration of electric vehicles.

The layout of this work

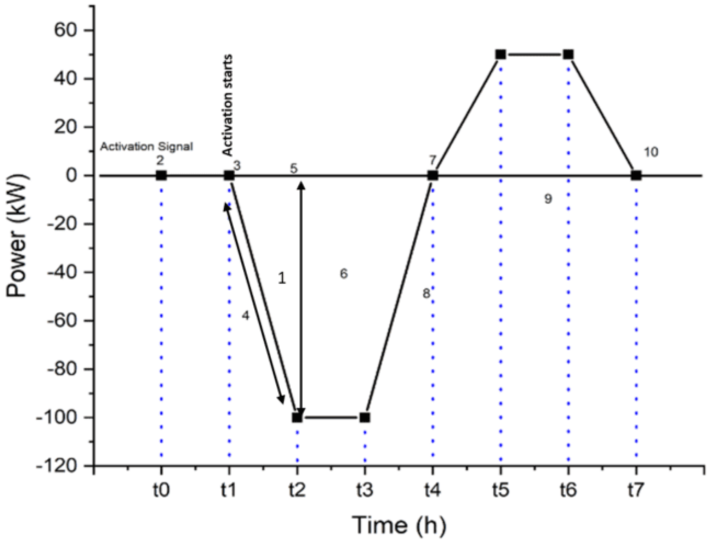
This work focuses on understanding the residential sector demand flexibility. Section II discusses the methods of DF assessment. Section III details various case studies utilizing DF as a flexible grid-scale energy storage technology. Section IV details the major flexibility-enabling technologies in the residential sector. This work also tries to combine most the work done on demand flexibility by the researchers in academia and the reports published by policymakers worldwide.

3. Methods of assessing demand flexibility

The primary step in assessing the demand flexibility potential is understanding the nature of controllable and uncontrollable loads in a residential building. This can be done by a load disaggregation process, followed by categorizing the load into controllable and uncontrollable loads. The availability of smart meters in every household with DSM and communication module facilitates easy analysis of the loads. Direct load control (DLC) helps to understand the load curve of each of the appliances over a day, week, and month. DLC also helps to monitor the changes in energy consumption with climatic variations.

Demand response in a flexible load

Fig. 1 explains the processes during a DR event for flexibility. When a flexible load receives an activation signal at t0, it takes some time to act (t1- t0) and decrease the power usage. Then it will operate for a period(t3-t2) with reduced power. At the end of DR event, it takes some time to return to original state (t4-t3). In a demand flexibility study, it is important to understand the power curve and response characteristics, including response speed, ramping duration, energy shifting and shedding potential. This is mainly because various devices have different flexibility capabilities and operational characteristics.



The demand response process of a flexible load [5].
Where 1) power capacity, 2) response time, 3) ramping time, 4) ramping downtime, 5) duration of flexibility, 6) direction, 7) ramp-up duration, 8) energy capacity, 9) duration of the rebound effect, and 10) rebound effect.
It is generally understood that thermostatically-controlled loads can be shed, shifted, and modulated. However, wet appliances are good for load-shifting services only. Lighting loads are good for load shedding and modulating services [5]. It is evident from researchers' findings that major potential at the household level is with HVAC equipment's. Hence, accurate estimation of the above is very important. Energy Plus, Transys and Modelica are some of the tools used for the flexibility potential assessment of individual HVAC.

Forecasting demand flexibility using smart meter data

Understanding the load composition is important for demand-side management and demand flexibility studies. Time-varying data of the aggregated load is essential for estimating the same. The method followed varies based on the facility available for data input. In a condition where the number of smart meters installed is less, following procedure is adopted [6]. A two-level approach; first, power measurements are carried out, decomposing all the aggregated household loads. Secondly, the data received from the first step is fed to artificial neural network (ANN), which forecasts the total aggregated household load and its decomposition. This work explores the number of smart meter users in aggregation to predict the overall aggregated load composition. It is estimated that with at least 5% of the smart meter population, it is possible to predict load composition at an aggregation point/substation with reasonably good accuracy. The work provided guidelines for demand flexibility estimation using submetering-enabled smart metering measurements and ANN. The flowchart for the same is given in fig. 2. The methodology adopted helped to estimate the share of different load categories and categorise controllable and non-controllable loads using a DR program. Smart meters with demand side management (DSM) facility are required for this methodology to monitor the active power demand of individual appliances.

Characterisation of the loads for demand flexibility assessment

This work assesses the flexibility capabilities and operation characteristics of the residential loads. The classification of loads followed here can be applied elsewhere and in commercial and industrial loads. All the flexible loads were categorized into adjustable, shifting, and shedding loads.

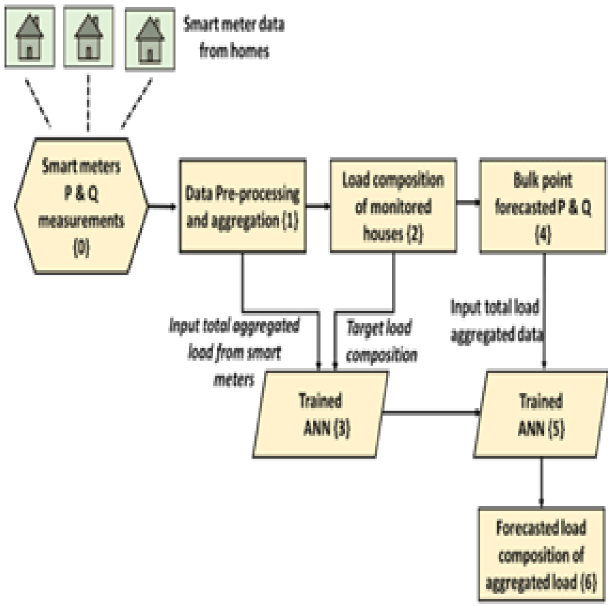


Fig. 2 **Procedure for load disaggregation in a smart metering system [6].**

Table 1. Categorization of residential loads [5]

Category	Appliances	Capability	Operation Characteristics	
			Running mode	*Frequency of Use*
Adjustable loads	HVAC	Shed, shift, and modulate	Intermittently	Almost every day in winter and summer
	Electric water heaters	--do--	Intermittently	Running all- day
	Refrigerators	--do--	Intermittently	Running all- day
Shifting load	Dishwashers	shift	Finite cycle with sequential processing	Depending on the occupants, once or twice a day
	Washing machines	--do--	--do--	--do--
	Clothes dryers	--do--	--do--	--do--
Shedding loads	Lighting	Shed and modulate	Continuous	Every day

Further sub-classified based on their running characteristics (e.g., Continuously, and intermittently running), usage frequency (day, week, or month), and energy changes (Consumption with time and weather conditions) [5]. Table 2 illustrates the classification of loads.

Based on the literature, the authors derived a pattern for the energy consumption of residential appliances. The proportion of energy consumption was found to be as follows: - Air-conditioner: 36.5 %, wet appliances: 25.6 %, electric water heaters: 14.7%, refrigerators: 9.6 %, lighting loads: 8.2 % and other loads: 5.5 %. The method followed in the study can be a reference for future researchers in DF studies.

Aggregated smart meter data and demand profiling

Researchers tried to conduct demand flexibility studies with available smart meter data. They used that data to train the ANN to predict the load aggregation of remaining households. Here data was collected from 50 households and later used for load aggregation of 950 homes. Fig. 3 shows the smart meter data of all the household appliances categorized into controlled and uncontrolled. CTIM1 and QTIM1 are controllable loads, and Rs, RUC, SMPS and lighting are uncontrollable loads. CTIM1 consists of a dishwasher, tumble dryer, washing machine, washer-dryer, and vacuum cleaner. QTIM1 Consists of- Chest freezer and refrigerator Rc: - Water heater, electric shower, storage heater; RUC:- R Iron, hob, oven. SMPS loads- high-fidelity (HiFi) appliances, Fax machines, PC, printers, TV, and microwave.

Fig. 4 shows the daily load aggregation of 10 houses (first row), 200 houses (second row) and 1000 houses (third row) for working days and holidays. It can be observed that when the number of households is more, stability in the load curve is achieved. i.e., Curve remain the same for all the working days (curve in row 3).

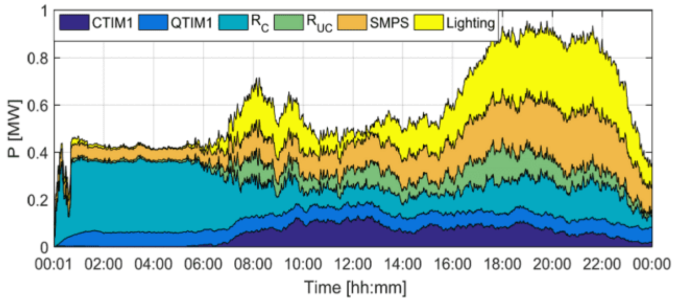


Fig. 3. Smart meter data on load demand of all the equipment [7].

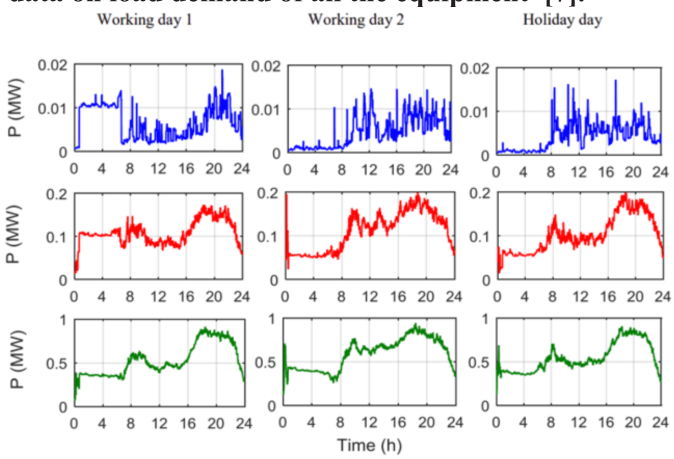


Fig. 4. Load curve from aggregated houses over a day [7].

4. Demand flexibility assessments- case studies

The use of demand flexibility as a DR mechanism is widely being tested in different countries due to its huge potential as a virtual grid-level energy storage unit. An overview of different case studies and research is presented in this section.

Demand response study in Norway

The study is conducted among 40 households in Norway. These houses were connected to smart meters with a direct load control facility, and time-of-use tariff was used. When 50% of Norwegian consumers having heating load can offer a demand response potential of 1kW/h, it would result in an aggregated demand response potential of 1000MW/hr. This is 4.2% of the peak load of Norway [8].

Consumers should be aware of the electricity price signals. Knowledge of the price signal helps consumers make conscious efforts to reduce consumption. A simple method is proposed here, combining the DSO's direct load control and predictable price signal to portray the current market condition to consumers. The price signal information given (reminder) during the peak hours called "El-button" is given to consumers, which helps the consumers to take needful steps to reduce the load. The message intimates the consumers about the upcoming peak load. Incentives are also offered to the consumers to participate in the above-said peak curtailment program. Fig. 5 shows the demand response of the heating load during peak hours. E.g., Between morning, 09:00-11:00 hrs., and evening, 17:30 to 19:30 hrs., demand reduction takes place, and the peak is eliminated. However, in weekends, peak elimination becomes difficult.

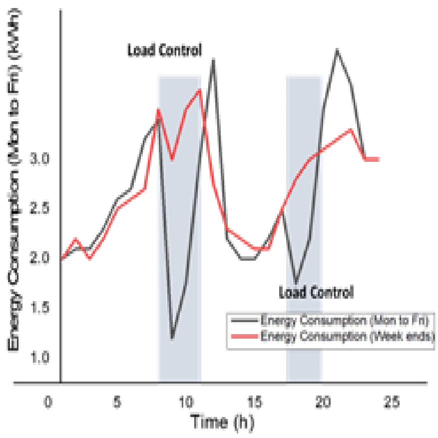


Fig. 5. Heating load profile of Norwegian household with direct load control in place [8].

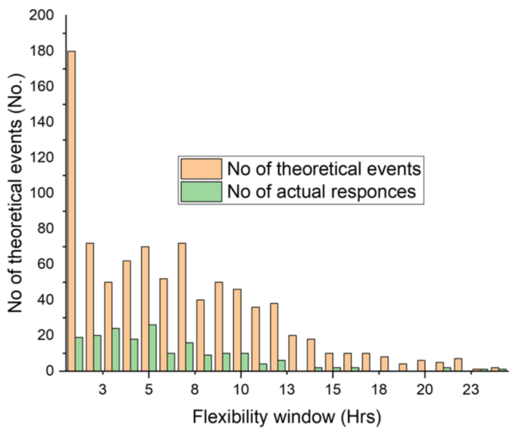


Fig. 6. EV configurations logged into the smart charging systems versus theoretical values expected [9].

Demand response study in Belgium

Belgium's demand response program titled 'LINEAR' was implemented among aggregated 239 houses. These houses, were installed with smart meters and had smart home appliances [9]. The following household appliances were studied for their demand flexibility potential: - washing machines, dishwashers and tumble dryers, domestic water heaters and electric vehicles. As reported by all other researchers' electric vehicles and household heating are the major sources that have the scope to provide maximum demand flexibility. Fig. 6 shows the number of consumers who have logged-in to offer the flexibility of their EV charging. It is observed that there is a huge gap between the expected number of events and the total turnout of consumers. The poor turnout shows poor consumer engagement resulting in reduced EV owners' participation in the flexibility. Hence, it is clear that for extracting flexibility from the EV's valiant efforts on consumer engagement aspects is mandatory. Since the smart configurations are too complex for consumers to understand, it has resulted in less participation.

A study in Belgium on consumers who owned dishwashers, washing machines and tumble dryers is done by researchers. A comparative assessment of the demand flexibility was done for three cases i) Consumers are flexible, and communication is good between utility and consumers. ii) Consumers are not flexible, and communication is also poor. iii) Communication is satisfactory, but consumers are not flexible. The results are shown in fig. 7.

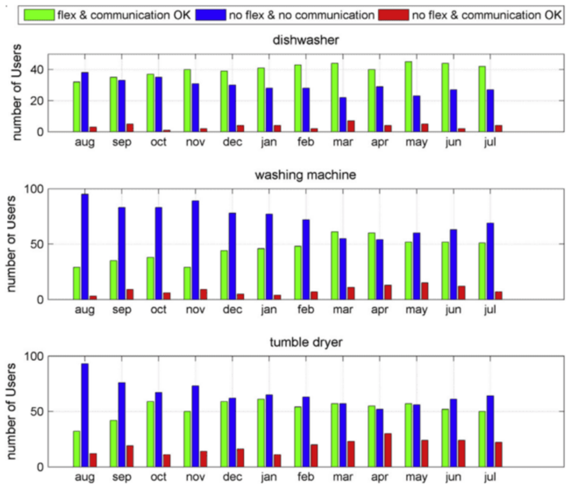


Fig. 7. Flexibility offered by consumers for three appliances dishwasher, washing machine and tumble dryers [9].

The fig. 7 shows the interest of consumers in offering flexibility for one year. The major contributions of this research work are as follows.

- Developed a method for DF assessment of residential home appliances. The method is considered as a standard method (flexibility instrument) for the demand response potential assessment of the appliances.
- The work assessed the maximum flexibility potential of five appliances. Implies capacity for maximum load increase and maximum load decrease. Also, the time in hours for which the flexibility can be sustained.
- For all the equipment except EVs, the flexibility potential is highly asymmetric. At any moment of the day, the maximum power increase surpasses the maximum power decrease.
- The flexibility of wet appliances significantly varies over a day, and the flexibility potential of EVs and electric water heaters (EWHs) is much higher than other appliances.
- The flexibility potential of a group of households varies from another group. The energy consumption of wet appliances for a group of households in a weekend reported a maximum value of 2GW, for a period of 2 hrs. However, the maximum decrease is only up to 300 MW for period of 30 minutes.
- With smart wet appliances, a maximum increase of 430 W per household can be realised at midnight. A maximum decrease of 65 W per household can be realised in the evenings [9].
- According to IEA, the estimated demand flexibility capacity of Belgium in 2021 is 356 MW [3].

Assessment of European demand response potential

- This research focused on the development of theoretical demand response potential in Europe. The DR potential is considered a factor that adds stability to the grid with more renewables. The focus of the work is given to the temporal availability of DR potential with geographical considerations.

Secondly, the possible reduction and increase in the hourly load per year. The data used are industrial production, electricity consumption and periodic and temperature dependent load profiles. Finally, it is estimated that the minimum load reduction capacity available is 61 GW and the maximum load increase is 68 GW every hour of the year [10]. Extensive research is being done in European countries on their demand flexibility potential. The following procedure was adopted. First, identify the list of equipment that can be a part of demand flexibility potential. Then, each equipment's load profile is assessed. Secondly, identification of annual electricity load and installed capacity. Finally, the flexible load share is evaluated. Some of the contributions of the study are given below

- The industrial, residential, and tertiary loads with demand flexibility potential (In MW) were classified into shifting, shedding, delaying, and advancing loads.
- The work also identified the parameters required to calculate the DR potential in industrial cross-sectional technologies and energy-intensive industries. This was also done for tertiary sector DR potential evaluation and residential sector DR potential evaluation.
- The work provided an overview of the sectoral share of average DR potential across the European countries (44 countries). The sectors investigated were industrial, residential, and tertiary. The largest residential share of DR potential is found in Ukraine, Malta, Lithuania, Lichtenstein, and Albania. And the country with the largest share of DR potential in the industry in Finland.
- The study categorized the 22 different loads in the country based on their minimum and maximum load reduction possible. Observed a substantial difference between the minimum and maximum values of load flexibility. The potential electric loads with a maximum difference (in MW) are space heating, air-conditioning and ventilation.
- The study has been extended to understand the equipment with minimum and maximum load increase in MW. The study found that among residential appliances storage heaters, washing machines, tumble dryers and dishwashers are the devices with a maximum load reduction potential.
- The research found an average load reduction potential for all the European countries in a year (2013). This was done separately for each sector - residential, industrial, and tertiary. Found that in the residential sector, Albania and Finland have the maximum potential.
- Greece is the country identified to have the maximum share of load reduction potential during the peak load conditions (up to 80%), followed by Spain (60%).
- The study calculated the daily average load reduction and hourly load reduction average for commercial air conditioner, heat circulation pumps, dishwashers, commercial ventilation, and water pumps [10].

Demand side flexibility in Northern Europe

In 2017 further investigations were done on demand flexibility potential focusing on 7 countries in northern Europe [11]. The countries were Denmark, Sweden, Norway, Finland, Estonia, Latvia, and Lithuania. The work compared the flexibility potential among the 7 countries and estimated the available potential. A flexibility potential of 12-23 GW for a peak system load of 77 GW is estimated. DF potential of Finland in residential and other sectors is given in table 2.

Demand response study in India

The energy efficiency and renewable energy wing of NREL USA have conducted demand response studies in Bangalore, a metro city in India. The work has been done with the support of the Bangalore electricity supply company (BESCOM). The uniqueness of this study by NREL is that when all the studies around the world considered residential, commercial, and industrial sectors as DF areas, this study considered the agricultural sector also in the study. The scope of agricultural load flexibility/

shifting is separately investigated. It is found that agricultural load shifting provides more value than other sectors. The advantage of agricultural loads over others in offering demand flexibility are that agricultural loads are not exposed to sub-daily operational constraints. Hence agricultural consumers could offer more hours of flexibility per day without much sacrifice in their agricultural work.

Load shifting is the most effective demand flexibility technique adopted in the agricultural sector. DR event and recovery can last up to 24 hours, a more relaxed recovery time than any other end uses. Also, each agricultural DR event can

last from 3 - 7 hours against 0.5 to 2 hrs of daily DR events for other sectors [12]. This implies a higher energy availability per unit of installed capacity of the equipment. When the recovery time and duration are more, the power availability and energy availability per DR events are high. The above factors put the agricultural sector weigh up over any other sectors. In the case of a DR call for increasing the load due to high generation from solar, the agricultural load is able to absorb the same too.

Table II. ESTIMATED DR POTENTIAL FOR FINLAND [11]

Technology	**2020 Deployment Status**	**2030 Deployment in line with Net Zero Scenario Milestones**
Commercial and residential energy storage systems	3.7 GW	510 GW
Smart thermostats	30.4 million	231.5 million
Home energy management systems	4 million	32.7 million
Residential air conditioners	1.9 billion	2.6 billion
Heat pumps	180 million	600 million
Residential electric vehicle smart chargers	117 000	28.7 million

5. High flexibility enabling technologies

Large number of distributed energy resources (DERs) and connected devices are operational in residential and commercial sectors in many parts of the world. They have an immense potential for demand response and contribute to the net zero measures adopted. When DERs are coupled with smart meters and DSM technologies, it helps the aggregation of resources easily. It helps smaller and medium resources and loads to be remotely controlled and be a part of the demand flexibility. According to IEA, residential and commercial sectors are the main DF-enabling sectors with a capacity of 250 GW. The next potential resource for DF is electric vehicles with an estimated potential of 50 GW. Table no. 3 shows the prime enabling technologies and their projected deployment level in 2030. Electric vehicles and smart chargers are projected to reach 28.7 million in 2030, a growth of 240 times as of 2020. Similarly, commercial, and residential storage systems are reported to grow by 137 times to 510 GW. A similar acceptance level is projected for smart thermostats, home energy management systems, heat pumps, and residential air conditioners. These growth rates and rapid digitalization of enabling technologies show promising potential for demand flexibility [13] [14].

6. Discussions and summary

The global energy demand is predicted to double by 2050. In the above scenario, with the current growth rate, more than 80% of electricity requirements can be satisfied by renewable energy. Within that, variable renewables like wind and solar are expected to contribute 60%. This study tried to present the scope of demand flexibility

(DF) as a demand response mechanism. DF can be an effective grid-scale virtual energy storage facility to meet the ever-increasing demand.

The various case studies discussed in this work clearly show that the residential, commercial, and industrial sectors are the primary focus of DF in most nations. Also, the huge penetration of electric vehicles and storage batteries is considered a major DF source. In developing nations where agriculture contributes greatly to their GDP, in addition to the above sectors, the agricultural load can be a major source. However, there is only minimal research that focuses on the agriculture sector as a source of DF. The study conducted in India points to the fact that the agricultural sector offers better DF than all other sectors. The magnitude of energy that can be made available through DF is in the Gigawatt scale. Buildings, industries, transport, and hydrogen production are promising sectors that can contribute to DF. As per IEA, by 2030, the prime contributor towards DF is buildings with a capacity of 250 GW. This target can be achieved if at least 10% of the building demand is flexible. The DF potential that can be provided by electric vehicles is separately estimated.

The role of consumer as a stakeholder rather than a ratepayer is mandatory to materialize the projected target of DF. Consumers should be engaged by the utility, respective governments, and policymakers so that they join hands for grid modernization. Demand flexibility as a demand response mechanism can be implemented in three ways direct, indirect, and automated. In the direct method, the utility implements the smart grid programs with consumer's consent. In the case of the indirect method, the consumers do the load management themselves once they are educated on the technologies for their benefit. In achieving DF using automation, consumers have smart appliances in their homes and are grid-connected. The demand response is automatically taken care-off without the interference of utility or consumers based on predefined programs. Here the investment needs for smart appliances are done by consumers themselves. Incentives, subsidies, and long-term returns are the motivation behind the investments. However, until consumers are convinced of the above returns, they can be reluctant to participate in any smart grid initiatives. In all the three said methods, consumers' awareness of energy issues and cooperation is evident in successfully implementing demand response programs.

Table III. ENABLING TECHNOLOGIES AND THEIR FLEXIBILITY POTENTIAL [3]

Sector	Potential DR Flexibility MW	Percentage of Peak Demand (%)
Industry	1360	9
Households with Electrical heating	1150-1450	7.6-9.6
Households with wet and cold appliances	392	2.6
Service sector	1500	10
Winter Peak	3474 -4380	23-29
Total	4500	30

7. Conclusion

This paper has presented a detailed perspective of demand-side flexibility focusing on the residential sector, which is expected to provide the maximum share of flexibility by 2030. The introduction has tried to establish the need for developing demand-side flexibility into a grid-side energy storage technology. This work systematically presented the method of assessing the DF using smart meters, with minimum smart meters and using artificial intelligence in the residential sector. This includes the characterisation of loads and demand profiling. A detailed study on demand response programs through demand flexibility in different nations is discussed, and their findings are reported. Various DF-enabling technologies in the residential sector and their projected capacity are presented. This work has tried to emphasise the importance of consumer engagement to achieve the DF targets of 2030. For DF to be realised as per the targets of IEA, it is mandatory to take the consumers into confidence. Demand flexibility as a source of grid-scale energy storage is promising and demands in-depth research.

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Feasibility Study for Implementing Smart Street Lightning System under Smart City Concept

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Abstract

The continuous improvement of smart devices like microcontroller, energy storage devices, Artificial Intelligent with wireless communication and machine learning has given rise to the Automation Technologies like Internet of things (IoT). Now a days almost every type of device can be connected to the Internet in a form of Internet of All Things. With such development, there are many opportunities have arisen to increase the efficiency and reliability of various systems. One system of system can be emphasis for the automation technology has been the development of a smart city. With increasing numbers of people moving into cities form the villages, the government have to consider how to operate their system more efficiently and effectively. The smart city will be characterized by smart parking system, smart weather monitoring, and cyber securities for different Internet access. Public Street Lights on Highway and local roads have the potential to provide bridge in smart cities where land resources for new infrastructure development is limited. Street Lights have many empty spaces for implementing external devices like antennas, Wi-Fi routers, cctv cameras, or weather sensors, charging slot etc. This paper represents the feasibility to implement Smart Electric Street Light that is the future for the developing country like India under the smart city project.

INTRODUCTION

The world's cities are growing. Over half of the global population live in urban centres, with over 23% of people living in cities with over one million residents [4]. This proportion is only expected to climb in the future with the current trends of population growth and increased urbanisation. If nothing else, the current trends show one thing: the future of humanity is in cities [5-7]. This increase in urbanisation poses problems for the future. Local resources such as water and electrical supply are put under an increased amount of strain [8]. Atmospheric pollution increases as industrial activity expands and traffic congestion builds [9], which decreases the effectiveness of the road network [10-12]. The high density of living in cities can also result in a loss of quiet areas, which can cause sleep problems and lower living standards [15, 16]. In response to these difficulties, the current paradigm is a push for cities to adopt more sustainable urban practices and initiatives to maintain and improve the quality of living for its citizens [17, 18].

- The primary aim of this research was to investigate whether a street light mounted sensor system for smart city applications is feasible with current technologies.
- To conduct this investigation, the following objectives were created to guide the study:
- The hardware solution must fit within the confines of a streetlight housing, roughly 200 x 100 x 60 millimetres, and weigh no more than 500 grams.
- Traffic detection had to be reliable from an overhead configuration at least 5.5 metres above the road level to coincide with preferred mounting heights in Australia in residential areas [11], and detect all traffic types (vehicle, cyclist, and pedestrian).
- The combined hardware costs should be less than Rs. 10000/- or at least break even with the expected savings of its functions (i.e.: dimming, etc.) in its given deployment conditions within a

10-year period.

- The detection system had to be made of already existing and commercially available components and sensor technologies to determine if the current state-of-the-art systems would function in the given circumstances.

SMART LIGHTNING

'Smart Lighting' is a term used by lighting and networking companies to describe LED lighting which has the ability to be controlled by a Central Management System (CMS) in order to provide functional and flexible lighting. The CMS is a system that enables two-way communication of information on the lamp life of individual lanterns to be relayed back to a control centre, informing the operator whether or not any given lantern is operational. Therefore, unnecessary day burning of lamps can be prevented, and costly night time inspections of installations may be avoided. CMS systems also provide operators with intelligent and flexible lighting control, individual control to street lights, dimming, and asset management. Smart lighting allows cities to adapt their lighting strategies to suit specific conditions - for example different colour lights or lighting profiles at different times, or in different places. Having a CMS system in place increases energy savings with additional dimming and enables a greater monitoring of the entire system. In addition to the lighting efficiencies associated with smart lighting and a CMS, many smart lighting products have inbuilt connectivity that can help connect other Smart City uses and products to the Internet. For example, a smart parking system (that monitors how long cars occupy a parking bay) can connect to the Internet via a smart lighting system to send data back to council officers or to car park users. The cost associated with adding this type of smart city functionality on-top of a lighting controller and CMS functionality is generally incremental. In one study, Arup found that adding smart city connectivity on top of a smart lighting system would increase capex costs by around 8%. Therefore, for the purposes of this research, the feasibility of smart lighting includes the benefits of CMS functionality as well as smart city connectivity.

This paper represents the Smart Lighting Feasibility Study, unpacks the feasibility of smart lighting as a connectivity option for the smart city by exploring the following issues: It offers the answer of following questions.

- What is Smart Lighting?
- How can Smart Lighting be leveraged to deliver a Smart City?
- What are the technology options to enable Smart Lighting?
- What are some of the considerations that could impact the use of Smart Lighting?
- What are potential pathways for implementing Smart Lighting?
- What other options are available for delivering a Smart City?

A. Implementing Smart Street Lightning System

'Smart Lighting' is a term used by lighting and networking companies to describe LED lighting which has the ability to be controlled by a Central Management System (CMS) in order to provide functional and flexible lighting. The CMS is a system that enables two-way communication of information on the lamp life of individual lanterns to be relayed back to a control centre, informing the operator whether or not any given lantern is operational. Therefore, unnecessary day burning of lamps can be prevented, and costly night time inspections of installations may be avoided.[1]

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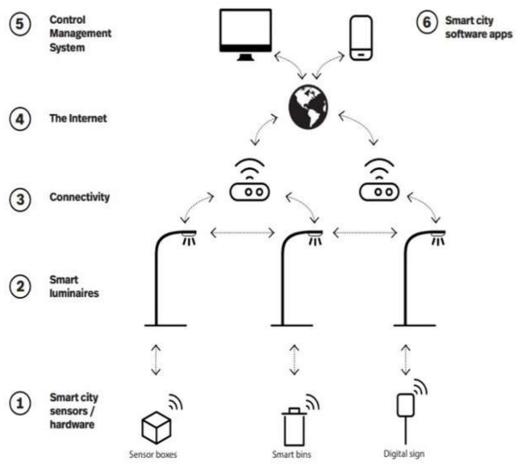

Fig 1. General configuration and components of a smart lightning system

A general, high-level architecture of a smart lighting system with smart city connectivity is provided above. The main elements are:

1. Smart city sensors/hardware (e.g., smart bins, smart parking sensors) that can be connected using smart lighting systems. Smart street lighting can be an enabler of these sensors/hardware, due to cities being conveniently scattered with light poles - providing an attachment location, connectivity, and a reliable power supply.
2. Controllers embedded in the street lamp luminaire, that can manage the individual lighting profile of that street light, and potentially provide connectivity and attachment for other sensors. This section describes the general configuration and components of a smart lighting system. The different configurations help to understand how a smart lighting system might be procured, and the considerations to take into account.
3. Connectivity to and between the street lights, including gateways where applicable.
4. Connection to the Internet.
5. A lighting Control Management System (CMS). The piece of software that allows control, customisation and monitoring of individual street lights or groups of street lights.
6. Smart city software and applications, connected to the Internet. Examples include smart bin monitoring software, or car parking mobile applications that show where the best place is to park a car.[19]

B. Smart Cities and IoT

Smart city initiatives, though debated in exact definition, are those that apply technological solutions to improve urban living and sustainability [17, 19-22]. This definition is broad, but generally these improvements seek to make better use of city resources, improve quality of living and comfort, and/or improve the social capital, cohesion, and education of citizens [17, 23-24]. For example, smart electricity grids can implement practices such as using renewable energy generation for a more sustainable network and monitoring demand to efficiently distribute power and quickly respond to any faults or changes [28, 29]. This study investigates the use of IoT concepts for smart roads. Road-centric approaches to improving city liveability and function have two distinct advantages. Firstly, roads and transport are vital to any city of any size and used by everyone within for commuting, transportation of goods, etc. Any initiatives and improvements that affect roads have the potential to positively impact a large proportion of citizens, businesses, and government organisations.

Similarly, roads are everywhere within cities; next to homes, businesses, industrial areas, tourist destinations, city centres, hospitals, utilities, etc. As roads involve all types of people and groups, they can also impact all kinds of geographic/demographic areas within cities. Secondly, the advantage of this road-centric approach is that there are many smart city applications around roads, covering multiple domains, that can be improved if additional information were readily available and in real time.[21]

Public lighting is another area that could be made more sustainable with real-time information. The problem with the current paradigm of public lighting is that lamps on roads and footpaths are typically run on an always-on basis, which wastes light and electricity when no one is active in the lighting area. This waste is alarming, as an estimated 19% of global energy generation is used to power artificial lighting [21]. But with real-time information on local traffic, lighting technologies such as LED can be dimmed down in accordance with actual activity levels on roads and paths [13- 15]. Not only would this decrease the financial burden that lighting places on the community, adaptively dimming public lighting could also mitigate the associated negative and environment affects without affecting road safety or user experience.

III. PROPOSED SMART STREET LIGHT SYSTEMS

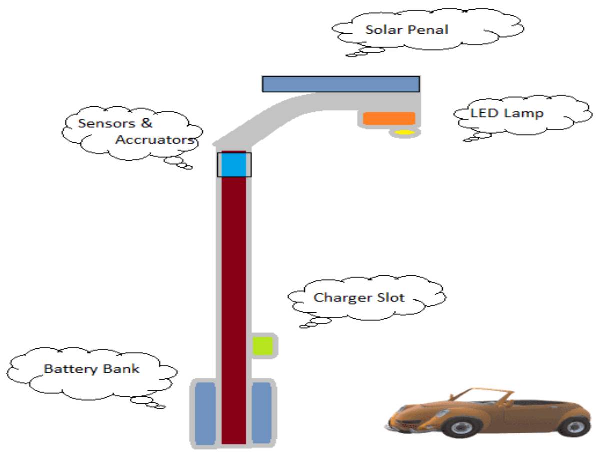

Fig 2. Proposed Smart Street Light Design

Main Parts of Smart Street Lights:

1. Solar Penal
2. Sensors & Actuators
3. Battery Bank
4. Fast Charging Slot
5. Energy Efficient LED Lamp

Solar Penal: The solar panel is one of the most important parts of a solar street light, as the solar panel can convert solar energy into electricity that the lamps can use. There are two types of solar panels commonly used in solar street lights: monocrystalline and polycrystalline.

Solar Energy is abundantly available in India and it has been estimated that solar panels installed on less than 1% of the country's landmass should be enough to meet the entire energy needs. Solar penal based smart light charges up during the day absorbing energy with the help solar cells. This energy is then stored in rechargeable batteries. At night time, this stored energy is converted back into light. This

is a green, sustainable way of lighting since it not only reduces the electricity bills but is clean and non-polluting as well. It avoids using electricity generated from fossil fuel-based power plants.
Sensors and Actuators: A smart street light controller consists of:

- Light source – the outstanding benefits of LEDs (extended lifetime and reduced power consumption) have favoured LED lamps in street lighting investments in the last few years, to the point where the older HID lamps are now rarely seen in street lighting upgrade projects worldwide.
- Lamp socket (optional, available mostly for HID lamps) – supports electrical connections and allows the lamp to be safely and conveniently replaced
- Ballast or driver – reduces the voltage and regulates the electric current to produce a steady light output. To support full-featured smart controllers, you will need an electronic ballast with dimming support (which is the case for most drivers nowadays anyway)
- Smart streetlight controller – enables individual lamp control, on/off/dimming functions, autonomous operation, smart scheduling, remote control, parameter measurements, malfunction notifications etc.

Fast charging Slot: An additional feature of the smart street lights is the charging module for vehicles equipped with an electric engine. The demand for electric vehicles, however, faces one major obstacle. To the date, there is a lack of a large-scale charging station network. Between 2011 and 2015, the ratio of two cars per charging station has risen to seven vehicles. The VDA assumes that in the future there will be a ratio of ten electric cars per charging station. The charging process is easy: once the battery power of an electric vehicle comes to an end, the driver can recharge it with an output of up to 22 kW. For this purpose, he must identify himself by scanning a printed QR code on the charging station. Then, the protective cover of the socket opens and the driver can insert a charging cable in order to recharge the battery of his vehicle.

Street lighting standardised plug-and-play connectors. As smart control is an important issue for all stakeholders in the outdoor lighting industry, there have been significant investments and initiatives in standardizing lamp connectors. The main reason is to facilitate smooth lamp upgrade and fast lighting controller installation. For instance, standardised connectors like NEMA or Zhaga come with plug & play mounting options that turn controller installation in a few-seconds job, keeping deployment costs at a minimum.

Energy Efficient LED Lamp with embedded controllers: A NEMA or Zhaga controller mounted on the lamp is simply not an option, but you still need the benefits of a smart, fully integrated lighting system. Embedded controllers are built to be particularly small, in order to fit inside the luminaire itself. This way, you favour aesthetics and also keep the advantage of creating a smart and integrated street lighting grid. If you are a smart lighting integrator or lighting service provider, you probably have the engineering capabilities to try to integrate the two devices yourself, but embedded controllers are mostly mounted inside the lamp directly from the production line.[7]

Communication is an essential element in any smart public lighting installation, acting as a binder among devices and software. The right communication technology can make the difference between a fully functional deployment and a syncopated one. Even though the lamp itself does not have an influence on the communication technology, the controller and the control solution provider have to be compatible with the communication technology you decide to use for your smart street lighting project. When it comes to communication, you should also consider whether a public or private network best suits your project's needs. [9]

Public networks (e.g., NB-IoT, LTE-M, GSM) are installed and maintained by telecom operators who make sure that the network is always secured and functional (carrier grade security and functionality).

Even though the user usually needs to pay for a monthly or yearly subscription, public networks rarely require installation fees.

Private networks (e.g., LoRaWAN, Wi-SUN etc.) are operated directly by the municipality or the street lighting provider (nobody has access to street lighting data). While installation costs are higher and users have to ensure the network maintenance and security themselves, private networks eliminate the cost of having to pay for a subscription and can be used for other smart city applications.

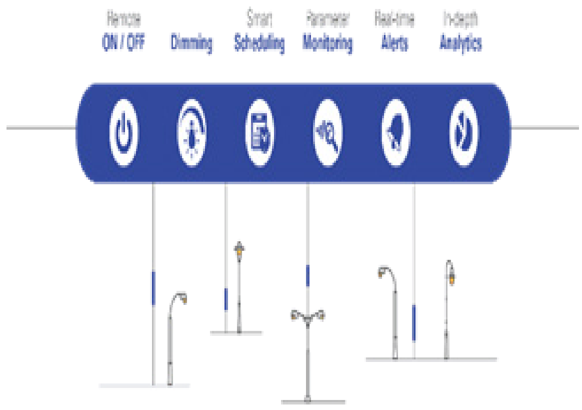

Fig 3. Proposed Smart Street Light Design

The most important benefit of individually controlled smart lamps is the access to information. With real-time data analysis, grid awareness empowers you to make informed, effective decisions.

IV. MAIN APPLICATION OF PROPOSED MODEL

The main application of proposed model fulfils following functions:

A. Vehicle Movement based Innovative Smart Highway Lighting System

Using a regression model with an adjusted R2 of 0.90, it is estimated that by 2050, an extra 3.0 - 4.7 million km of road will be paved. The goal of this application is to design and implement advanced development in embedded systems for energy conservation in street lights. This work aims at creating a dynamically programmed automatic street lighting system with the main focus on scalability. Our goal is to create a synchronized array of nodes that may accept new nodes without requiring any changes to the existing nodes. This allows the ability to increase the size of the automation-network swiftly.

B. Auto-Intensity Regulation of Streetlights using Arduino

Untimely switching on and off, and incessant glowing throughout the day without intensity regulation contribute to tremendous energy wastage. Also, manual control is tiring and outdated in this day and age of automation. The ultimate goal is to save energy, long term costs, and manpower along with attaining management of time and a systematic cycle of operation. This application, a befitting model that makes use of Arduino board is proposed which addresses these concerns. Light dependent resistor (LDR) and infrared (IR) sensors are some of the major components used in smart street lighting. IR sensor detects movement and LDR powers the street lights only after evening. Another vital component is the Real time clock (RTC) which gives the real time to circuit.

C. Smart LED Streetlight System with Web-Based Management System

Integration of sensors and ZigBee-based wireless sensor modules can furnish an optimal platform for an innovative LED streetlight application. Psychological studies suggest that a different level of color temperature can significantly affect human circadian rhythm. For this reason, correlated color temperature (CCT)-based illumination gives a significant lighting performance both in terms of energy efficiency and in overcoming traffic accidents in low visibility areas. Previous works usually assume only specific platform and did not consider CCT-based illumination toward smart LED streetlight system. In this application, consider the importance of CCT-based illumination and propose a novel integration of public weather data awareness, ZigBee-based wireless communication, and dynamic web-based management system for the state-of-art of smart LED streetlight system applicable to smart city. In particular, a central web server that can receive weather information and real-time sensor data from each LED streetlights and provides a dynamic and flexible web interface for authorized users. Furthermore, real-time implementation of the proposed system shows perfect transmission-reception parameters, such as throughput and signal strength among the different LED streetlights, which fulfils the wireless communication range and signal quality between each LED streetlights.

D. Energy Efficient Smart Street Lighting.

A Smart Street Lighting System uses IoT sensors and can interact with software to improve its effectiveness and utility. Since streetlights must be turned on for the entire duration of the night, it is essential to find ways of reducing energy consumption to actualize a greener society. It can be done by integrating sensors that can detect movements and control the way streetlights behave through the gathered data. This application aims to reduce the energy consumption needed for the operation of streetlights by applying appropriate IoT based techniques. An extensive discussion on the existing literature and similar systems reviews the current developments critically. The research gathered public insights through a quantitative research approach and applied this information in recommending a solution. With the help of a prototyping model, the authors demonstrated how a Smart Street Lighting System could achieve optimal performance.

E. SMART STREET LIGHT FOR ENERGY SAVING BASED ON VEHICULAR TRAFFIC VOLUME

Streetlights are one of the significant sources of electricity consumption, and an enormous amount of energy could be saved by converting conventional streetlights into smart streetlights. This application has discussed a novel idea of developing smart streetlights by utilizing the preinstalled surveillance cameras. Cameras are installed at entry exit points of each street, to vary light intensity based on pedestrian and vehicular traffic volume using CNN-based Artificial Neural Network Algorithm YOLOv5. The system is further integrated with a control module which could vary the light intensity between 50 to 100 percent on receiving a signal from the processing unit (Jetson Nano). The system can save around 25 percent of the total cost consumed by the conventional LED streetlight.

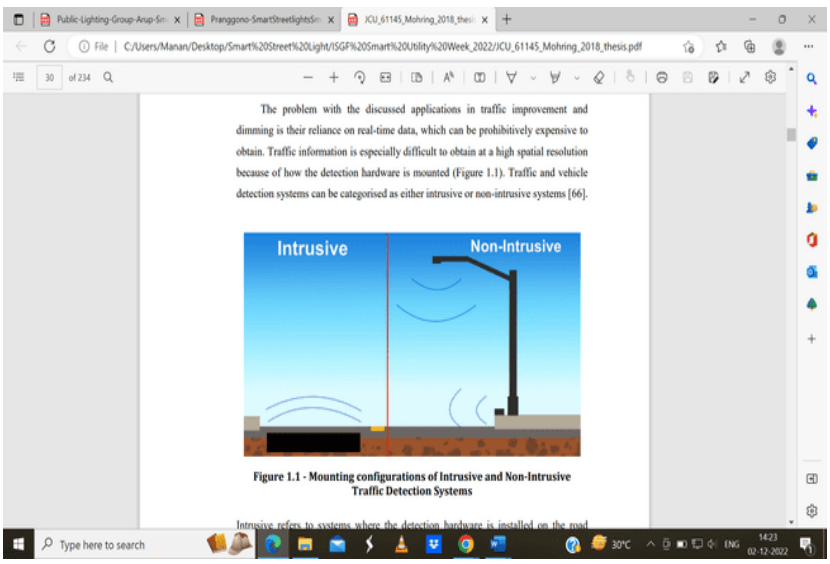

Fig 3. Energy Saving system based on Vehicular Traffic Volume

CONCLUSION

This study showed that participants were mostly accepting of the technologies and applications that a smart streetlight network could afford. For traffic optimisation, the communities most likely to show support for traffic improvement were those that relied on vehicles as their primary form of transport, as opposed to public or pedestrian transport. This finding indicates that rural areas, which tend to have fewer public transport options and are less likely to have implemented traffic optimisation solutions of their own, are prime candidates for trialling the smart streetlight network. Due to the low number of responses from metropolitan areas, future research should concentrate on major cities to determine if support can be determined by the same factors. The literature suggests that there is a possible link between support and feelings of vulnerability within the home, and level of physical activity, which both warrant further investigation in future studies. The proposed model of Smart Street Lightening represents the feasibility to implement cost effective Smart Electric Street Light that is the future for the developing country like India under the smart city project. By adopting such concepts all proposed applications including development of small capacity Electric Vehicle Charging infrastructure, Traffic Management, dimming projects, use of Renewable Energy sources etc. can be fulfilled and manage the effective representation of Smart City concept. Further studies should also aim to establish how smart street light is viewed by the community, either in a positive or negative context.

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Critical Infrastructure Asset Discovery and Monitoring for Cyber Security

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Abstract

Asset inventory is the first step in identifying and securing the Cyber ecosystem. The philosophy says “We can safeguard a thing only if we know that it exists and then if we know its security challenges and loopholes”. Thus, if we can secure the assets, we can secure the Cyber ecosystem as well, which is made out of such embedded assets.

Keywords

ICS: industrial control system; OT: Operational technology; SCADA: supervisory control and data acquisition

1. Introduction

Industrial control systems (ICS) compose a core part of our nation’s critical infrastructure. Energy sector companies rely on ICS to generate, transmit, and distribute power. Given the wide variety of ICS assets, such as programmable logic controllers and intelligent electronic devices, that provide command and control information on operational technology (OT) networks, it is essential to protect these devices to maintain continuity of operations. These assets must be monitored and managed to reduce the risk of a cyber-attack on ICS-networked environments. Having an accurate OT asset inventory is a critical component of an overall cybersecurity strategy.

Energy companies own, operate, and maintain critical OT assets that possess unique requirements for availability and reliability. These assets must be monitored and managed to reduce the risk of cyber-attacks on ICS-networked environments. Key factors in strengthening OT asset management capabilities are determining which tools can collect asset information and what type of communications infrastructure is required to transmit this information

The capabilities in this guide address several key tenets of asset management:

- Establish a baseline of known assets
- Establish a dynamic asset management platform that can alert operators to changes in the baseline
- Capture as many attributes about the assets as possible via the automated capabilities implemented.

In addition to these key tenets, offers methods of asset management that address particular challenges in an OT environment, including the need to

- account for geographically dispersed and remote assets
- have a consolidated view of the sum of OT assets
- Be able to readily identify an asset’s disposition, or level of criticality, in the overall operational environment.

Provide energy-sector entities with the means to establish a comprehensive OT asset management baseline that can be monitored over the life of the asset. Implementation of these capabilities provides an automated inventory that can be viewed in near real-time and can alert designated personnel to changes to the inventory.

This will prove useful from both a cybersecurity and operational perspective, as it can otherwise be difficult to quickly identify any anomalies due to a cyber-attack or operational issues

2. Ease of Use

- The solution implemented is quite easy to use. The software identifies all connected assets automatically and places them into similar groups having similar kinds of assets for e.g., all network devices are grouped in Network devices, servers in server groups, end point devices into Endpoint Devices, etc. The administrator can also move assets across groups to better place them as well as move them into new groups based on functionality of the assets like Development servers, Quality servers, Production servers, L# Switches, L2 Switches, Cisco devices, and so on, this gives the administrator easy understanding of the assets and also to plan activities on the assets based on the criticality and priority of the assets.

3. Abbreviations and Acronyms

ICS: industrial control system

OT: Operational technology

SCADA: supervisory control and data acquisition.

4. Challenges faced

Many energy-sector companies face challenges in managing their assets, particularly when those assets are remote and geographically dispersed. Organizations may not have the tools to provide a current account of their assets or may not be leveraging the existing capabilities required to produce an adequate inventory. Existing asset inventories may be static, one-time, or point-in-time snapshots of auditing activities conducted previously without a way to see the current status of those assets. Adding to the challenge, asset inventories may be kept in documents or spreadsheets that may be difficult to manually maintain and update, especially considering that inventories can change frequently. Without an effective asset management solution, organizations that are unaware of any assets in their infrastructure may be unnecessarily exposed to cybersecurity risks. It is difficult to protect what cannot be seen or is not known.

USE CASE: DEVICE DISCOVERY

- Device discovery is the process of discovering and collecting data on the assets (devices, users, software, and instances) connected to a network for management, tracking, and security purposes.
- But with so many connected devices both on a network and remote, gaining a credible and comprehensive asset inventory can quickly become a daunting task.
- Unmanaged devices are IP-connected devices that may or may not be known and accounted for in an asset inventory. They aren’t being actively managed from an IT and security perspective and are only known to the network or network scanners.
- Security tools can only protect the assets they know about.
- When it comes to finding the “unknown unknowns,” asking Active Directory (AD) to show any unmanaged device doesn’t work. Manually comparing AD data, network management, and endpoint security software is tedious and error-prone. If a device is unmanaged, it’s impossible to know if it’s secure. Data from the network infrastructure or network scanners, often limited to just an IP address, doesn’t yield adequate details.

USE CASE: ENDPOINT PROTECTION

The organization has likely implemented several endpoint protection tools. But endpoint detection and response consoles can't answer questions like:

- Which devices aren't protected but should be?
- Where are devices that have the agent installed, but the agent isn't sending back data to the console?

While organizations mandate that specified devices must be covered by a certain endpoint agent.

USE CASE: VULNERABILITY MANAGEMENT

- Vulnerability assessment tools do an incredible job of identifying known vulnerabilities present on devices they're aware of. But how can you ensure that all devices, including VMs and cloud instances, are being scanned?
- The problem lies in knowing which devices should be scanned but are not part of the VA scan schedule. Put simply, devices not being scanned for vulnerabilities are at risk of being exploited.
- Every system even the most advanced and well protected is inherently vulnerable. And most organizations have more vulnerabilities than they could possibly remediate.
- The mismatch between vulnerabilities and resource capacity means that organizations have to prioritize which vulnerabilities to address. And prioritization is a conscious decision about what you're willing to ignore.

USE CASE: INCIDENT RESPONSE MANAGEMENT

- Finding devices that may be associated with an incident can be a daunting task. While security analysts often receive alerts that tell them what happened and how, analysts are forced to spend a lot of time tracking down assets to resolve security incidents.
- Security analysts need rich, correlated data on devices, users, and cloud instances to accelerate incident response investigations. An alert is often a harbinger of an incident or breach. The sooner it can be investigated and remediated, the lesser its impact.

USE CASE: COMPLIANCE AUDIT

- One of the most common challenges for organizations when dealing with asset & vulnerability management for compliance and audits is accurately tracking and accounting for all in-scope assets in their environment.
- Another challenge? Unifying and analysing data from disparate sources across the organization.
- A lack of visibility into all assets and how they're configured means it's harder to track and secure these assets, opening organizations to risks and consequences of non-compliance.
- Organizations also waste numerous, expensive person-hours of expert resources in preparation and remediation of compliance audits. When the device inventory isn't up-to-date, it affects compliance audit preparation — and audits tend to have negative results.

5. Solution adopted

Energy organizations can use commercially available OT security tools that are consistent with cybersecurity standards, to address the challenge of establishing, enhancing, and automating their OT asset management.
OT asset management solution that consists of the following characteristics:

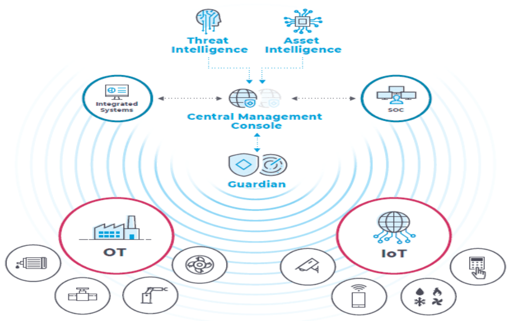
- The ability to discover assets connected to a network
- The ability to identify and capture as many asset attributes as possible to baseline assets, such as

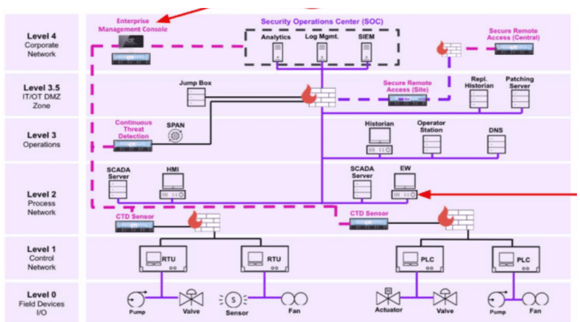
manufacturer, model, operating system (OS), internet protocol (IP) addresses, media access control (MAC) addresses, protocols, patch-level information, and firmware versions, along with physical and logical locations of the assets

- Continuous identification, monitoring, and alerting of newly connected devices, disconnected devices, and their connections to other devices (IP based and serial)
- The ability to determine the disposition of an asset, including the level of criticality (high, medium, or low) and its relation and communication to other assets within the OT network
- The ability to alert on deviations from the expected operation of assets
- Maps security characteristics to standards, regulations, and best practices from NIST and other standards organizations
- Provides a detailed architecture and capabilities that address asset management
- Describes best practices and lessons learned
- Provides instructions for implementers and security engineers to re-create the reference design
- Is modular and uses products that are readily available and interoperable with existing energy infrastructure

Site Topology

- One of the most common challenges for organizations when dealing with asset & vulnerability management for compliance and audits is accurately tracking and accounting for all in-scope assets in their environment.
- Another challenge? Unifying and analysing data from disparate sources across the organization.
- The following figure shows the Site Topology for the installed solution

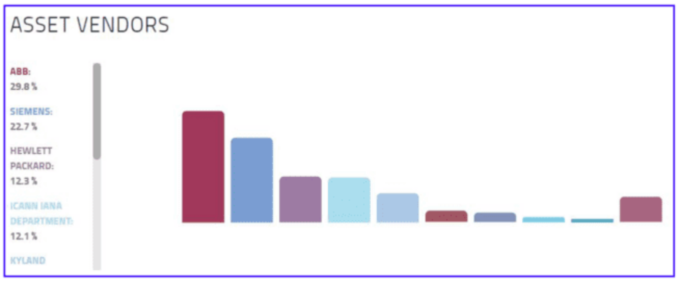




Asset Management Dashboard

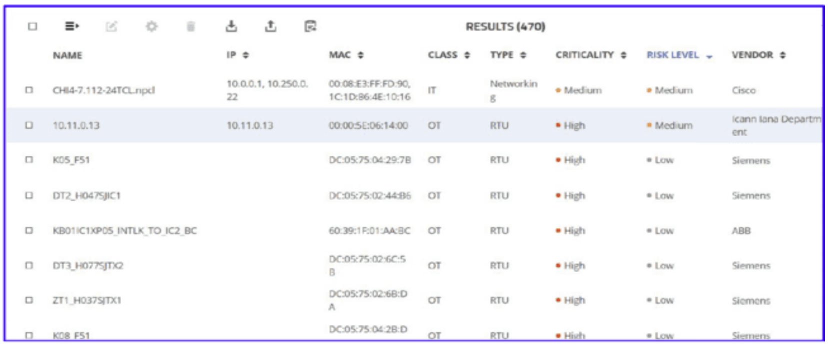
The below screens provide the list of various vendors which were discovered through the traffic captures from the switch. The assets were discovered and classified as IT Endpoint, PLC, HMI, RTU etc. based on traffic patterns observed during the assessment.

Figure 1 Asset vendors wise details



The below screenshots shows a glimpse of the Assets discovered.

Figure 2 Asset list details



RESULTS (470)

	NAME	IP	MAC	CLASS	TYPE	CRITICALITY	RISK LEVEL	VENDOR
☐	CHI4-7.112-24TCL.npcl	10.0.0.1, 10.250.0.22	00:08:E3:FF:FD:90, 1C:1D:86:4E:10:16	IT	Networking	Medium	Medium	Cisco
☐	10.11.0.13	10.11.0.13	00:00:5E:06:14:00	OT	RTU	High	Medium	Icann Iana Department
☐	K05_F51		DC:05:75:04:29:7B	OT	RTU	High	Low	Siemens
☐	DT2_H047SJIC1		DC:05:75:02:44:B6	OT	RTU	High	Low	Siemens
☐	KB01IC1XP05_INTLK_TO_IC2_BC		60:39:1F:01:AA:BC	OT	RTU	High	Low	ABB
☐	DT3_H077SJTX2		DC:05:75:02:6C:5B	OT	RTU	High	Low	Siemens
☐	ZT1_H037SJTX1		DC:05:75:02:6B:DA	OT	RTU	High	Low	Siemens
☐	K08_F51		DC:05:75:04:2B:D	OT	RTU	High	Low	Siemens

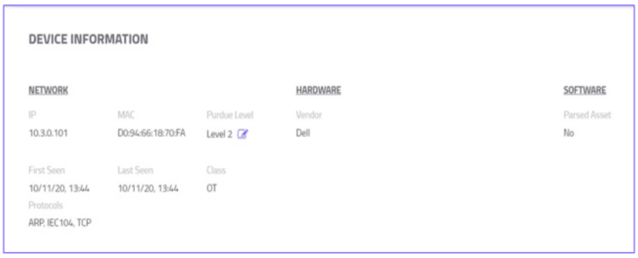
Device Discovery using Discovery Module

The Device Discovery Module is used to get "Enhanced OT Visibility" with the outcome of the Layered Network Map along with how the Assets are communicating with each Other. A snapshot of the same is shown in the screen below. We can see devices which have been placed in the various Levels as per the OT Layered Architecture and the connecting lines shows the direction of communication between the various assets.

Figure 3 Asset wise connectioin flow

Each discovered Asset is discovered to the granularity that the device information as IP, MAC, Vendor, type, protocols are visible. A snapshot of the same is shown below:

Figure 4 Asset details



The below screen shows the list of top different applications which are running on the OT machines and the amount of traffic these machines are generating

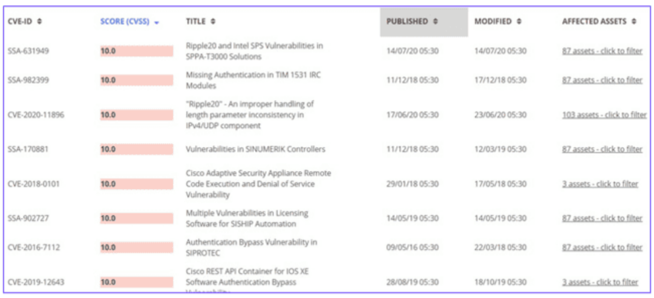
Figure 5 Asset wise Application Details

Application Name	Category	Risk	Traffic	Logs
IEC 60870-5-104 - Measured Value-Short Floating Point Value	SCADA Protocols	2 Low	41.5MB	6
LLMNR Protocol	Network Protocols	2 Low	8.4MB	45
NTP Protocol	Network Protocols	2 Low	2.2MB	30
SNMP Protocol	Network Protocols	2 Low	1.7MB	5
NetBIOS Name Service	Network Protocols	1 Very Low	1.5MB	45
Multicast DNS Protocol (mDNS)	Network Protocols	1 Very Low	432.0KB	38
NetBIOS Datagram Service	Network Protocols	1 Very Low	213.9KB	56
IEC 60870-5-104 - Control Functions - TESTFR ACT	SCADA Protocols	2 Low	30.6KB	1
TFTP Protocol	Network Protocols	3 Medium	20.0KB	1

Protocols containing security weaknesses that attackers can leverage to compromise the network's security

Figure 6 Asset wise Vulnerability Details

PROTOCOL	REASON PROTOCOL IS UNSECURED	ASSETS USING THIS PROTOCOL	ACTIONS
SNMP	SNMP versions 1/2 are considered unsecured because they contain plain-text community string that can lead for information disclosure or change of settings on devices.	6 assets - click to filter	✔ Mark All as Completed
SSL	SSL/TLS of early version have been deprecated and considered unsecure due to weak cipher keys that can be recoverable and therefore can lead to deciphering of the encrypted channels.	2 assets - click to filter	✔ Mark All as Completed
TFTP	This protocol has no authentication and transfers data in a plain-text manner.	1 asset - click to filter	✔ Mark All as Completed



CVE-ID	SCORE (CVSS)	TITLE	PUBLISHED	MODIFIED	AFFECTED ASSETS
SSA-631949	10.0	Ripple20 and Intel SPS Vulnerabilities in SPPA-T3000 Solutions	14/07/20 05:30	14/07/20 05:30	87 assets - click to filter
SSA-982399	10.0	Missing Authentication in TIM 1531 IRC Modules	11/12/18 05:30	17/12/18 05:30	87 assets - click to filter
CVE-2020-11896	10.0	"Ripple20" - An improper handling of length parameter inconsistency in IPv4/UDP component	17/06/20 05:30	23/06/20 05:30	103 assets - click to filter
SSA-170881	10.0	Vulnerabilities in SINUMERIK Controllers	11/12/18 05:30	12/03/19 05:30	87 assets - click to filter
CVE-2018-0101	10.0	Cisco Adaptive Security Appliance Remote Code Execution and Denial of Service Vulnerability	29/01/18 05:30	17/05/18 05:30	3 assets - click to filter
SSA-902727	10.0	Multiple Vulnerabilities in Licensing Software for SISHIP Automation	14/05/19 05:30	14/05/19 05:30	87 assets - click to filter
CVE-2016-7112	10.0	Authentication Bypass Vulnerability in SIPROTEC	09/05/16 05:30	22/03/18 05:30	87 assets - click to filter
CVE-2019-12643	10.0	Cisco REST API Container for IOS XE Software Authentication Bypass	28/08/19 05:30	18/10/19 05:30	3 assets - click to filter

Benefits

The asset management challenges for cybersecurity has been solved by using the following measures:

- Reduce cybersecurity risk and potentially reduce the impact of safety and operational risks such as power disruption

- Develop and execute a strategy that provides continuous OT asset management and monitoring
- Respond faster to security alerts through automated cybersecurity event capabilities
- Implement current cybersecurity standards and best practices, while maintaining the performance of energy infrastructures
- Strengthen awareness of remote and geographically dispersed OT assets
- Additional data for organizations to address business needs such as budget planning and technology updates
- Improved situational awareness and strengthened cybersecurity posture.

Acknowledgment

I would like to express deep sense of gratitude to Head of the Department (IT), Mr. Arijit Mitra, Vice President (IT), all members of the IT Application Development Team, members of BE & CR team and other IT team personnel for their unending support for this research paper.

Securing Advanced Metering Infrastructure using PKI

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Abstract

Critical infrastructure is the backbone of any nation. It plays a key role in the proper functioningof society. Security of critical infrastructure is necessarynot only to keep our society functioning but also as a national security concern. The threats and incidents in these sectors have been growing at a rapid rate. The attackers are trying to take either control of the system or shut down the system. To enhance the security of the critical infrastructure from cyber-attacks the security practices have to be improved and it has to be considered as thecrux from the development of the critical infrastructure systems to the operation. This paper addresses the security gaps in one of the key areas of the power sector and provides the practices to be followed to enhance security to the desired level. Advanced Grid metering infrastructure (AGMI) is one of the key areas in the power sector for efficient management of the power grid. In this paper, we propose a novel methodology for the implementationof public key infrastructure (PKI) in the field of AMI to improve security.

Index Terms

DLMS-COSEM; sub-station interface energy meters; power system; security; PKI, Advanced Grid Metering Infrastructure

INTRODUCTION

A. General

Advanced Grid metering infrastructure (AGMI) is oneof the vital building blocks of a smart grid. In grid metering, the energy flow is computed by special energymeters/availability-based tariff (ABT) meters, which are lodged at copious interface points of sub-stations. The grid metering module aids in interpreting energy flows from the smart meter at the interface point. Meter datais one of the precarious data sources which is able to be used for various grid management functions like load forecasting [1], renewable energy forecasting, outage prevention and management, online energy accounting and transmission loss calculations, and economic dis-

patch and energy scheduling and schedule deviation settlement, robust, dispute-free billing, accounting, and settlement of energy transactions [2], etc. So, the deployment of the smart grid requires the use of safe and trustworthy tamper-resistant meters data exchange. Automation of the power system is vital for the dependable and secure functioning of the power system. AGMI, a component of automation, was being used in the power system. Energy meters with smart interfaces, data concentrator units (DCU) for collecting and sendingmeter data, redundant communication networks for high meter data availability, a central data acquisition system (CDCS), and grid management software make up the AGMI, as depicted in Fig. 1.

DCU is a communication device, which collects data from sub-station interface energy meters and sends it to the control center, similarly it will accept control commands from the control center and pass those commandsto sub-station energy meters. DCU transfers collected data to the control center in dual communication modes for high data availability. DCUs are the DLMS based clients for the data aggregation, control of meter parameters. DCU provides data to the control center after regularly requesting it from the meter. Additionally, it is in charge of delivering requests from the control center for any modification of meter characteristics, including changes to the billing cycle, time zone, load profile, etc.

B. ***Motivation of the present work***

In recent years, when we are shifting the infrastructurefrom manual to automatic, there have been instances of the data being lost during the process and hacked at different times. Thus, there is a necessity for applyinga protection scheme for the AGMI. Especially, when it comes to the smart grid, when the load flow design of the

system requires truthful data from the metering system, cyber security of AGMI is necessary for data protection and authentication. One of the most efficient ways to carry out the same is using public key infrastructure(PKI). PKI works on the issuing of digital certificatesto protect the data.

The metering system's security aspects were covered in [10]. It is necessary to offer the matching keys neededfor the first encryption. Using the security mechanismID provided in further sections, it may be observed that the security level would increase from level 3to level 7 as shown in Table I. The highest level ismore beneficial for regular updation of the encryptionand enhancing the security. To improve the security and its automatic upgradation, PKI adopts a systematic approach for implementation in AGMI.

C. ***Contribution of this work***

The paper's contribution proposes developing amethodology for the implementation of the PKI in the field of AMI. In brief, the major works done here maybe summarized as:

(a) Implementation of PKI in smart metering infrastructure
(b) Usage of Device language message specification (DLMS)/ companion standard of energy metering (COSEM) protocols for generation, removal, and transfer of certificates to and from the server/meter

D. ***Paper orientation***

After a brief introduction in this section, SectionII explains the metering standards, including the authentication mechanisms and security suites, followedby the introduction of PKI in Section III. Section IV describes the need of DLMS/COSEM for PKI and the methodology adopted for implementation. Finally, the paper is concluded in Section V.

II. METERING STANDARD-DLMS

DLMS/COSEM is a globally accepted standard for energy metering [3][4]. COSEM specifies meter functional- ities in the form of interface classes and methods. DLMS specifies the messages and transportation details of thedata. In the DLMS-COSEM communications applicationassociation (AA), the establishment is the first phaseof communication. After the successful establishmentof AA, meter data exchange takes place. Applicationrelease is the last phase of the communication which happens after the completion of the meter data exchange.The authentication process occurs during the AAphase. As shown in Table I, in DLMS there are 3 typesof authentication mechanisms *i.e.,* no security authentic-cation, low-security authentication, and HLS mutual authentication mechanisms. In

HLS, there are six differenttypes of authentication mechanisms. Mechanism ID-7 is the strongest and more secure authentication mechanism[5]. HLS based mutual authentication mechanisms procedure is followed similarly to that in ref. [5].

The security elements that are offered by the DLMS- COSEM are thoroughly explained in this document, along with their whole structure. It provides the various authentication procedures of the client and the server, data encryption algorithms available and how they wouldbe selected based on the security suite, the key exchangemechanisms and the key management procedures and thebest choice of algorithms to provide a highly secure dataexchange between a client and a server.

For secure DLMS communications, it is strongly re- commended to use security suite-2 in AGMI infrastructure[6]. DLMS security suite details are shown in Table II.

Table I: Authentication Mechanisms of DLMS-COSEM

S. No.	Name of the Authentication Mechanism	Mechanism ID
1	No Security	0
2	Low Level Security	1
3	High Level Security (HLS)	2
4	HLS using MD5	3
5	HLS using SHA-1	4
6	HLS using GMAC	5
7	HLS using SHA-256	6
8	HLS using ECDSA	7

III. PUBLIC KEY INFRASTRUCTURE (PKI)

A PKI is necessary to create, manage, distribute, use, store, and revoke digital certificates and to manage public-key encryption. PKI makes it easier to store and distribute electronic data securely. The security services offered include [7]:

1. Confidentiality- Make sure the message is encrypted, not tampered and the owner of private keycan decrypt the message
2. Integrity-It is the proof that the message has not been altered with the use of a digital signature
3. Authenticity- Confirming identification or authenticity with the use of a digital signature
4. Non-repudiation- Including a feature that the message cannot subsequently retract

A PKI is often necessary for systems that employdigital certificates. Traditional PKIs need certain entitiesto fulfill specific tasks. Certification Authority (CA) is most important. CA works as organization in chargeof managing, renewing, issuing, and emitting digital certificates. The CA uses its private key to signthe digital certificates, certifying that they belong to the specified companies. The top-most CA in the hierarchy for certification is the Root Authority (Root-CA). The Root-CA oversees auditing and confirming the other CAs. Additionally, it manages, renews, issues, andemits digital certificates for the CAs.

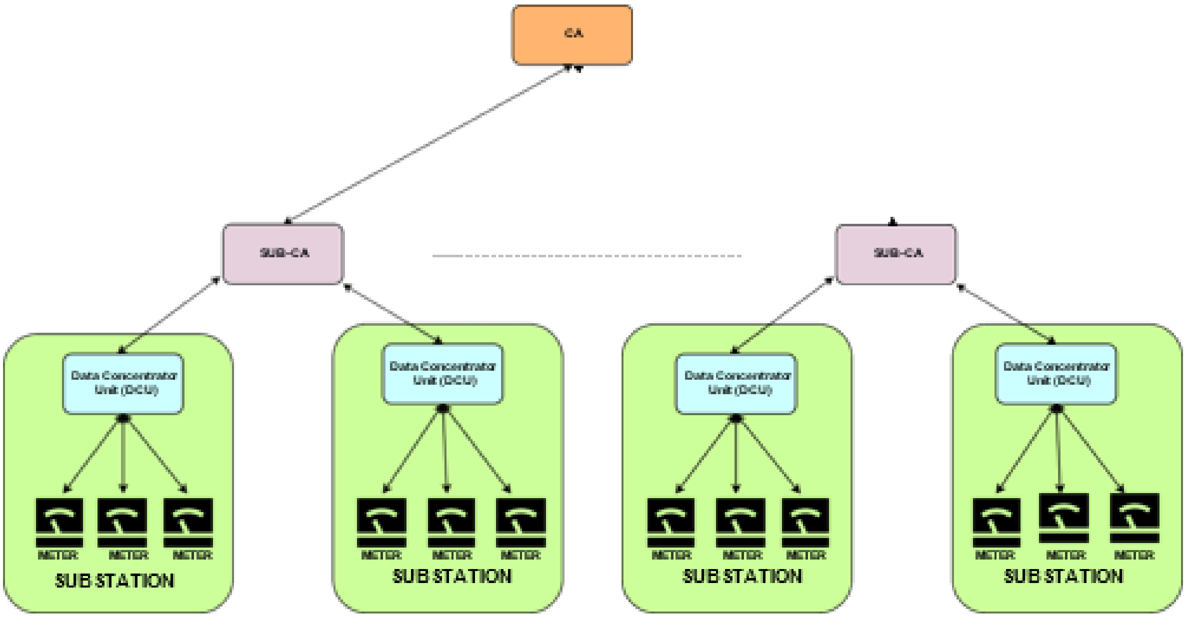

Figure 2: PKI for grid metering.

Registration Authority (RA) serves as the conduit between the CA and the owner of certificate. It is the last (*i.e.,* the entity that acquires the digital certificate). Requests are received, verified, and forwarded to the CA by the RA. The repository stores and distributes certificates and the revocation lists. They are periodically updated and contain information about the expired certificates as well. The digital certificates are issued to end entities by organization known as Sub-CA. Each Sub- CA is permitted to do so by the Root-CA. The Root- CA Certificate Policy must be followed by each Sub-CA when handling a certificate policy. Additionally, sub-CAs keep track of a CRL and the list of certificates issued to end organizations. Owner of certificate 'C' is a Sub-CA. Root-CA issues these certificates. The private key of the Sub-CA is used for signing end entity certificates.

One of the primaries uses for public-key cryptography is the digital signature [8]. It guarantees the objectivity, veracity, and non-repudiation of a piece of information. A pair of asymmetric cryptographic keys are requiredfor its implementation technique. The sender generatesa cryptographic hash (digest) of the data and uses her private key to encrypt it. Additionally, any entity may confirm the digital signature by decrypting the digest using the sender's public key and comparing the results to the original bit of data. This procedure verifies the accuracy and reliability of the data. In turn, utilizing digital certificates provides non-repudiation proof. A digitalcertificate is a Trust Third Part (TTP)'s declaration that the recipient is the public key owner.

Every DLMS/COSEM server must use X.509 v3format and contain either:

1. P-256/384 ECDSA-capable key for sign
2. P-256/384 ECDH-capable key for agreement Every certificate must be signed using ECDSA. Depending on the security policy, DLMS/COSEM end entitieshandle the certificates using Table III.

The security suites of DLMS provide the availability of the different securityalgorithms to implement for the data protection and authenticity. There is also a provision for key agreementand key exchange.

Digital signatures can effectively defend against fraud and security breaches of smart meters. This hypothesisis based on the idea that a smart meter has the capacityto store and protect a pair of asymmetric cryptographic keys. A meter has the ability to sign its measurements, raw data, or any other information by utilizing this capability and, by doing so, offer proof of its validity andintegrity. Additionally, more complex security methods like access control based on cryptographic tokens and theassurance of software updates can be made possible via cryptographic directives. No one can contest any signed information if the meter has a digital certificate linkedto its public key (*i.e.,* we also obtain non-repudiation).

Table II: Security Suites for the DLMS/COSEM Standards

Security Suite ID	Security Suite Name	Authenticated en-cryption	Digital Signa-ture	Key agree-ment	Hash	Key transport	Compression
0	AES-GCM-128	AES-GCM-128	-	-	-	AES-128 key wrap	-
1	ECDH-ECDSA-AES-GCM-128-SHA-256	AES-GCM-128	ECDSA with P-256	ECDH with P-256	ECDH with P-256	AES-128 key wrap	V.44
2	ECDH-ECDSA-AES-GCM-256-SHA-384	AES-GCM-256	ECDSA with P-384	SHA-384	ECDH with P-384	AES-256 key wrap	V.44

Table III: DLMS Security Suites

Security Suite 1	Security Suite 2	Role
Root-CA Self-Signed Certificate (SSC) using P-256 signed with P-256	Root-CA SSC using P-384 signed with P-384	Trust anchor; there may be more thanone.
Sub-CA Certificate (SCC) using P-256signed with P-256	SCC using P-384 signed with P-384	Certificate of an issuing CA. Subordinate CAs may also be used astrust anchors
-	SCC using P-256 signed with P-384	
End-entity signature Certificate (ESC)using P-256 signedwith P-256	ESC using P-384 signed with P-384	Public Key for ECDSA signature generation and verification
-	ESC using P-256 signed with P-384	
End-entity Key Es-tablishment Certifi-cate (EKC) using P-256 signed with P-256	EKC using P-384 signed with P-384	Used with the One-Pass Diffie Hellman C (1e, 1s) scheme or with the Static Unified Model C (0e, 2s, ECC, CDH) Scheme
-	EKC using P-256 signed with P-384	
End-entity TLS Es-tablishment Certifi-cate (ETC) using P-256 signed with P-256	ETC using P-384 signed with P-384	
-	ETC using P-256 signed with P-384	

Thus, these features can potentially increase the depend-ability of smart meters significantly.

IV. PKI IMPLEMENTATION USING DLMS/COSEM

The implementation of scheduling, accounting, meter-ing and settlement of transaction (SAMAST) regulationsin the smart grid has led to the provision of implementingsmart meters with DLMS-COSEM protocol standard for energy metering across India. The DLMS-COSEM standards for the smart meters offer the necessary functionalities for importing, deleting, and altering the certificates. The use of PKI, public keys, and private keys improve the security and dependability of the data in the metering area.

As shown in Fig. 2, the DCUs act as an interface between the meters and the certification agencies formanaging the certificates in the meters. In order to have secured communication with the meters for theauthentication and encryption, there is a requirement of the establishment of public and private keys for the meter. As the meter communication is based on DLMS protocol, a DLMS based client is required to trigger the certificate generation, extraction of certificate, placementof client certificates in the meter and removal of meters' certificate.

To access the security control features or the public key certificate (PKC) featuring DCU, the meters need tobe mutually authenticated by each other using the HLS feature of DLMS-COSEM, as described in the earlier section. The proper HLS mechanism of authentication should be chosen by the client in order to get privileged access to the public key objects of the meter.

Key management systems provide a set of guides- lines to maintain cryptographic keys. The security of cryptography depends upon the proper key management systems. It includes a set of procedures for generating, be provided by invoking the export certificate methodof the security setup class of the server. These digital certificates of the server can be changed or deleted by invoking the appropriate methods and proper AA. PKI manages the digital certificates.

DLMS-COSEM protocol provides certain classes and objects for security implementations in meters. Clients need to invoke the corresponding classes and objectsfor the usage of the security features of DLMS. The following are the provisions in the protocol for the PKI implementation in the metering infrastructure

1. Provision of meter with PKC.
2. Import of certificates from meters.
3. Export of client's certificate to meters.
4. Certificate removal from the meter.

importing, exporting, storing, and replacing the keys. DLMS-COSEM [3] provides proper key management procedures for the secure operation of cryptographic algorithms.

A set of keys for data encryption are provided byDLMS-COSEM. Additionally, it offers the steps for managing keys, such as key transfer, key agreement [9],DCU

Meter

______Request for generation of __key-pair _____ Response for generation of ________Key-pair(success/fail) Request for generation ofcertificate data Response for generation ofcertificate data and key wrapping. The security setup class includes several techniques the client must adhere to in order toachieve key management. It also provides approaches __Request for Certificate Signing Request __ Certificate Import the Certificate _____ ______ Response for import of ______certificate(success/fail) for managing certificates that the client must adhere to when importing, exporting, deleting, and creating digitalcertificates. The server's security setup class [4] provides all the key management objects. The clients can access the key management objects by authenticating themselves witha proper authenticating mechanism, so the access rights to these will be granted to the client by the server. The client's invocation of these methods helps establish and understand keys between the client and the server.

The key for the algorithms is being agreed upon eitherby key agreement or key transfer procedures. But these algorithms require asymmetric keys to agree upon a shared standard key between the client and the server. These asymmetric keys must be provided by a CA accepted by DLMS-COSEM protocol to create a trust anchor that the keys belong to an authorized network client.

The manufacturer should provide the keys for the initial communication before agreeing upon the keys. These are required for high-level security authentication and the ciphering of the APDU data. For the key establishment, the client must provide the server witha digital certificate from a CA. Digital certificate of the client can be provided by invoking the import certificate methodology of the security setup interface class of the server. The digital certificates of the server can

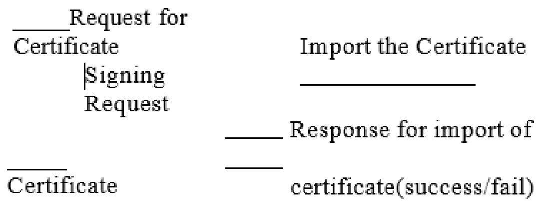

Figure 3: Provision of meter with PKC.

Request for import ofCertificate

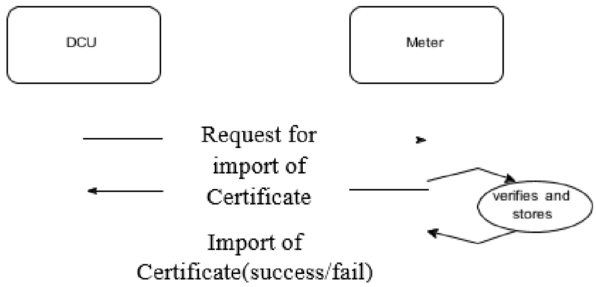

Figure 4: Import of certificates from meters.

A. Provision of meter with PKC

The placement of the PKC at the meter takes placein four steps, as shown in Fig. 3. The meter receives requests from DCU for the creation of key pairs and replies with either success or failure. The meter givesthe DCU the necessary data when it receives a request from the DCU to create data for certificate generation. Itasks the CA to sign the certificate, and it gets the signed certificate in return. The certificate is imported into the meter, which then validates it and reacts with successor failure. New key pairs will be used in answers when the meter replaces the old certificate on the following request.

A. Import of certificates from meters

For the DCU to have secure communication with the meter, it needs to have the public key of the meter so thatDCU imports the certificate from the meter by requestingthe meter using the export certificate method of the security setup class of the meter. The DCU receives the certificate from the meter and uses the public key for theauthentication and encryption.

For the placement of client certificates in the meteras shown in Fig. 4, the client/DCU invokes the import certificate method of the security setup object of DLMS-COSEM and sends the certificate in the meter along withthis request. Meter verifies the certificate and stores the certificate in the certificate attributes of the meter.

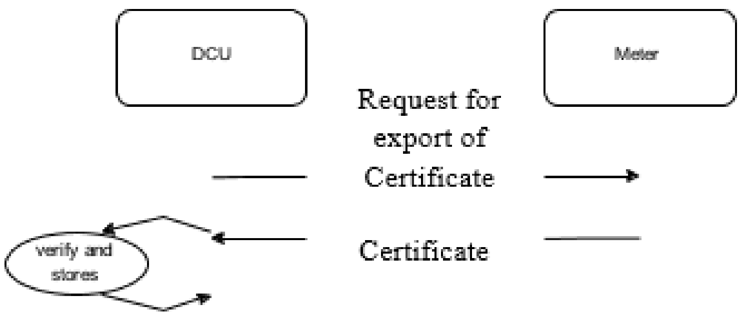

Figure 5: Export of client's certificate to meters.

A. ***Export of client's certificate to meters***

In order to verify the digital signatures and static key agreements with the client *i.e.,* DCU meter requires the appropriate public keys of the client or DCU.

Fig. 5 depicts that the DCU requests for the export of the certificate from the meter and the meter sends the certificate in response to the DCU request. DCU verifiesand stores the certificate.

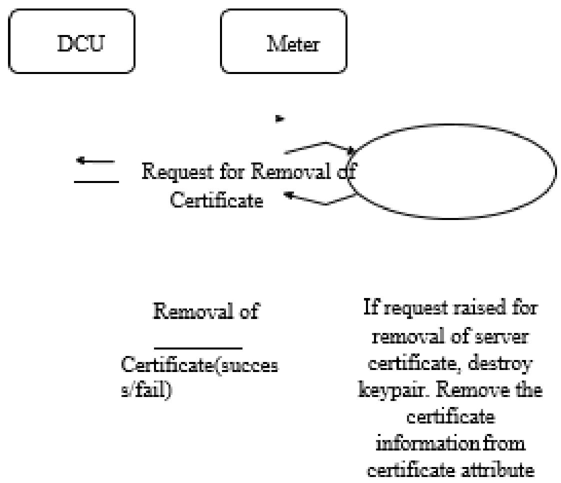

Figure 6: Certificate removal from the meter.

A. ***Certificate removal from the meter***

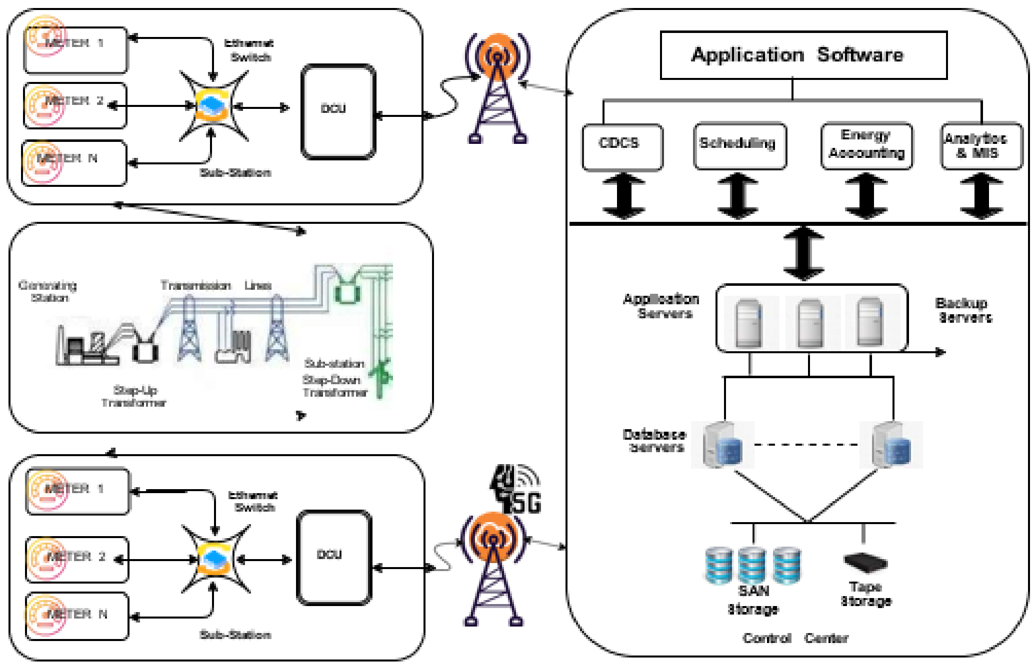

Figure 1: Advanced Grid Metering Infrastructure.

DLMS-COSEM provides the provision to remove the PKC from the meter as shown in Fig. 6. The provision for removal of server or client's PKC has been provided.If the PKC of the server has been removed; the corresponding private key will be destroyed.

With the availability of all the above mentioned fea- tures, the implementation of PKI in the area of energy metering not only enhances the security energy grid on Consumer Electronics (GCCE), Nagoya, 2017, pp. 1-2.

CONCLUSION

In this paper, the role of importance of security in the field of grid metering is discussed. Moreover, the need for PKI for addressing the security gap in AGMI has been established. The provision of PKI in smart meteringenhances the security and reliability of data in the powergrid. Here, the procedure for the implementation of PKI in the field of AGMI using the DLMS-COSEM protocolhas been discussed in detail. Using PKI, DCU and all thesmart meters are authenticated through their certificates. Thus, digital certificate-based authentication with less overhead best suits to protect the AGMI by preventing the catastrophic effects of cyber invasions.

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Remodelling E-Rickshaw Charging Hub: Bringing a Change in EV Charging Practice & Efficiency

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Abstract

Intermediate Para transit is preferred by the citizens for intra-city commutes due to their route adaptability. With the lower adoption cost of e-rickshaw, they are opted in large numbers and have become a preferred choice for travel up to a few Kms within the city. It is estimated that more than 1 lakh + unregistered e-rickshaw are plying in Delhi itself and out of the total EVs registered in Delhi around 48% are e-rickshaws. Such a large number of E-Rickshaws demand a deeply penetrated charging infrastructure. Currently, at e-rickshaw hubs, charging practices adopted are unsafe and do not comply with the safety guidelines. Also, as non-standard charging practices are adopted, they have no upstream potential as a Public EV charging station. EV Charger Installation, if done at such charging hubs, can ensure safe charging practices along with lowering the cost of charging and losses. Such standard charging stations would lead to potential public charging locations, adding a new revenue stream and supporting them financially. This paper proposes a strategy to onboard e-rickshaw hub operators to shift from unsafe practices to EV charger installation and meet safety standards. Further initiatives are required to reduce the financial cost of transformation in network augmentation and capacity enhancement.

Keywords

Electric Vehicle (EV), E-Rickshaw Charging Point (ERCP), Battery Swapping Station (BSS), Electric Vehicle Supply Equipment (EVSE), 2-Wheeler (2W), 3-Wheeler (3W), 4-Wheeler (4W), unauthorised colonies (JJ Clusters), Alternate Current (AC), Direct Current (DC), E-Rickshaw Charging Hub (ERCH), Light Electric Vehicle AC (LEVAC), Bluetooth (BLE), State of Charge (SOC)

1. Introduction

With Climate Change, specifically, Pollution being a matter of Importance for segments of Society and rising fuel prices with disruptions in global political activities; Battery Electric Vehicles (BEV/EVs) have come up as an alternate mode of transport for People of India and adoption of EV's is picking up the pace in 2W, 3W and 4W segments of transport. The advent of breakthroughs and improvements in energy storage is transforming vehicular technology and energy solutions. EVs are now becoming a promising alternative to ICE vehicles which is further fuelled by government incentives, rising fuel costs and society's will to act on climate change. India is the 4th largest automobile market in the world with approx. 30.9 million vehicles are on road and every day around 50K new Vehicles are registered in the country.

Electric Vehicle have been between us since early 2000 with the launch of REWAi which was followed by the launch of Mahindra e2O. The visibility of EVs in the car segment was not much popular back then. Around 2010, only e-rickshaw EVs could be spotted on Indian roads. Due to their low cost over ICE (Internal Combustion engine) auto rickshaw, they were largely adopted by operators and eventually became the most preferred mode of Intermediate Para Transit in the Country.

3W has been dominating the Indian electric market with a share ranging from 60-80% of registered EVs across states. In both the passenger and Cargo segments, 3W are a preferable choice for consumers and fleet operators keeping in view their price range, government support, mileage and sufficient payload capacity. It is estimated that more than 1 lakh unregistered e-rickshaws are running in Delhi. Further, between Aug 19 to till date, out of the total EVs registered, 38% (47,356) are e-rickshaws.

Such a large adoption of electric 3-wheelers especially e-rickshaw demands a deeply penetrated and accessible charging infrastructure. E-rickshaws have become a preferable choice over auto rickshaws for city cab services and to earn a livelihood. Also, e-rickshaws are majorly owned by underprivileged segments of society residing in unauthorised areas and clusters. EV charging stations within such localities should be carefully engineered ensuring all safety provisions to prevent any threat to life and property. Also, to make them sustainable in the competitive market, provisions can be made to reduce their charging and operational cost along with digitizing their operations.

2. Prevailing ERCP Practices and Models

Parking over Charging

E-Rickshaws come with a battery pack of capacity with a small battery pack generally ranging from 3 KWH to 7 KWH which is charged using a slow AC charger with a rate of 500 KWH to 700 KWH per hour. As the load required to charge an r-rickshaw is very less they can be charged from an existing domestic electricity connection and do not find an inevitable need for a charging station for fuelling up the vehicle.

But, in vertical growing cities, only a few are blessed with the privilege to park their vehicle inside their homes. Concerning, e-rickshaw owners residing in JJ clusters do not have space to park their e-rickshaw inside or in front of their homes. Hence for the owners, it is preferable to find a space where they can park their vehicle overnight and charge it at the same time.

Existing Business Model

E-Rickshaw hubs majorly exist around the unauthorised colonies where utility Parking or open lands are used for the charging e-rickshaws. Vehicle owners ply their vehicles mostly during the night time to reserve a safe parking spot and utilize the power connections at the site for overnight charging. Operations of such hubs are 100% manual wherein owners pay a fixed charge per day (Around INR 100 to 150 per night) to the operator for parking and charging.

Confuguration of ERCH

E-rickshaw charging hubs generally built on open land spaces extend their electrical power network around the land space on a wall or temporary structures. To Plug and charge the rickshaw they provide a wooden extension 2 Pin or 3 Pin board affixed to the wall or temporary support structure.

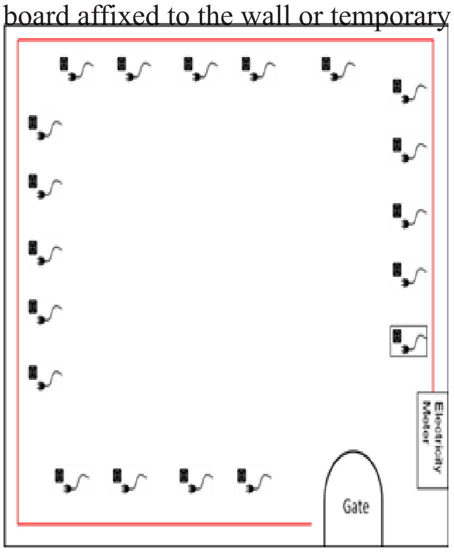


Fig 1: Diagrammatic representation of ERCH

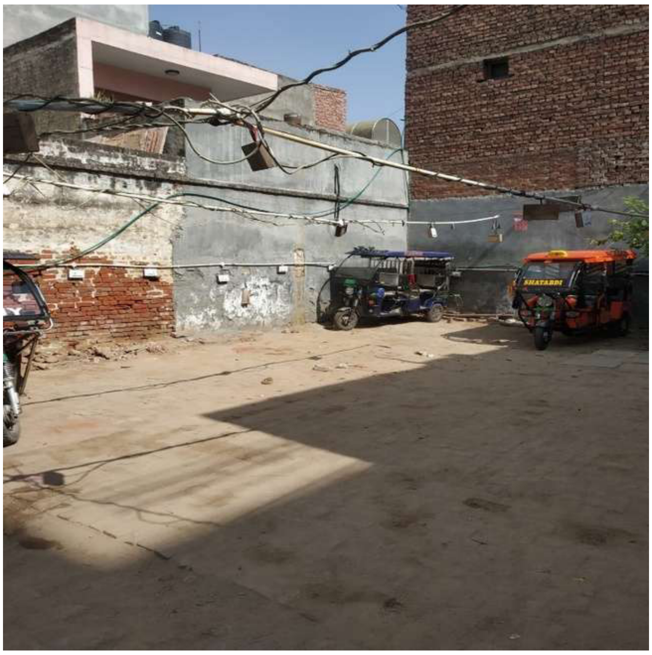


Fig 2: Image of an E-rickshaw Charging Hub

Unsafe charging conditions at ERCH

Internal wiring / Domestic wiring is a matter of very little concern for the Indian mind set. Whether it is a home, shop, factory or even a charging hub; we pay very little attention to electrical safety. Switchgear installed after the electricity meter to the end load point, a safe and protected electrical line is essential for the safety of the owner /operator.

Unsafe consumer switchgear panels, damaged wiring around the hub, burnt/damaged output plug points, use of 2 Pin sockets for plug-in of charger, damaged wiring of the charger and open joints are some common electrical risks which can be easily found across all e-rickshaw hubs. Further without any control over the upstream line capacity, charging and plug-in of rickshaws at such hubs is done as per traffic and hence pose high chances of overloading and damage to the line.

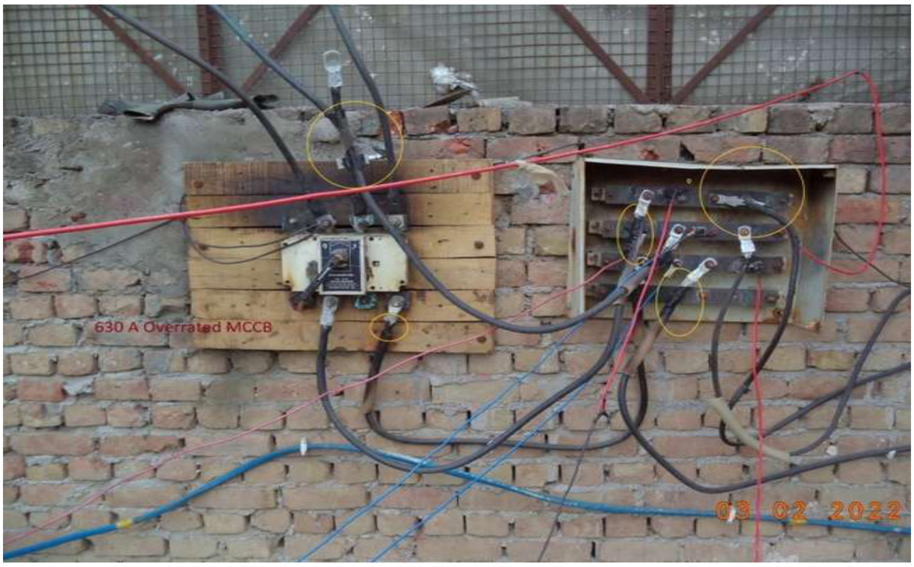


Fig 3: Bypassed Consumer Panel at E-Rickshaw Hub

Fig 4: Unsafe output Plug Points at ERCH

Fig 5: Unsafe Wiring at ERCH

Further, as a vehicle is plugged in overnight power is continuously fed to the batteries due to the absence of a charger (Monitoring unit) resulting in overheating of batteries and degrading their life. Also, the energy required to charge each rickshaw is increased due to heat dissipation. On average a lead acid battery is designed to last 15. To 2 years gives a driving range of only 6 to 12 months due to such damages. This has a financial impact on the owner and operator of the hub.

3. Power requirements and challenges with EV charger

E-rickshaw is a low-load vehicle with a battery pack capacity ranging from 3KWH to 7 KWH. Also, legacy rickshaws running on roads are majorly powered by lead acid batteries which support only slow charging. Further new rickshaws with lead acid batteries are also charged generally using an AC slow charger at the rate of 0.5 KW to 0.7 KW per hour at 230V. The portable charger of the rickshaw is plugged into a wall outlet point which converts the AC power into DC to be fed to fuel up the battery.

Battery Size (KWH)	Charging Rate (KW)	No. of Vehicles Plugged at a Time	Charging Time (10% to 85%) (Hrs.)	Load Required (KW)
3	0.5	30	6	15
3	0.6	50	5	30
5	0.7	30	7	21
7	0.9	50	8	45

At Present, LEVAC Charger as per IS 17017 is rated for maximum output of 3.3 KW. Further, the charger comes with an Industrial socket at the output point and is operated through a mobile application based on BLE Communication. These features of LEVAC are bottlenecks for safe EV Chargers at e-rickshaw charging hubs.

As the load required to charge an EV is 0.5 KW to 0.7 KW, hence having a 3.3 KW is oversizing of the network. Also, as the nameplate rating of the charger is 3.3 KW hence for having a LEVAC Charger installation you need a sanctioned load of 3.3 KW and for charging 30 e-rickshaws overnight u-sing LEVAC, the load required is 50 KW against an actual requirement of 15 KW (As per MoHUA guidelines 1 AC Slow Charger is optimum against two 3W).

Also, the LEVAC charger comes with an Industrial connector and the e-rickshaw charger has a universal male plug. Hence the operator needs to bear an additional cost of Industrial to the universal convertor. Also, the BLE based command to operate the charger bounds consumer to have a Smart Phone with a mobile application of Charger OEM and send a start command before each session.

4. Remodelling of ERCH and ERCP

With EV Charger Installation, solving issues associated with existing chargers, digitizing the operations, and ensuring the life cycle of the e-rickshaw for the owner is aimed to bring a transformation in the ecosystem.

Finding the Best fit of EV Charger for Safe Charging

EV Charger IS 17017 set some safety and monitoring standards for LEVAC Charger which monitors the charging of vehicles. Using those standards an EV Charger with a rated output of up to 1 KW will be the best fit for charging e-rickshaw. Also, the outlet point can be converted to a universal female plug point along with manual on-off command buttons on the charger to avoid the need for mobile application-based control. These measures shall also bring down the cost of the charger further reducing the ownership cost of charger installation.

Having a 1 KW LEVAC Charger will reduce the cost required for network upgradation and electricity connection cost as it avoids oversizing done with a 3.3KW charger. This mitigation of network costs makes it easier for hub operators to opt for safe charging practices.

Safe and Affordable EV Charging

Charging of e-rickshaw through a universal plug has no monitoring of voltage, current and SOC of the battery. Further in event of an overvoltage / under voltage or any surge such devices do not protect the battery and EV. Installation of a LEVAC Charger and connecting the portable charger to it monitors the line parameters across the charging period. Also, it protects EVs from abnormalities occurring in line due to internal or external factors and delivers a safe EV Charging experience.

Charging Mode	Time of Charging (Hours)	Energy Required to Charge 4 KWH Battery (KWH)	Cost of Charging (INR 6.4/ Unit)	Saving @ INR 100/ Charging
Universal Plug Point	8	6	48	52
Charger	5	4	20	80
Additional Benefit with LEVAC Charger		**2**	**28**	**28**

Charging an e-rickshaw through LEVAC Charger also reduces the charging time by providing a constant current and controlled voltage to the vehicle. Also, as soon as the battery is charged up it automatically cut off the power supply reducing losses due to overheating and mitigating the risk of overcharging. Thus, the cost of charging for the operator and owner is reduced along with ensuring battery life and integrity.

Fig 6: Deployment of LEVAC Charger at E-Rickshaw Hubs

The average cost of a new lead acid battery for e-rickshaw costs around INR 35,000 to 40,000 and a lithium-Ion battery costs around INR 85,000 which is almost 50% of the cost of the vehicle. Any damage to this costly part of the vehicle is a huge financial blow to the owner. Hence charger used for charging over a universal plug provides a steady supply and ensures protection from abnormal line parameters. It enhances the life of the battery during use and once unfit for vehicular applications can find usage in some other applications.

Expanding the horizon

Within the national capital city, most residents except those in societies face the challenge of a dedicated vehicle parking space. Vehicle parking is not feasible inside the premises and on-street parking comes with the risk of damages and theft along with making streets congested. With the adoption of electric vehicles on-street parking will become more challenging as nighttime is the preferential duration for charging the idle plying vehicle and in the case of on-street parking vehicle owners will not have access to EV Chargers and electricity connections to fuel up the vehicle.

Vehicle Type	Time of Charging (Hrs.)	Energy Used (KWH)	Revenue (10 Rs/ Unit) (Rs)
2-Wheeler	3-4	3-4	30-40
4-Wheeler	7-8	20-30	200-300

E-Rickshaw hubs spread across the city have been EV Charging points for a long and conversion of the hubs from makeshift arrange of charging the vehicle to standard charger-based powering will build up the trust of EV owners on such hubs to park and charge their vehicles. Through this remodeling, the hub operators can generate additional revenue with EV parking and charging across the day and expand their business.

Fig 7: Vehicle parked in Authorised parking with charging facilities

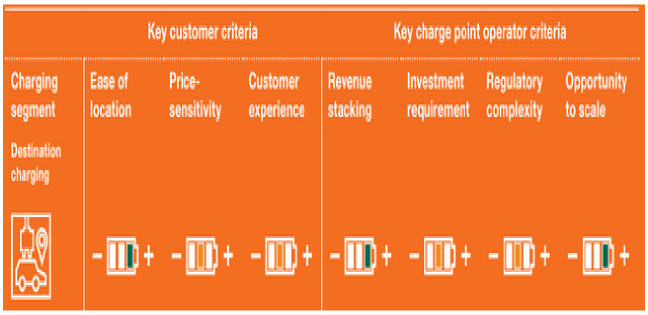
Digitizine the ERCH Operations

Each time a rickshaw owner enters into the hub, a manual interaction between the hub operator and owner initiates the transaction to park and charge the EV. When the traffic at hub is high the EV owner struggle to find a vacant spot at any nearby hub to ply his vehicle.

As with remodelling the cost of charging per vehicle is reduced, hub operators and owner can save the balance or invest to insure their vehicle. Hub operators can partner with financing institutions to deposit a premium out of daily fees paid which over period takes care any maintenance or battery replacement cost of EV owner. In this way with daily small contribution the EV owner can ensure his vehicle and build a strong relationship with hub operator and banks.

Destination charging is an emerging segment with high potential to exploit alternative revenue streams. Destination charging also offers significant potential due to revenue stacking such as advertising. Display the number of charging points at Charging Hub, their vacant and occupancy counts. To charge an electric vehicle on a public network, the vehicle owner can typically choose between pay-as-you-go, with no fees or commitment but higher rates, or use a subscription or membership with an e-mobility services provider (eMSP). The eMSP provides value to the vehicle owners within their membership by enabling access to their charging points and facilitating the charging transaction.

For each charging hub, real-time charger status as vacant, occupied, and not working to be shown to customer as per availability of slots. At charging hub provision to book a charging slot with help of operator for load distribution during the peak hours. Few of the charging point should be fixed as operational only through booking and others available as priority charging. Profit Center is for Priority charging to turn a profit as its rates will be higher than nominal fee to cover costs through advance booking.



5. Conclusion

Uncontrolled and Unmonitored charging of Electric vehicles poses a risk of damage to vehicles along with resulting in accidents causing threat to life and property. With the strengthening of norms and concerns regarding pollution, restrictions are being posed on fossil-fuel-run vehicles, especially in public transport. The Ministry of environment, forest and climate change has put regulations on diesel-run auto-rickshaws in NCR which shall further increase the adoption of electric rickshaws. Hence robust and safe charging facilities for them are essential.

EV Charger installation enables safe charging and reduces stress on the battery and damages due to fluctuations. Further, the cost of charging and charging duration is also reduced. ERCH operators can generate additional revenue from expanding business for other segments of electric mobility.

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Photovoltaic Integrated Electric Vehicles Charging station for Isolated location

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Abstract

Future mobility plan has accepted replacement of engine by an electric operated mechanism for establishing carbon free, efficient, improved, and smarter vehicular system. An electric vehicle typically employs battery bank, electric motor, power electronic converters and control mechanism. Battery bank supplies energy for motor operation to drives the vehicular mechanism and discharges the battery. In locations where grid supply is available battery charging is either done in charging centers interfaced with power grid. This causes rise in peak demand of utility-grid and power quality issues. Locations where grid is not erected charging electric vehicles is indeed a challenge. Electricity generation by using renewable energy sources for battery charging seems rather effective option. In this paper photovoltaic integrated electric vehicles charging station for isolated location has been proposed. The system aims elimination of erecting power grid besides providing clean and free energy for battery charging. The dynamic model of the 30kW system has been developed and the system is simulated in MATLAB/ Power-system Block set. The performance of the system during steady-state and load perturbation has evaluated by simulation results. The performance validates effectiveness of the proposed system to meet charging requirements of electric vehicle in isolated locations.

Keywords

Electric mobility, solar photovoltaic, vehicle charger, renewable energy, PWM inverter

1. Introduction

Pressing concerns imposed due to climate changes, air pollution, and energy security has forced researchers and engineers to investigate new schemes for energy conversion which may present pollution free and quality electricity. Energy extraction by using conventionally available energy sources such as coal, petrol, diesel, and gas are facing downtrend curve due to concerned challenges viz limited reserves, costlier, and leaving carbon footprint on atmosphere. Growing electricity requirement across the globe has widened due to adoption of electric mobility in transportation sector which otherwise uses petrol/ gas driven IC-engines. This shall provide energy efficient and eco-friendly solution in transport sector and encouraged researchers to develop new schemes presenting promising scopes to replace existing vehicular system [1]. An electric vehicle (EVs) typically integrates electric motor, controller, battery bank and power management system. The battery is charged in charging centres with grid interfaced converters. Power drawl from grid-supply may cause stress in distribution system and deteriorate power quality. Moreover, in locations where grid supply is not available adopting electric mobility is rather challenging issue as long charging time is taken by battery. This may lead limited driving range of the vehicle. Lack of charging infrastructure availability has promoted methods like employment of diesel-generator sets for charging or charged battery swapping. This causes increased charging overheads in unreliable manner. Investigations to develop a system to provides cost effective, reliable, ease and efficient schemes for charging e-vehicles have vital future scopes. Also, global policy focusing on deploying renewable energy sources for battery charging of e-vehicle will open new paths in its research. Among available renewable resources such as wind, mini/micro hydro, biogas, and photovoltaic (PV), energy extraction by solar PV is well established. This offers clean, free, long lasting, pollution free and quality electricity with low carbon footprints in isolated locations where grid supply is not available at all. Investigations are due to explore new possibilities of research by using renewable energy for isolated charging stations of electric vehicles.

This paper proposes solar photovoltaic fed battery charging system for electric vehicles in the locations of remote road sides where grid supply is generally not available. This will relieve power-grid erection in isolated locations for e-vehicles charging and providing reduced system cost and carbon emissions. The mathematical model of isolated PV-system with converters, battery support, local utility and chargers has been developed. The proposed system model is simulated in MATLAB/ Power System-Block set and the performance of system has been evaluated by simulation results. The attained results validate effectiveness of the proposed system when it caters demand side energy requirement for charging of e-vehicles in remote locations.

2. Literature Review

Energy extraction by using conventional resources viz coal, petrol, diesel, and gas are facing downtrend since they are costlier, leaving carbon footprint and have depreciating reserves. Adopting electricity in transportation sector has promising future scopes. Investigations are still due to explore effective methods of battery charging and its size/cost optimization, effective charging, renewable energy sources (RESs) integration, and demand-side management (DSM). Researchers have proposed schemes to meet significantly rising requirement of e-vehicle charging points. Lam et.al. formulated the problem for e-vehicle (EV) charging station placement and investigated to minimize the total construction cost for the charging station coverage and the convenience of the drivers for EV charging [1]. Further, Investigations on optimization in location scheme for electric charging stations was proposed by Mehar et.al [2]. The investigation on alternate fuel mixed-integration with a programming model to address EV round-trip itineraries was proposed by the researcher [3]-[5]. Investigations were also made on data-driven optimization-based approach for siting and sizing of electric taxi charging stations [6]. Zheng et.al reported investigations on traffic equilibrium and developing electric vehicles charging facility locations [7]. The demand of fast charging station placement with elastic demand has been addressed by W. Dait et.al [8]. Charging station with mobile battery integration for reducing electric vehicles charging queue and cost by using renewable energy curtailment recovery was proposed [9]. Further, issues based on fast charging and simultaneous charging station location-routing problem issue was addressed by the researchers [10]-[11]. Recently investigations addressing hybrid electric vehicles charging stations in microgrid pattern were reported [12]. It is observed that investigations reported so far have mathematically addressed the issues of charging stations and/or have designed and simulated the scheme. Investigations utilizing renewable resources forming microgrid in isolated manner and its grid connectivity is not attempted in practical manner. Investigation on solar photovoltaic fed battery charging system for electric vehicles in remote road sides where grid supply is not available requires improved attention by researchers. The investigation aims to relieve power grid erection in isolated locations for e-vehicles charging with reduced system cost and carbon emissions. Dynamic e-vehicles isolated charging system fed through solar PV system is not reported in available literature so far.

This paper proposes isolated solar photovoltaic fed electric charging station. The system is supported by battery and caters local load of charging station. The investigation aims to reduce both system cost and carbon emissions and relieves the requirements of power grid erection in isolated locations for e-vehicles charging. Analysis and simulation model of the proposed photovoltaic fed e-vehicle has been developed. The system is simulated in MATLAB power system block-set and performance of the system is evaluated by simulation results. The results validate that the proposed system effectively caters demand side energy requirements for e-charging in remote locations.

3. System Configuration

The block diagram of the proposed system for electric vehicles charging in isolated manner is shown in Fig. 1. The system integrates solar photovoltaic (PV) modules and supplies power to the dc bus via boost converter interface. The dc bus integrates voltage source converter (VSC) which has coupling inductor and ripple filter at PCC for switching harmonics reduction and makes currents sinusoidal. The ac-supply caters local utility load of the charging station. The PV output is supported by a battery storage interfaced with a voltage controller and bidirectional charge regulator for supporting/topping optimal charging/ discharging of batteries. Energy balance is maintained by evacuating excess power by chopper-based load-controller at dc-bus. The charging ports of EVs are extended through at dc bus and presents load perturbations during charging cycles. The proposed system effectively caters the requirements of isolated charging system and is suitable for its deployment in locations where grid supply is typically not available.

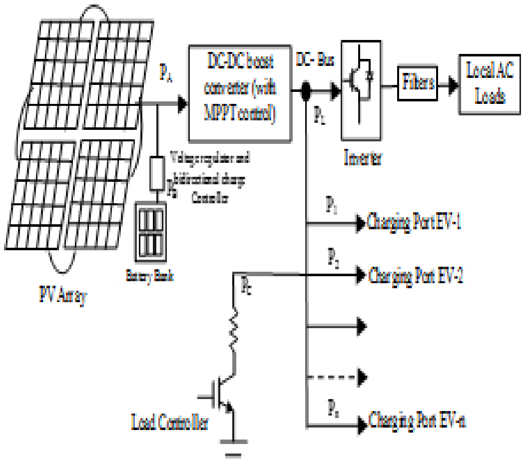

Fig.1 Block diagram of the proposed system for PV integrated e-vehicles charging station

4. System Modelling

The proposed e-vehicle system for isolated locations integrates solar-PV panels, battery storage, boost converter, voltage source converter, load controller and control mechanism. The mathematical model of the system has been realized in the following sub sections of the paper.

Solar PV Module

Network of solar cell presents solar module. Modules are connected to form a solar network to maintain requisite voltage across the terminals. The mathematical model of a solar cell is approximated as diode and its modelling is based on simplified irradiance model. The output power is determined by factors viz irradiance, panels area and photoelectric conversion efficiency. The power output (P_{PV}) of solar array is given as.

$$P_{PV}= G_T A \tag{1}$$

G_T is forecasted irradiance, A is the area of solar panels, and η is efficiency of solar power conversion.

Boost Converter

It operates by periodically opening and closing of switch and produced the output voltage larger than the input. The source voltage (V_s) is regulated by duty cycle (D>0) to attain larger voltage output (V_s)

$$V_0=V_s/(1\text{-}D) \tag{2}$$

The output voltage (V_o), L_{boost} and C_{boost} are

$$V_{DC} = 1.1-D_b\, V_P\, V \tag{3}$$

$$L_{boost} = V_{DC}\, D_b\, \Delta I_{Lf} \tag{4}$$

$$C_{boost} = V_{PV}\, D_b\, R_o \Delta V_{PV.}\, f \tag{5}$$

where V_{PV}, ΔI_L,f, ΔV_p V and R_o are the input voltage, inductor ripple current, switching frequency, capacitor ripple voltage and output impedance of boost converter respectively.

Voltage Source Converter (VSC)

The VSC supplies both real and reactive power demand of locally available loads of the charging station. The transacted real power(P) and the reactive power(Q) are given by equation

$$P - Q = 3\frac{v_a e_a}{x_f}\sin \quad - j3\left(\frac{v_a e_a}{x_f}\cos \quad - \frac{v_a^{\;2}}{x_f}\right) \tag{6}$$

The real- power (*P*) depends on the load angle (α), and the reactive power flow (*Q*) depends on the voltages v_a and $e_{a.}$ Gating pulses are accordingly supplied with the control algorithm for IGBTs switching to maintain regulated voltage across the load.

The volt-current equation of VSC output is given as

$$v_a = R_{f.}i_a + L_f\dot{p}_a + e_a - R_f i_b - L_f\dot{p}_b \tag{7}$$

$$v_b = R_{f.}i_b + L_f\dot{p}_b + e_b - R_f i_c - L_f\dot{p}_c \tag{8}$$

$$i_a + i_b + i_c = 0 \tag{9}$$

$$v_b = R_f i_{cb} + L_f.pi_{cb} + e_b + R_f i_{ca} + L_f.pi_{ca} + R_f i_{cb} + L_f.pi_{cb} \tag{10}$$

Rearranging eqn. (9) and eqn. (10) result as,

$$L_f.\dot{p}_a - L_f.\dot{p}_b = v_a - e_a - R_f.i_a + R_f.i_b \tag{11}$$

$$L_f.\dot{p}_a + 2L_f.\dot{p}_b = v_b - e_b - R_f.i_a - 2R_f.i_b \tag{12}$$

VSC current derivatives are estimated as

$$\dot{p}_a = \{(v_b - e_b) + 2(v_a - e_a) - 3R_f i_a\}/3.L_f \tag{13}$$

$$\dot{p}_b = \{(v_b - e_b) - 2(v_a - e_a) - 3R_f i_a\}/3.L_f \tag{14}$$

dc bus regulation

The dc-bus voltage of VSC is maintained by regulating duty cycle of boost converter. The converter draws real-power from the PV source. The dc bus voltage of VSC must be greater than twice the peak of the phase voltage at the ac terminals of VSC for satisfactory power transaction. Therefore, in self-supporting mode minimum dc-bus voltage required for effective operation of VSC is given as

$$V_{DC} = \left(2\sqrt{2}/\sqrt{3}\right)m.V_a \tag{15}$$

For '*m*' is 0.9 and line voltage (V_a) is 410V, and the dc bus voltage (V_{DC}) is obtained as 602V. In the considered system the nearby value of dc bus reference voltage is selected as 600V. The dc bus voltage of VSC is maintained in self-supported mode. Sensed dc bus voltage (V_{DC}) is passed through low pass filter (LPF) and sampled *k* times over a period *T*.

$$V_{DC}(k) = \frac{1}{k}\sum_{l=n-k+1}^{l=k} V_{D}(k) \tag{16}$$

The filtered dc voltage is compared with reference voltage. The error (e_{vDC}) is estimated as

$$e_{V_{DC}}(k) = V_{DC}^{*}(k) - V_{DC}(k) \tag{17}$$

The error is processed through a controller (PI) and current (I_{dDC}) is determined. This corresponds to real power to be drawn from the source to maintain DC bus voltage (V^{*}_{DC}) constant

$$I_{ddc}(k) = K_{pd}\left\{e_{V_{DC}}(k) + e_{V_{DC}}(k-1)\right\} + K_{id}\, e_{V_{DC}}(k) \tag{18}$$

Load Controller

The chopper-based load controller is implemented in parallel to dc bus of VSC for evacuating excess power during light load when e-vehicles are not presented at charging station. Voltage swell at PCC may occur as excess energy may be accumulated in the capacitor at dc-bus. The real power transacted in the dc bus contributes comprises the real-power for dc-bus voltage regulation and power drawn for charging. The power balance equations during steady state are expressed

$$P_C = P_g - P_{LC} \tag{19}$$

Where, Pg is the net active power output transacted from VSC and PLC is the active power dispensed to the load controller. Current drawn by the capacitor IDC for maintaining voltage VDC is related by power accumulated in the capacitor (C) by

$$P_C = V_{DC}\, I_{DC} \tag{20}$$

Implies

$$P_C = V_{DC}\, C\frac{dV_{DC}}{dt} = \frac{C}{2}.2.V_{DC}\frac{dV_{DC}}{dt} \tag{21}$$

$$= \frac{C}{2}\frac{dV_{DC}^{2}}{dt} \tag{22}$$

Rearranging eqn. (22) and integrating both sides

$$V_{DC}^{2} = \frac{2}{C}\int P_C\, dt \tag{23}$$

$$V_{DC} = \sqrt{\frac{2}{C}\int P_C\, dt} \tag{24}$$

Substituting P_c in eqn. (24), the dc bus voltage (V_{DC}) can be expressed in terms of generator output power (P_g), and the power dissipated to the load controller (P_{net})

$$V_{DC} = \sqrt{\frac{2}{C}\int (P_g - P_{LC})\, dt} \tag{25}$$

In terms of duty cycle, the power (P_{LC}) dissipated in bleeder resistance (R_b) is given as-

$$P_{LC} = \frac{(V_{DC})^{2}}{R_b} \tag{26}$$

Load Presented by e-Vehicle

Electrical loads presented by a typical e-vehicle charger presents constant-power loading (CPL). The response of such load is analyzed through piecewise linearizing the nonlinear supply perturbations. The loads intermittency due to charging perturbations in a proposed weak system often causes voltage sag ΔV(say), which may result in current displacement of 'ΔI' from 'I_1', thus, disturbing the equivalent resistance perceived at common coupling. The resistance is expressed as-

$$R_{e1} = \frac{P_{load}}{(I_1 + \Delta I)^2} \approx \frac{P_{load} / I_1^2}{1 + \dfrac{2\Delta I}{I_1}} \tag{27}$$

From Taylor's series expansion and approximation in equivalent resistance in eqn. (24) becomes,

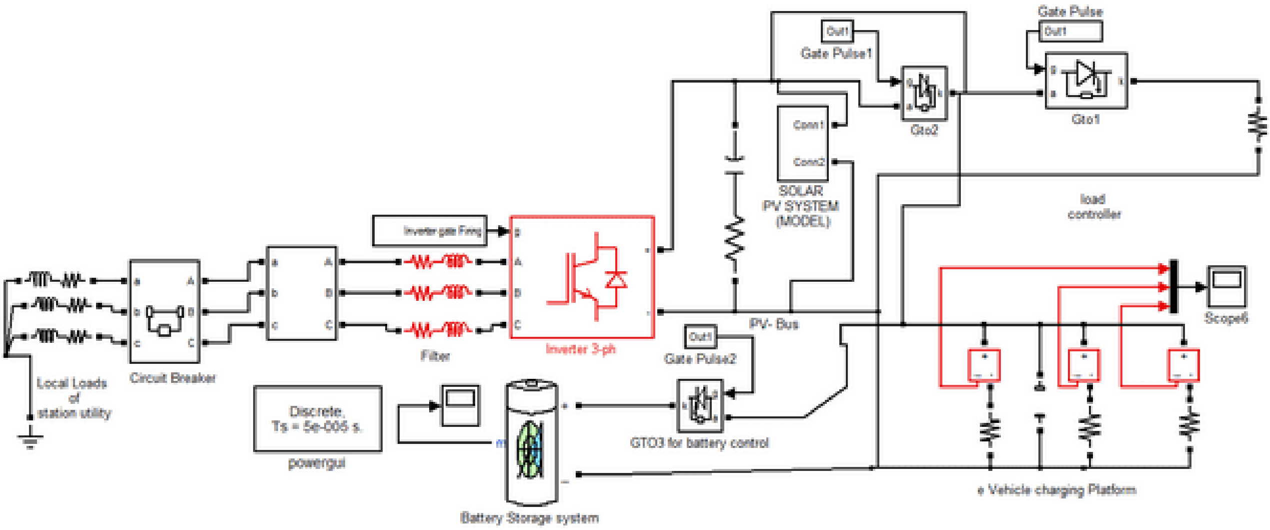

Fig.3. Configuration of Proposed system in Matlab Simulink

$$R_{e1} = \frac{P}{I_1^2}\left(1 - \frac{2\Delta I}{I_1}\right) = \frac{P}{I_1^2} - \frac{P}{I_1^2}.2.\frac{\Delta I}{I_1} = R_e - 2.R_1\frac{\Delta I}{I_1} \tag{28}$$

It is observed in eqn. (25) that fall in resistance (R_e) provokes escalation in current drawl leading sag in voltage. Such loading produces cascading effect in voltage (v_{abc}) and may lead voltage collapse. Dynamic compensation of power may prevent the further fall in voltage and prevents the voltage collapse.

5. Control Algorthims

The block diagram of the proposed control algorithm is shown in Fig.2. The scheme ensures to maintain energy balance by effective regulation of power transaction through photovoltaic generation, battery storage, boost converter, local utility loads, inverter, and load controller operation in isolated manner. Solar PV arrays integrated with battery energy storage system maintains seamless voltage across terminals which otherwise fluctuates due to change in irradiance in panel. The battery bank provides power topping and fulfills excess energy requirement of the system during transient overload conditions. A boost converter pertaining maximum power point tracking (MPPT) control algorithm maintains regulated voltage across the dc-link by requisite duty cycle control. Charging of electric vehicles is implemented through ports at dc bus which in turn exerts electrical load. Real power is estimated and the controller assures energy balance during light load and overload condition. During light load at point of common coupling (PCC) power matching is maintained by optimal charge transfer to battery storage lead by evacuation of real power via chopper-based load controller. To caters local utility loads viz lighting, pumping, heating of charging substation a 3-phase PWM inverter is employed at dc-bus of converter. The scheme assures to maintain regulated voltage and frequency at ac-link and cater loads presented by e-vehicle chargers.

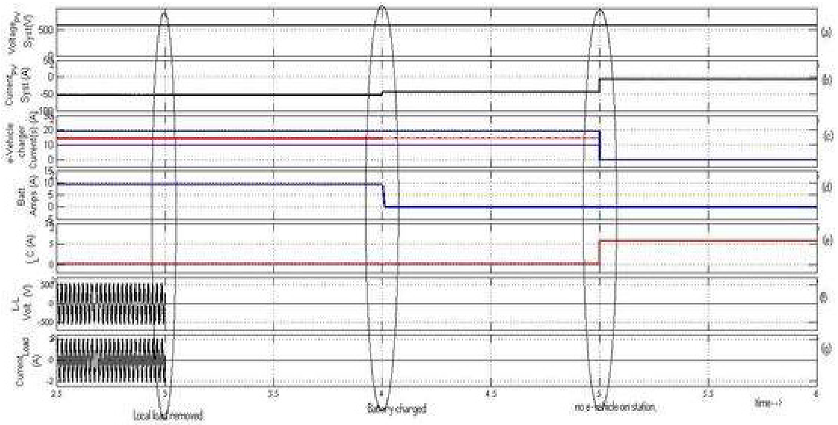

Fig.4. System performances of isolated e-vehicle charging station.

6. Matlab Simulations

To evaluate the performance of solar-PV fed isolated charging station the system is simulated in MATLAB/ PsBlockset environment. Mathematical blocks of system components such as solar-PV array, battery storage, boost converter, local utility loads, inverter, and load controller are realized for simulation studies and requisite system model has been developed. The simulation parameters of the considered e-charging station are kept close to the actual enabling correct assessment of both control parameters and power circuit interfacing system (Refer Fig.3). Electrical load perceived in a typical e-vehicle charging system is presented as a constant power load (25kW). Hysteresis band of 0.1A is considered for realizing carrier less PWM signals for inverter control with switching frequency of 10kHz. The attained results presented in the next section of the paper clearly demonstrate that the proposed control scheme offers effective voltage and frequency regulation to cater local loads and present effective energy balance on the system.

7. Performance Of The System

The performance of e-vehicle charging station in isolated manner of operation has been evaluated using MATLAB®/Simulink. The parameters of system components under investigation are kept close to the actual parameters. The attained results are shown in Fig.4. For the sake of clarity, the results are arranged in two separate sections. One-part deals with steady-state performance of the system and the other part dealt with the system performance during load perturbations. The performance of the proposed system has been discussed in the following sections.

Steady State Performance of the System

The steady state performance of the system has been studied when system caters rated load during charging of e-vehicles and caters local utility loads/gadgets of charging station at point of common coupling (PCC). Further the load is reduced (light load) when vehicle is not presented at charging station. The performance of the system is evaluated and the attained results are depicted in steady state section of Fig.4.

Steady-State Performance of the System at Rated Load

Simulation based performance of the system when rated load is applied is shown in first section during the interval from t=2.5s- 3.0s. The line voltage per phase at PCC of inverter and current drawn from the source is depicted in Fig.4 (f, g). It is clearly observed that line to line terminal voltage is well balanced and regulated. Also, the currents are balanced and frequency is regulated.

Section t=2.5 to 3.0s of the same figure depicts dc-bus voltage. In this section the system caters rated load. The performance of system during steady-state operation is presented by current drawn from e-vehicle, current transacted to/from battery, and load controller current. It may be observed in Fig. 4(a) that dc-bus voltage well regulated. It is also shown in Fig. 4(b) that current drawl is well maintained under limits. Fig. 4(c) depicts that current drawl by e-vehicle charging is under limits. Current transaction to the load controller is near zero since the loading is close to its rated capacity and energy balance is maintained in effective manner. Fraction of real-power is compensated in diode rectifier losses. The results present that the system smoothly operates in steady-state.

Steady-State Performance of the System at Light Load (Local Load Removal)

Simulation performance of the system when light loading at PCC is shown in section t=3.0s-6.0s of Fig.4(a-g). DC-bus voltage, current, e-vehicles charging currents, Battery current, load controller current, line voltage and line current at PCC respectively are clearly depicted. The results are explained during load perturbation when local load is not presented from t=3.0s-4.0s and from t=4.0s-5.0s when battery storage is optimally charged. In section t=5.0s-6.0s electric vehicle is not available at charging station. The dynamic performance of the system under local load changes has been presented in the following sections.

a. Performance of the System with local load blackout

It may be observed in Fig.4(f,g) that local loads are not presented at PCC leading current is not drawn by local loads. A glitch is observed in the current transacted by the battery storage and is clearly depicted in Fig.4 (d). It is also observed in Fig 4(a-c) that dc-bus voltage, load current and e-vehicle charging currents are well regulated.

b. Performance of the System Pertaining step loading during charging

As observed at t=4.0s of Fig.4 step loading is presented by charging station of e-vehicle. Accordingly, a glitch is observed in the current drawl at dc-bus. The current drawl above rating of PV capacity is transacted via battery storage. In same duration it is observed that dc-bus voltage is well regulated and presenting effectiveness of the proposed system.

c. System Performance with evehicle blackout

Complete load removal is observed in Fig.4 (t=5.0s) when all local load and e-vehicles are not presented for charging at the station. A droop in current drawl by e-vehicle is clearly observed and is depicted in Fig.9 (b). Energy balance is maintained by dispensing real power to load controller and rise in current is shown in fig 2(c). Effectiveness of the proposed system is presented by the fact that dc-voltage is well regulated and is under control limits.

8. Conclusion

Performance of proposed system with solar photovoltaic pertaining energy self-sufficient e-vehicle charging station has been successfully demonstrated under load perturbations. The system attains battery charging of e-vehicle in isolated manner besides catering local loads such as lighting, heating, and local pumps. Regulated voltage and frequency have been maintained at point of common coupling. The operation of load controller presents rated power drawl from the source in effective manner. The proposed scheme is simple, fast acting and prevents complex hardware circuits. It is also successfully demonstrated that the system remains under synchronism even under extreme load perturbations. The scheme is effective for charging e-vehicle in isolated locations

9. Further Scopes

In this paper, an isolated charging station is proposed to charge e-vehicle. The scheme provides feasibility of charging e-vehicle where grid supply is not available reducing grid erection burden. The scheme provides opportunity of e-vehicle utilization in remote locations by PV. In this paper electric loads are connected at dc bus. The scheme provides further scopes of research by implementing power exchange between local source and grid during the load blackout or reduced sunlight enabling battery storage elimination from the system. The scheme will also have scopes to charge battery of electric vehicle during load/ source perturbations.

10. Appendix

Electrical loading 25kW. Switching frequency 10kHz dc-bus voltage 600V, Solar PV array with boost converter: V_{dc}=600V, I_{sc}=45A, Line voltage (V_a) is 410V,50Hz, Local Load 2kW, Storage battery: 360V, 14Ah (Lead Acid)

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Minimizing Dependency on Grid Power in a Residential Home with Retrofits

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Abstract

This paper proposes a model residential two-bedroom house with 100 m^2 of rooftop area retrofitted for cost effective storage and utilization of solar energy aiming to minimize dependency on utility power. It is a Win-Win model both for the consumer and the utility. This model will utilize both light and heat energy of Sun. A vapor compression-based freezer will produce ice in daytime, powered by Solar Photovoltaic modules through an inverter. The ice blocks made so will be used to cool the rooms later with an Air Handling Unit. Hot water requirement for bathing and cooking will be met through a solar water heater. A stand-alone Solar DC system will be retrofitted with DC lamps and fans for entire house. All these measures and reflective coating will make the model house economically viable. Also, the solar power is growing at a faster rate towards surplus energy during daytime; this model will become still cheaper and greener.

Keywords

SPV, light energy, Rooftop, heat energy, utility, retrofit, Solar AC system, Solar DC system, installed capacity, RE integration.

Introduction

In the transition period from fossil fuel to RE sources for power generation, there seems an imminent chaos in the grid management. Though the RE power is a small portion of the total power available now in India, the grid managers are struggling a lot every day for RE integration with simultaneous reduction in thermal power generation. The strategies are still uneconomical and in fact indirectly contribute to CO_2 emission. Till date, the base load in India is managed by the fossil fuel power plants and RE sources fail to make it for peak load. The installed capacity of RE is significant, but the energy generation is low. Since 50% of the energy demand is used to support indoor thermal comfort conditions in commercial buildings [1], this model house will help the utility manage the peak hour crisis as part of Demand Side Management. It will also give the consumer a comfortable living with ensured power supply for lighting, AC, and many essential gadgets, in addition to the savings in the utility bill.

II. DESCRIPTION OF APPROACH

Two rooms of size 3.5m x 3.5m x 3m are considered for air conditioning. Solar energy will be stored in a Phase Changing Material (ice) during daytime using Solar PV modules. Later, the ice so formed will be utilized for cooling the rooms using an Air Handling Unit, as shown in Fig. 1. However one room is considered to be air conditioned in daytime with conventional air conditioner using utility supply assuming least occupancy on week days.

The AHU will have a disposable pre-filter and a final filter rated in accordance with ASHRAE Standard 52. A thermostat operated switch for the AHU will control the temperature. Utility supply will power the AHU. During power failure AHU can be run from the solar AC system which is provided mainly to run the freezer.

A. Space load characteristics

The space load characteristics of the room are found as follows:

Fig. 2 shows the various cooling load components in the zone. Let us assume that the air to be cooled is at a temperature T_w Kelvin with relative humidity Φ_1. This air will be cooled by the Thermal Energy Storage to a temperature of T_a Kelvin with relative humidity Φ_2.

Transmission Loads Q_T *:* These are sensible heat gain through the floor, walls and roof and it may be computed using the relation,

$$Q_{T=}\frac{UxAx(T_w - T_a)}{1000} kWh/day \tag{1}$$

$U = Overall\ heat\ transfer\ co-efficient,\ W/m^2K$

$A = Surface\ Area\ of\ the\ roof, walls, ceiling, floor, m^2$

b. Internal Heat Load due to human beings Q_p *:* It is the heat generated by the occupants and is calculated as

$$Q_p = n_p \times t_p \times q_p \quad kWh/day \tag{2}$$

$n_p = Number\ of\ Persons\ in\ the\ space$

$t_p = time\ spent\ in\ the\ space\ per\ person, h$

$q_p = heat\ lost\ per\ person\ per\ hour, watts$

c. Internal Heat Load due to lighting Q_l :It is the heat generated in the buildings' interior by the lighting system and is calculated as

$$Q_l = \frac{n_l \times t_l \times \times w_l}{1000} \quad kWh/day \tag{3}$$

$n_l = Number\ of\ lights\ in\ the\ space$

$t_l = daily\ usage\ hour\ of\ lighting, h$

$w_l = power\ rating\ of\ lighting,\ watts$

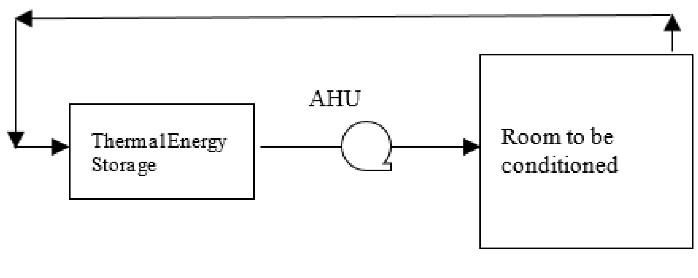

Fig. 1 Schematic view of the TES

d. *Equipment Load* Q_e *:*

It is the load due to the heat generation by any equipment in use and is calculated as

$$Q_e = \frac{n_e \times t_e \times w_e}{1000} kWh/day \tag{4}$$

$n_e = Number\ of\ equipments\ in\ the\ space\ t_e = daily\ usage\ hour\ of\ equipment, h$

$w_e = power\ rating\ of\ equipment,\ watts$

a) Infiltration Load Q_f *:*

This load is due to an infiltration of outside air through the use of doors and calculated as:

$$Q_f = \frac{n_v \times v_s \times e_n \times (T_w - T_a)}{3600} \; kWh/day \quad (5)$$

n_v = *Number of volume air changes*
v_v = *volume of space, m^3*
e_n = *energy entering per cubic meter, kJ/K*

b) *Total Cooling Load* Q_{tot} :

The total Cooling load is computed by summing all the above.

$$Q_{tot} = Q_T + Q_p + Q_l + Q_e + Q_f \quad (6)$$

B. *Determination of mass of PCM*

By applying the heat balance equation between TES and the space to be conditioned, the mass of ice to be produced is calculated using the relation,

$$m_{ice} \times L_{ice} = Q_{tot} \quad (7)$$

III. RETROFIT MEASURES

A holistic retrofitting approach is considered that includes reduced energy consumption, reduced capital investments, and envelope construction [2].

PCMs may offer an increase in a building's overall energy efficiency with little or no additional space required [3].

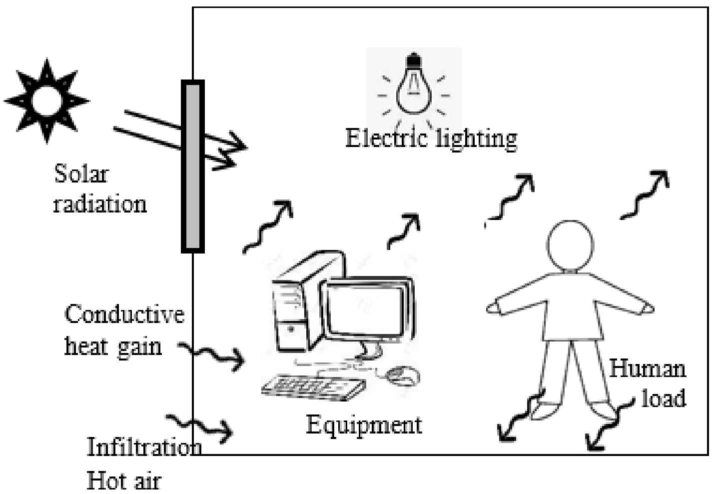

Fig.2. Cooling Load Components

A. *Retrofit No.1: Solar DC system*

A separate DC circuit will be developed for entire house with DC (LED) lamps and DC ceiling fans as shown in Fig.3. in addition to the existing AC circuit. Table No. 1 shows the powers of lights and fans and the energy consumed by them.

Thus, the energy consumed by the system is calculated to be 1080 Wh, as tabulated in table no. 1. For this energy requirement, the capacity of battery and charge controller are calculated as follows:

$$\begin{aligned} Energy\ Requirement &= 1080\ Wh \\ Rounded\ to &= 1200\ Wh \end{aligned} \quad (8)$$

a) *Battery capacity:*

12V battery is considered for this system, and its capacity is calculated as,

$$Energy = V \times Ah$$
$$= 1200\,Wh \quad \text{as per equation (8)}$$

$$\therefore Capacity\ of\ battery\ Ah = \frac{1200}{12}$$

$$= 100\ Ah \qquad (9)$$

$$Cost\ of\ battery = Rs.8000/- \qquad (10)$$

b) *Power of Solar Panel:*

Solar PV panel requirement is calculated using the relation:

$$Output\ power\ of\ SPV \times hours\ of\ generation = Energy\ generated$$

$$P \times 6\ hours = 1200\,Wh \quad \text{, as per equation (8)}$$
$$\therefore P = 200\,W \qquad (11)$$

∴ Solar PV panel of *200 W* is required for the DC system.

$$Cost\ of\ solar\ panel = Rs.8000/- \qquad (12)$$

TABLE 1 Energy consumption for various gadgets of solar dc system

S. N	Gadget	Power W	Running time h	Energy consumed Wh
1	DC ceiling fan for the hall	30	6	180
2	DC Ceiling fan for room no. 1	30	4	120
3	DC Ceiling fan for room no. 2	30	4	120
4	LED tube light for hall	20	8	160
5	LED tube light for Room 1	20	6	120
6	LED tube light for Room 2	20	6	120
7	LED bulb for Kitchen	10	6	60
8	LED bulb for Portico	10	12	120
9	LED bulb for Bath room / toilet	10	2	20
10	LED bulb for Verandah	10	6	60
Expected energy consumption *Wh*				1080

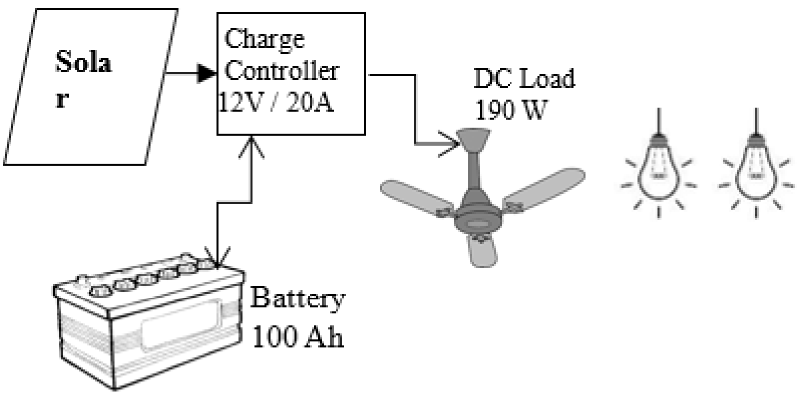

Fig.3. Solar DC System

c) *Rating of Charge Controller:*

Charge controller is chosen according to SPV output. The current output of SPV is calculated as follows:

$$Power = 200\ W \quad \text{as per equation (11)}$$

$$\therefore Current = \frac{200}{12} = 16.7\ A \qquad (13)$$

Hence, a *12V / 20A* Charge controller will be suitable.

d) *Cost of solar dc gadgets*

$$Cost\ of\ charge\ controller = Rs.1000/- \qquad (14)$$

$$Labour\ charges\ for\ DC\ system = Rs.10,000/- \qquad (15)$$

$$Cost\ of\ wires,\ connectors,\ Lighting\ arrestors\ and\ switches\ etc. = Rs.4000/- \qquad (16)$$

Total cost of gadgets = *Rs. 9850/-* (17)
as calculated in Table No.2.

$$\therefore Total\ cost\ of\ DC\ system = Rs.\ 40,850/- \qquad (18)$$

B. Retrofit No.2: Solar AC system

Solar AC system comprises SPV module, inverter, and battery. It will supply the main load (freezer) for making ice. Running and maintenance cost of this system is comparatively low compared with conventional Air Condoning Unit. A battery of optimal capacity connected to this solar AC system will smoothens the variations in SPV output. This system will also serve as an emergency supply for few gadgets such as TV, AHU blower, and laptop charging outlets etc. during a power failure, as shown in Fig. 4. The remaining heavy loads will continue to use utility power, to cut cost. Since most of these gadgets run only for shorter durations, utility power would be more economical.

Power requirement for freezer for making *m* kilogram of ice = *1000W (the mass of ice is found from Equation 7).*

TABLE NO.2 TOTAL COST OF GADGETS FOR DC SYSTEM

S. N	DC gadget	Rate in Rs.	Quantity	Amount In Rs
1	LED lamps	Rs.100	4	400
2	LED tube lights	Rs.150	3	450
3	DC ceiling fans	Rs.3000	3	9000
Total				9850

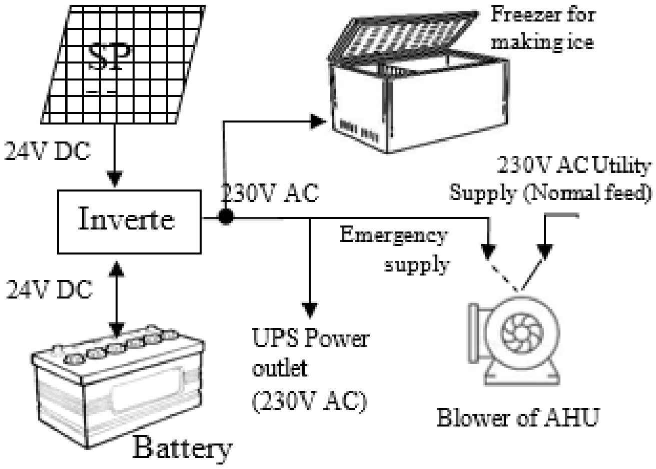

Fig. 4. Solar AC System

For other AC loads for which the system will run as an emergency supply, the power will be *350W* and the expected energy consumption is *700Wh* as per Table No.3. For this energy requirement, the capacity of battery and inverter are calculated as follows:

$$Energy\ requirement\ = 700\ Wh$$

$$with\ Safety\ \ factor\ \ = 1000\ Wh \qquad (19)$$

a) *Battery capacity*

24V battery is considered for this system. The capacity of battery is calculated using the relation,

$$Energy = V\ x\ Ah$$

$$= 1000\ Wh \quad \text{as per equation (19)}$$

$$\therefore Capacity\ of\ \ blower,\ Ah\ \ = \frac{1000}{24}$$

$$= 42\ \ Ah$$

Since the battery is available in the market with *12V, two 50 Ah batteries* are proposed.

$$Cost\ of\ \ batteries\ = 7000\ \ x\ \ 2$$

$$= Rs.14\ ,000/- \qquad (20)$$

Since the battery has to cater for the fluctuations in the solar input for running the freezer, a safety factor is introduced again.

b) ***Power of Solar Panel***

Solar PV panel requirement is calculated using the relation:

1) Power requirement for freezer = 1000 W (21)
2) For calculating emergency supply to the gadgets mentioned in Table no. 3

$$Energy\ Requirement = \ 700Wh$$

Assuming 6 hours of sunshine, the power requirement of solar panel for catering the gadgets,

$$\frac{700}{6} = 117\ W \qquad (22)$$

Adding (21) and (22),

The solar panel power requirement is *1200 W.*

Four 250W panels and one 200W panel are proposed.

The cost of all the solar panels

$$= 3600 + 8000$$

$$= Rs.4\ ,000/- \quad (23)$$

c) *Inverter for the system*

For a peak solar power output of 1200 W, a Sinewave Inverter of *1200 VA* will be sufficient.

$$Cost\ of\ the\ inverter = Rs.10,000/- \quad (24)$$

$$Labour\ Cost\ for\ the\ solar\ AC\ system$$

$$= Rs.10,000/- \quad (25)$$

Cost of wires, switches, fuses, lightning arrestor, connectors etc.

$$= Rs.4,000/- \quad (26)$$

$$\therefore Total\ cost\ of\ the\ AC\ system = Rs.\ 82,000/- \quad (27)$$

C. Installation of Solar Passive water Heater

Four occupants are considered for this model. A *200 lpd* capacity evacuated tube water heater will suffice for bathing and kitchen usage.

Expected cost of solar water heater along with the piping system and labor cost,

$$= Rs.35,000/- \quad (28)$$

D. Use of cool roof

Painting with white reflective paint for reducing solar heat through conduction,

$$= Rs.25,000/- \text{ for 1000 sq. ft} \quad (29)$$

IV. COST CALCULATION

A. *Capital investment*

1) *Total cost of DC system = Rs.40,850/-*
2) *Total cost of Solar AC system = Rs.82,000/-*
3) *Cost of Solar Water Heater = Rs.35,000/-*
4) *Cost of cool roof = Rs. 25,000/-*
5) *Cost of freezer = Rs. 25,000/-*
6) *Cost of the auxiliaries, blower, piping system, diffusers, ice storage = Rs. 7000/-*

Adding above all,

Rounded to Rs. 2,15,000/-

Cost savings for one air-conditioner = Rs. 40,000/-

Net investment = Rs. 1,75,000/-

TABLE NO.3 POWER AND ENERGY REQUIRED FOR AC SYSTEM

Details	Power
Freezer for making ice (Will run as long as the sun shines)	1000 W
Energy for the gadgets other than freezer for emergency supply	

Gadget	Power W	Running time Hours	Energy consumed Wh
Blower of AHU	200	2	400
TV	100	2	200
Other loads such as laptop charger, modem etc.	50	2	100
Total energy			700

C. *Energy savings and return of investment*

Total energy savings

= 19.2 kWh / day (30)

as calculated in table no. (4)

Cost of energy savings per day

= Cost of one unit X energy savings per day

= Rs. 5/- x 19.2 (assumed as Rs. 5/- per kWh)

= Rs. 96/- per day

Cost of energy savings per year

= Rs. 96/- X 365 = Rs.35,040/-

Return of investment

= Capital investment / Cost of energy saved per annum.

= Rs. 1,75,000/- ÷ Rs. 35,040/- = 5 years

However, for every 5 years the batteries may have to be replaced with new ones. The savings in cooking by hot water utilization is not considered.

V. ANALYSIS AND DISCUSSIONS

The unbalance between the day time surplus solar energy and the shortage of energy during peak hours force the utilities to ramp up and down the thermal power plants which are not designed for such load variations. A thermal power plant cannot run without oil support with less than 50% load. As a result, the per unit CO_2 emission increases as the load factor reduces.

A base load plant is forced to run as a peak load plant. This reliable and economical micro level system will reduce the burden of utility by daytime storage and peak hour utilization of the stored energy at large scale.

Fig.5 shows a typical curve of power consumption in a day with and without TES. It is clearly seen that the peak load is flattened distinctly.

TABLE NO.4 TOTAL SAVINGS BY PROPOSED SYSTEM

S. N	Details	Quantity	power, W	running Hours	energy, Wh
I. Energy consumption for the retrofitted gadgets					
1	AHU blower (additional energy due to retrofitting)	1	200	12	2.4
II. Energy savings due to retrofit					
1	Energy saved after changing the AC ceiling fans into DC ceiling fans	3	40	5	0.6
2	Energy savings in utility supply to air conditioners	2	1000	10	20
3	Energy saved in utility supply to Geyser The home is assumed to be using LED light fittings)	1	1000	1	1
	Total savings in energy in kWh/day				19.2

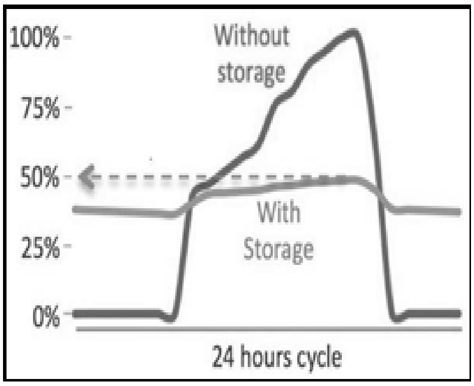

Fig. 5. A typical curve for power consumption in a day with & without Thermal Energy Storage System.

VI. Conclusion

The proposed model is a Win-Win situation for the consumer and the utility.

A. *From the consumer side*

- Uninterrupted power supply for lightings and fans and emergency supply for some of the essential gadgets.
- Air conditioning is provided with low investment.
- Air conditioning is ensured during peak hours and during power interruption.

B. *From the Utility side*

- Energy generated is utilized locally and hence line losses are drastically reduced.
- Reduces the peak hour burden.
- Provides load for the envisaged surplus daytime solar power.
- Harmonic generation is reduced at the micro level. (Consumer End)

This is a less automated system which avoids investment in additional gadgets. But this may require some basic skills for using change over switches etc. from the user.

ACKNOWLEDGMENT

We would like to express my sincere thanks to Er. S.E.S. Syed Ahamed, M.E., Chief Engineer, IC, R&D and DSM, TANGEDCO and Er. K. Chandra Sekar, B.E., Superintending Engineer/P&A, NCTPS, TANGEDCO for their encouragement and valuable inputs. I would like to thank all the members of TTI&RC for their co-operation extended during the work.

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Electricity Distribution Utility

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Abstract

Power Utility Industry throughout the world including India is undergoing considerable change regarding structure, operation, and regulation. In India, after enactment of Electricity Act'2003, the power sector is going through a substantial amount of change; unbundling of the value chain, opening up the sector to competition by creating the right environment has been a priority of the sector reforms for formation of deregulated power market for improving the operational efficiency and make electricity distribution business specially financially viable thru reduction of AT & C loss and Gap between ACS (Average Cost of Supply) and ARR (Actual Revenue Realization) within the justifiable range in line with the bench mark of best performance Electricity distribution sector in India . In this scenario, a Smart and effective Energy Auditing system (EAS) is required to account the energy flows through various feeders, transformers, substations, or various electrical equipment of network systems with the support of Smart Metering Architecture i.e., AMI Architecture, SCADA and GIS (Geographical Information System). Such auditing and accounting shall provide precise accounting of the input and output of energy for any desired time to monitor and control the energy flow across value chain of Electrical Distribution system by building many analytics with the help disruptive technology like AI (Artificial Intelligence) and ML (Machine Learning) Technology. The system shall be capable of providing customizable management reports and interactive dashboards of identifying gaps in the energy supply, consumption trend analysis, segregation of technical and commercial losses area/voltage level/ network segment wise for any specified. This will not only help utility engineers to identify the potential problem area but also help to further drill down to reach the root cause of the problem for making corrective measure to improve overall health of the utility.

Keywords

Energy Accounting & Auditing, Energy Management, Smart EAS Solution, Technical & Commercial**.**

1. Introduction

The aggregated Technical and commercial losses (AT&C) are currently at an unacceptably high level in the Indian Electricity Distribution system and one of the objectives of the solution is to provide a detailed area/voltage level/network segment wise smart energy accounting and auditing system thru integration with CIS , Energy Billing, SCADA, AMI (MDM),and GIS system to provide a user-friendly analysis for efficient monitoring and taking appreciate actions to reduce technical and commercial losses for reduction of gap between ACS (Average Cost of Supply) and Average Revenue Realization (ACS) to improve the overall efficiency of Utilities as well as financially viable..

2. Features of Smart Energy Audit System

- The system shall be primarily developed for power distribution utilities of India
- Configuration of the system shall be made suitable from different regulatory requirements across different utilities
- There should not be any hard coding in the system.
- The system should be flexible to integrate with the CIS, Consumer Indexing, SCADA, GIS, AMI Systems
- The system should be flexible to interface with the existing Billing system

- The system should have inbuilt technical loss calculation library which can be changed or configured as per requirement.
- The system design is such that it can be easily interfaced with external system as discussed under interface requirement section of the document.
- The system should have the robust functionality to meet the Energy Accounting and Auditing requirements of different Indian Utility companies under various government program under RAPDRP/RDSS etc.

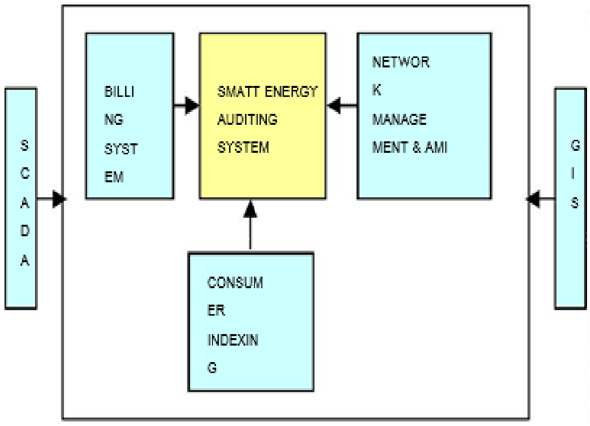

Fig.1 Interfacing Architecture of Smart EAS system

3. INTEGRATION OF SMART ENERGY AUDIT SYSTEM

a. Role of CIS / Energy billing system in Smart EAS

One of the major roles provided by CIS and energy billing system is to provide an account for the 'billed energy' in the specified time for which the energy accounting activity is being performed. This will be a guiding factor to deduct the commercial loss of the distribution system and thus help in calculating the AT&C loss figure. In the Indian distribution scenario, consumer billing is normally being done on monthly basis and the system keeps a monthly record of energy consumption against a consumer. With the adoption of the indexed consumer database, a consumer can easily be mapped with his/her electrical address (Substation / HT Feeder / DT/ LT Feeder/ Pole etc.) and thus the aggregation of the consumption data can easily be performed at any EAS policy level (feeder wise, DT wise etc.).

1. Though all the consumers are billed in a specified billing period (a specific month for the monthly billing scheme), their meter reading date are not same as the reading cycles differs from one group of consumers to other group of consumers. The aggregated consumption figure directly taken from the billing system does not depict the true picture in terms of consumed energy.
2. The billing cycle for the distribution utility may or may not match with the energy accounting cycle.
3. Both factors can be tackled by adopting daily average consumption computation method and multiplying the aggregated daily consumption of the group of consumers (under the scope of energy accounting) with the number of days in the energy accounting cycle. Consumption figures for the current month (from CIS / Billing system) as well as
4. historical consumption figures (from consumption history database) are used to calculate the average consumption in daily basis. Different offsetting and prorating algorithm can be used to attain further accuracy.
5. With the introduction of smart metering system (also gaining popularity in Indian distribution

sector) accurate consumption data at a specific interval (half hourly or 15 minutes date) can be obtained and accurate computation of the consumption figure is possible for any accounting period overcoming all the challenges mentioned above.

b. Role of SCADA/AMI system in EAS

The Main Objectives of the SCADA / AMI system are as follows:

- To acquire and monitor the Real time electrical parameters of each energy transaction points for automated Energy Accounting and auditing each feeder, Substations & DT (Distribution Transformers) level.
- Data sharing with the office of CEO, Operation & Maintenance staff for effective monitoring and energy Management.
- Information obtained from the Substation, Feeder & Distribution transformer & consumers.

c. Role of GIS enabled Consumer Indexing & Network mapping:

GIS technology can be effectively used for correct marking of the various Distribution Circles on Geographical Area Map. GIS mapping of Sub transmission and Distribution network from 66kV or 33 kV substations down to LT feeders becomes handy in proper identification, locating and documenting of electrical network assets. All the existing connections and consumer details can be graphically displayed on the GIS map linked to the database. The mapping of electrical network on GIS base maps and linking with the indexed consumer database is a multi-step process:

- Develop Database of Electrical Network from 66 KV /33 kV to LT System with related parameters of Lines, Substations and DTs
- Develop Consumer Database based on the Physical, Electrical and Commercial parameters of the consumers and linking them on GIS map
- Segregation of Consumers - 11 kV Feeder-wise and Distribution Transformer-wise - to evaluate energy supplied, billed and system losses with rendering and visualization on GIS map
- Superimposition of GIS-based Network and Consumer mapping database on a scale of 1:4000 or better
- Evaluation of feeder-wise and DT-wise Energy Losses, correlating with load flow studies and their depiction on GIS map Mapping and Indexing of Electrical Consumers

The purpose of GIS Mapping and Indexing of the consumers is to identify and locate all the consumers on geographical map, which are being fed from the Distribution Mains. There may be cases where electric connection exists, but it does not exist in the utility’s record. It may be a case of unauthorized connection.

On the other hand, there may be cases where a connection exists in the utility’s record, but it may not exist physically at site.

Following reasons could be attributed for such anomalies:

- The connection might have been disconnected long back but the record may not have been updated.
- It may be a case where the address and other details of the consumers are not correctly recorded.

Using GIS, the LT lines coming out from Distribution Transformer and all service connections from the LT mains can be checked with reference to the consumers connected and accordingly the consumer database can be updated. Mapping and documentation of Electric Network

The complete electrical network and network route are digitized and mapped on suitable scale over the base map, using suitable GIS software, so that the change in the network can be timely and correctly updated on a periodic basis.

Through software application, queries can be generated to find out the network details like the make and specifications of network elements, the length of feeders and LT conductors, number of transformers of the network.

The network database should have the important details of 66KV/33 KV substations, 11KV feeders, DTs, and LT lines. Feeder-wise and Distribution Transformer-wise consumer segregations to identify the areas of high losses, it is essential to segregate the energy input and consumption Distribution Transformer-wise and 11 KV feeder-wise.

The losses are assessed by subtracting the total energy utilization of the consumers from the energy supplied to the respective DT and 11 KV Feeder. Using GPS-based survey of 11 KV feeders, DTs and LT poles, the connected consumers can be identified on the GIS map and segregated Distribution Transformer-wise and 11 KV feeder-wise.

4. Functional Specifications OF smart energy Audit solution

The solution is based on statistical process for energy accounting of the electrical network, separate database for assets, location and customer should be one of the features.

The energy accounting and auditing solution should be dynamically linked to the customer data base (billing system) through Consumer Indexing and shall consider all the charges in the network and connected customer time to time.

It should be possible to obtain a comprehensive view of the customer via a single database used to store and access critical account and service data. For calculation of ATC (Aggregated Technical & commercial) losses the changes that take place in the feeding arrangement of the network and connected consumers should be considered.

For the purpose of energy accounting relevant metering data of all the incoming and outgoing feeders from 66KV/33 Substation and distribution transformers has to be available to system.

The figures of import and export of energy through any segment of network during a particular period and figure of energy billed accounted in respect of the connected consumers during the same period will enable calculating AT & C loss of the system.

The application shall be such developed that it can be deployed at various administrative and functional offices (e.g., subdivision, division, circle offices etc.) of the utility.

It should serve the loss requirements of various levels Like Substation wise, Feeder wise or transformer wise.

The proposed Energy accounting system shall contain the following 5 modules:

- Utility Details
- Metering

- Meter Reading
- Network Management
- Audit and Loss Analysis Module

1. Utility Details:

This module captures all relevant information regarding the utility (including the type of Utility) including all the administrative and functional segments.

The basic information about the organization, its administrative hierarchy level, geographic spread (e.g., section, subdivision, division etc.) shall be available, as also the information regarding functional segment like number of various electrical network under a particular administrative level. This module would also give us the type of Power Purchase agreements entered with external Utilities.

Process 1.1 Utility Information:

Entering Relevant Utility Information: As outlined previously, this process would be responsible for capture of all relevant Utility information including basic information like the type of Utility, its geographic spread, no of sections, divisions, subdivisions. This information is necessary for accurate information regarding Energy Balance reports.

List of Inputs:

Data from Utility to be entered in the system. Organization Name, Address, mailing Address, contact Number; email address, etc. Utility Administrative details mentioning the hierarchy level, its name and number. The functions of each administrative segment should be mentioned along with the network hierarchy under this segment.

Process Outputs:

- Acknowledgment indicating generation of utility code. Regret message-giving reasons – existence of utility details, code, and administrative and functional Segments.

Process 1.2 Power Exchange Point Details:

External Utility Details:

This process captures all the relevant information regarding the external supply feeding point to a particular Utility network for which the energy accounting and auditing solution will be applied. This should consist of details about the external grid supply point, the external supply agency, the contracted capacity, the validity and type of the contract, its details, number of incoming feeders, outgoing feeders, their voltage level, grid inter connection points (e.g., for import or export of energy).

List of Inputs:

- Name, Address, Company_ID of the External Grid supply Point from where power import/export takes place.
- No of Incoming circuits along with voltage level
- No of Outgoing circuits along with voltage level The Contractual Capacity.
- The validity and type of contract.

List of outputs:

- Acknowledgement indicating generation of External Utility code. Regret letter giving reasons – like non-existence of Company_ID, contractual capacity.

- Power Exchange point details.

1. Metering:

Process 2.1: Meter Movement

Meters delivered at stores are subject to acceptance tests and upon clearance are entered in the meter database. All onsite and off-site tests conducted on the meter are to be recorded from the meter test reports in the database. Installation of the Meter or removal thereof from the body of the equipment to be audited is to be recorded from the meter sealing certificates.

List of Inputs:

From manufacturer test certificate –

- 10-digit meter serial number Purchase Order number Manufacturer's name
- Category- Direct, CT operated, CT/PT operated TVM/ Non TVM
- Meter specification - single/ poly phase; capacity and accuracy class.
- Type – electronic / electromechanical Date of delivery at stores from the challan
- From the Sealing Certificate –
- Date of installation / removal, consumer number, bill number, multiplying factor, dial factor, CT/PT Serial number and ratios, reason (and sub reason) for installation (New Connection /load change/ replacement with defective or burnt meter or others) / removal – PD /load enhancement / Defective / Burnt or others.
- Opening/ Closing readings (kWh, kVArh, max. demand, TOD registers)
- From the meter test reports- date of testing, % error, readings at the time of testing and meter testing personnel code.

Process Outputs:

- Update Meter database
- Update Application database
- Report on meter installations for each reason – Meter No. Equipment,
- Date of installation,
- Report on meter removals for each reason –
- Meter No. Equipment, Date of removal,
- Reasons Meter History
- Report on Meter Testing – Meter No., Date of testing, Meter makes, Percentage Error, Accuracy Class, Installation details – Equipment and location
- For all cases in a given period
- For cases exceeding permissible limits in each period. Vendor wise meter failure report – Meter No. Make, PO no., failure reason, Period of service (Date of removal –date of delivery)
- Inventory report for determining number of meters in circuit and off circuit- Meter Type, total number of in-circuit meters, off circuit meters,
- Schedule for meter testing for a given period – Meter No. Equipment,
- Last testing Date, % Error from meter database
- Name Address and Load from Consumer Database Consumption pattern for last 3 billing periods (Configurable in system) from the Billing database.

Process 2.2: Meter Replacement:

Any replacement of meter arising due to changes in load, defective meters / burnt meters shall be accompanied with date of replacement, closing, and opening readings, MF, Dial Factors and other sealing details in the Sealing Certificate.

Entry Screen should be available in the Meter Movement module (installation details). In case of burnt or sluggish meters, a provision for debit adjustment for the next audit metering cycle may be made for sluggish or burnt meters.

List of Inputs:

Data from Meter movement module – Closing reading and date of old meter and opening reading, date and MF of new meter. Debit adjustment for sluggish or burnt meters.
Process Outputs:
Update meter change details in Meter database Update debit adjustment for next Meter reading period.

Module 3: Meter Reading
Basis system feature for obtaining meter reading would include Interface capability with SCADA/Meter Reading Instrument (MRI) data for uploading meter readings. Interface capability with Automatic Meter Reading (AMR)/ Smart Metering (AMI) devices.

Capability of capturing meter reading data from a Meter Reading Book in case of manual reading system. Ability to cater to changes in the metering cycle. Metering in certain cases maybe hourly, daily, fortnightly etc.

Process 3.1: Maintain Reading Schedule

The system generates a meter-reading itinerary at for all locations where audit meters are installed using the number of meter readers available and the Audit equipment where the meter readings are to be taken.

The frequency of these itineraries can be weekly, fortnightly, or monthly. After itinerary generation, it is sent to the department, which may be expected to manage these readings.

Process Outputs: Location specific reading itinerary Dispatching the above to the local SBU Unit of the concerned department.

Process 3.2: Capture and Validate Meter Readings Depending upon different mode of meter reading as described above, the system should be able to capture and store the readings to populate the reading data store of the application. For SCADA or MRI or AMI interface the application will accept flat file input in a pre-defined format. For manual input, the entry screen is provided to capture manual readings.

After reading data is captured, the system should generate an Exception Report highlighting possible inconsistencies in the metering data. Reading exception list specifying the range of consumption variation (based on average consumption per day) can also be generated.

The system provides the facility to review the metering data. In case any discrepancy is found, the system will allow the data to be edited, with proper access rights and audit trails.

List of Inputs:

- Group wise readings for current month in a flat file or manual entry of meter reading having Equipment ID, present readings, reading dates, remarks and meter reader code
- Average consumption per day of last 3 audit cycles (configurable in the system) with firm readings. Range of permissible variation for generating exception list.

Process Outputs:
Exception list for variation in consumption
List of cases with remarks Meter Mismatch, Not Read because Meter not traceable, Meter not accessible and Meter faulty.

Group wise / Meter Reader wise performance reports – Total Meters to be read, No. Of Meters Read, no of reported Meter Mismatches, Meter Faulty.

Module 4: Network Management
This module deals with the mapping of Electrical Assets in the electrical network of the Utility. In other words, the scope of this module includes mapping the Poles/ Feeder Pillars to the Distribution Transformer, the Distribution Transformer onto the HT feeder, and the feeder onto distribution Station and finally onto the substation of the Transmission network.

Process: Asset Mapping

The asset to be mapped is first selected, and then the asset to which the previous asset is to be mapped is selected.

List of Inputs:
- Equipment type, as to whether it is a transformer, substation, Pole
- The Equipment location.
- The Voltage level of the equipment from the different voltage levels.
- The Asset to which this equipment is to be mapped into

Process Outputs:
- The selected asset mapping details The Asset mapping history

Module 5: Audit and Loss Analysis

Functionalities covered under this module include the total audit and loss trend analysis of the Utility network for a specified time period

The audit and loss analysis may be applied to any Network component or to a particular administrative segment of the Utility. The system should be capable of segregating the technical and the commercial losses administrative section/ area wise, voltage level wise/ asset wise. It should be able to compute the aggregate technical and commercial loss (as defined by the regulatory body). It should also be able to estimate the consumption profile of each network segment of the utility and provide an insight into the losses.

This system shall be capable of providing customized management reports, identifying gaps in the energy accounted, consumption trend analysis, segregation of technical and commercial losses area/voltage level/ network segment wise for any specified duration

Process 5.1: Loss Analysis

This process deals with the depiction of the Technical Commercial, and the Total loss (i.e., the aggregate technical and commercial loss) for a specified period of time.

List of Inputs:

- Equipment Id, Administrative level, voltage level
- Audit Cycle.

Process Outputs:

- Technical loss for the audited area, equipment for the above audit cycle
- Commercial loss for the above in MU or percent)
- Aggregate Technical and Commercial (ATC) Loss

Process 5.2: Audit Result reporting and trending

This process takes care of customized management reports regarding technical, commercial, and total losses for an audit location / asset for a particular period. The System should also cater for trending of the losses/ energy consumed over a period of time as may be specified by the user

List of Inputs:

- Audit device/ Audit location
- Report choice- Energy consumed or Loss Specified time period
- Loss category- Commercial, Technical, Total Process

List of Outputs:

- Loss analysis reports location/Voltage/ equipment wise for a particular period
- Energy consumption reports location/Voltage/ equipment wise for a particular period.
- Loss and Energy consumption trends.

5. Conclusion

With the help of Smart Energy Auditing System following reports can be generated in regular interval for better energy monitoring & management of energy to improve the operational efficiency as well as improve the financial viability of the utility service provider:

- Area wise/voltage wise /feeder wise/DT wise technical & commercial loss
- Consumption trends of different consumer base along with their consumption pattern
- Details of Input & output of Energy of Substation, Feeder & Distribution Transformer • Finally Identification of potential energy loss areas both technical as well as commercial

6. Acknowledgement

The authors are grateful to the Energy and Utility Competency Group of Virtuoso Consulting in India and UAE, and Business Solution Innovation Group of Virtuoso Consulting in UAE.

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250 Million Smart Meter ROLLOUT AND ROAD BLOCKS (TPCODL Case Study)

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ABSTRACT

Since 2016, with publication of National Tariff Policy 2016, Smart Meters have been made mandatory for all consumers with consumption > 200 units per month. Since then, utilities are working on deployment of Smart Meters using various strategies and funding schemes. There have been various other Gazette Publications issued from time to time for clearing the roll out strategies and making deployment simpler. The paper highlights the roll out process being followed in TPCODL and Challenges being faced while deployment of AMI. It will also touch regulatory framework which are conducive for deployment of the AMI project and where challenges are being faced for full scale deployment. This paper will also cover to some extent consumers' aspect on deployment of AMI.

INTRODUCTION

National Tariff Policy, 2016 along with IS16444 has carved the path for introduction of AMI and Smart Meters in India. Prior to this there was no mandate for deployment of Smart Meters and Small POCs were going on in various parts of country. The said policy has helped Tata Power Delhi to implement one of the first large scale deployment of Smart Meters in country. There were many uncertainties, what should be scale of deployment, areas of deployment, communication technologies, skill set to be developed, manufacturers who can support, consumer engagement, benefits to utilities and consumers. These questions were answered and project was started taking shape in terms of tender document followed by procurement cycle and thereafter deployment. The learnings from this project have paved the way to deployment of Smart Meters in TPCODL. Various aspects have been reviewed again, all the questions have been answered again and finally a tender document has been drafted. Strategy has been finalized and entire supply chain has been divided in 2 Parts. Meters, Communication and HES has formed one set and lead bidder for same had been finalized as meter OEMs. Second tender was MDMS, Integration with TPCODL IT OT systems and Upgradation of SAP for handling billing. Communication was decided as 4G out of all available technologies. Why these decisions were taken will be discussed in paper.

2. DESIGN FINALISATION AND PLANNING (ROLL OUT)

AMI consists of following components: 1. Smart Meters, 2. Communication Media, 3. Head End System, 4. Meter Data Management, 5. Billing System, 6. Operational Technology Integration for Use cases other than Billing, 7. Mobile Application for Consumer Engagement, 8. Mobile application for Material

Management and Meter Installation controlling, 9. Training Modules for Executives, Non-Executives, BA staff and Core Team handling Project.

Major Decision is how to make packages of the above-mentioned modules. This decision is dependent of following enablement: 1. Skilled Manpower available for integrations of all components in utility, 2. Products are available with Single OEM, 3. Cost of the Components, 4. Dependency on the AMI component (if can be replaced with negligible cost), 4. Long term impact, 5. Demographic conditions, 6. Regulatory framework applicable in state. 7. Global Sociopolitical Environment. 8. Pandemic environment

a. **Smart Meter:** Smart Meters are being manufactured by many leading manufacturers in India as per BIS guidelines. When the work was started in Tata Power Delhi, BIS certifications were not available, unlike then, now most of manufacturers are having BIS license for the product and for required communication technologies. Sufficient skilled staff are available in industry to manufacture Smart Meters with full range of applications as are desired from Smart Meters, which 2 years back were under development. e.g., Provision of converting Meter from Forward metering to Net Metering was specific demand for which development had to be done, however now it is given from day one of supply of meters. Some OEMs are also working on having forward integrations by developing in-house HES for receiving data from meters. Smart meters constitute major cost of the project, and since all the inputs are coming from meters it is most important part of entire roll out plan. Another important factor which makes meter most critical part is, meter is having interface with consumers and meter cannot be replaced time and again as this leads to resistance by consumers.

b. **Communication Technology:** Communication is lifeline of the entire project. As of now 2G, 4G, NBIOT, RF, PLC technologies are available in market. TPCODL has evaluated all the technologies and has narrowed down to **4G preferably with fall back on 2G**. So, three TSPs have been finalized for the same and are being given Purchase Orders. This has been done to ensure maximum communication coverage of TPCODL area. TPCODL comprises largely of Rural belt with remote areas, forests, hill, and Coast line. NBIOT has not been selected for 2 major reasons i) OEMs are not ready with NBIOT compliant Meters for all required variants, ii) All TSPs are not offering NBIOT communication network in TPCODL area. **Radio Frequency** in ISM band with frequency range of 865-867 MHz has been reviewed, this communication technology network needs to be set up and maintained by utilities. Since TPCODL falls in cyclone prone area and every year there is probability of cyclone, setting of own networks is not feasible. Network along coastline up to 50 KMs can be damaged by cyclonic winds. Moreover, many places are very sparsely populated thus DCUs will not be utilized to their full potential, leading to wastage of resources. **PLC Technology** is where meter uses its own power line for sending communication. This technology works well when there are minimum joints in the service line. Further, as the signal travel through LT line, it will stop at LT side of transformer, thus on every transformer, there must be a DCU which increased the count of DCU and thus the cost of installation and maintenance. Converters are available to shift the signal from LT side to HT side of transformer, still, this adds additional equipment in circuit and thus effects the reliability of signals. In typical network, where there are joints, this method of communication taken lot of efforts to commission. In addition, in distribution utilities we are not having PLC experts as it is not deployed at large scale.

c. **Head End System (HES)** is supplied by various OEMs across the globe. This Application is used to receive and keep track of meter data. This application ensures that data of all the meters is received and pushed to next stage, if any data is not received, same is pulled from the meters and then passed on to the next stage. HES is responsible for interacting with meters for getting data, programming meter etc. In TPCODL, HES has been deployed from an OEM who already had integration with various leading meter OEMs and with this came an added advantage of quick integration and thus the results come faster. Any HES which has not been integrated with meter OEM may take longer time for integration and thus results from meter deployment will get delayed to that extent.

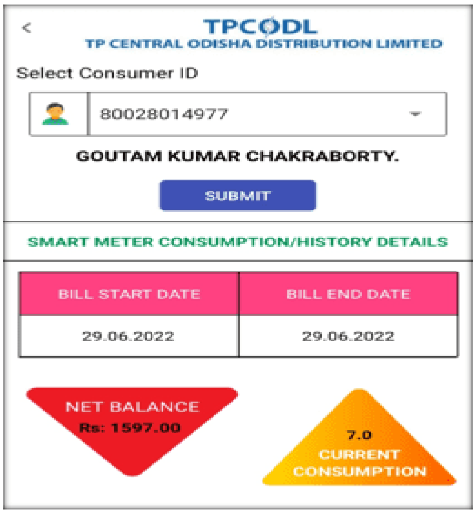
d. **Meter Data Management System (MDMS)** is the brain of entire system which receives the data of all the meters from HES, processes it and then feeds to various systems including Billing system, Revenue protection systems etc. TPCODL has taken a decision to deploy 2.0 lac Smart Meters which includes all 3 Phase meters, Single Phase Government Meters, and DT / Feeder Meters. This decision has been taken due to regulatory condition whose details are mentioned in challenges part below. Considering small scale of installation, TPCODL has decided to deploy in-house solution of MDMS which has already been deployed in other Tata Power company and has given desired results. Since this is in-house solution, there is flexibility of making required changes as per the need arising and integration with various IT OT systems based on use cases. Global products though are reliable in terms of handling data, at the same time, making changes on need basis is very time consuming as changes are made on global platform and on the basis of available resources. If change request handling is not addressed in tendering stage, it may be very costly as well. However, now a day, OEMs are giving India specific patches to address the change requirements faster.

MDMS Screen showing communication rate

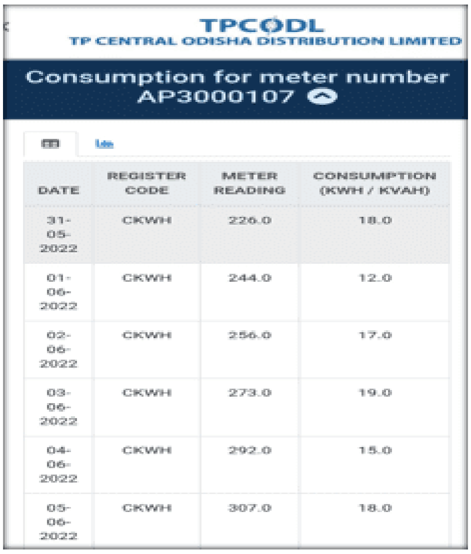
e. **Billing System Alignment:** In TPCODL billing engine is SAP for all Three Phase cases and for Single Phase Domestic consumers spot billing is used by integrating it with OCR application. To integrate SAP with MDMS, SAP AMI license has been used. For all upgradations as required for deployment of AMI, in-house resources have been deployed and has been completed in less than 2 months' time.

f. **Other Use cases** like integration of GIS is being done for Energy Audit, Outage management system etc. is also envisaged and is under deployment. Revenue Protection is another use case of MDMS, loading of transformers w.r.t. rating, over loading of any meter, checking of voltage on any feeder is another use case.

g. **Mobile Application** for sharing data with consumer is a mode of engaging consumers. Mobile App has been developed to show daily reading, daily consumption, left over Balance, last 7 days' consumption, 15 min interval data of KWh. This helps consumer to monitor its daily consumption and can see by when the current balance will last, thus, consumer can recharge in time or can control the consumption.



Current Balance & Consumption Details



DATE	REGISTER CODE	METER READING	CONSUMPTION (KWH / KVAH)
31-05-2022	CKWH	226.0	18.0
01-06-2022	CKWH	244.0	12.0
02-06-2022	CKWH	256.0	17.0
03-06-2022	CKWH	273.0	19.0
04-06-2022	CKWH	292.0	15.0
05-06-2022	CKWH	307.0	18.0

Daily Reading & Consumption for last one Month

h. **Mobile Application for Meter Installation Monitoring** is another application which has been developed in-house. This application is tightly integrated with SAP and parameters like old meter number, old meter reading, old meter remarks, New Meter Number, New Meter readings, Seal no's, Cable length and Size all are captured from site and pushed to SAP for regularization of the meters & consumption posting of material. This helps in immediate updation of database and final bills of the old meter is also generated. Mobile app is also enabled for capturing various pictures of the site like old meter pic, new meter pic, cable sag, house where meter is installed along with Latitude and Longitude capturing. Material reconciliation will also be part of use case of this application. This application will help in paperless work as Service order will be mailed to the consumer over email ID or through a link in SMS.

i. **Training Module** is designed for all the Staff members of TPCODL, there will be 2000-man days (appx) of training to educate entire Executive, Non-executive staff including outsource staff of metering team for the part they have to handle. These training modules are covering features of Smart Meters, HES, MDMS and the way it will be deployed in TPCODL. Call center staff are given trainings on how to handle queries of consumers and guide them on the way forward and making payments. Other front-end staff are also taught how to make payments and how to check their consumptions. Metering team is given training on how to install meters with which communication can be maximized. Executive are educated about the regulatory framework based on which this project has been made mandatory and other sequence of deployment of project. After start of the project, second round of training will be done to refresh and to update the modifications done in the project. Field level experience will also be covered as will be collated from various on the ground experience.

1. CHALLENGES AND WAYOUTS

No project is executed without challenges and way out for same. While deployment of AMI project following Challenges have been faced. a. Finalization of Smart Meters specification with required data set and getting those data sets provided in Smart Meters. b. Push mechanism implemented in 4G technology of meters. c. SLA compliance finalization with TSPs. d. large lead time in delivery of Hardware due to global crises of microprocessors, e. Delay in supply of meters due to global crises of components of meters. f. Multiple systems deployment in parallel, 6. Regulations still under alignment for supporting Prepaid Systems, g. Payment gateways alignment for prepaid system, h. Government consumer's payment system designed as per postpaid billing i. Tariff not cost reflective for 100% deployment of Smart Meters. j. Internal policies alignment for the system to be shifted from postpaid to prepaid. k. Change management in Employees. L. Other Challenges

a. **Smart Meters Specification and data model :** While finalizing the specification of meters data set has to been designed to make the meters data suitable for billing under regulatory framework, Revenue protection and other IT OT applications e.g. ToD parameters have been asked for in Monthly and daily push data, Meter Serial Number has been asked as a mandatory field in all data sets which is not a regular data parameter and is made master key, whereas earlier NIC serial number was master key and on replacement of NIC this was leading to updating wrong meter data against a connection, additional parameters over and above IS have also been asked for with utility specific or manufacturer specific OBIS codes.

b. **Push mode of communication for critical data sets in 4G communication mode** has been asked for to ensure increased communication rate. Earlier all the data communications were on pull basis where in HES was sending commands to meters for pulling data. This increases the count of commands to double the numbers. Considering geography of TPCODL and rural belt, this could have hampered communication rate. Further, to take care of the data which is not received in HES on push mode, schedulers have been designed to pull the selective data of meters. Thus, Push mechanism has been deployed successfully with support of meter OEMs

c. **SLA compliance** for communication technology has been finalized after multiple rounds of discussions. One of the major issues was to ensure 100% coverage of consumer base which was not possible with one TSP in place, so services of all TSPs on 4G technologies have been ensured for. However, after multiple rounds of discussions, SLA has been committed on best effort basis, which indicates that there may be vulnerability in terms of coverage of all the consumers. However, after review of all the available options for communication, this was the best available option as on date and another major factor was communication technology obsolesce, where 3G has already lived its life cycle, 2G is vulnerable, 4G has just come up and is expected to stay for at least next 5 years and may become fall back after deployment of 5G communication mechanism. This becomes a critical factor in sustenance of project.

d. **Large Lead time in delivery of hardware** due to global crises of Microprocessor chips has pushed the project back. The lead time has increased from 6 weeks to 16 weeks and that too not sure. With no clarity on timelines, project team decided to move ahead with placement of tender for supply of hardware and start development of the system, as production system had to be rolled out, it was decided to roll out application on development hardware (which was allocated from existing hardware in utility) and there after production application will be migrated to actual production hardware once same is delivered and installed. With this decision, production applications were rolled out and meters installation started in timely manner, but at the same time, vulnerability in terms of deploying patched directly on production was there. However, with supply of hardware for production, now Production, Development and test environment have been put in place and delay has been curbed.

e. **Delay in supply of meters due to global crises of Microprocessors** has badly hit the project. Being third year of takeover in TPCODL, there are target for AT&C losses and Capitalization, in which AMI deployment had to play a major role, however, as there were global crises in supply of components like microprocessors, supply of meters got delayed by 6 months and this has led to delay in deployment of the meters. To compensate for this, additional teams have to be deployed for installation of meters in consumers, DTs, and Feeders. Since this is initial stage of deployment of AMI, second source of supply of Smart Meters is also not existing which in general is ensured to keep supply chain risk low. However, since there were global crises, so another source may would have of little help. Second source of Smart Meters is being worked upon to ensure seamless supply of meters.

f. **Multiple Systems being deployed in parallel as** TPCODL has taken over central part of Odisha for power distribution, so revamping of numerous IT OT systems was in progress**.** This has led to multiple challenges like sharing of IT resources, so dedicated resource for development of the system was not present leading to delay in deployment of the HES, MDMS and Billing system upgradation. Further, training of employees to use these new systems was another concern and thus has added to difficulty level in making officers acquaint to these systems. To address this challenge, training coordinators have been deployed and multiple rounds of training have been done.

g. **Payment gateways alignment for prepaid billing** as the payment systems are designed largely for postpaid systems where payments are received against a bill, so when TPCODL moved to pre-paid mode only RTGS, Cheque and case mode of payment was working and other avenues of payment were not aligned. Another issue was that even if some consumer wants to make payment through website of TPCODL, multiple times payment for a Consumer Number in a month through specific payment gate way was not allowed. If some consumer wants to make payment more that last bill due amount, it was also not allowed. To the top of it, since TPCODL has decided to work on pre-paid mode of billing, if supply is disconnected, on receipt of payment supply should get connected immediately, however payment gateways were taking long time to show credit of amount in TPCODL account and thus auto reconnection command would get delayed. To cater to all above issues **first step** which was taken was, reduction in delay in posting of payment which has been kept in postpaid system, **second** VAN account numbers have been issued for all consumers with support of central banks, **third** cash posting was checked and aligned to bring updation in system within 2 hours, **fourth** daily intimation to consumer from 7 days in advance though SMS when balance is less than 7 days of consumption, **fifth** daily balance is shown on mobile application so that consumer can keep track on their own consumption and balance, **sixth** for institutional and government connections, provisions are developed in system to send SMS to multiple officer for intimation of low balance, **seventh** intimation are also planned to be sent through WhatsApp and email IDs wherever available, **eighth** on disconnection of power supply, intimation SMS is sent to consumer on all mobile numbers, **ninth** to engage all consumers about these updates, intimation letter have been sent to the consumers along with bills, **tenth** Welcome letter is given to consumers while meters are replaces and they are moved to prepaid billing net, **eleventh** to bring payment wallets back in use, discussion were done with various officer to understand the constrains and then it was decided that if any customer wants to make payment from payment wallets, an amount equal to one month's consumption + arrears (if any) will be shown as bill for the day, this has brought back all wallets in utilization and thus the payment avenues have been increased again, moreover there was no restriction of count of payments which can be made through these payment wallets. **Twelfth** option has been given to consumer to increase the amount to be paid as advance.

h. **Government consumer's payment system** is designed to make payment as per postpaid billing logics as funds are allocated for Power supply in discrete basis. With this type of arrangement, if funds are not allocated and payment is not made in time bound manner, supply will be disconnected. There are critical connections like water supply, schools, and hospitals. To ensure allocation of funds, matter is being discussed with government finance departments and fund allocation agencies. Meetings are also being conducted with administrative officers and DDO at district and block levels for effective engagement. Discussion is also going on for integration of Utility website with government portals to map electricity bills to concerned DDOs rather than distribution of physical bills.

i. **Tariff not cost reflective** for deployment of Smart Meters in Singe Phase consumers. As per Tariff declared in 2022 for TPCODL, the meter rent which has been declared cannot offset the cost of Smart Meters including installation cost of the meters. Thus, utility cannot install Smart Meters in Single Phase connections which restricts utility for taking full scale advantage of AMI project implementation.

j. **Internal policies of utilities** which need to be deployed for adapting prepaid meters also had to be finalized. Policies like, which consumers should be taken in Phase -1 of meter deployment, change is process of new connections by not charging SD amount and taking advance EC, replacement of defective meters with Smart Meters, billing logics for daily simulation bills, arrears handling as high arrears can lead to immediate disconnections, billing dispute resolutions on high priority, intimation process to consumers on low balance and disconnections etc. Another major decision which has been taken is about liquidation of arrears. Three options have been taken 1. Upfront payment of arrears in totality, 2. Making up to 6 monthly installments, 3. Conversion of arrears in daily installments up to 180 days.

Smart Meter Daily Simulation Status					
MRO Status	10/12/2022	11/12/2022	12/12/2022	13/12/2022	14/12/2022
No Read	298	295	308	335	349
Read Received	11710	11817	11811	11927	12037
Grand Total	12008	12112	12119	12262	12386
%	98%	98%	97%	97%	97%

Daily Bill Simulation tracker

k. **Change Management** for **employees** is a big task which has to be structures so that acceptance of Smart Meters is there. Redeployment of **meter readers** in other activities, training of billing staff on how to use Smart Meters readings, Tamper identification, intimation of disconnection of consumers to field staff so that No supply complaint is not registered, meter installation practices have to be changed as meters cannot be installed in metallic panels and in basements. **Consumers** have to be convinced for replacement of meters as it will have impact of rent on consumers' bills. Benefits are to be explained to consumers for deployment of the meters. Meetings with RWAs and IWAs are being organized to ensure that their engagement.

CONCLUSIONS

In this paper, various strategies of deployment of AMI as has been deployed in TPCODL has been discussed. This paper also takes about the reasons as why this strategy has been followed, along with risks which are considered. Deployment of AMI project for Three Phase meters will help in ensuring 40% of revenue of the utility. This paper also talks about the challenges which TPCODL has faced in deployment of the project and way out identified so far. A total of 6000+ meters have been deployed in prepaid mode for Whole current meters and postpaid meters in CT meter category. As TPCODL has overcome major challenges, we are good to go for mass scale deployment for all three Phase meters and this will help TPCODL to achieve its target of AT&C and implementation of technology.

Bio data of Authors along with Photographs

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I am currently working as Head –AMI in TPCODL and instrumental in deployment of Smart Metering Project. I am having a total experience of around 20 years. I have worked in Tata Power Delhi Distribution Limited for 17 years before getting transferred to Odisha. In Delhi I have in AMI project deployment, AMR department, Revenue Protection department, Power Plant Installation and commissioning and field meter testing.

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Paper Less and Contact Less Operation System

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ABSTRACT

This paper provides an insight of a shift towards Paper less and contact less operation system in utilities. In this competitive environment, topmost priority is providing Quality and Reliable power supply to consumers

Trigger - As a result of Covid-19 outbreak as a pandemic, country wide lockdown was imposed. Electricity being essential services, we work in shifts to provide services to our consumers. Operation Engineer does a large number of routine and emergency operations at site while on duty, and all the operations are to be noted down in Logbook after completion of operation. Remembering the exact timing of all the operations while updating logbook after operation ends is quite difficult. During pandemic Engineers faced difficulties in shift hand over, as it involves physical handing over of logbook. And it defeats the objective of avoiding contact between engineers to contain spread of virus.

In order to avoid interaction between shift engineers and reduce travel time, we implemented Voice to Text Conversion feature & Auto Updation of Digital Logbook.

Using Mobile app, Operation Engineer will update operation details through Log Dictation from the site itself. Entire data can be viewed/downloaded in standard Digital Log-Book Excel format from the dashboard of Data Storage server. Engineer will be able to Hand over & take over, operation shift charge without any hassles.

Keywords - Field Duty Engineer, Network Operations, Log-Book, Mobile App, Digital Log-Book.

INTRODUCTION

Tata Power Distribution serving Mumbai, the commercial Capital city of India, is committed to provide reliable and uninterrupted power to Mumbai City, caters to the power supply requirement of large number of Residential, Commercial & Industrial customers. Tata Power being committed to lead adopter of latest technology has taken up the drive of modernizing its Distribution network with introduction of Digitalization for ease of Field Duty Operation Engineer.

To provide the power supply to customer, Operation Engineer (Field Duty Engineer) needs to visit the site and complete the peration activity. Then each & every Operation has to be updated in sequence in Physical logbook after stationed at office and similarly, operation Engineer has to do this activity frequently after each operation.

A. ***The Problem:***

Tata Power Distribution Mumbai, License area of 484 km^2 Serving 7.4 Lakhs consumers, 4700 km of Network ,36 Distribution Substation, over 1000 customers substation in the city of Mumbai. In Shift duty, Operation Engineer (FDE) has to visit the various sites for network operation, Maintenance outages, Customer visit and Engineer must note down each activity during his shift in Paper-Base logbook.

Difficulties faced by shift duty FDEs (Field Duty Engineer) in Updating Logbook:

a. FDE does numerous operations at site while on duty & all the operations are to be noted down in currently maintained b. Digital Logbook (Excel File) after completion of shift.
b. Digital Logbook is maintained on One Drive & due to network issues, problems of saving or logging in are faced through mobile so FDE needs to come back to office.
c. Also, it is quite difficult to update the logbook in small screen of mobile.
d. Remembering the timings of all the operations while updating logbook after shift ends or after reaching office is quite difficult.
e. There are chances that correct timings of operations are not updated in Logbook.
f. Tedious work of typing all the operations after shift ends.

B. IMPACT OF PROBLEMS AND EFFECTS:

I. Safety concerns
II. Danger to working Personnel
III. Delay in supply restoration.
IV. Consumer dissatisfaction.
V. Decrease in Environmental sustainability.
VI. Increase the cost for print hard copy.

C. OBJECTIVE

I. To Improve the Efficiency of Engineers.
II. To increase the productivity of Employee
III. To reduce the usage of paper.
IV. To improve the Environmental Sustainability

D. THE APPROACH:

C onsidering the overall scenario, change in technology was the need of an hour. The Tata Power engineering team has worked for several options to reduce the footprint.

The use of excel Sheet was immediate available alternative, but dependency on access of Excel sheet at site on mobile and access of big Excel file which is again time consuming for Filed Duty Engineer (FDE) to update the logbook.

Developing solution with Voice to Text Conversion Feature & Auto updation of Digital Logbook is Golden middle to provide the ease of operation to Field Duty Engineers (FDE).

E. PROBABLE SOLUTION:

Develop suitable software to avoid manual writing of Log book in Excel.
Logbook can be filled from site itself along with required Time stamping.
The Voice to text feature is used & the text will be automatically updated in the form of Digital Logbook.

All the data will be stored in Data Storage Server & can be downloaded in Excel format as & when required.

FDEs will be able to Hand over the charge from site.

F. IMPLEMENTATION MODELITIES:

Using "***Site Companion***" mobile application, Field Duty Engineer will update operation details through Log Dictation from the site itself.

After Login in the App, Engineer will speak pressing the Log Dictation button & simultaneously will be able to see the input text on the screen.

After verification of text on screen & editing the same if required, press the submit button so that the text entered will be pushed from the device to the data storage server along with Time stamp.

Entire data can be viewed/downloaded in standard Digital Log Book Excel format from the dashboard of Data Storage server.

Through this app, FDEs will be able to Hand over & take over shift charge without any hassles.

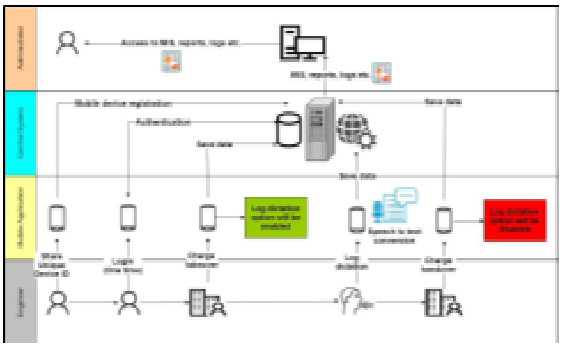

Fig. 1 - Working Flowchart

G. THE CHALLENGES & REMEDIES**:**

Maintaining Document Security

Challenges:

Electronics documents are becoming more and more prevalent. With the increase in the number of emails, PDFs, and other documents, there is an ever-growing need to ensure security and confidentiality. Documents often contain personal and sensitive information

Remedies:

Ensuring that data is backed up and that there are security measures in place to protect confidential information.

Implementing an Effective Document Management System

Challenges:

Document management systems are the backbone of any company.

They organize and store old and new documents to make sure that everyone on your team is working with the best information.

They also keep track of who has signed off on an important document so that you know who has a copy and what they need to do next.

Remedies:

App is Design in such way that Everyone in the team can access updated data which was last updated.

Mobile App is incorporated with the features of Taking Over and hand over the tabs so that Engineer can easily put the check on logbook and not possibility of missing the data

Plan Change Management

Challenges:

Paperless technologies have the potential to save companies enormous amount of money.

However, employees continue to resist these new methods by not properly following procedures and not being adequately trained on how to operate them.

Remedies:

Provide them appropriate training for handling the APP.

Make Engineers more comfortable by preparing the simple and easily accessible technology.

Initial Cost

Challenges:

The initial Cost of a digital technology can be significant.

Organizations resist due to initial cost investment for digital technology, train staff and maintenance of Software.

Remedies:

Initially Prepare the POC (Proof of Concept) for Project. In POC provide the glimpse of Software, impact of new technology to organization.

Also Explained to organization effectiveness of new technologies regarding the employee's ease of operation & customer satisfaction.

Convinced to management with Phase wise Plan of Technology which involves Preparation of Software, integration of software with our server, training to engineers.

Before proceeding ensure that management is well aligned and that a budget is in place to ensure that team can complete the path to digital technology.

Ensuring the long-term viability of Technology

Challenges:

Electronics Documents can be created and updated easily and at low cost. They can also share easily.

As technology is easily revolving rapidly and it is very difficult to ensure the long-term viability.

Remedies:

Ensure that the document formats are standardized and are constantly updated and maintained in order to have access to and not lose any documents in the future.

Ensuring Compliance

Challenges:

For Paperless Digital Technology organization need to ensure that compliance with different rules and regulations is managed to decrease the possibility of breaching laws.

Remedies:

Document compliance provides the destruction of documents after a set amount of time and retention of records.

Training

Challenges:

Organization needs to train the Engineers on how to use Paperless App.

Remedies:

Availed the updated procedures, handbooks

Provide the appropriate training to Engineers.

H. RISK & REMEDIES:

Deferring the conventional approach of old technology for Log book update with new technology was slightly disruptive.

While update the Logbook through Site Companion App, it is possibility for loss of Network as operation Engineers are working in first Basement of building and it leads to loss of Data due to Network issue.

Software was prepared in such a way that Engineers can update the documents in low Network area. In this scenario, data is stored in app itself instead of server Excel. As soon as Engineers reached in network, stored data in app automatically update in server and there is no loss of data.

I. METHODOLOGY:

II. Site Companion App is the mobile application to help on site Engineers (Field Duty Engineers) to maintain logs.

III. Perquisites: Minimum mobile device configuration required to run the application

a. Android OS-Minimum Build Version -5.0.
b. Minimum 2 GB RAM
c. Minimum 2GB internal Storage
d. Active internet connectivity.

IV. Login:

a. At the time of the very first login, user will be redirected to the Application Permissions screen.
b. This application only needs the Microphone permission. It will be used for log detection.
c. Once user has granted the microphone permission to the application, he/she can proceed for the login using the given credentials.
d. On the very first Successful Login, the user will be prompted to change the password.
e. Once the user Log in with valid credentials, he/she will be redirected to home screen.

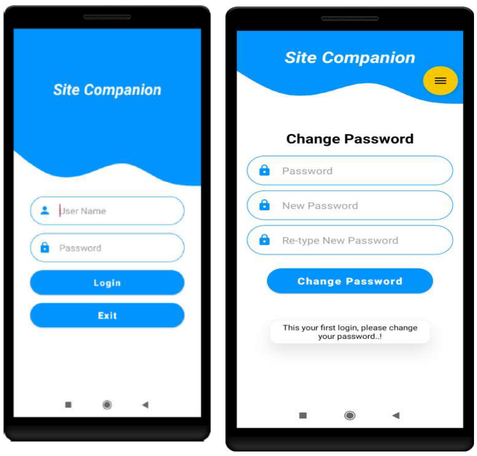

Fig. 2 - Login Screen

I. Home Screen:

a. Message at the bottom of the home screen shows the current status of Charge.
b. In this case, the user is an Engineer. He/ she assign the charge to another Engineer.

c. In this case, the supervisor has assigned the charge to the engineer. Engineer will be able to see the 'Takeover Charge' menu on the home screen.

Fig. 3 – Home Screen

II. Assign Charge:

a. Only Authorized Engineer will be assigned to charge another authorized Engineer. If Engineer already has the active charge, the charge cannot be assigned to him/ her.
b. User will have to select the name of the engineer to whom he / she wants to assign the charge.
c. Once the user starts typing the name, the auto suggestion list will appear with usernames.
d. Once the name is selected the user must enter remarks and click on the submit button.
e. The charge will be assigned to the selected Engineer.

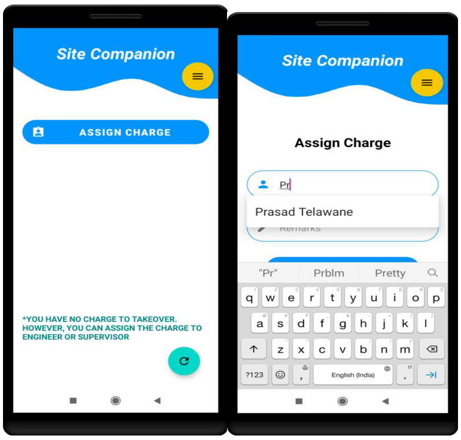

Fig. 4 - Assign Charge

III. Takeover Charge:

a. The Application will show the name of the user who has assigned handed over the charge to current user along with remarks.
b. Current user has to enter the remarks while taking over charge
c. Once the transaction is done, user has to navigate back to the home screen.
d. The User will be able to see the "Handover Charge, End Shift, Log Dictation" menus, once he takes over the charge.

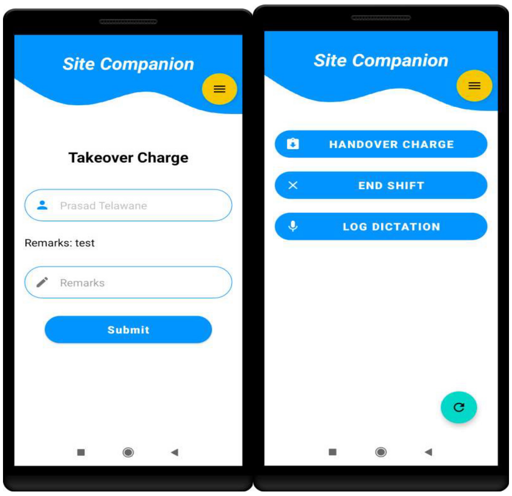

Fig. 5 - Takeover Charge

I. Log Dictation:

a. This menu is used to detect the logs to the mobile application.

b. User will have to click on the microphone button to start the dictating the log.

c. The application will do the speech to text conversion and shown the log. The user can modify the log manually if needed.

d. Once the log dictation is done, user has to click on the submit button.

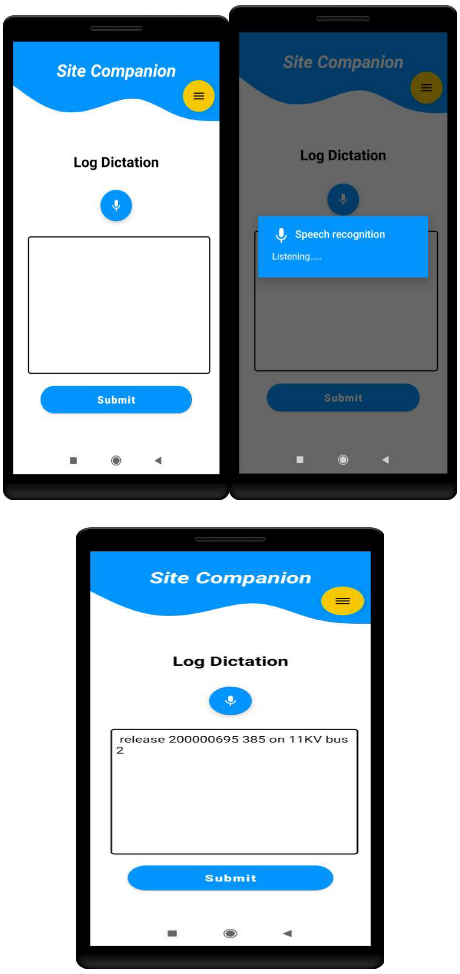

Fig. 6 - Log Dictation

II. Handover Charge:

a. Once the user has completed the shift, he can handover the charge to another user.

b. User has to enter the name of the user to handover the charge to, enter remarks and click on the submit button.

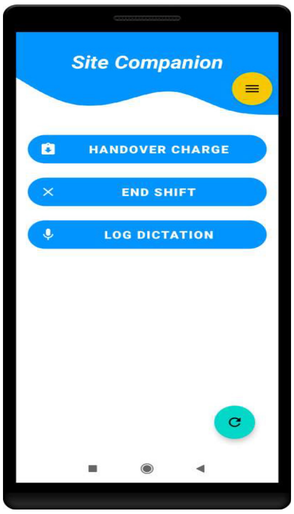

Fig. 7 – Handover Charge

III. End Shift:

a. Once the user has completed the shift and there is no further handover required, user has to use the' End Shift' menu.

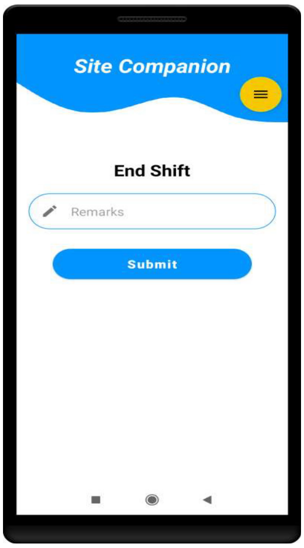

Fig. 8 - End Shift

IV. Other Menus:

This menu contains 3 applications:

Change password

About

Logout.

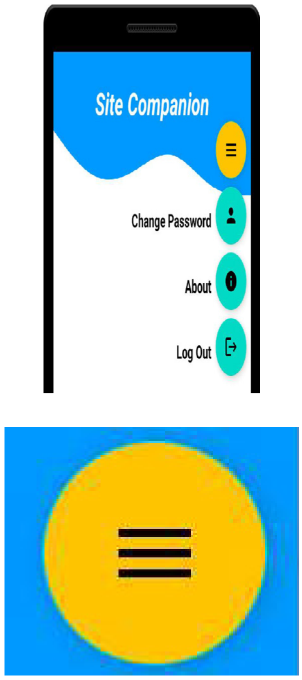

Fig.9 – Other Menus

J.THE FINAL PRODUCT:

Fig. 10 – The App.

A. RESULTS:

A Monitoring mechanism is developed for checking the improvement in process:

a) After implementation and usage of Site Companion App, Operational Efficiency/ productivity get increase.

b) Saving of 45-Man Days which can be utilized for some other critical activities.

c) Improvement in Environmental Sustainability

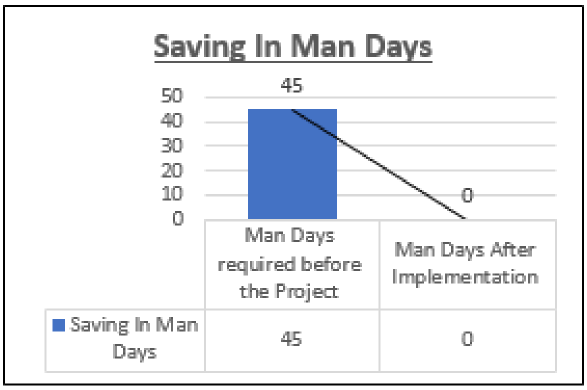

Fig.11-Graphical Representation - Saving in Man Days.

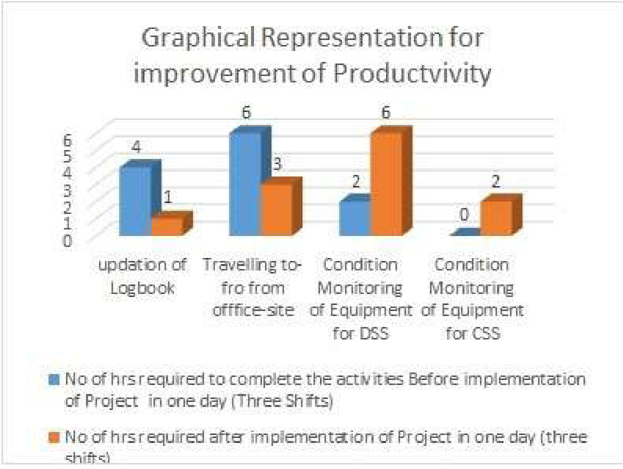

Fig.12 - Graphical Representation for improvement of Productivity

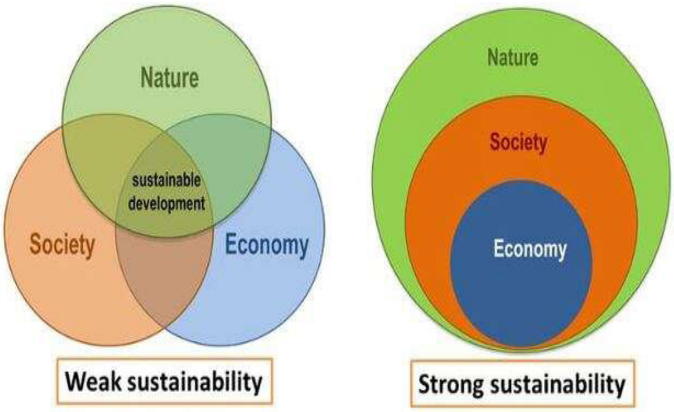

Fig.13 - Graphical Representation for sustainability

BENEFITS

Cost Benefit Analysis:

1. Saving in Man Days: -

   Time Saving of Approx. 1 Hr. Per Day i.e., 30 Man Hrs. per month. Around **45 Man Days** will be saved in a Year by using this app.
2. These Man days can be utilised for some other critical work like condition monitoring.
3. Reduction in carbon Footprint as travelling of FDE; to & from office will decrease.

- Average decrease in Travelling of 10 Kms. /Day, lead to saving of 3650 Kms. /Year.
- This will reduce the Diesel consumption by 405 Litres.
- So total carbon footprint will be reduced by **1.06 Tonnes in a Year**. (2.62 Kg. / Litre.)
- Saving in cost of Printing Hard Log Books.
- Saving of Trees as physical log-books will not be ordered/used.

Intangible Benefits:

1. Increase in availability of productive time.
2. Increase in operation Efficiency
3. Ease of handing over and taking over

4. Increase in Accuracy of Logbook reports.
5. Ready availability of Operation Data at any point of time.

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Challenges for Utilities: Digital Disruption

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Abstract

The Electric Utilities are facing multiple challenges. Its main source of revenue, sale of electricity, is going down due to Prosumers. Besides, Renewable Energy, Energy efficiency is also affecting its revenue. The Digital disruption is the change that occurs when new digital technologies and business models affect the value proposition of existing goods & services. It is dependent on 24/7 quality service. The monopolistic attitude of Utilities in South Asia has already created image problems. Bangladesh had significant success by unbundling State-owned Utilities with Consumer cooperatives with private status. Today's Grid limitation is massive growth of distribution network, aging of existing infrastructures, renewable integration, which are all new threats to its existence. CX is not satisfactory due to monopoly. Utility industry is seeing the business challenges which are dynamic and diversified and under pressure to reduce cost, make operations efficient and meet regulations. The Future Electric Utilities will have to take care of its customers and community service. Another disruption will be Digital Utilities by Big Five. Uber is a burning example on how Taxi business wiped off globally. The cream of Utility business will go to them and original Utility will be working thankless job of O&M. With energy crises due to Ukraine war, Asian Super Grid which would have deep integration of renewable infrastructure and ICT is getting importance. Transactive Energy is one step ahead of Smart Grid. So future grid and utility will be fully ICT or IT/OT based environmentally friendly and customer centric.

Keywords

Digital disruption; Customer; Asian super grid; Transactive Energy; Future grid

Introduction

The Digital disruption is the change that occurs when new digital technologies and business models affect the value proposition of existing goods & services. Today we find Digital Disruption is taking over our all activities, like Digital transport services viz. Uber, Grab, Pathao etc., Online lodging like Airbnb, Cross-platform instant messaging apps like WhatsApp, Viber etc., Digital currency like Bitcoin, Online education like Udemy, online universities etc.

Why electricity is important? The digital disruption is dependent on *uninterrupted* 24/7 and quality electricity supply. Almost every way we make electricity today, except for the emerging renewable & nuclear puts out CO_2. And so, what we are going to have to do at a global scale is create a new system. And so, we need energy miracles - Bill Gates. Can you name a product whose quality cannot be measured before its delivery" It is electricity. But you have to continuously supply quality electricity. It can be compared with Japanese "Just in Time" (JiT) service. Imagine the complexity specially when parameters for quality electricity supply are more complex today due to massive digitization in all other sectors, harmonics, renewable integration, and demand variation? The electrical system could be compared with a huge battery where millions of lights are being on/off, air-conditions etc. getting on/off, extreme variation of demand with which supply is to be harmonized. But today Digital Disruption has made it possible to realize the electricity quality at the time of delivery through digital simulation.

II. Cost of Electricity

The actual cost of electricity interruption or outages may not be significant, but the overall economic losses due to electricity interruption are immense. With the world moving towards automation and digitization, the necessity to have round the clock uninterrupted power supply became inevitable. The difficulty with stable electricity supply was to make a balance between electricity production and its consumption. If unbalancing is substantial the whole system may become unstable. There were many prolong blackouts due to grid imbalance. The problems of today's grid may be summarized as under.

A. *Electricity Demand Growth*

Massive growth of distribution networks with increase in electricity use and dependency on it. This has led to more use of electrical products. Again, less expensive electrical gadgets are also more electricity consuming leading to more and more consumption. The present Ukraine-Russia war impact on global economy and energy need to be analyzed in case of prolong war.

B. *Existing Infrastructures*

Aging of existing infrastructure. Existing age-old grid is inefficient which has led to excess power loss in transmission and distribution. The load growth made the system more vulnerable and loss prone.

C. *Cyber Security*

Limitation to cope with real time challenges those to cyber concern. Electric grid is now more vulnerable to cyber-attack than physical attack.

D. ***Expertise*** Shortage

Expertise shortage specially Engineers. This is almost a global concern.

This led to overcapacity of generation to cope up with so many variables, as a result cost of electricity increased and became uneconomical. From Consumer point of view, another concern was monopoly of the Electric Utilities. Often their attitude made

Consumers helpless. They were compelled to accept whatever services provided by the Utility at their predetermined cost though they are paying for the services. The Energy Regulators were entrusted to look after the Tariff and Consumer's interest in a balanced way, but they had many new issues. Today Energy sustainability and security is one of the main agenda for any Country.

The Electric Utility industry is seeing the business challenges which are dynamic and diversified. They are also under pressure to reduce cost, make operations efficient and meet tight regulations for security and environment issues

III. Renewable and Clean Energy Sources

Mainly we have six sources. Solar which is abundant but Grid integration is a challenge. Water flow which gives us mini hydro or large hydro. Their water supply variation is a problem. Wind is another source in most of the countries. Biomass is another product which is sometimes an environment concern. Geothermal and Hydrogen are two important sources but more research is required. Nuclear is clean but hazardous if not properly maintained. There were many accidents and their consequences were fatal. But today many are advocating for inclusion of nuclear energy in clean energy. Renewable is clean. So, no more renewable, rather go for clean energy.

IV. Disruptions due to Electric Vehicles

The future of the electric utility will be tied to the future of the grid which will be mainly low carbon. The Electric Vehicle will play a significant role in diminishing the role fossil fuel-based vehicles. Unlike fossil fuel run Cars which have many moving parts, the Electric Vehicles have very fewer moving parts. As a result, they are more sustainable. It has been found that Electric Vehicles run on fossil fuel-based electricity generation still make less pollution and global warming. With cost reduction we may not find any new fossil fuel-based Car after 2025/26. You may find old fossil fuel-based Cars on road in developing countries. Then V2X will bring another revolution. Another disruption will be Driverless cars.

V. Disruption due to Solar Powered Generation

Another disruption is due to reduction in solar panel cost together with improved efficiency and storage system. As per IEA, the new utility-scale solar projects now cost $30-60/MWh in Europe and the US and just $20-40/MWh in India, where “revenue support mechanisms” such as guaranteed prices are in place. The Solar electricity will cost less than Coal generated electricity. This will be due to massive addition of renewable and a connected, digital webbed grid in much the same way the Internet today will develop. In addition, Distributed Generation will have significant impact. The biggest challenge will be “How to balance an entirely different sort of grid with so many variable inputs. The aging Grid’s renovation and modernization with digitization will be time consuming and expensive affair and will require the participation of Distributed Generators to make overall system sustainable. Micro Grids may become favorable to counter localized blackouts.

VI. Disruption due to Roof Top Solar with net metering [2]

With Net-metering in place, the Vendors will approach the Roof Top Owner with proposal to lease the roof on Profit sharing basis and electricity cost adjusted through Net Metering. This will have disruption in two aspects. First the Utility income will be minimized due to Roof Top Solar and Electricity Consumer will also become seller. Another aspect is abnormal tariff during Peak hour. Due to reduction in energy storage cost, Consumers will have the option to charge the batteries during lean period at late night and consume the same during Peak hours.

Result - Utility business and monopoly gone.

VII. Technology itself is not real disruptor, non-Customer centric biggest threat [1]

The Future Electric Utilities will have to take care of its customers and community, including all the stakeholders. The Regulators will want the utility to stay in business and earn a fair return. At the same time, Electric Utilities will have many opportunities to provide better services. The Future Electric Utility will have to give more emphasis on Demand Side Management. There is massive growth in electricity demand which could not be predicted. The Utility may be compared with a battery. There are tens of millions of customers making random decisions every second, turning lights on and off, turning on/off their TVs, Air Conditioners, and other electric gadgets. The Electric Utility will have to efficiently handle all these massive variations in consumption without any interruption. The Utilities will have to make enough profit to sustain in the competitive market satisfying its customers in the digital era.

VII. Asian Super Grid [3]

After Fukushima Tsunami and then nuclear crises, there was huge hue and cry to shut down the nuclear electricity generation plants. But Japan had no primary fuel of its own but huge electricity demand. So Future Grid was planned which would have been deep integration of renewable infrastructure and ICT which was crucial for New Grids to come online. Initially four countries Russia, China, South Korea, and Japan signed MOU to form Super Grid. Then Mongolia also joined the Super Grid. The resources of various regions like Wind and Solar from Mongolia region, Hydro & Thermal power in Russia's Far East region, PV & Wind power in South Korea and Japan, Wind and Solar power in China all were combined to form Pan Asian multinational grid. It will have a total transmission line of 36,000 km. This will be a replacement to fossil fuel and/or nuclear power generation in the long run. Again Ukraine-Russia conflict may have an impact on this project.

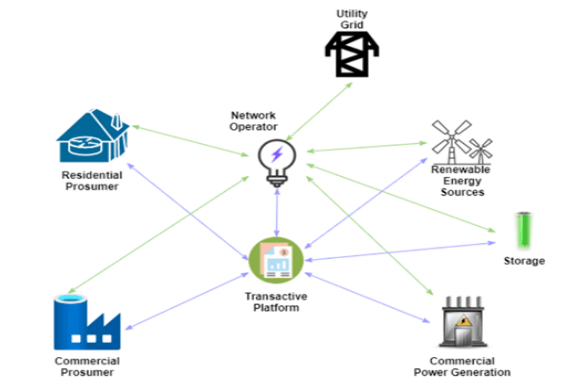
https://www.renewable-ei.org/en/asg/about/

Figure 01. Asia Super Grid

IX. Transactive Energy: One Step Ahead of Smart Grid

Transactive Energy is a hot topic in the energy industry. It was developed considering the existing limitations. Carl Imhoff, manager of electricity infrastructure for the Pacific Northwest National Laboratory summed it up by saying, "Transactive energy is a means of using economic signals or incentives to engage all the intelligent devices in the power grid from the consumer to the transmission system to get a more optimal allocation of resources and engage demand in ways we haven't been able to before." The customer has options to have energy from multiple buyers or sources through same infrastructure. [4]

The intelligence driving Transactive Energy is based on instantaneous market value and economics (instantaneous pricing) of the energy or electricity. The Smart grid technology refers to the ability of the electric grid to communicate between generation, end-user and even points in between, but the Transactive Energy takes this at least a step further and introduces the additional consideration of electricity financial or economic value at the time of delivery. This whole process is fully automatic with M2M contact with decision making capability as per Customer requirement or desire. The concept of Transactive Energy is based on role of dynamic pricing in the energy industry. Wholesale power markets use dynamic pricing to value energy based on demand at the time of transaction or delivery. So, the price of electricity can vary throughout the day as per multiple Suppliers. The Customer has the options to avail it from any supplier through the same receiving system. The Transactive Energy system makes electricity use decisions based on price signals. This could include a building energy management system programmed to respond to a high price signal by curtailing energy use through automated demand response, using micro grid generation, or even shifting load to onsite energy storage, renewable etc. minimizing the peak demand and demand charge. The Supplier can also fix variable price depending upon competition, power quality etc. The technology that makes this possible includes software capable of interpreting essential data, and distributed generation sources such as micro grids, energy storage, and even energy reduction in the form of automated demand response. In fact, facilities with distributed generation resources can even contribute excess electricity back to the power grid in a Transactive Energy system.



Conceptual Model of a Transactive Energy Market. Image adopted from Zia, Elbouchikhi, Benbouzid and Guerrero (2019)

Figure 02. Conceptual model of T.E market.

Transactive Energy is truly a two-way transaction system where Utility monopoly ceases and pricing is competitive. In the end Customers are contended with the service of their choice. [5]

X. Conclusion - The Future Utility

The Future Grid will deploy digital and Transactive technology. Grid will be green and renewable energy will govern. For sustainability micro grid may come up. Super Grids will come up to substitute fossil fuel power. Monopoly of Utilities will go. Renewable energy will prevail. "Today's Electric Utility will be Tomorrow's Internet of Electricity."

The integration of variable and distributed generation of any volume is a challenge to the Utility. While today we discuss how to integrate the rapidly growing intermittent Renewable Generation, and how Disruptive Technologies such as Distributed Generation, low-cost successful Electricity Storage, and low-cost Electric Vehicles (EV) will reduce the value share of business of utilities in the electricity system.

Then comes 'BIG DATA' which no human can analyze in short time but machines created by human can. BIG DATA will be a complete game changer. With the roll out of Substation Automation Systems, GIS Integration, Distribution Automation, Smart Homes, Machine-to-Machine (M2M) communication, etc., we expect the annual rate of data intake to increase by at least factor 20 over the next years. And that might only be the start.

The future of the electricity ecosystem will be forming an intelligent 'plug and play' electricity grid in which every device down to our solar cells on the roof, and our air conditions, LED lighting, coffee machines, washing machines communicate and adapt for an overall optimized generation, grid, and demand performance.

The Internet of Electricity will be the King; sitting in the center connecting any kind of grid assets with each other, as well as with, for example, application servers and a cloud based integrated system supervision and optimization process. This will shake up things substantially. The technical challenges are one thing relatively easy to solve. Energy Markets will need to be adopted too and there will be new services which need a price, i.e., reliability of power supply and provision of ancillary services such as synthetic inertia from wind turbines to stabilize the grid frequency. The big challenge will be that this integrated approach will obviously need to cut across the entire value chain from generation to use, with the target to optimize the system performance rather than the individual asset. This comes with a shift from a ‘provide services to an end-user’ to a ‘user in the center’ approach. In the extreme case no human interaction will be required anymore on the generation, transmission, and distribution side. Most of the utilities would therefore, if they remain in their current setup, degenerate to commodity providers providing maintenance to the assets they own (or are) Their value share in the Internet of Energy would be marginal, and it does not appear to be ludicrous to assume that Data Power Houses like Big Five e all have a very good chance to be the main power in the electricity industry soon providing the platform, including communication, data storage, data analysis, process control, reporting, billing, user interfaces, etc.

So, what to do if you are a utility? No one really knows today how things will exactly look like in future. Also, there will most probably be some evolutionary (and costly) iteration until we have truly entered into the new era outlined above.

What is left to remain relevant is accepting the change to come, it will happen, and it will probably bring with it a consolidation of the utility sector and we will see take overs and mergers happen between utilities and Information, Communication and Technologies (ICT) firms.

There is an Energy Revolution ahead. And as the Computer Scientist - Alan Kay famously once said: “the best way to predict the future is to invent it.”

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SMART Technology for Remote Station Condition Monitoring

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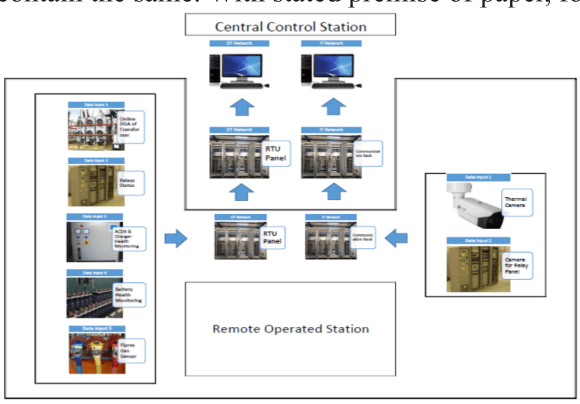
Abstract

Substations are the most important part of the Power system. Complexity of transmission and distribution system is growing day by day and Substation computerization has become requirement to increase reliability and effectiveness of power system. There are various substations which are operated remotely. The proposed paper focuses on various techniques which can be used to enhance remote condition monitoring and control of substations. This includes condition monitoring of outdoor switchyard equipment like Power Transformers, EHV breaker and isolator and indoor equipment like auxiliary system and relays. Real time monitoring of isolator, breakers, and relays is carried out using SCADA and confirmed visually through cameras. For remote operation emergency preparedness is most important aspect. Based on analysis of historical data it is observed that electrical substations have two major challenges. A-Uncontrolled fires B- Loss of auxiliary. To overcome this challenge fire suppression system for electrical panels, for electric equipment remote operation of fire emulsifier system and auto restoration of auxiliary system using Battery energy storage system are used.

Introduction

As per the studies Fire and loss of auxiliaries are the two major concerns in the operation of remote operated station. Fire incidences can directly result into loss of assets or loss of protection/ control/ observability of the system from remote control center. Similarly, Loss of auxiliary will also result into loss of control, observability, reliability, and sustainability of system. In last five years in the TATA Power Mumbai operations, there were total 6 number of incidences, in which there was loss of auxiliaries or fire. So, for remote operation of station, finding solution, to know the potential causes which can trigger the chances of fire and to know the chances of loss of auxiliaries is must. The solutions developed shall also possess the mechanism by which, in case of any eventuality, the system shall give the earliest signs of the incidence and measures to contain the same. With stated premise of paper, following will be discussed.



System Integration for Remote Monitoring

1. Various technological interventions
2. Merits of various technological intervention
3. Futuristic approach for reliability and sustainability of local & remote station.

II. Utilization of SCADA

SCADA system is the backbone of condition monitoring for remotely operated station. It not only helps in controlling the equipment remotely but also ensures complete situational awareness for the remote operator by integrating relays & alarms generated from equipment and other sensors installed in the field with SCADA which gives event data recorded. It helps the operator to take informed decision, without visiting the site.

III. Developed Solution So As To Operate Station Remotely

1. Integrated fire arrestor system

To reduce the impact of fire incidences, preventive measures are taken in the remote operated station in TATA Power Mumbai Operations. These precautions include special fire-retardant paint for control cables and use of fire doors for operational areas and use of gas suppression system in the protection panels. Also, automatic AC cut off system is used to reduce spread of smoke.

Gas suppression system:

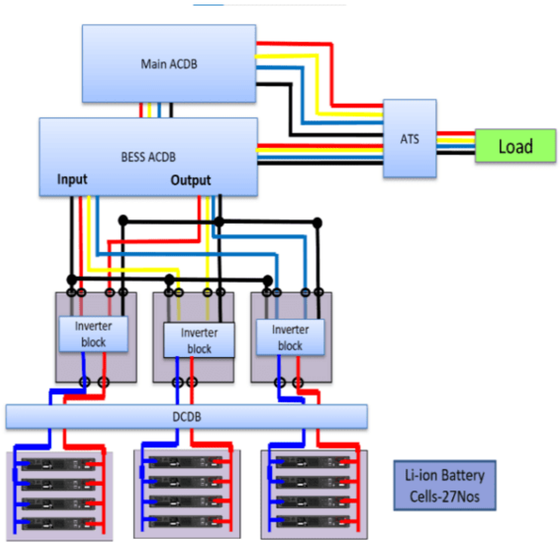
Gas suppression system is mainly used for relay & control panels. In TATA Power we have used Fire suppression System for relay panels and server racks. It is self-activated and does not require any power or human interference. Cylinder filled with extinguishing agent is connected to heat sensitive pneumatic polymer tubing. When flame comes in direct contact with heat sensitive tube and reaches temperature to 110^{o} C approximately, heat causes bursting of pressurized sensor tube at the hotspot. In case of such untoward incidence, alarm is generated on SCADA. Fire is quickly suppressed just moments after it began, hence minimizing damage and reducing repair downtime.

AC auto cut-off system:

To reduce the circulation of the smoke in case of fire, Air conditioning systems are auto cut off by operating the damper in the main outlet of air conditioning system, which is triggered by the fire detection system.

2. BESS

For reliable monitoring and control of remote operated station resilient auxiliary system is required. Battery Energy Storage System is used to provide auxiliary AC and DC in station in case of loss of power. It is very good substitute to old DG generator system of which online health monitoring & remote operation is not possible. Also, BESS ensures reduction in carbon footprints. Online health monitoring installed on Solid state BESS batteries ensures reliability of backup. Automatic transfer switch (ATS) is used to provide supply to all the essential loads in the station e.g., battery chargers, essential lighting. Raw AC supply is given to ATS as a main and BESS as a backup.



Auxiliary backup system-BESS

At TATA Power Kolshet RSS, which is remote operated substation we have used BESS of 70 kWh, 1502 AH capacity, which was installed to cater important station auxiliary requirement of 15kW for around 5 hours.

3. Online health monitoring of Other Equipment's

To reduce efforts of condition monitoring of remote operated station equipment, different online condition monitoring systems are developed in house at TATA power.

MO which includes online thermal monitoring of electrical joints, Online DGA, and breaker health monitoring.

Online thermal monitoring:

There are two types of electrical joints- One which is visually observable and other which is enclosed in casing.

So, for outdoor switchyard fixed type thermal camera with remote visualization facility is developed in-house. System has range of 30m and angular movement of 0-270° angle & will be used to monitor all HT equipment which includes Isolators, breaker palms, CT & PT palms and V jumper joints between main bus and equipment bay.

For indoor distribution bus systems instead of fitting camera in the casing, electric joint monitoring system is used for thermal monitoring. Thermo-labels are installed on the electric joints to be monitored and when the temperature of joint rises, it heats the thermo-label. On reaching the activation temperature thermo-label releases the gas. The 4 number of gas detector placed inside the bus bar casing sends the gas concentration to the FPA. If concentration of signal gas reaches 140 PPM and above, it generates alarm. Generated alarm is transmitted on SCADA as it communicates on RS-485 with mod bus protocol.

In case of ducts and cable trench auto explosion balls and heat sensing cables are used. For indoor AIS flame detectors are used and alarms for same are integrated with SCADA.

Online DGA:

Power Transformers in the remote operated station are equipped with online DGA facility to ensure online health monitoring of the transformer. DGA is carried out after fixed interval and results are streamed on SCADA. For DGA of transformer oil various standards are available out of which we are following very stringent limits as follows:

Sr. No.	Gas	Normal
1	Hydrogen	<20
2	Methane	<50
3	Acetylene	<1
4	Ethylene	<50
5	Ethane	<50
6	Carbon Monoxide	<300
7	Carbon Dioxide	<2000

With the help of real time analysis of DGA values Duval's triangle is drawn and real time health monitoring of transformer is conducted and if found any deviation alarms are generated on SCADA and proper and appropriate action can be initiated.

Online Humidity monitoring and LT cable box in Transformer:

Humidity inside the LT cable box of transformer is monitored by using humidity sensor. In addition to that thermal cameras are also provided for hotspot detection inside cable box. This humidity sensor and thermal camera is integrated with SCADA.

Live relay monitoring system using cameras:

Relays are monitored by using cameras which are integrated with image processing for the visual confirmations and monitoring the relay panels remotely.

Auxiliary condition monitoring system:

Battery charger and battery health is monitored though SCADA. All the parameters of ACDB and DCDB & Chargers are made available on SCADA with the help of transducers. For ACDB voltage limits are set as ±6% as per standards.

Breaker health monitoring:

Presently essential condition monitoring alarms of the breaker are utilized to monitor the condition of breaker and online breaker monitoring system is currently being under commissioning.

Lighting Arrester condition monitoring:

Counters used for LA are equipped with 4 – 20mA analog output and are integrated with SCADA to monitor the healthiness of the lighting arrestor.

IV. Remote operation of the station

As the equipment and system healthiness & situational awareness are now ensured, all breaker and isolator operations are carried out remotely from SCADA through electrical interlocks ensuring error free operations. Operations are confirmed with the help of visual confirmation devices from remote control centers. Sequential SCADA operations are developed for transmission lines having GIS bays at both at ends. Also Auto restoration scheme is implemented for LV bus. This is to reduce the operation time and restoration time thereby reducing the downtime of the equipment.

V. Conclusion

Integrated fire arrested system and BESS has ensured remote observability and operability of the system which is basic requirement of remotely operated system. Online condition monitoring devices like thermal camera, DGA and breaker & battery monitoring system ensures healthiness of the equipment with least human efforts and also provides data for analysis of equipment health over its service life. During major shutdown in Mumbai, the remote operability of substation was tested critically. Despite loss of major supply, all station auxiliary supply was working which helped in restoration of HT interconnections. Station auxiliaries were restored after approximately 5 Hours remotely after normalization of all interconnections, till that time auxiliaries were catered by BESS.

VI. Future work

1. Remote isolation of indoor LT rack-in type breaker

Currently all operations of the remote operated station are done remotely using SCADA except the rack-in/rack-out operation of the LT switchgear. Currently robotic mechanism is under development, ensuring complete remote operation of the substation.

2. Battery online health monitoring

Using specific gravity of individual cell and voltage measurement health of battery cell is derived online. And development is under process.

3. Online LA-LCM of lightning arrestor

Live LA-LCM can be conducted and same can be integrated with SCADA so that alarms will be generated if there is any sudden change in LA counter or leakage current reading

. Applications of Weightless™ LPWAN in AMI and DER Management

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Abstract

Due to the intermittent nature of solar and wind, the grid system needs to upgrade with more resilience to maintain its generation-demand balance to embrace higher penetration of renewables. Communication technology plays a significant role to enable that. Weightless™ is a bidirectional, synchronous LPWAN technology for connecting a high volume of end devices that require moderately frequent uplinks/downlinks. Weightless™ supports all types of large-scale IoT applications in both licensed and unlicensed bands. AMI and feeder automation are normally the first step for power distributors to kick off the transitioning into smart grid. The next step is having more and more distributed energy resources (DERs), including solar and energy storages tied into the grid to decentralize the power system. This paper will be discussing the technical features of wireless communication technologies that are needed in smart grid upgrading and use cases of Weightless™ connecting over 520,000 smart electricity meters and DERs in Taiwan.

Keywords

Advanced Metering Infrastructure, Distributed Energy Resource, Weightless™, LPWAN, IoT, Solar, Energy Storage

Introduction

While standard cellular wireless technologies have their uses for Internet of Things (IoT), they do not always scale well to the battery powered applications and lossy environments typical for some IoT devices. When these cellular technologies are not appropriate, Weightless™ technologies can allow for Low Power Wide Area Network (LPWAN) communication needs. This paper compares Weightless™ with existing wireless technologies used for LPWAN and Cellular IoT and provides case studies of its use, first, in Advanced Metering Infrastructure (AMI) and then in the wider area of Distributed Energy Resource Management Systems (DERMS). The paper notes that Weightless™ shows a significant advantage over existing LPWAN technologies for these applications.

II. Applicability of Weightless™

Weightless™ is a synchronous LPWAN approach that is best suited for applications which involve low mobility or stationary End Devices (EDs) operating in lossy environments (requiring deep penetration) under tight power constraints and moderate but predictably frequent uplinks or downlinks. Particularly notable is the ability of Weightless™ to operate at long ranges (up to 1 km urban to 10 km suburban) while supporting a high density of devices. Firmware-Over-The-Air (FOTA) updates, long battery life, and reduced maintenance costs are also the benefits created by Weightless™. This capability is accompanied by communication security and reliability, flexibility of deployment in international regulatory and licensing environments and low cost of integration with existing end devices. Weightless™ provides adaptable rate bidirectional throughput for monitoring or control. However, throughput is moderate and applications most applicable are those that are tolerant of relaxed latency constraints of between 10 - 100 milliseconds [1]. Application use cases can range from AMI and DERMS (as discussed in this paper) to asset management, smart heating, and cooling, and more.

III. Comparing Weightless™ to Other Technologies

There is a bewildering array of choices for wireless data transmission which makes it difficult to select and compare approaches [2][3]. For instance, for LPWAN approaches we might have: Wireless HART, Weightless™, LoRa, Sigfox, Telensa, QOWISIO, DASH-7 and INGENU RPMA. And for cellular approaches we might have: NB-IoT or LTE-Cat-NB, LTE-M or LTE-Cat-M. Most technologies within the area of LPWAN sacrifice mobility, reliability, or high data rates in favor of lower power consumption, stationary, and scalable longer-range applications that can potentially support more end devices. Cellular technologies typically do the opposite and favor mobility and high data rates in exchange for higher power consumption and a reduced support for the number of end devices - something not ideal for AMI, at least.

*A. **Sigfox***

Sigfox is an Ultra-Narrowband (UNB) protocol operating in the sub-GHz range and at low bits-per-second (bps) but with deeper penetration for urban environments and greater range and immunity to lossy environments. However, it has no bidirectionality, acknowledgement or hand over support limiting its applicability to control applications or mobile applications. It has typically been used for asset management. And while operating on a licensed band with low interference, it is a proprietary protocol that is potentially facing concerns over insolvency [4]. This puts into question its longevity as a viable solution.

*B. **WirelessHART, LoRa***

Wireless HART and LoRa both typically operate on unlicensed spectrums in mesh topologies that are prone to interference, error, and security concerns. LoRa operates at sub-GHz and has improved penetration depth, typically in the medium bps to low kilo-bps (kbps) range. Deployment scale is significant and some limited bidirectionality in transmission is possible. Given LoRa's topological arrangement and low reliability it would not fit the AMI or DERMS application use cases presented in this paper.

*C. **Qowisio***

Qowisio provides combined LoRa and proprietary technologies in the sub-GHz range but at very low bit rates and high latencies (500 ms) that limit its capabilities drastically for AMI and DERMS.

*D. **WirelessHART, INGENU RPMA***

While bidirectional and with bit rates in the low to mid kbps range, the higher GHz operating frequency of WirelessHART and INGENU makes urban communication a challenge because of lower penetration depth and interference on ISM bands. This would typically make WirelessHART and INGENU challenging in dense urban AMI applications.

*E. **Telensa***

Telensa provides a UNB approach with proprietary technology operating in sub-GHz and GHz unlicensed spectrum and faces similar challenges with penetration depth and interference from ISM band operation. Telensa solutions appear limited to smart lighting applications, however, they also come with some advantages afforded by a star topology.

*F. **DASH-7***

DASH-7 makes significant improvements operating on sub-GHz frequencies and in star topologies with greater penetration but compromises on power consumption and the CSMA approach can lead to increasing interference and damping of bandwidth as deployment densities increase.

G. *NB-IoT, LTE-M*

NB-IoT offers significant advantages as a standardized cellular protocol in terms of infrastructural costs, however, decreasing reliability and reducing support for number of devices has been seen in lossy environments with NB-IoT. Some companies have even suspended or scaled down their NB-IoT AMI services in favor of LTE-M or LTE-Cat-1 [8]. LTE-M is also a cellular protocol providing higher data-rates than NB-IoT and LPWAN solutions at the compromise of power consumption and device density. As a new protocol, LTE-M, however, has seen little deployment in the arena typical of LPWAN solutions. And so, its performance for AMI, at least, remains unknown. Despite these challenges, standardization appears a key value proposition for cellular technologies in comparison to proprietary LPWAN solutions.

H. *Weightless*

Based originally on an open standard, Weightless™ attempts to provide a compromise between very low-rate solutions such as Telensa or Sigfox and higher rate solutions such as LTE-M. It operates in a range of user selectable licensed and unlicensed frequencies in the sub-GHz and provides TDMA and FDMA support suited best for applications with defined characteristics (such as AMI) as opposed to randomized access. The sub-GHz combined with bidirectionality, and star topology allows for deep penetration and resilience to indoor urban environments. Multiplexing allows for high densities, over long range for applications with high reliability and known traffic patterns. LoRa, Sigfox and Weightless in some ways may be classed as competitors within the class of LPWAN. It operates in the high bps to low kbps range like LoRa. However, in many respects, field trials have shown Weightless to outperform these and some cellular technologies by a significant margin at national deployment scales of AMI (approaching a million devices). In practice, there is a crossover point in terms of device density where the lower densities of NB-IoT, for instance, outperform Weightless™. AMI and DERMS are two applications that Weightless™ is suited for.

IV. Use Case 1 - Advanced Metering Infrastructure (AMI) in Taiwan

Taiwan completed the smart metering deployment for all the high-voltage power consumers in 2015. Since 2018, Taiwan has been aggressively rolling out the AMI infrastructure for low-voltage power consumers. It is targeted to deploy 6 million smart meters in total by 2030. Taipower Company, the sole power utility in Taiwan, separates the AMI tender into three (3) parts: meters, communication systems and the meter data management system (MDMS). For the communication system, a wide range of connectivity technologies can be accepted if the performance requirements are met.

A. *Project Specifications*

The key requirements of Taipower's AMI communication system are shown in Table 1 below. Taipower's strict requirements of 15-minute interval meter readings with 99% success rate during trials and 95% for actual deployment can be met by only a few industrial IoT technologies. Weightless™ has fully met Taipower's requirements and has achieved long-range, low power, low cost, and high reliability specifications. Among several other connectivity technologies being used in Taiwan's AMI project, including NB-IoT, PLC, Wi-Sun, and proprietary RF, Weightless™ so far accounts for the largest proportion regarding number of meters deployment. As of December 2022, there have been over 520,000 meters connected with Weightless™ in Taiwan. More than Weightless™ 2,200 DCUs have been deployed to cover all the meters. For the Taiwan AMI deployment, Ubiik chose to operate Weightless™ in the 839MHz-847MHz licensed bands which is dedicated for the smart meter reading of public utilities in Taiwan.

Table 1. Taipower AMI Project Requirements

	Downlink Actions	Uplink Actions	Security	Backup Battery	Network Restoration
Requirements	Key Exchange	Every meter to send 'load profile' meter readings every 15 minutes.	End-to-End security	In case of power outages, DCU and communication module must be able to send a "last gasp" notice to the cloud server.	After a power outage, the smart meter network must establish all network connections within 30 minutes.
	Single Meter Control and Reconfiguration	Meters to send readings on-demand during unscheduled times. Data to be sent within 60 minutes of request at 99% success rate.	Encrypted packets	Send status notification to Taiwan Power Company in cases like power outages	
	Firmware-Over-The-Air	During power outages, the FAN module should manage to send a notice, 'last gasp', to notify such outage.			
	Control from cloud to establish Firewall, set HDLC frame data limitation and to request meter readings and full data logs	Every midnight (12:00AM), every meter must register with the network and send all event data within 4 hours at 95% success rate. All missed meter data shall be read back and send to the cloud within 7 days.			

B. ***System Architecture***

Like cellular technologies, Weightless^{TM} utilizes the star topology that the gateway or data concentrating unit (DCU) is directly connected to each end-device meter. Weightless^{TM} narrow band modulation occupies just 12.5 kHz per channel. This allows a single eight-channel Weightless^{TM} base station only to occupy 100kHz of bandwidth to connect a large-scale network of meters [1]. With Taipower's AMI payload specifications, a single Weightless^{TM} DCU can support over one thousand end devices. WeightlessTM provides the optimal coverage in a dense city environment. For example, in the Taipower tender, Weightless^{TM} DCUs demonstrated ideal network range and penetration through metal obstructions and complex city infrastructure. Signals were still able to reach smart meters located in stairwells and even basements (over -70 dBm). Authors have seen -70dBm to -120dBm sensitivity for meters situated in the basement in some cases [1].

V. Use Case 2 - Microgrid Management of Residential Unit in Taiwan

Weightless^{TM} is also being used to connect individual DERs to the central DERMS platform in Taiwan. There is a clear trend in Taiwan that more and more distributed rooftop solar, energy storage systems and EV chargers are emerging across the country. Some of the solar systems are paired with batteries for self-consumption, while the others are directly selling power back to the grid at Feed-in-Tariff (FIT) rate. In either form, the distributed solar and batteries need to be monitored by the grid operator to better maintain the grid stability.

C. ***System Architecture***

A use case discussed in this paper is a large residential unit with rooftop solar and behind-the-meter battery to form the microgrid system. A hybrid inverter is used to couple the solar generation and battery on the DC side with a DC-coupling topology. The inverter converts DC power into AC power to supply the load and connect to the grid. The WeightlessTM module connects to the inverter through Modbus over RS485 and transmits data to the smart controller through Weightless^{TM} protocol.

A smart controller, acting as a Weightless^{TM} gateway is installed at the household to continuously collect real-time uplink data from the Weightless modules, thus from the inverter and meter, with a time interval of 1 minute. It also sends downlink charging and discharging commands to the inverter whenever it is needed. Smart controller connects to the cloud DERMS platform through its Ethernet backhaul.

D. ***Technology Advantages***

For utilities to gain visibility of the distributed energy resources, the selection of the last-mile communication technology to the end-device highly depends on the facility or power consumer's environment. Compared with the common connectivity technologies embedded in the off-the-shelf inverters or meters, such as Wi-Fi and cellular, WeightlessTM is possessing several advantages: long-coverage range and low operational cost. Wi-Fi connectivity is only suitable for residential facilities where meters, inverters and batteries are located close enough to each other in the garage. However, for commercial and industrial facilities, such as factories, schools and hospitals, the equipment is normally distantly separated from each other. Moreover, complete Wi-Fi coverage is normally absent. Whereas using one single WeightlessTM smart controller can easily cover the whole area within several kilometers in radius and connect all the microgrid components all together to the cloud DERMS platform.

Also, thanks to the fact that Weightless™ supports sub-GHz ISM bands in many countries like USA, Europe, and India, running Weightless™ also avoids any spectrum license fee compared with cellular technologies. In the long term, it reduces operational cost significantly. In this use case, Ubiik is running Weightless™ in the 915MHz-920MHz ISM band in Taiwan. The communication specifications are following the regulations set for ISM band usage by Taiwan's National Communication Commission (NCC).

VI. Conclusions

As a fully bi-directional LPWAN communication protocol with great scalability, Weightless™ is the optimal last-mile connectivity for building up the foundation of smart grid applications, including AMI, feeder automation and DER management. Especially in cases like dense urban areas where one single DCU/gateway can cover several kilometers in radius with great signal penetration to support a large number of end devices. Weightless™ also supports both licensed and unlicensed bands in the sub-GHz spectrum, giving users the flexibility to reduce long-term operational cost.

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Emerging Technologies and Regulations in Clean Energy Market

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ABSTRACT

India's current installed power capacity is 400+ GW, consisting of coal-based 204 GW (50%), renewable energy sources 114 GW (28%), and hydro 47 GW (12%). Nuclear power generation capacity is 7 GW, gas-based power 24 GW, and lignite and diesel-based 8 GW. As a part of its commitment to UNFCCC, India has set an ambitious target to establish 500 GW of renewable energy capacity by 2030 which requires a $300 Bn investment, giving it the flexibility to generate 50% of its electricity from non-fossil fuel sources by then.

Clean energy installation must accelerate further for the country to meet its climate targets. The grid needs new creative solutions for managing significant amounts of variable renewable energy sources, like solar and wind. Blockchain technology can be used to support the production, storage, transportation, sale, and use of alternative energy sources throughout the supply chain to achieve this. These solutions work together to make it easier to track progress toward sustainability. Additionally, digitalization will facilitate the integration of clean energy and assist the EPC through analytics and artificial intelligence (AI).

Keywords

Utility, Renewable Energy (RE), Green power market, Renewable portfolio obligations, Digitization

Introduction

India is one of the top 3 producer and consumer of electricity in the world. To advance Access to energy, Economics development, improve energy securities and climate change the primary objective is to deploy the clean energy in their portfolios [1]. Further, a net zero emissions aspiration by the year2070 sets the tone for the continued pursuit of sustainability and renewables led energy transition in the long term. some of the key basic benefits for installing the green energy are:

- RE is clean and sustainable that produces no greenhouse gas emissions and reduces air pollution.
- Reducing dependence on other fuels.
- Using RE will not only save money but also make
- money by selling excess RE into grid.
- RE helps in reducing the effect of Climate change due to global warming.

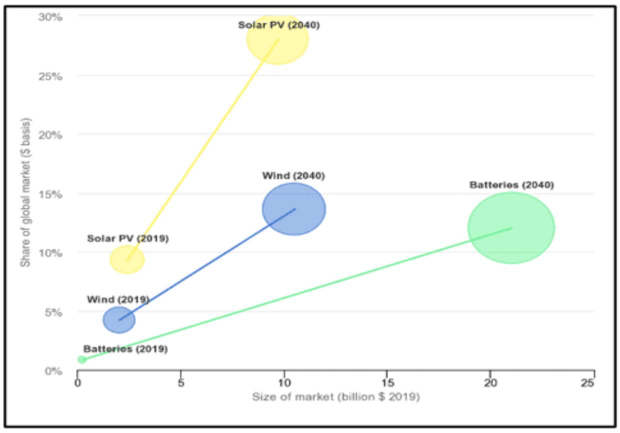

Fig 1; - India's market size and global share in clean energy technologies as per IEA

Four principles for India's clean energy and economic recovery programs

- Investment in least cost power keys

The steeply falling expenses of RE advances present a valuable chance to seek after a financially practical clean energy change. Examples include solar and wind sources emerging as India's lowest-cost electricity sources, even without subsidy [4].

- **Support resilient and secure energy systems**

As climate change accelerates, the likelihood of pandemics and extreme weather shocks will likely increase.

- **Prioritize efficiency and competitiveness**

Given India's size and stage of development, effective and careful resource management is critical. Circular economy solutions should be incorporated into India's future economy.

- **Promote social and environmental equity**

Given India's position as one of the world's largest and fastest

growing economies, albeit with large social inequalities, additional weight on social and economic equity must be considered when applying these principles in the Indian context.

Solar Photovoltaics (PV)	Concentrating Solar Power (CSP)	Onshore Wind	Offshore Wind
▪ PV refers to the process of converting light into electricity using semiconducting components that have the photovoltaic effect. ▪ Cost of Solar PV has decreased by 82% in the last decade (2010-2019). ▪ Low installation and maintenance cost	▪ CSP systems produce electric power by converting sun's energy into heat by using mirrors or lenses to concentrate a large area of sunlight into a receiver. ▪ Cost of Concentrating Solar Power has decreased by 47% in the last decade (2010-2019). ▪ Capable of storing energy, can be used for large scale power generation	▪ The generation of electricity through a group of wind turbines on land. ▪ Cost of Onshore Wind energy has decreased by 39% in the last decade (2010-2019). ▪ Less expensive and quick installation	▪ The generation of electricity through wind farms in bodies of water, usually at sea. ▪ Cost of Offshore Wind energy has decreased by 29% in the last decade (2010-2019). ▪ High efficiency and greater consistency due to lack of interference

Fig 2; - Opportunity in wind and solar with respect to prices

Challenges: -

- A comprehensive regulatory framework is not available in the renewable sector to promote the growth of RE technologies, policies, and plans.
- Every state has different policy and regulatory outline and RPO targets which leads to higher risk of investments in the sector.
- When compared to fossil fuels, the initial unit capital expenses of renewable energy projects are quite high, which creates initial financing difficulties.
- Every renewable energy project installation creates complicated risk challenges due to environmental uncertainty, natural disasters, planning, equipment failure, and lost revenue.
- The RE sector depends on the climate, and this varying climate also imposes less popularity of renewables among the people.
- The storage system increases the cost of renewables, and people believe it too costly and are not ready to use them.

Major Techno initiatives for renewable energy

World is rapidly moving towards a low carbon energy system with an increase affordable cost and solution to meet the multifaceted demand of the consumer [3].

- **Using AI in Clean energy sector**

Artificial intelligence (AI) is having transformative results across utility and energy sector, which helps to forecast demand and resource management, to ensure power is available with affordable rates with a minimum of waste.

- **Using blockchain technology to drive green & Clean energy solutions**

The blockchain solution also supports the production, storage, transport, sale, and use of alternative energy sources along the supply chain. Together, these solutions make it easier for the GSE to track progress towards sustainability.

- **Green hydrogen energy**

The most abundant element in the universe, hydrogen ignites with an almost no greenhouse gas emissions. On the other hand, green carbon is produced by a process including electrolysis, water, and the production of the necessary electricity from renewable sources.

- **Energy storage to take center stage**

The popularity of battery storage technologies has been significantly influenced by the global shift toward renewable energy sources. Both short- and long-duration battery storage technologies will be essential in 2023 and beyond.

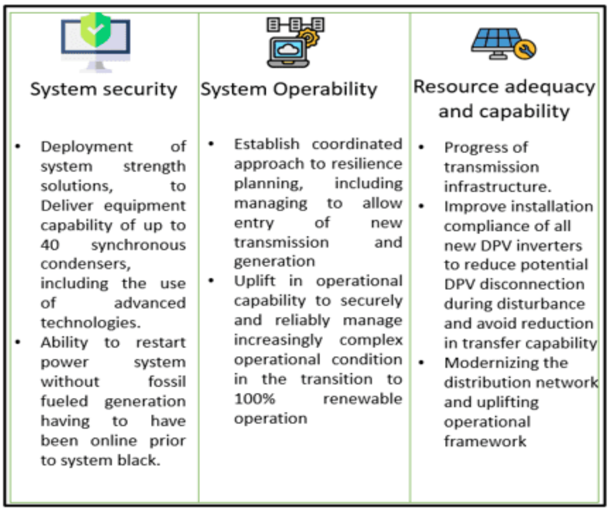

Fig 3; - Actions and technical preconditions required penetration of renewables

India has several clean energy incentive policies some of them are [1]:

- **Feed-in tariffs**

Feed-in tariff in general is a government driven policy to promote and support investments in clean energy generation. Scheme enables the RE Gencos, such as solar, wind or small hydropower to receive an incentive for electricity generation.

- **Renewable Energy Mechanism**

Renewable Energy Certificate (REC) mechanism is a market-based instrument to promote renewable energy and facilitate compliance of renewable purchase obligations (RPO). It aims to address the gap between the state's RE resource availability and the obligated firms' need to fulfil the renewable purchase obligation (RPO). The accounting or tracking mechanism for solar, wind, and other renewable energies as they enter the grid is called a Renewable Energy Certificate (REC).

- **Accelerated depreciation**

For commercial and industrial users of electricity, the tax incentives offered on installing a solar power plant by the Government of India are quite beneficial and solar power a viable and sustainable option for commercial users. The benefit of accelerated depreciation allows commercial and industrial users in India to depreciate their investment in a Solar Power Plant at a much faster rate. This in return allows the user to claim tax benefits on the value depreciated each year.

- **Sustainable Energy**

India has set a target to reduce the carbon intensity of the nation's economy by less than 45% by the end of the decade, achieve 50% cumulative installed electric power by 2030, and achieve net-zero carbon emissions by 2070. L ow-carbon technologies could generate a market worth up to $80 billion in India. To build long-term solar energy infrastructure, there should be a circular solar economy in which waste from solar cells and modules can be diverted and reused as valuable sources for new solar modules.

Conclusion

Renewable energy projects are defined by large-scale initial investment and relatively low costs for operation and maintenance forever after. Governments can implement policies that help commercialize new energy technologies through direct support, or by introducing environmental taxes and standards or specific pollution-reduction targets, or through targeted activities aimed at specific technologies. There is a delay in the authorization of private sector projects because of a lack of clear policies. The country should take measures to attract private investors. Hence, to decrease the cost of renewable products, the country should become involve in the manufacturing of renewable products. Another significant infrastructural obstacle to the development of renewable energy technologies is unreliable connectivity to the grid.

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Smart Hybrid Renewable Energy Mini-Grid for Off-Grid and Grid-Connected Environments

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Abstract

Solar PV-based distributed energy generation systems combined with battery energy storage systems (BESS) are considered to be an economically viable option for commercial and industrial (C&I) consumers for demand-side management and reliable power supply, particularly where electricity supply is erratic. Apart from diesel generator replacement or runtime reduction, solar PV combined with battery storage can bring multiple benefits, such as power quality management, peak demand management and energy arbitrage when the time of the day tariff structure is applicable. An optimally designed PV BESS mini-grid system in conjunction with grid power supply and with or without diesel backup can be implemented for the supply of reliable and uninterrupted power for both rural off-grid consumers and urban grid-connected consumers.

The objective of this paper is to present technical, economic, and business models of smart solar PV-based hybrid mini-grid systems under a virtual power plant (VPP) platform. The system architecture of mini-grid systems is to be operated under a simplified virtual power plant platform. In this configuration, solar PV systems with battery storage will be installed at the premises of different electricity consumers which will be connected to a common mini-grid distribution network. Individual PV systems with battery storage and DG backup will be able to interact with each other and will be operated by a common load-control system. The distributed solar PV and battery systems connected through a common distribution network will work like a single reliable energy supply source under the VPP platform and supply power to consumers as per demand.

Key Words

Solar photovoltaic-based mini-grid; virtual power plant, battery energy storage, renewable energy

I. INTRODUCTION

Solar photovoltaic-based mini-grid systems are ideal solutions for the supply of clean electricity in remote areas where either conventional grid power supply is not available or is erratic or inadequate in order to provide for personal and commercial needs. More than 14,000 [1], [2], [3] mini and microgrid systems installed in India are operated and maintained by government and private renewable energy service companies (RESCO) and not-for-profit organisations (NGOs) with community support. According to the World

Bank, nearly 47 million people worldwide are already connected to 19,000 mini-grids, of which more than 2,500 are operational clean-energy mini-grids (ESMAP, 2019) [4]. But around 180,000 more mini-grids would need to be built to supply electricity to 440 million people. This directs us to represent a significant step towards meeting the goal of providing universal energy access by 2030 (SDG7).

On the other hand, scheduled power outages are a major challenge in developing countries and have a severe economic impact on commercial and industrial activities and on the general living conditions of residential electricity consumers. For example, India has more than 90 GW of behind-the-meter diesel generators, mainly used as power backup to cope with frequent power outages [5], particularly in the Commercial and Industrial (C&I) sector. Solar PV-based distributed energy generation systems combined with battery energy storage system (BESS) is considered to be an economically viable option for commercial and industrial (C&I) consumers for demand side management and reliable power supply, particularly where electricity supply is erratic [5]. Apart from diesel generator replacement or runtime reduction, solar PV combined with battery storage can bring multiple benefits, such as power quality management, peak demand management and energy arbitrage when the time of the tariff structure is applicable. An optimally designed PV BESS mini-grid system in conjunction with grid power supply and with or without diesel backup can be implemented for the supply of reliable and uninterrupted power for C&I and urban residential or institutional consumers.

The objective of this paper is to present technical, economic, and business models of smart solar PV-based hybrid mini-grid systems under a virtual power plant (VPP) platform. The system architecture of mini-grid systems is to be operated under a simplified virtual power plant platform. In this configuration, solar PV systems with battery storage will be installed at the premises of different electricity consumers which will be connected to a common mini-grid distribution network. Individual PV systems with battery storage and DG backup will be able to interact with each other and will be operated by a common load-control system. The distributed solar PV and battery systems connected through a common distribution network will work like a single reliable energy supply source under the VPP platform and supply power to consumers as per demand.

II. Mini-grid definition and technical configurations

There is no single definition of 'Mini-grid' or 'Microgrid' systems, which are essentially small-scale electricity distribution networks powered by small-capacity electricity generators that operate independently. The International Renewable Energy Agency (IRENA) in its report 'Policies and Regulations for Renewable Energy Mini-grids, 2018 [6] defines 'Renewable Mini-Grids' (using technology to harness energy from solar, hydro, biogas, biomass, wind and/or hybrid sources) with capacities that range from under 1 kW to up to 10 MW which may be interconnected to the main grid or remain autonomous. The World Bank ESMAP (Energy Sector Management Assistant Program) classifies mini-grid based on customers' reach. According to reports published by ESMAP, mini-grids reaching 20 -100 customers are called micro mini-grids and mini-grids reaching over 500 customers are called full mini-grids [7]. IEC TS 62257-9-2:2016: Recommendations for renewable energy and hybrid systems for rural electrification, provide the **definition of a micro power** system in terms of a distribution system that covers low-voltage AC, three-phase or single-phase, with a rated capacity of the power plant at the electrical output less than (or equal to) 100 kVA [9].

As per the draft National Policy for renewable energy (RE) based mini-grids published by the Ministry of New and Renewable Energy (MNRE) [10], "a mini-grid is defined as a system having a RE-based electricity generator (with a capacity of 10 kW and above), supplying electricity to a target set of consumers (residence for household usage, commercial, productive, industrial and institutional setups) through a public distribution network (PDN)". The draft policy states that 'mini-grids generally operate in isolation to the electricity networks of the distribution company (DISCOM) grid (standalone), but can also interconnect with the grid to exchange power. If connected to a grid they are termed a grid-connected mini/ micro grid' [10].

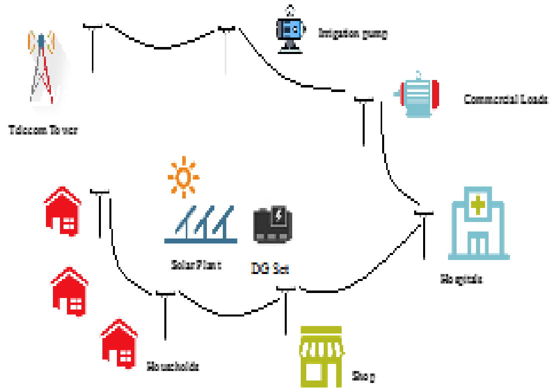

Figure 1: Conceptual layout of a solar PV-based mini-grid project with different loads

It is possible to have multiple configurations for RE-based mini-grid power systems whether it is a standalone, a hybrid system with more than one renewable resource, or a hybrid system with a renewable resource and a fuel-based generator. The draft national policy for mini-grids allows the use of fossil fuel-based generators as backup power with renewable energy-based systems to improve system reliability.

II. LITERATURE REVIEW AND RESEARCH GAP

A number of research studies covering operational challenges for standalone, and hybrid mini-grid systems are covered in the present review to identify the policy issues and research gaps. Several reports and studies show that the key challenges for mini-grids are high capital expenditure, limited availability of finance, lack of supportive policies and regulations, lack of assured energy demand, operational challenges due to lack of skill, community issues and remote location of the plant **[11]**, [12], [14]. All these challenges are applicable to commercially operated mini-grid projects.

One major challenge for a mini-grid developer is uncertainty in the government's grid expansion plan and the lack of clarity around the integration of mini-grids with the government grid [15]. The draft national mini-grid policy (2016) has the provision to interconnect a mini-grid to a DISCOM grid to sell excess power in accordance with CEA Regulation 2013 – Technical Standards for Connectivity of the Distributed Generation Resources [10]. To ensure the co-existence of mini-grids with the DISCOM grids where the DISCOM grid pre-exists and where the DISCOM grid is yet to arrive, the draft policy suggests that the mini-grid developers will be allowed to:

(a) "Open Market": Continue supplying to its consumers and exist in parallel with the DISCOM grid, or
(b) Continue to supply to its consumers and sell excess or unsold electricity to the DISCOM grid at the interconnection point and draw power from the grid if required, or
(c) Supply all electricity generated to the DISCOM grid at the interconnection point.

The draft policy further suggests that the mini-grid developer:
(a) Will be allowed to work in and migrate to an operating option of its choice.
(b) Will abide by the tariff norms as prescribed under the existing policy or program of the states.
(c) Will be allowed to change a tariff mutually determined with the consumer, if operating in an open market option
(d) May be offered to undertake the role of a distribution franchisee, whenever possible.

Since electricity is a concurrent subject in the Indian Constitution, interconnection regulations must be adopted by the states through respective State Electricity Regulatory Commissions (SERCs). Till now, mini-grid policies and regulations have been adopted by only three states, namely - Uttar Pradesh, Bihar and Odisha [16], [17].

Mini-grids are primarily designed and built for standalone operation with a small distribution network to serve rural and remote areas where electricity demand is much lower in comparison to urban and semi-urban areas. There is much scope to understand the applications and feasibility of implementing mini-grids in urban and semi-urban areas where the electricity supply is not stable and consumption is higher. It is most likely that upcoming mini-grids will be implemented with emerging smart technologies and the internet of electricity (IoE) which will make them ready to integrate to a larger utility grid network. Therefore, it is high time to analyse the technical and commercial impact /issues in integrating mini-grids into a larger utility grid.

Solar PV-based hybrid mini-grid systems are generally designed and developed with a central PV power plant, and central battery storage and are often supported by a fuel generator. This type of system configuration is not flexible and there are inherited challenges in the optimization of such a system to congregate with the dynamic energy demand of a wider group of consumers. With the recent development of technologies and the internet of electricity (IoE) platform, it is possible to develop a mini-grid with multiple distributed PV systems, battery storage and backup power supply systems connected to a single mini-grid network. Thus, an innovative model for solar PV-based hybrid mini-grid systems can be developed and optimized with considerable flexibility under a Virtual Power Plant architecture.

Mini-grid policies and regulatory frameworks are primarily developed to provide basic electricity access to rural consumers and accordingly they are confined to a limited objective to achieve. Once mini-grid are designed and developed to serve diverse consumers with multiple service portfolios, it would be necessary to update the existing policies and regulations or a new policy and regulatory framework has to be framed to enable the proliferation of mini-grids both in rural and urban areas.

Iii. Development of mini-grid under vpp system architecture

A virtual power plant (VPP) is a cloud-based virtual control platform that aggregates and controls large numbers of distributed energy sources (generator and storage) connected to a grid network. A solar PV-based VPP consists of multiple solar PV and battery storage systems centrally monitored and operated by a load-control system to form a single reliable energy supply that can be discharged instantly at peak demand hours. VPP can be used for demand-side management by linking small-scale independent decentralised PV systems and batteries into a network, with communication and controls to allow the units to act together like a conventional power station controlled by an operator. Virtual power plants are implemented in the United States, Europe, and Australia.

3.1 VPP system architecture for mini-grids

A novel system architecture of a mini-grid system to be operated under a simplified virtual power plant platform has been proposed. In this configuration, solar PV systems with battery storage will be installed at the premises of different electricity consumers which will be connected to a common mini-grid distribution network. Individual PV systems with battery storage and DG backup (if required) will be able to interact with each other and will be operated by a common load-control system under a simplified virtual power plant platform. The distributed solar PV and battery systems connected through a common distribution network will work like a single reliable energy supply source under the VPP platform and supply power to consumers as per demand. The mini-grid system under this arrangement can be operated independently and managed by an independent power producer/ energy service company (ESCO) or it can be connected to the conventional power grid through an existing VPP arrangement provided by demand response providers such as energy retailers or demand response aggregators. PV system size and battery storage capacity will be decided based on the consumers, based on their energy and load demand. It is also possible to have multiple ownership of distributed PV systems. The energy service company managing the VPP can install PV systems with storage at the consumer's premises or consumers themselves can invest in the PV power plants. It is also possible to provide electricity to those consumers where PV systems are not installed. *Khizir Mahmud et al. 2020* [21] discuss a concept of a small-scale VPP network with distributed renewable energy systems connected to a power grid distribution network where the author classified three different types of consumers namely standalone consumers (prosumers) who will just produce the required amount of energy for self-consumption, energy buying consumers who do not meet the requirement and buy power from other consumers and lastly, energy selling consumers (prosumers) who generate surplus power and sell to other consumers in the network.

Figure 2: Conceptual diagram of a mini-grid with distributed PV & Battery systems operated under a virtual power plant

3.2 Advantages and challenges of mini-grid developed under a VPP architecture

The primary advantages of a mini-grid developed and operated under a VPP platform are –

(1) Flexibility in system sizing
(2) Size distributed PV systems and BESS according to the demand of individual consumers
(3) Higher overall system efficiency as power will be consumed where it is produced
(4) Advanced load and demand management
(5) Possible to have a distributed PV system with or without BESS
(6) Flexible and lower capacity energy storage requirement
(7) VPP is less expensive in comparison to a smart micro-grid and offers a coherent solution [22]
(8) Flexibility to integrate additional BESS and DG backup power
(9) Flexibility to integrate into an existing power grid
(10) Easy expansion of system capacity
(11) Flexible component replacement and repair
(12) Maximum availability of the system with minimum downtime as VPP continues to operate normally in the event of failure of one system in the network
(13) Flexible consumer participation as a prosumer, consumer, or electricity seller
(14) VPP uses artificial intelligence to develop single algorithms that can ensure optimal generation and demand management [22]

(15) Can be implemented in both rural and urban areas

The main challenges of a mini-grid operated under a VPP platform are perceived as follows –

(1) Complex energy management system and financial settlement process
(2) Integration of VPPs to the power grid will require adjustments to existing policies

3.2 Mini-grid system configuration

An appropriate and flexible system configuration will be developed to connect multiple energy-generating and storage systems connected to a common mini-grid distribution network. Each generating and storage system can be controlled through a virtual power plant platform to operate the entire network as a single power supply source. A conceptual schematic diagram of the system configuration is presented in Figure 3. The primary considerations for system configuration will be:

1) Load size
2) Time of operation
3) User-specific preferences
4) Future expansion/ upgradation
5) Consideration of integration to the distribution grid

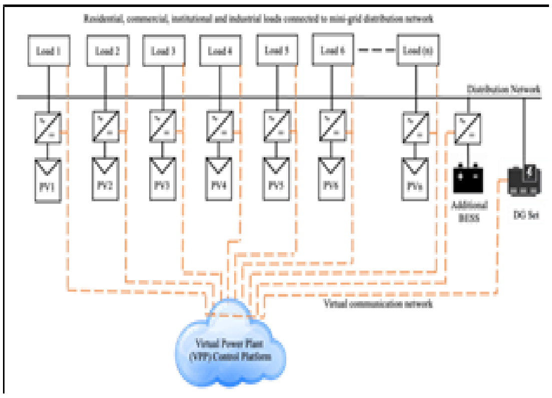

Figure 3: Schematic diagram of a mini-grid system configured with distributed PV, Battery and a fuel generator operated under a virtual power plant architecture

3.4 System Optimization

The design of a PV-BESS-DG hybrid power system is extremely flexible and highly dependent on the consumer's demand and consumption behaviour, making general guidelines to be found for such systems' design difficult. The primary objective of optimization of mini-grid hybrid systems is to optimize the sizing of PV and BESS and the minimum run time of DG generator to minimize the Levelized cost of electricity (LCoE) with minimum loss of load probability (LoLP). A detailed financial analysis is to be carried out to determine LCoE in different scenarios, considering the initial cost (fixed cost) and operating costs (variable cost) over time. As demand-side energy management plays a critical role in optimizing a PV-BESS-DG hybrid system, a load management strategy needs to be incorporated as part of an optimization exercise. This will also include setting up of time of the tariff structure to control targeted loads.

The following parameters will be considered for system optimization.

- Meet user demand as per the load management strategy
- Size solar array for maximum use
- Minimize battery storage capacity
- Minimizing specific fuel consumption for generator

- Control hours of generator run time
- Control the number of ‘generator starts’ in any month or in the year

The following decision flowchart will be used for system optimization of a solar PV-based hybrid mini-grid power plant under a VPP platform.

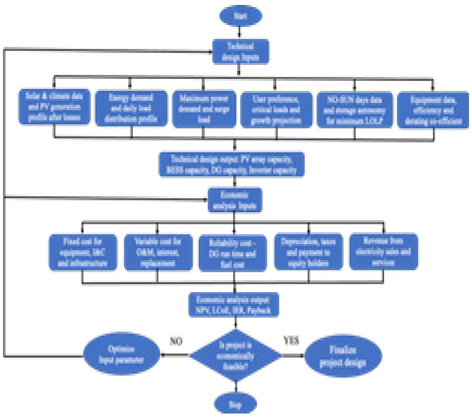

Figure 4: Decision flowchart for system optimization of a solar PV-based mini-grid system

3.5 Operation and control system architecture

The operation and control system architecture of a solar PV-based mini-grid power plant under a VPP platform is presented in Figure 5 below.

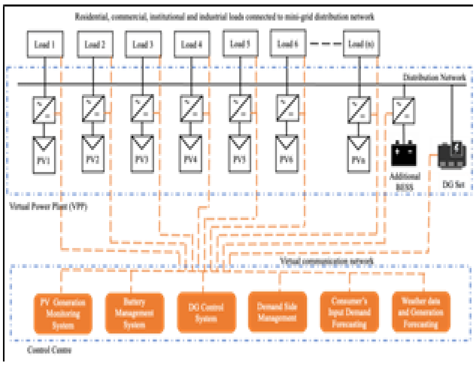

Figure 5: Operation and system control architecture of a solar PV-based hybrid mini-grid power plant under a VPP platform

4. ANALYSIS & SIMULATION

Daily load profiles of multiple electricity customers as presented in table 1 have been analysed. All consumers are having distributed PV systems of different capacities at their premises.

Table 1: Details of electricity customers in a VPP platform

Type of customer	No. of units	Daily energy demand (kWh/day)	Peak load (kW)	Distributed PV at the customer premises (kW)
Rural residential	100	661	70	50
Hospital	1	1044	58	200
Urban residential	10	422	25	50
Corporate office	1	820	82	100

Small EV charging station	1	289	18	20
Small manufacturing	1	660	28	50
Cold storage	1	305	14	25
Flour Mill	1	370	18	25
Combined load		4572	248	520

There are substantial variations in power demand for different customers (Figure 6). However, combining of power demands of all customers resulted in a flat and smoother load curve (Figure 7).

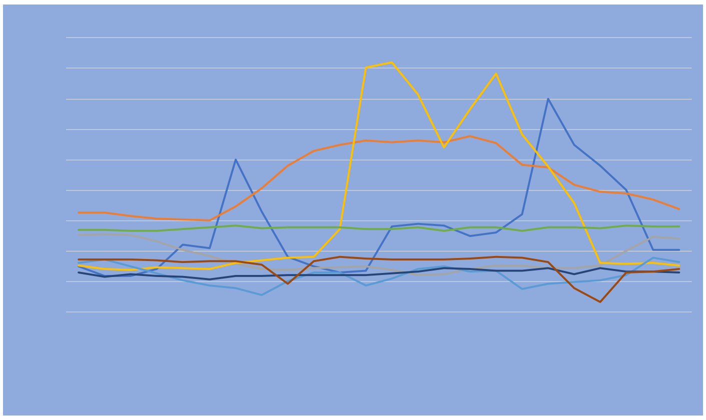

Figure 6: Daily (hourly) load profile of multiple customers

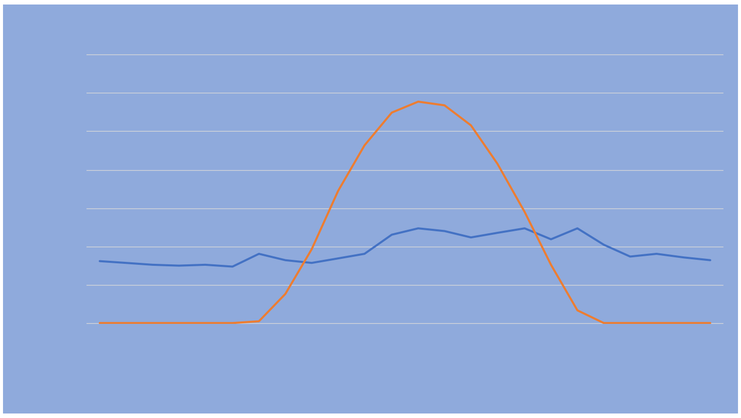

Figure 7: Combined daily load profile of all customers. A typical daily solar power generation profile is superimposed on the load profile

Homer grid and *Homer Pro* software were used to carry out optimization simulation exercises for a hybrid mini-grid system considering variable power demand of multiple customers using PV systems at their premises. Different scenarios have been created adding different capacity centralised PV and BESS systems to the mini-grid network. These scenarios are further analysed by considering a stand-alone mini-grid with and without a diesel generator (DG) and with and without the presence of the main grid. Conditions and results of these analysis are presented in table 2 below.

Table 2: Scenario analysis of different configurations

	System 1	System 2	System 3	System 4	System 5	System 6
Distributed PV	520 kW	520 kW	520 kW	520 kW	520 kW	520 kW
Central PV	No	No	No	500 kW	2000 kW	4000 kW
BESS	No	No	250 kWh	250 kWh	2500 kWh	4500 kWh
Grid	Yes	Yes (20 hrs. power cut/ month)	Yes (20 hrs. power cut/ month)	Yes (20 hrs. power cut/ month)	No	No
Grid tariff	₹7.5	₹7.5	₹7.5	₹7.5	₹ 0	₹ 0
DG	No	360 kVA	No	No	360 kVA	360 kVA
	Capital cost (INR Crore)					
	₹2.6	₹2.75	₹3.60	₹6.10	₹22.65	₹40.65
IRR	**18%**	**7%**	**11%**	**15%**	**n/a**	**n/a**
Average cost of electricity (25 years basis) in INR/ kWh						
	₹4.21	₹8.07	₹5.78	₹4.63	₹13.78	₹9.37
	Payback (Years)					
	6 years	9 years	9 years	7 years	n/a	n/a

CONCLUSION

The analysis clearly shows that the average cost of electricity is much higher (Rs.9.37/kWh and Rs.13.78/kWh) when the mini-grid system operates standalone without connecting to the grid (system 5 and 6). The average cost of electricity is lowest (Rs.4.21/kWh) when a mini-grid is formed with distributed PV at the customer's premises and it is connected to the grid and no backup power is required (system 1). When this system is connected to the main grid but the grid is not reliable, a diesel generator is considered for standby power supply for 20 hours a month (system 2). In this case, the average cost of electricity is Rs.8.07/kWh. Under this condition, if DG set is replaced by a BESS for required power backup (system 3) cost of electricity was found to be Rs.5.78/kWh which is much lower than the previous case. When an additional central PV plant (500 kW) is added to the system 3 configuration, cost of electricity further reduced to Rs.4.63/kWh (system 4). It may be concluded that a mini-grid system comprised of multiple distributed PV systems at customer premises and a central PV system and BESS combined will provide reliable electricity at cheaper price in rural, urban, and sub-urban areas. The BESS used in the mini-grid can also be used to provide auxiliary services to the DISCOMs such as power quality improvement and peak power management.

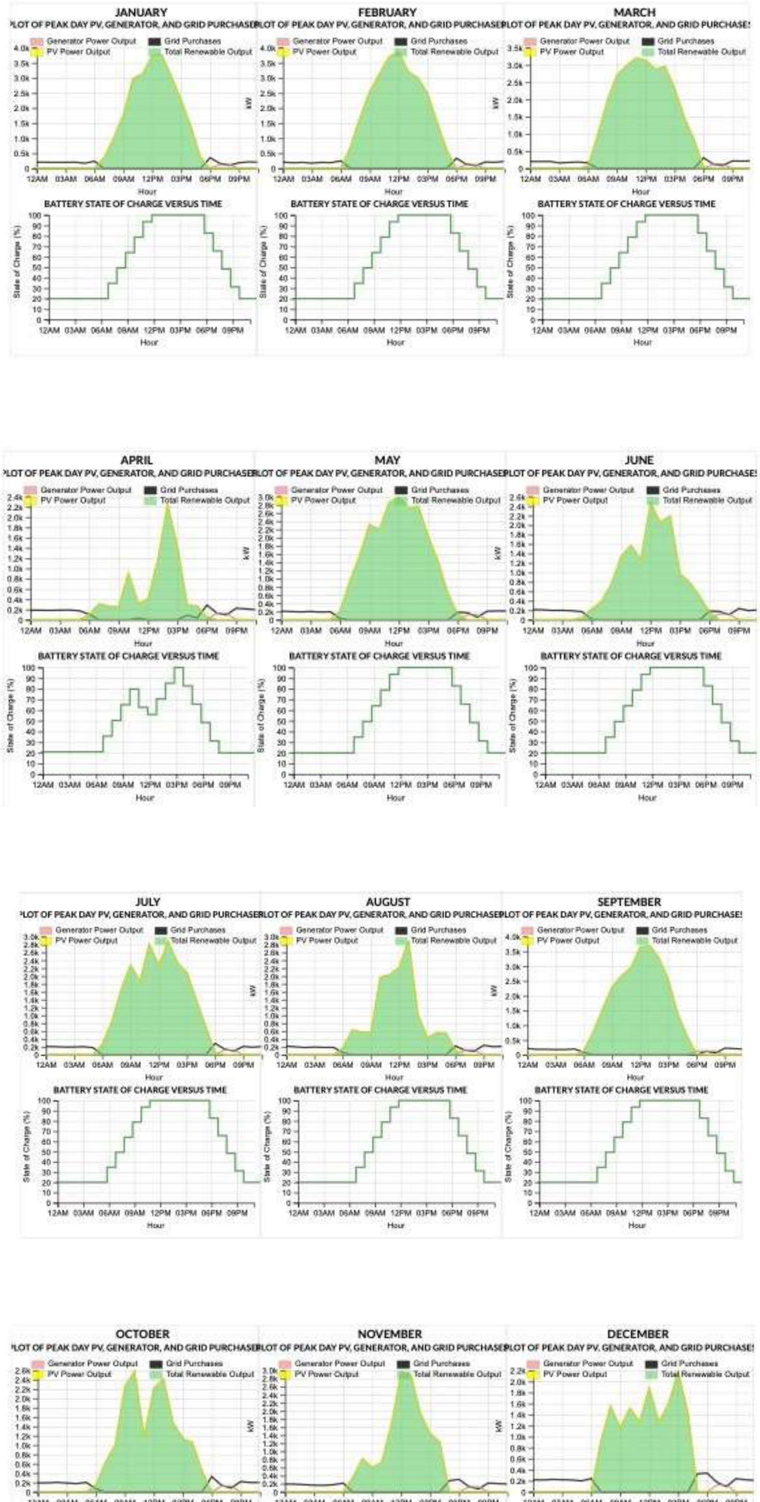

Figure 8: Snapshots of Homer grid analysis for mini-grid system with distributed loads and generation

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Integration of EV Battery with Low Voltage Power lines and Study their Impact

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Abstract

Battery swapping is an alternative which involves exchanging discharged batteries for charged ones and provides flexibility to charge them separately. Battery swapping is generally used for 2Ws and 3Ws with smaller batteries that are easier to swap, compared to 4 wheelers. Battery Swapping Stations are picking up the pace and being installed at distributed locations in DISCOM distribution area. Batteries placed at swapping stations remain idle at certain hours and can be a Power Source readily available for distribution systems (Low Voltage Lines) during peak hours. The paper proposes to study interconnection of battery charging stations with low voltage distribution system. During lean period such battery charging stations will feed power back to grid serve as extensive network of Battery energy storage systems helping Distribution Transformers in load management and loss reduction by improving the voltage profile of low voltage lines. Further during off peak period such batteries will be charged again to be ready next morning. Through this mechanism Battery swap operators can reduce their operation expenses.

Keywords

Battery Charging Station (BCS), Battery Swapping facility/stations (BSF/BSS), Electric Vehicles (EV), Low Voltage (LV) Lines, Distribution Transformer (DT), Aggregate Technical and Commercial Loss (AT&C), Average Power Purchaser Cost (APPC), 2-Wheeler (2W), 3-Wheeler (3W), EVSE (Electric Vehicle Supply equipment), Single Line Diagram (SLD)

Introduction

India's commitment for net zero by 2070 and rising concerns among common man towards environmental issues and climate change is attracting policy makers and government attention towards sustainable lifestyle adoption. Transport sector is a major contributor to India's carbon market and hence it is essential to choose right fitment of alternatives for a sustainable future. Electric Vehicles (EVs) are a promising alternative to ICE (Internal Combustion Engine) vehicles. Innovations in battery technology, reduction in moving parts, and zero tailpipe emissions make EVs an economically viable and sustainable mobility solution that is finding global support from Policymakers and Industry leaders alike.

Unlike electric vehicle charging stations where EV Batteries are charged inside the vehicle, BSS facility is one where discharged batteries of EV are replaced with charged ones. This de-links charging and battery usage and keeps the vehicle in operational mode with negligible downtime. Battery swapping is generally used for vehicles with small battery packs such as 2Ws and 3Ws which are easier to swap, compared to 4 wheelers.

With increasing adoption of electric vehicles, among electric segment 2 wheelers and 3 wheelers have seen rapid adoption. Further their low cost of operation have made them a preferable choice for last mile delivery. With increasing adoption of these segments for last mile delivery, inter para transit and personal use market for BCS, BSS is growing at rapidly.

BSS are being installed at distributed locations in the city. During night time these BSS are a Power Source readily available for distribution systems (Low Voltage Lines) which can feedback power to distribution transformer improving the voltage profile of line and reducing line losses. Further utilization of this power during peak will reduce cost of power procured along with improving grid reliability and easing out grid congestion.

II. Battery swapping ecosystem

A. **Swappable Battery Electric Vehicles**

Organizations and industries are focused on adoption of sustainable solutions within day-to-day process and systems. Companies operating in segment of last mile delivery, passenger movements are among early adopters of electric vehicles replacing their ICE fleets.

Aggregators are concerned about the range of EV models to meet up their daily travel requirements. Also, last mile delivery operators are bound to meet up standards and hence delay on account of refueling cannot be accepted by this segment. Further intra paratransit service operators demand fast refueling to keep their vehicles on road and increase the revenue per day. Hence aggregator's fleet majorly depends on battery swapping technology over charging systems to refuel their vehicles.

Swappable battery electric vehicle models come with small size pair (s) of battery which is detachable from parent vehicle. These batteries once discharged can be exchanges with a charged unit at any battery swapping station. As manual handling of batteries is done in this process, this form of recharging system is feasible currently for electric 2W and 3W segments which come with a small size battery pack.

B. ***Battery Charging and Swapping Ecosystem***

The domain of battery swapping has two major segments i.e., charging of a discharged battery known as battery charging system and replacement of this charged battery with discharged one at swap point known as battery swapping facility. Either of the system can operate as singular system or clubbed within a single unit.

Recharging of electric 2W or 3W using a EVSE takes 3-5 hours of time. Similar vehicle can be recharged through a swapping system in 5-10 mins. Due to very low recharger time aggregators of electric 2 wheelers and 3 wheelers majorly depend on this form of refueling system to power up the vehicles.

III. Battery to distribution grid integration

A. **Connectivity with Distribution Network**

Capacity of individual battery within a BSF ranges from 1.4 KWH to 2.5 KWH. Further any increase in capacity of battery increases its weight making unfit for swappable system. Thus, based on no of batteries in a BSF, the total load of a BSF ranges between 20KW to 30KW spread across an area of 100 to 120 Sq.ft. As the space and power requirement of an individual unit is not high, such system is being installed across the city at distribution locations. As the EV penetration increases so will the need of such facilities and their cumulative capacity.

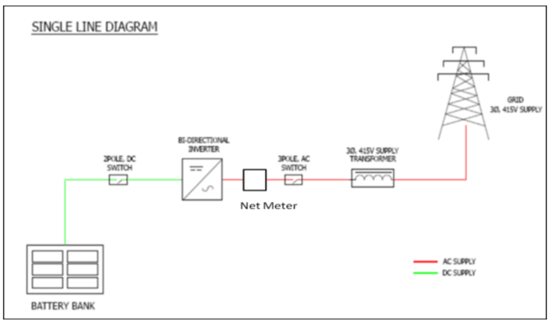

Fig 1. SLD of Connectivity of BSF with Grid

BSF installed near to end use consumers are connected at Low voltage network of distribution utility. Utility lines through an energy meter feed power directly to BSF. Batteries require DC power for recharging; hence a rectifier converts AC grid power to DC at required voltage to be fed to batteries being recharged

B. Potential for Bi-directional Power flow to Distribution Network

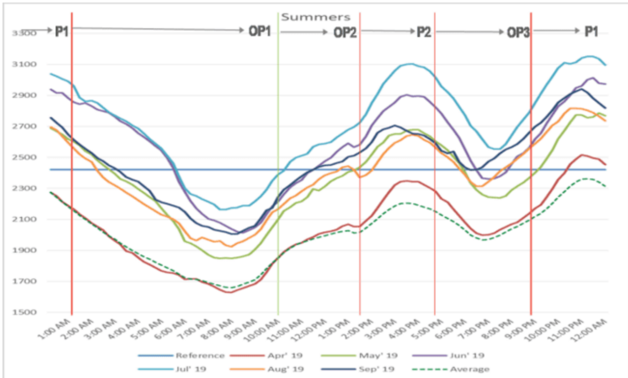

Fig 2: Peak Power Period for DISCOM during Summer

BSS/BCS provide facility to an EV user to exchange his discharged battery with charged one. This model of EV Charging is prominent among 2W & 3W aggregators and fleet operators. The operating time of such segment of users is largely during 09:00 to 21:00 hours.

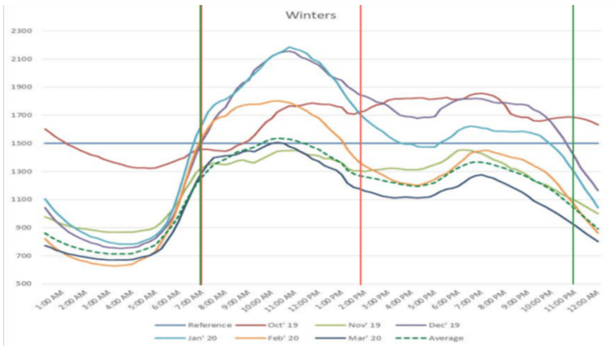

Fig 3: Peak Power Period for DISCOM during Winter

DISCOM power peak is experienced during evening time where maximum cooling load is plugged in the network which is around 22:00 to 01:00 hrs. in summer season and heating load during 07:00 to 12:00 hrs. in winters. Hence during the DISCOM peak power period the BSS/BCS are not being utilized by the EV users and are kept idle.

These BSS/BCS complete unit comprise of multiple smaller batteries in a single system and hence they as a whole unit can be considered as a small battery storage system connected to distribution network. During Peak Power period as these units are not being utilized for swapping, they are a readily available source of power ready to feed in electricity on demand/schedule of Discom to end low voltage distribution lines.

3. Assessing the Impact of integration and power flow

The study is assessed on integration of a 100KW BSS with a 400 V +/- 5% LV power line emerging out of a 990KVA Distribution Transformer. For energy accounting of reverse power flow to grid, net metering was considered at interconnection point.

A. **Reduction in Line Losses at Low Voltage Network**

As voltage of line is step down the system loss of network increases as to transfer same amount of power from source end to load end the current flowing through the line increases which increases the resistive losses in the line. In general, a low voltage line experiences a loss of 4% from distribution transformer to consumer meter. This loss of power is accounted for utility as system inherent technical loss and impacts the billing efficiency of the DISCOM.

BSS feeding a power of 100KW directly into the power lines for 1 hour of schedule provided by the DISCOM reduces the requirement of such power flow from the distribution transformer. Hence the 4% of technical loss occurring from transformer to consumer meter for 100KW of power flow is mitigated. Further power source available at consumer end improves the voltage profile of the line hence further reducing the line loss due to voltage gradient.

B. **Mitigation of Transformer overloading**

Distribution transformers are designed to operate at maximum efficiency with loading of 60-70%. During summer season, due to increase in power demand loading on distribution transformers increases beyond this efficient limit to 80% and above. Hence at such loading conditions the transformers are under thermal stress, have increases losses and eventually may result into failure due to degrading insulation.

BSS feeding power directly to LT lines acts a power source available at point of consumption, reducing the loading to about 10% from on distribution transformer.

C. **Deferring Capex Requirement for transformer and line Augmentation**

Loading on power distribution network increases gradually each year. Every year DISCOM plan their network based on past load growth trend and peak loading recorded on DT meter in last financial year. On an averaeg this load growth range from 5% to 10% each year in normal habitated localities. The cost of augmenting end distribution network involves transformer, land space and LV power lines to consumer doorstep. Thus this is cost as well as land intensive activity.

BSS during peak power period aid the peak power demand through stored electrical energy within the batteries and hence shave off the peak recorded on DT meter. Hence this bi-directional power flow system could defer capital expenditure for period of 1-2 years.

D. **Reducing Power Purchase Cost during Peak Periods**

During summer cooling load connect to grid increase the demand of power which is maximum during nigh time where majority of domestic cooling appliances are plugged to power network. Power demand during peak periods increases and to meet this rising power needs, DISCOM has to purchase costly power from exchanges.

Hence through support from BSS during peak power periods, DISCOM can avoid costly power purchase during peak period which is illustrated as below:

Representative power purchase saving to DISCOM = 7.73 Rs/KWH (MCP for May 2022 of 23:00 to 01:00) – 6.10 Rs/KWH (APPC as per DERC tariff order FY 21-22) = 1.63 Rs/KWH

Acknowledgment

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Integrating EV's as an Independent Energy resource

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Abstract

The annual global energy consumption is estimated to be 580 million terajoules, thus demand rises for new technologies to generate, distribute, and consume energy. Distributed Energy generation has become a major trend across globe. To handle this distributed generation and to intensify its visibility within power markets; Virtual Power Plants (VPPs) have become an attractive idea.

VPPs are playing major role in maintaining the balance of the power system. Electric Vehicle (EV) fleets have the potential to be an important component of these VPPs. As per market Insights PEVs market will be potentially growing ~78% by 2023.It is anticipated that the global population of PEVs could reach 190 million, By 2030.

EVs, that sit idle in the parking lots or garages for more than 90% of the day, are a perfect fit for this purpose. With vehicle-to-grid (V2G) technology; EV batteries can be charged to store energy during the off-peak hours and sell it back to the grid during the peak hours.

VPP is an advanced technology based on aggregation, orchestration, Artificial Intelligence (AI)-based forecasting, and optimization to integrate diverse DERs to support smart grid. The proposed paper talks about the benefits of Electric Vehicles (EV) with Virtual Power Plants (VPP) by:

Cost optimization by minimizing capital investment on new generation facilities

Allowing higher flexibility to grid system by energy injection during peak hours.

Keywords

Electric Vehicle, Distributed energy, Energy demand, supply, EV Batteries, Vehicle-to-grid

Introduction

EV market share continues to grow across both residential and commercial and industrial (C&I) fleets. The deployment of EVs can cause strain on localized grid infrastructure, particularly as higher numbers of EVs connect to the grid to charge during periods of peak demand. A virtual power plant (VPP) platform can optimize EV charging and potentially support the discharge of EV batteries to support the electricity grid during periods of peak demand.

As well as maintaining the proper balance of the electricity grid at the lowest economically and environmentally feasible price, VPPs work to maximize profit for distributed energy resources (DER) asset owners. Vehicle grid integration (VGI) has emerged as one of the next frontiers in smart device management because of the symbiotic relationship between VPP platform solutions and plug-in EV (PEV) adoption.

Reports analyze both unidirectional (V1G) and bidirectional (V2G) smart charging applications, as managed through VPP software. This study analyzes market trends, including drivers and barriers, as well as regional developments in VGI-based VPP deployment.

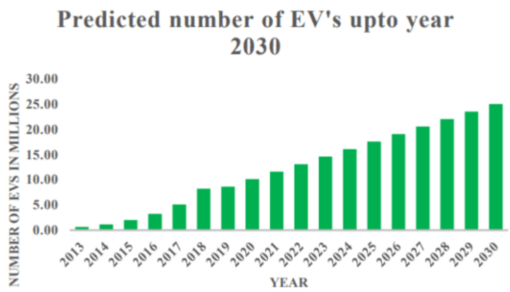

Figure 1 Predicted EV's till 2030

Figure 1 shows that predicted EV's count 2030, Globally there will be approximately $22-25 million electric vehicles by 2030. This means that we will have at least 140 million tiny energy storages on wheels with an aggregated storage capacity of 7 TWh. Global market forecasts for capacity, implementation spending, and revenue, broken out by region and customer segment, extend for both V1G- and V2G-based VPPs through 2029 as shown in figure 2.

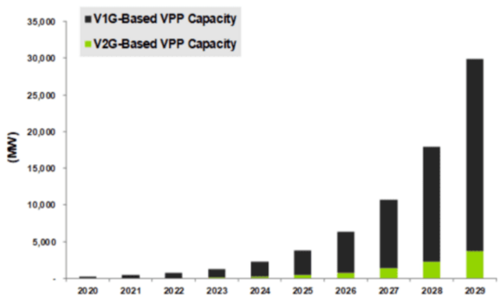

Figure 2- VGI-Based VPP Capacity by Technology

II. Challenges

The problem is not the overall capacity of the grid, it is the peak capacity of the grid that is the challenge. We all know these peaks are getting higher and coming more often as we grow more reliant on power. Extreme weather events add more strain on the grid. With semiconductor technology, V2G bidirectional charging could smooth out these peaks, which would benefit us all.

III. Proposed solution:

A. Integration of EVs into VPP

VPP Control Centers are responsible for the optimal coordination of their resources and representing them as single entities to the market, DSOs, and TSOs.

It centrally takes care of the optimization of the operation of all individual VPP resources. The use of ICT solutions allows it to monitor and control in near real-time. Charging Point Managers are entities responsible for operating several EV Charging Points (CPs). It can be classified into three different categories based on their location. The CP location may be either in public areas with public access, private areas with private access, or private areas with public access. In each of these areas, the VPP

Control Centre may communicate with the EVs in different ways. Below figure 3 shows the overall architecture of VPP technology.

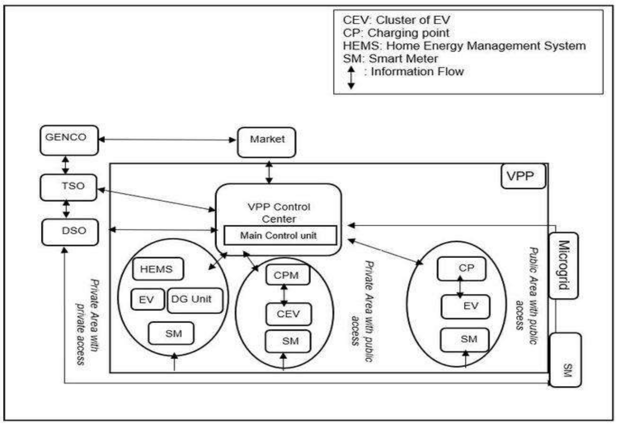

Figure 3- VPP technical Architecture

For example, communication with EVs in private areas with private access may be realized through Home Energy Management System (HEMS). HEMS is an application that enables energy consumption management in a house considering the user preferences and allows interaction with the utility.

For the market participation, the VPP Control Center prepares bids and offers for the day-ahead and intraday markets based on the forecast about generation and demand of VPP resources in real-time, using the measurement data from Smart Meters (SMs) and the updated input from market and the SO, and then after decision it sends out adjustment requests to VPP resources.

B. V2G as commercialization

Energy should be either used where it is produced or stored somewhere for later usage. Due to the growth of renewable energies, our energy system is becoming more volatile, requiring new methods of balancing, and storing energy. Since electric vehicle batteries require no additional hardware investment, they are one of the most cost-effective energy storage methods.

In comparison to unidirectional smart charging, V2G allows the battery to be utilized more efficiently. With V2X, EV charging becomes a battery solution rather than an electrical demand response. With this technology, the battery can be used 10x more efficiently than with unidirectional smart charging.

In the long run, vehicle-to-grid technology has the potential to transform the energy system. Electric cars are equipped with a technology that allows them to send back energy to the grid from their batteries. Electric vehicle-to-grid technology, also known as car-to-grid, lets a car's battery charge or discharge based on external signals, such as nearby energy consumption or production.

V2X means vehicle-to-everything. The concept encompasses a wide range of applications such as vehicle-to-home (V2H), vehicle-to-building (V2B), and vehicle-to-grid. Different abbreviations are used for electrical loads from EV batteries, depending on whether you wish to power your home or build one. In some cases, your vehicle can work for you even if feeding back to the grid is not possible

Conclusion:

V2G's transformation into reality is ultimately a data-driven operation that requires smart communication between both EVs and their charging infrastructures. The need for advanced connectivity solutions as well as smart energy meters will be crucial for grid operators to anticipate and adjust the power load required by EVs as they move from one location to another. EV owners will need a reliable and secure real-time communication system if they wish to get charged or compensated for returning power to the grid

The demonstration test involved connecting a dedicated server with the smartphones of EV owners, and the test provided us with useful data and technological insights. Such data will be analyzed and further studied in order to increase power control accuracy. Furthermore, we will refine the technology to control a greater number of energy equipment in an integrated manner and address any business issues toward implementing VPP in practice. This prototype can be developed into an enhanced electricity demand control system that encourages the use of renewable energy, which contributes to the efficient use of electricity throughout society.

V. Overall benefit can achieve by implementing this process

- Reduce total cost of ownership of fleets
- Car OEMs (manufacturers) can sell vehicles with added value
- Energy market parties can trade and optimize their balance
- Network operators can optimize investments & stabilize the grid

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Powering Indian Mobility Sector Through Battery-As-A-Service Model

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Abstract

The Electric Vehicle (EV) market has emerged as a dynamic business area in the clean energy space with sales of EVs doubling to 6.6 million in 2021[1]. EVs also present opportunities for India as it aims to achieve Net-Zero by 2070. However, EVs and its charging infrastructure face a plethora of challenges in India, which include high cost of EVs (primarily batteries), long charging wait-time, lack of optimum and sufficient charging space in congested cities, among others.

This paper proposes Battery-as-a-Service (BaaS) model which enables customers to exchange their depleted batteries with charged ones at a battery swapping station BaaS trumps charging stations in all three focus areas i.e., cost, time, and space.

- Cost: BaaS decouples battery costs from the vehicle's cost, making it 30-50% cheaper to own EV [2]
- Time: Swapping is a few-minute process, as opposed to an hour (with fast-charging)
- Space: It only takes a fraction of space as compared to charging stations, making it easier to integrate into congested city infrastructure

The model aims to provide batteries on a monthly subscription fee with an additional per swap fee. This concept can be applied to a range of mobility requirements – personal, commercial, and public.

Keywords

Electric Vehicle, Charging Infrastructure, BaaS, Subscription, Swapping.

Introduction

The EV industry in India is picking up pace with substantial investments, manufacturing hubs, and an increased push to improve charging infrastructure. Subsidies and policies from the government favouring discounts for Indian-made electric two-wheelers as well as a boost for localized Advanced Chemistry Cell battery storage production are other growth drivers for the Indian EV industry. In 2021, the Indian EV industry attracted US$6 billion in investment and is becoming more and more attractive to venture capital investors/private equity [3]. EV push in India opens an abundance of opportunities across segments of infrastructure, energy, and mobility.

II. Challenge

EV market is poised to grow but companies and industry must overcome some obstacles to capitalize on the market entirely; Some of these challenges are explained below:

Range anxiety: The fear that EV will not have sufficient charge to complete its duty or cover the required distance poses major barrier in the transition toward electric Mobility [4].

High initial cost: There is a huge investment involved in setting up an EV charging station for which requirements like location, land, power stability, vendor, etc. need to be taken care of.

Location: Location of a charging station should be such that it is easily accessible and saves charging time and finding such a prime location in India can be a big roadblock.

Scarce battery technology: Number of OEMs for manufacturing batteries is quite limited in India and it relies heavily on China and Korea which hinders country's growth in EV space [4].

III. Proposed Solution

BaaS Solution can tackle the above-mentioned challenges in a cost-effective manner as this solution offers multiple advantages over traditional charging such as lower cost of EV, lower cost of charging infrastructure, less space requirement for charging operations, and a faster charging experience. A successful BaaS model stands on three pillars – Ecosystem, Swapping Infrastructure and Subscription Model.

A. Ecosystem

Most long-range EVs are powered by Lithium-ion batteries which are manufactured by only few companies. Developing in-house battery capabilities would require time and investment in both, R&D, and manufacturing. This could lead to loss of market opportunity, hence, partnering with a well-established EV battery manufacturer and co-develop swappable EV models would be the best choice for swift market entry. Co-development also helps in establishing technical and operational requirements of their respective products. From a long-term sustainability view, both EV and battery providers must also consider end-of-life battery recycling/disposal cost and look to partner with specialized battery recyclers.

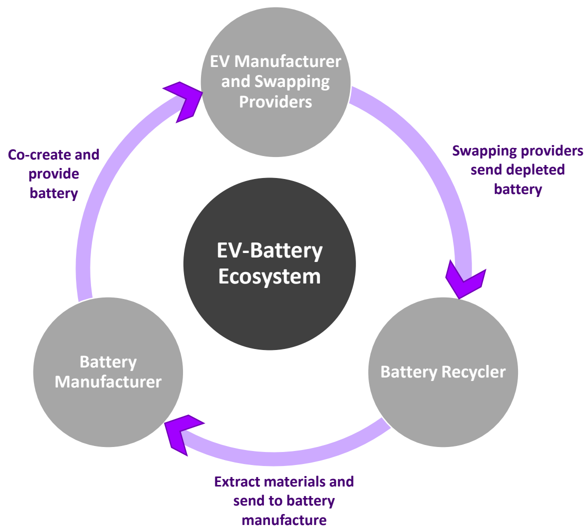

Figure 1- EV-Battery Ecosystem

Once the EV-Battery ecosystem is in place, the swapping business model is created based on hub-and-Spoke model wherein swapping stations are spread out across the cities while battery charging is centralized. Refer Figure 2 for a detailed model

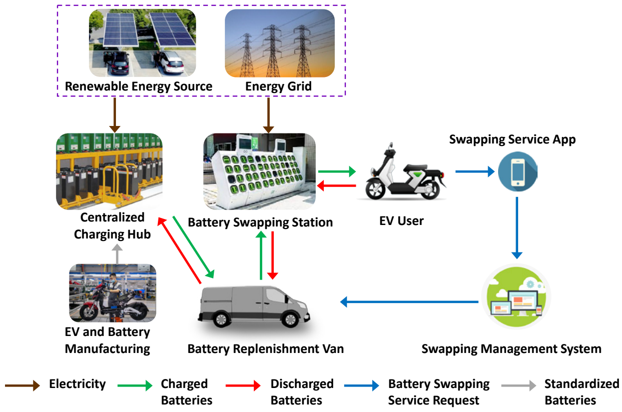

Figure 2- Battery Swapping Business Model

B. Swapping Infrastructure

The success of BaaS model depends on the accessibility of swapping points, as a customer looking for a swap will probably have only a few KMs worth of charge left and would not be able to travel far with that. With its compact size, finding space is not a constraint for swapping stations, however, calculating the optimum number of stations and their locations to cover the entire customer base is a challenge.

Problem Statement: How to select battery-swapping station sites such that it maximizes user satisfaction and minimize the electricity consumed by the customers to reach station.

Location and Station Size Identification Methodology:

- Conduct a GIS mapping to track traffic flow and identify nodes with the highest vehicle footfall. This will serve on-the-move swapping customers
- Identify high-volume two-wheeler parking, such as malls, and mark the nodes. This covers destination-based swapping customers
- Finalize the optimum area of service per station 'R' e.g., 1km, 2km, etc., and mark circular perimeters across the identified nodes
- Identify the optimum spot to install swapping station keeping three factors in mind – station visibility, accessibility, and safety
- To identify number of slots required at each swapping station, we propose below equation

N=((EV1*SR1) +(EV2*SR2) ...)/RP

N=No. of slots required per station

EV=No. of EVs crossing a Swapping Station serving radius per day while the numeric value represents the type of EV i.e., personal use, commercial 2-wheeler, 3-wheeler, etc.

SR=Swap required per day per vehicle type. E.g., a personal vehicle might require one swap in two days (0.5/day) while a commercial 2-wheeler requires one daily.

RP=No. of replenishment per day per station

- To identify EV and SR values, traffic cams and drone surveillance data can be leveraged

Validation:

Swap Grid (N) required for a station serving radius in which 200 personal 2-wheeler, 140 commercial 2-wheeler, and thirty 3-wheeler pass every 24 hours, and is replenished 3 times per day

N= ((200*0.5) +(140*1.0) +(30*1.0)/3

N=90

- Once all station locations and capacity are decided, the centralized charging hub is finalized.

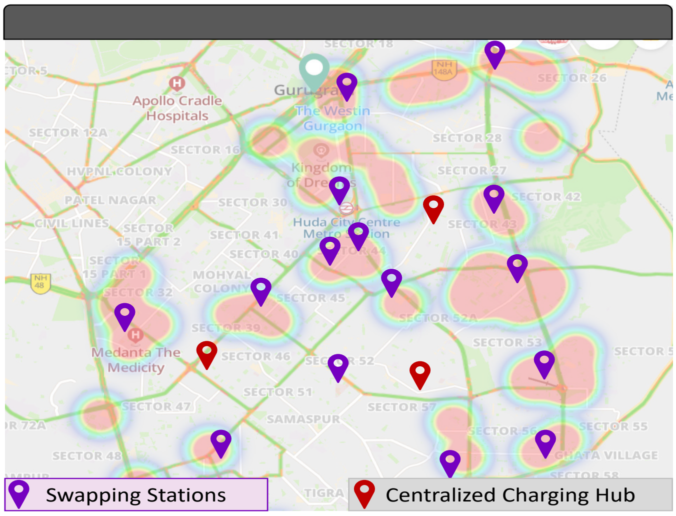

Figure 3 – Swapping Station Location Mapping

C. Subscription Model

With no prior experience with subscription-based models in vehicles, customers might face challenges in understanding BaaS model, hence, the model needs to be simple and straightforward explanation of payment terms, benefits, customer support, etc.

Table 1 – Proposed Subscription Models

EV Swapping Subscription Models	Personal Use 2-Wheelers	Commercial Use 2/3 Wheelers
Upfront Vehicle cost Paid	60%	0%
Monthly Subscription	Fixed Flat Fee with fixed # of free swaps (e.g., INR1,200 per month with 10 free swaps)	Fixed Flat Fee with no free swaps (e.g., INR3,000 per month) as no upfront cost is paid
Per swap fee	Flat rate e.g., INR40 per swap	Flat rate e.g., INR30 per swap
Comments	Multiple plans can be made by changing above three component	No upfront cost will lead to proliferation of swappable EV's generating future revenue stream

IV. Conclusion

Taking above model as blueprint, companies can setup mutually beneficial product partnerships, plan optimal swapping infrastructure locations, and create practical subscription plans, which will collectively enable them to create battery swapping ecosystem in India swiftly and at scale.

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EVs as Virtual Power Plants (VPP)

Virtual Power Plant (VPP), Definition, Concept, Components and Types.

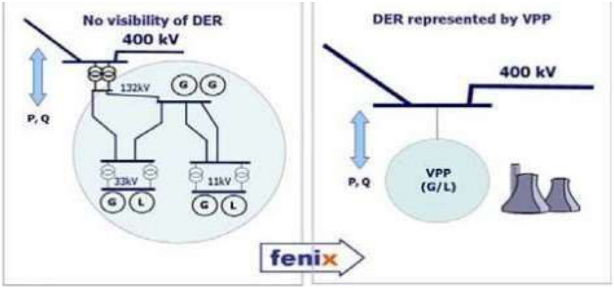
A virtual power plant is a cluster of dispersed generator units, controllable loads, and storages systems, aggregated in order to operate as a unique power plant. The generators can use both fossil and renewable energy source. The heart of a VPP is an energy management system (EMS) which coordinates the power flows coming from the generators, controllable loads, and storages. The communication is bidirectional, so that the VPP can not only receive information about the current status of each unit, but it can also send the signals to control the objects. The mentioned Energy Management System (EMS) can operate according to its targets which can be, for example, the minimization of the generation costs, minimization of production of greenhouse gasses (GHG) and maximization of the profits. In order to achieve such targets, the EMS needs to receive information about the status of each unit on the one hand, and on the other hand forecast - especially for renewable units like wind and photovoltaic (PV). Furthermore, the information about the possible bottlenecks in the grid plays a relevant role in the optimization process of the VP operation. In this way the EMS can choose the optimal "modus operandi"

General Concept: -

A virtual power plant is a cluster of dispersed generator units, controllable loads, and storages systems, aggregated in order to operate as a unique power plant. The generators can use both fossil and renewable energy source. The heart of a VPP is an energy management system (EMS) which coordinates the power flows coming from the generators, controllable loads, and storages. The communication is bidirectional, so that the VPP can not only receive information about the current status of each unit, but it can also send the signals to control the objects The mentioned Energy Management System (EMS) can operate according to its targets which can be, for example, the minimization of the generation costs, minimization of production of greenhouse gasses (GHG) and maximization of the profits. In order to achieve such targets, the EMS needs to receive information about the status of each unit on the one hand, and on the other hand forecast - especially for renewable units like wind and photovoltaic (PV). Furthermore, the information about the possible bottlenecks in the grid plays a relevant role in the optimization process of the VPP operation. In this way the EMS can choose the optimal "modus operandi."

Due to the fluctuating nature of renewable energy sources, the prediction of the energy production is not an easy procedure.

Actually, for Wind Park, the day ahead forecasting errors are between 9 and 19 %. Due to such errors, power networks with a high penetration of renewable energy sources, can easily have bottleneck and balancing problems. These problems can be faced either by using ESS or NSM. Although ESS and NSM are the most used instruments, in some cases alternative solutions can be also used. For example, in regions poor of fresh water, desalination plants that are driven by the electricity surplus can be an optimal solution to face bottleneck situations.



Virtual Power Plant consists of three main parts including:

A. **Generation Technology: -** The DG specification is useful to broadly mention the range of capabilities for various technologies, generally falling under the distributed generation category. DER considered for integration in VPP.
B. **Energy Storage Technology: -** Energy storage systems can be considered today as a new mean to adapt the variations of the power demand to the given level of power generation. In context of use renewable generation, can be used also as additional sources or as energy buffers in the case of non-Dispatchable or stochastic generation, e.g., wind turbines or PV technologies especially in weak networks. ESS considered for integration in VPP.
C. **Information Communication Technology (ICT): -**
The important requirement for VPP is communication technologies and infrastructure. In many different communications, media technologies can be considered for communications in Energy Management Systems (EMS), Supervisory Control and Data Acquisition (SCADA) and Distribution Dispatching Center (DCC)

TECHNICAL VPP (TVPP) & COMERCIAL (CVPP)

A. Technical VPP (TVPP): - The TVPP consists of DER from the same geographic location. The TVPP includes the real-time influence of the local network on DER aggregated profile as well as representing the cost and operating characteristics of the portfolio. Services and functions from a TVPP include local system management for Distribution System Operator (DSO), as well as providing Transmission System Operator (TSO) system balancing and ancillary services. The operator of a TVPP requires detailed information on the local network; typically, this will be the DSO” [17]. The TVPP enables:

- Visibility of DER units to the system operator(s)
- Contribution of DER units to system management

Optimal use of the capacity of DER units to provide ancillary services incorporating local network constraints This allows small units to provide ancillary services and reduces unavailability risks by diversifying portfolios and capacity compared to stand-alone DER units. A comprehensive overview of the technological control capabilities of distributed generators and the resulting possibilities of providing ancillary services are analyzed in 18 and [19]. The technological potential is investigated by application of a new assessment approach that considers the grid-coupling converter separately with its capabilities. An enormous technological potential is identified. DSOs that use the TVPP concept can also be considered as Active Distribution Network (ADN) operators. An ADN operator can use ancillary services offered by DER units to optimize their network operation. On the other hand, an ADN operator can also provide ancillary services to other system operators. A hierarchical or parallel structure of ADNs may exist where the TVPP concept is applied, for instance according to different voltage levels or different network regions. Many examples of ADNs can be found in the Active Network Deployment Register.

Some of the functionalities that have to be performed by TVPP are:

- Continuous condition monitoring - retrieval of equipment historical loadings
- Asset management - supported by statistical data
- Self-identification/self-description of system components
- Fault location - automatically integrated with outage management
- Facilitated maintenance
- Statistical analysis and project portfolio optimization

A. **Commercial VPP(CVPP)**

A CVPP has an aggregated profile and output which represents the cost and operating characteristics for the DER portfolio. The impact of the distribution network is not considered in the aggregated CVPP profile. Services or functions from a CVPP include trading in the wholesale energy market, balancing of trading portfolios and provision of services (through submission of bids and offers) to the [transmission] system operator The operator of a CVPP can be any third-party aggregator or a Balancing Responsible Party (BRP) with market access; e.g., an energy supplier."

The CVPP enables:

- Visibility of DER units in energy markets
- Participation of DER units in the energy markets
- Maximization of value from participation of DER units in the energy markets This allows market access of small units and reduces the risk of imbalance by portfolio diversity and capacity compared to stand-alone DER units. CVPPs perform commercial aggregation and donot take into consideration any network operation aspects that active distribution networkshave to consider for stable operation. The aggregated DER units are not necessarily constrained by location but can be distributed throughout different distribution and transmission grids. Hence, a single distribution network region may have more than one CVPP aggregating DER units in its region.

Basic CVPP functionalities would be optimization and scheduling of production based on predicted consumers' demand and generation potential. When actual needs differ frompredicted ones, DRRs (Demand Response Resources) are introduced to fill the gap between production and real consumption. In general, CVPP functions should be include:

- Maintenance and submission of DERs' characteristics
- Production and consumption forecast
- ODM (Outage Demand management)
- Building DER bids
- Bids submissions to the market
- Daily optimization and generation scheduling
- Selling energy provider by DERs to the Market

CONCLUSION

Through the VPP concept Individual DERs can gain access and visibility across all energy markets, and benefit from VPP market intelligence to optimize their position and maximize revenue opportunities. System operation can benefit from optimaluse of all available capacity and increased efficiency of operation. Benefits from the Virtual Power Plant concept have been identified for different stakeholders.

Main benefits for owners of DER units:

- Capture the value of flexibility
- Increasing value of assets through the markets
- Reduced financial risk through aggregation
- Improved ability to negotiate commercial conditions
- Main benefits for DSOs and TSOs:
- Increased visibility of DER units for consideration in network operation
- Using control flexibility of DER units for network management
- Improved use of grid investments
- Improved co-ordination between DSO and TSO
- Mitigate the complexity of operation caused by the growth of inflexible distributed generation

Main benefits for Policy Makers:

- Cost effective large-scale integration of renewable energies while maintaining system security
- Open the energy markets to small-scale participants
- Increasing the global efficiency of the electrical power system by capturing flexibility of DER units
- Facilitate the targets for renewable energy deployment and reduction of CO2 emissions
- Improve consumer choice

New employment opportunities Main benefits for suppliers and aggregators:

- New offers for consumers and DER units
- Mitigation commercial link
- New business opportunities

Integration of IOT Based Dynamic Load Management to EV Charging Infrastructure

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Abstract

In the past decade we have seen exponential growth of the electric vehicle (EV) market across the world. Zero emissions and decarbonization driving the transformation of transportation sector from ICE to EV. As electric vehicles growth increasing rapidly, it possesses a greater challenge to power utility companies. The existing power infrastructure cannot support the number of charging stations that needed to charge electric vehicles, the total energy consumption can rise to exceptionally high while large number of EVs are getting charged simultaneously and lead to electrical grid, overall system overload. Not only grid level but also the major problem at EV charging stations to allocate required amount of energy to each EV and charging session prioritization.

The problem can be solved by upgrading physical infrastructure, but this solution is not cost effective. The best way to resolve this issue is to manage the existing power infrastructure in the best way to avoid peak loads and break downs. IOT based Dynamic Load Management (DLM) system is the alternative solution to resolve this issue. The IOT technology helps to fetch the real time information across the network which enables DLM to distribute the required (optimal) energy to all charging sites within the grid limit, it ensures that the grid is not overloaded. At the charging station the DLM prioritize charging sessions and distribute the available power efficiently to all EVs that are being charged simultaneously, the DLM make sures that all the EVs are charged evenly based on electric vehicle battery SOC.

Keywords

electric vehicle, internet of things, dynamic load management, IOT architecture, charging session

Introduction

The dynamic changes are happening in the transport sector to address environmental pollution which is happening due to this industry. The adaptation of electric vehicles (EV) over internal combustion vehicles growing rapingly. To have long run sustenance the EVs are require sufficient charging infrastructure. Implementation of bulk number of charge points will address the market concerns like driving range anxiety. To install large scale of charging stations the industry needs to address the issues like charging station management, uninterrupted power supply by avoiding overload, system failure and monitoring EV battery health at every charging session. Along with these charging of multiple EVs simultaneously without effecting power distribution grids.

In this paper we will try to propose a one of the solutions to overcome these issues. Smart charging and dynamic load management (DLM) can management charging sessions effectively with integration of IOT.

2. Dynamic load management

Dynamic load management allows charging multiple electric vehicles simultaneously by splitting available energy efficiently at the site. Dynamic load management useful who operate multiple charging stations and multiple charging guns for single charging station. During charging of multiple vehicles and demand hours the DLM will consider all the limitations of charging infrastructure then distribute the energy to the all the EVs without overload the grid and charging station. DLM also prioritize the charging sessions of each EV based on battery SOC and subscription type.

3. The Internet of things (iots)

The Internet of things (IOTs) allows physical objectives to communicate with each other without any human interference using internet connection. The major challenge in EV charging infra market is not just installing large number of chargers but the ability to manage and distribute the energy seamlessly without effecting the power system. The EV charging operator need real time data. The IOTs are capable of transferring real time data efficiently.

4. The role of connectivity in ev charging

Interoperability of charging depends on Open Charge Point Protocol (OCPP) & Roaming. The charging stations are installed in different locations to serve the customers Uninterrupted and reliable connectivity is very crucial to operate charging stations across network. Any interruption in connectivity could affect EV session, user payments.

5. Implementation

2. Integration of IOTs with Dynamic Load Management:

The IOT (Internet of Things) market is an emerging technology, and it is connecting all common objectives and devices into smart and connected. The IOTs consists several interconnected sensors to read and analyze the real time data. Presently the peak load is being managed by using time of use (TOU) and dynamic pricing. Dynamic load management concept is being used at electric vehicle supply equipment (EVSE) to distribute energy to multiple electric vehicles (EVs) simultaneously. When charging connector gun (CG) connected to EV, the vehicle will share certain parameters of battery like state of charge (SOC), vehicle energy requirement, voltage etc., with EVSE through CAN communication. Based on requirement of EVs and considering limitations at charging station the EVSE will charge the electric vehicles. But technology limited to EVSE level only. If operator / DISCOMS wants to monitor and control multiple charging stations they cannot access the data with existing system. Through this paper we are trying to leverage use cases of IOTs and DLM to build better solution which can bring value addition in controlling the charging sessions remotely. The operator can avoid grid overload and expensive upgradations. To achieve this level of intelligence the IOTs equipped with embedded sensors, actuators, processors, and transceivers. IoT is not a single technology rather it is a combination of various technologies that work together. Majorly the IOTs categorized into two, those are event based and time based. The event based IOTs consists of sensors which transfer data when event is activated. But in time based IOT architecture the sensors will continuously transmit the data on specified time intervals. The time based IOTs are suitable for EV charging and dynamic load management to read and transfer continuous data. During charging session several data parameters will be generated. We require relevant IOTs that capture these parameters to process further. In order to manage dynamic load management, we require to read current, voltage, temperature & SOC percentage of battery data parameters. These IOTs to be integrated with EVSEs, electric vehicle and micro grids so that the required data will be transmitted.

A. Architecture of IOT

There is no standard architecture that accepted universally. The basic architectures are 1) Three layered Architecture, 2) Middle Layered Architecture and 3) Five Layered Architecture and 4) Fog Architecture. The first two are not sufficient to this concept as it cannot transfer finer aspects. This requires additional layers to process finer level details, the third and fourth consists additional layers which can do the job.

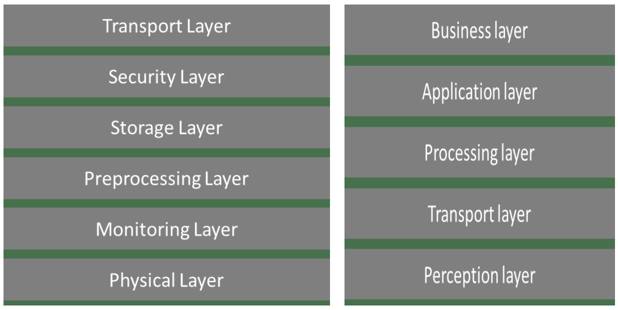

Figure-1: (a) Five Layered Architecture; (b) Fog Layered Architecture

vi. Conclusion

In this paper we proposed a solution to overcome overloading and avoiding grid, charging station level power disruptions during the EV charging sessions. By capturing required data from charging station, EV, power distribution stations with the help of internet of things. The dynamic load management will perform the necessary actions after analyzing the data from IOTs. Not only at charging session level but also battery life can be improved by managing charging cycle at EV battery. We have also explained and proposed the suitable IOT architecture for EV charging dynamic load management system.

Customer Engagement Strategies and Social Media for Utilities

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Abstract

[2]Customer engagement is how a company creates a relationship with its customer base to foster brand loyalty and awareness. This can be accomplished via marketing campaigns, new content created for and posted to websites, and outreach via social media and mobile and wearable devices, among other methods.

[7]In today' industry it is known that customers have high expectations. There is increased focus by companies on protecting their customer base and improving outcomes for them. Both B2B & B2C customers prefer a personalized experience and nearly 65 percent of them will leave if you do not deliver as per their expectations. This puts huge pressure on customer success managers to deliver as per the wish of customer. When the number of customers is high, some customers may suffer from lack of attention.

Effective [3] customer engagement strategies can help make the most of the relationship with existing customers. They can also provide us with many benefits, including higher conversions, lower churn rates, and more referrals.

This paper is to create a tech-touch engagement model for customer success which includes social media, web portals, chat bot, email campaigns and automated health checks along with the usual traditional customer engagement methodologies. Through webinar and community's customer can relate and learn from other in the same fields but also provide them visibility and limelight. This model aims to offer a great experience to customers and creating value for them.

Introduction

Customer engagement is widely used in industrial sector however the manner of engagement has changed drastically. In old time information was available in newspapers, TV news, fax messages now it is the internet which develops customer engagement. Engaging with right customer results in right sales and brand loyalty.

[1]The customer engagement has drastically changed from old style to notifications on phone or bill payment using a simple text message. Customer engagement is no longer defined by the sales, services, or customer support. Now days it is an ongoing practice for brands to anticipate customers mindset. This helps the brand to retain old customers and engage new customers which helps is business growth. In energy sector the strategy is to enhance customer education, bring more programs to participate in conversation which helps to build brand trust.

1. Use case and Problem Statement

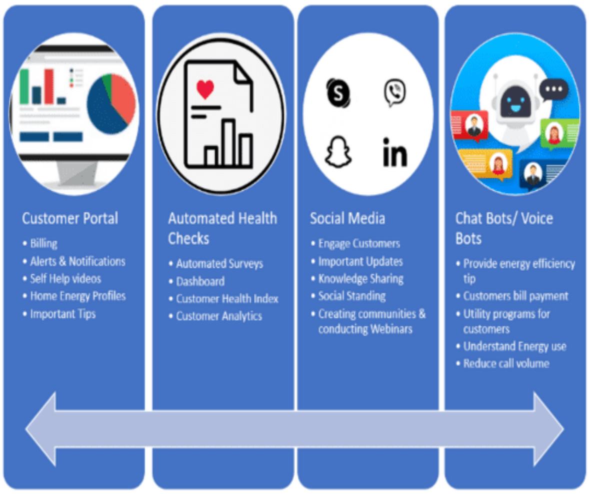
Customer Engagement in Digital Market: In the world of digitalization the utilities need to keep up with the mindset of customer in regulated market from just services to beyond commodity delivery. Failure to make an emotional connect with customer can lead to missed opportunity.

In Deregulated market, the utilities realize the importance of customer loyalty & the challenges in order to retain customer base with competitors available.

Quick availability of Customer Support / Resolution: Some basic requirement of any utility customer will always remain to make sure the power is on; gadgets are running & auto billing is working etc. The customer happiness depends on how soon the support or resolution is provided to them. Eventually having a good CSAT score.

High Churn Rate: In this fast-moving economy with numerous options available in the hands of customer it is important to keep the customer satisfied & engaged to achieve customer retention & reduce churn rate.

Demand Management: Utilities need to make it easier for customers to understand their usage patterns, so that they can decide to manage their utility bill. Creating an awareness of green energy option available & giving them the freedom to choose & manage their usage mix.



Solution

Fig. 1 – Customer Engagement Model Through Tech Touch

A customer portal is quick solution for the customers to know about their account status, correct any issues & be more informed about making any decision. Providing a friendly UI & lean customer portal makes helps customers make the most of it with core functionalities like –

- eBilling
- Alerts & Notification
- Customer Usage Analytics
- Any Outages
- Home energy profiles.
- Self Help videos
- Information on upcoming product features, product demos
- Important tips on how to save cost to keep the customer well educated.

Customers can get a good understanding of their usage, billing & demand management. The more aware the customers are the happier they will be.

Fig.2 – Illustration of a Customer Portal & functionalities

Automated Health Checks – It is also important to see how proactive utilities are to understand the health status of the customers in terms of availability of services, quick resolutions, billing status etc. This can provide us very useful insight in getting to know the mindset of the customer what pain areas are there in a particular customer segment areas & the root cause can be analyzed accordingly.

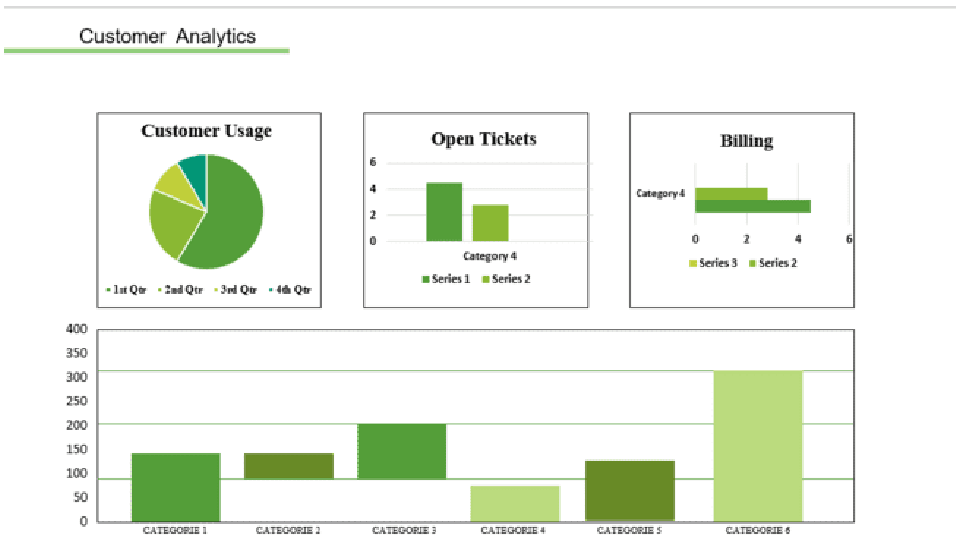


Fig. 3 Illustration of a Customer Analytics Dashboard

Along with feeding information to customer using customer portal, social media, or any other means it is also important to hear from the customer. Having some level of automation in gathering feedback from customer would help utilities to connect better.

- **Automated Surveys** - Simple thumbs up/down on completion of tickets
- **Health Index** (KPI such as NPS, Utilization, Adaptation, Tickets etc.)
- **Dashboard** based on customer segmentations, areas etc.

Fig. 4 Illustration of an Integrated Dashboard Overview for Customer Health Index

Social Media –
[1]Approximately 3.6 billion people are using social media worldwide there is a projected of 4.4 billion using it by 2025, one cannot miss the opportunity of customer engagement that social media provides.
Unlike other large organization like retail or ecommerce, utility brand often has limited options to their impress customer. Social Media is a good way to build reputation & create customer engagement.

- **Engage with your customers** swiftly and consistently. E.g., Sharing Outage update is vital to communicate with customers
- **Understand how customers respond** to campaigns by using social media sentiment analysis. By tracking the mentions & we can get an idea what the customer feels about your brand
- **Making content more accessible**
- **Show the Human Side of Your Business**. E.g., CSR activities, Energy Optimization, EV
- **Knowledge sharing** by events like Webinars & Tech Talks are also a great way for maximum reach
- **Take a stand on a social issue**. E.g., Relating to current issues of carbon footprint & showcasing how utility is contributing as well

Fig. 5 Example of Tata Power Utilizing social media for social issues like Clean Energy & Energy Efficiency [9] below

Fig. 6 Example of Northern Ireland Water Utilizing social media for Knowledge Sharing of Important Tips[10]

Chat Bots/ Voice Bots –

[1]Customer service is vital to every business & with the progress in technology Chat Bots/ Voice bots in customer support are inevitable in coming days. With smart tech voice assistants like Alexa & Google Assistants some utilities are already exploring their capabilities

Fig.7 – Illustration of a chatbot & its benefits in time, cost & efforts

[1]With more than 320 million smart speakers in use in 2020, Statista predicts that the number of smart homes worldwide will surpass 350 million by 2023. Some examples energy utilities could use voice assistants, are: [6]

- Provide support with FAQs
- Reduce pressure on customer support & increase efficiency as chatbots do not sleep
- Help customer with tasks like bill payment, enrollment, set limits etc.
- Help raise tickets or request for human assistance

2. Customer Segment

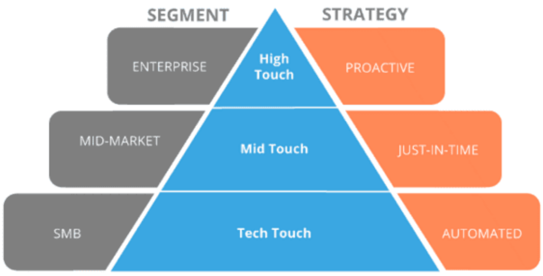


Fig.8 – Illustration of a customer segmentation

[7] For the utilities mostly being B2C customers the area of focus should be to utilize the power of "Tech Touch", where is limited interaction with customers but the impact is large. This is managed by majorly by automation or software. This helps improve the customer experience at low cost. Tech touch customer success focuses on providing value to customers keeping scalability and cost in mind.

2. BENEFITS

- Manage brand perception & drive contract value
- Improve overall customer experience & satisfaction
- Complement existing customer service channels if not a replacement
- Increase customer loyalty which will help in fostering a long-term relationship
- Increase the Net Promoter Score

2. How to overcome challenges

CHALLENGES	POSSIBLE SOLUTIONS
Low presence and oversight on customer forums	[5]Effective management of customer forums. Proper team set up & planning needs to be done
Lack of connection between departments	Importance & urgency of addressing issues in social needs to be aligned with all departments
Negative comments & legal issues	Negativity to be dealt with maturity & support of cyber security & legal needs to be taken
Social Listening & actively engaging with customer	Assess top performing posts & engaging with customers to keep the continuity

Way Ahead

[4]The right social media content can help utilities build a strong digital relationship with customers and eventually increase customer satisfaction by making energy utility relatable and accessible. Combined with an innovative customer portal that drives customer conversations and allows utility customers to manage their entire account, social media is a fantastic way to improve utility's overall customer engagement.

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Remote Supervision System using Body Worn Camera

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Abstract

Cable faults are detrimental for any urban utility like CESC LTD as it leads to power outages and consumer interruption. Underground cable faults are difficult to locate and proper repairing of these faults are very important as the cable joints at the faulty portionare the weakest point in the network. Hence, ensuring proper repairing of faults is important. Job quality audit is a vital part of the operation of a technical organization like CESC LTD. Quality assurance and safety adherence is of paramount importance in view of minimizing the equipment failure and effecting Operating Cost curtailment in the organization. Quality of breakdown job execution and stringent operating procedure adherence is possible only through vigilant monitoring of job sites. This paper delineates a novel approach introduced in CESC in order to assure remote supervision of breakdown jobs using body-worn camera with two-way audio communication. The system architecture, data collection philosophy and audit format have been detailed and the alternative uses of this technology have been briefly explored. This method of job supervision is first of its kind in this field.

Keywords

Underground cable fault, quality audit, body worn camera, two-way communication

INTRODUCTION

In any utility like CESC LTD., various types of breakdowns as well as programmed jobs are carried out in the field daily. Most of the jobs are done by contractual employees. For efficient execution of jobs maintaining quality standards, various job audits are carried out on a regular basis. Keeping in mind the huge volume of jobs executed daily, it is clear that we need a large number of skilled eyes to supervise each and every job on a daily basis. However, sometimes it may so happen that the skilled eyes required for job supervision are not available at each job site. Further, to ensure job execution maintaining the accepted safety standards, ever-vigilantmonitoring of workmen is of paramount importance.

In this perspective, remote surveillance of field work can be highly beneficial in that it allows the auditor to audit multiple job sites at the same time. This paper introduces a novel approach with the use of Body- Wound Cameras which are used for live videostreaming from the job sites as well as for providing a two-way audio communication for real-time instructionand site feedback.

This method eliminates any kind of physical movement of the auditors, thereby saving time and increasing the efficiency of surveillance of field works.

II. Need for remote surveillance usingbody worn camera

supervision of fault repair job: Cable faults are detrimental for any utility like CESC LTD as it leads to power outages and consumer interruption. Underground cable faults are difficult to locate and proper repairing of these faults are very important as the cable joints at the faulty portion are the weakest point in the network. Hence, ensuring proper repairing of faults is important. Remote surveillance using body wound camera with two-way audio communication is a comprehensive method that allows the auditors at the Quality Control Centre to supervise multiple fault sites at the same time without any physical movement.

Ensuring safety at job sites: Remote supervision process will allow the Engineers to ensure adherence to safe practices at job sites at any point of time.

Job surveillance at any location: Method of remote monitoring will allow the auditors to virtually assess the quality of jobs at any location, which is practically impossible by physical supervision.

Archiving videos for assessment at future date: It is not possible to audit all the job sites at the same time even with a live streaming owing to manpower and bandwidth constraints. But the videos of the jobs being performed canbe stored and uploaded in the cloud storage, which may be later downloaded and assessed. This will ensure surveillance of a large number of jobs without fail.

III. SYSTEM ARCHITECTURE

- This is a remote monitoring application. A Camera willbe given to field Contractors/Field Engineers/ CESC Vendor. A person/supervisor at the Quality Control

Centre can monitor and give feedback based on video.They can see live as well as old videos.

- There are following type of user for this application –

1. Users with view access. – User can only see the video feed.

- User Group 1 – Viewers

2. Admin User/Supervisor at Command Centre - User can watch the video view. They can supervise the ongoing work. They need to give feedback on the ongoing work by seeing the Video View and Filling the Safety Checklist.

- User Group 2 – Supervisor/Administrator

3. Users who will carry the body worn camera. These User can be contractor's group as well as individual employee of CESC.

- User Group 3 – Contractors/Field Engineers/CESC Vendors.

IV. PROCESS FLOW

Whenever a fault (distributor/service etc.) is detectedby our technician, it is entered with details in the IT based system and a fault number is generated in the system automatically. Then, concerned engineers allocate a vendor for execution of the fault repairing job.

- The IT system will consume APIs of the solution and push the fault information to the solution DB. The data fetch will be API based. The following data will be fetched

A) District
B) Fault ID
C) Address
D) Set ID
E) Contractors/Field Engineers

- The field workers of the vendor will carry the cameras at the site. On switching ON the cameras, it will be available for live video streaming once the connection via internet is established.
- The viewers/ Administrators present at the Command Centre will launch the application using web URL or user can open the mobile PWA app on clicking on shortcut from the mobile. User authentication request will be initiated from the login page after entering username and password. User will be verified from CESC database and Video Management Server (VMS).
- After successful authentication, user will land ontothe dashboard, which allows options for live streaming, past video view etc.

- The live view mode will allow viewing the field work in real time. The two-way communication feature, which is unique in this field, will allow the auditors to give instructions to the field workers via the camera while at the same time the workers/supervisors can express their views from the field.
- The videos captured by the camera are stored in the internal memory of the camera itself. Those videos may be uploaded to the cloud storage for archival purposes. 2 months old videos will bearchived.

V. FEATURES OF THE USER INTERFACE

- The LOGIN AND AUTHENTICATION:
  - User will login to system with username and password.
  - Customer launches the application using web URL or user can open the mobile PWA app on clicking on shortcut from the mobile.
  - User authentication request will be initiated from the login page after entering username and password.
  - Unfilled/blank input submission will prompt an error message requesting user to enter the missing detail (username or password)
  - user will be verified from CESC database and Video Management Server (VMS).
  - Administrator means User group 1 (Supervisor/Administrator). They have access to add users and devices in the system.
  - On successful authentication user will land tothe dashboard.

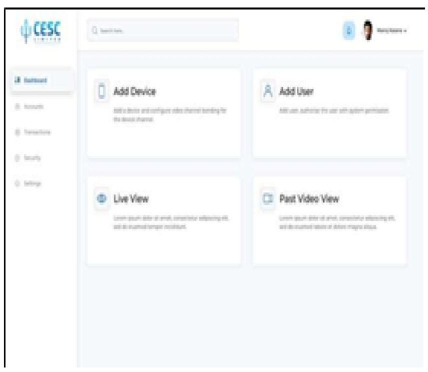

Fig.1: The Dashboard

- THE DASHBOARD:
- Dashboard will contain the following Buttonsto navigate to the respective screens

1. Add Device – Active only for User Group2
2. Add User – Active only for User Group 2
3. Live View – District/Zone wise
4. Past Date Video View

Fig.2: Features incorporated within the system

- **Live View tab** from dashboard will open a pop up for selecting District (Drop down), Fault ID (Drop down), Address (Text filed), Set ID (Drop down), Contractors / Field Engineers (Drop down). The same filed canbe used for selecting a different video view.
- On Selection it will open a window with two Video View.
- User needs to select Set ID and Technicians.
- User can select maximum up to 2 VideoView.
- User can change the selection based on thebelow fields-
- District (Dropdown)
- Fault ID (Dependent dropdown on district)
- Address (Auto populate on selection of FaultID)
- Set ID (Auto populated based on Fault ID. It can be changed but it will not flow to CIS system)
- Contractors/Field Engineers (Dropdown

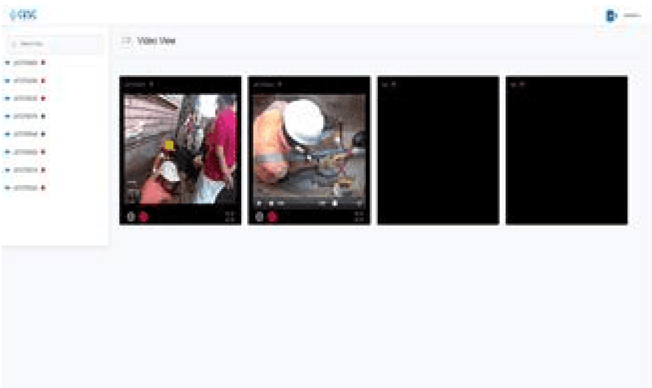

FIG.3: LIVE VIEW MODE

- **Past Video View tab** from dashboard willopen a pop up for selecting Date Time, District, Fault ID, and Address.
- Filed Details –
  a) From Date
  b) To Date
  c) From Time
  d) To Time
  e) District – Dropdown
  f) Fault ID – Dropdown
  g) Address - Text field
  h) Set ID – Multi Select Dropdown

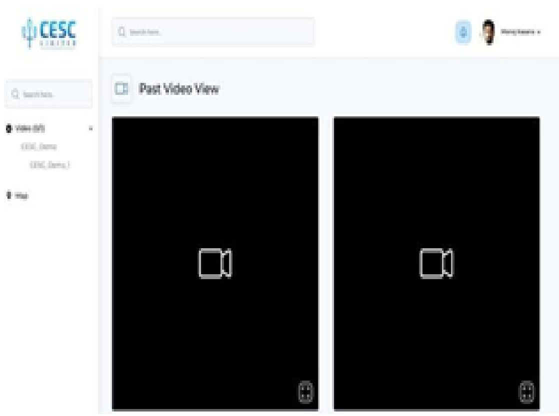

Fig.4: Past video view

- On Selection it will open a window with two Video View.
- User needs to select Set ID and Technicians.
- User can select maximum up to 2 Video View.
- The features of the past videos are as follows:
- **Scalability:** App will be capable enough to handle user data like (caches, stored data etc.) without delay.
- **Responsiveness:** Application Will be responsive to the user Input or to any external interrupt which is of highest priority and return to same state
- **Useability:** The application will be reliable to perform the business, when user perform some important action, it will acknowledge with confirmation.
- **Security:** All the app data will be secured andbe
- encrypted with minimum needs so that it is protected from outside environment also from internal attack
- **Screen Adaption:** Application will be able to render its layout to different screen sizes. Along with automatic adjustment of Font size and image rendering.
- **Availability:** User will be able to view app from website or download app to their mobile device by clicking “Add to HomeScreen” options from the browser menu.
- **Data Archival:** All the six months old video feeds from the body worn cameras will be archived automatically. And once it is archived it has to be accessed manually from the archival drive.

➢ **AUDIO COMMUNICATION**:

- Audio communication feature will allow the person at command center to communicate with the person at site. Auditors can give instructions to the workers while assessing thejob quality by live video view, also the technician at site can express their views or clarify the doubts by communicating with the auditors via the microphone embedded within the camera.
- Upon Clicking of a video view the full screen mode will open.
- On full screen mode a mic and a speaker icon will be given.
- User can click on mic to pass his audio message to the technician at field.
- Technician at filed can press on their hard micbutton and communicate with the person at command center.
- It will be walkie-talkie mode of communication.

- SUPERVISORY FEATURES INCORPORATED:

- Checklists have been incorporated with the live video window so that supervisors/auditors can comment about thequality of the job. For ease of operation, different checklists have been prepared, each of which has been customized based on the type of fault/job done and safetyconsiderations.
- User can click any of video view to make itfull screen.
- It will open a video view window in fullscreen mode.
- In the bottom half of the screen, a supervisionform will be populated.
- User needs to fill the supervision form, safetychecklist (Pre jointing, Jointing forms).
- User can attach any screenshot with the form.
- User can enter the feedback comment on the Technician work based on video.
- For past video view the form will be populated with the filled data. User can verify the form and enter his own comment.
- Check lists will be auto populated based on the fault type / joint type

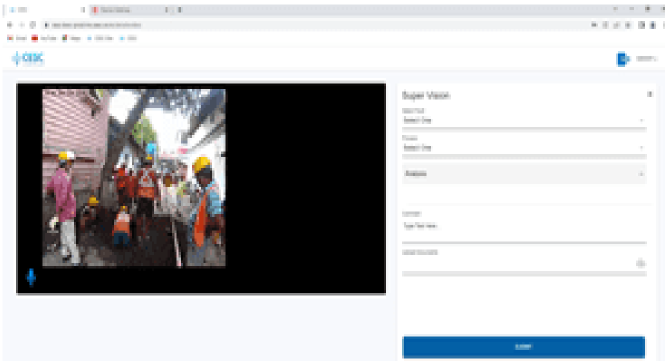

Fig.5: Preparation of report during live view mode

- PREPARATION OF SUPERVISION REPORT:
- On successful submission of supervision checklists corresponding to a particular job, a Supervision Report will be sent to a certain group of users' mail ID. These reports along with the archived past video data will help the users to assess the performance of the workers in long run.
- Based on their performances, the workers may be incentivized or those with weaker skills may be sent for further training. This will enhance the efficiency and reduce chances of further faults in same cables leading to saving in R&M and CAPEX cost. Lower number of faults mean less interruption period leadingto improved SAIDI and SAIFI figures and better customer satisfaction.

Path Forward

- Due diligence in the study and analysis of the archived job videos will result in transparency in the identification of the shortcomings of theexisting Standard Operating Procedures w.r.t site constraints. This would go a long way in the modification of organizational job standards to adapt to the ever-volatile job site conditions.
- The identification of workforce in need of upskilling will be a lot easier through the implementation of machine learning algorithms that would identify the skill deficiency of particular workmen though the audit format associated with the archived videos. This would result in pin-point need-based training of the workforce to upgrade thejob quality standard across the organization.
- A novel use of the body-worn cameras would be the large-scale horizontal deployment of the devices to outsourced employees in order to carry out inspection jobs for effecting supply to future consumers. The existing process of skilled technical workforce deployment in order to assess the requirement of potential consumers is a manpower and skill intensive endeavor which could be completely altered to a much more economical method via deployment of unskilled outsourced workmen for carrying out inspection jobs for effecting new connection from CESC to potential consumers.

Conclusion

This state-of-the-art approach of introducing remote surveillance by using body worn cameras in the field of LT distribution network has proven to be highly beneficial in the practical scenario. Real time monitoring of the field work has proved to be beneficial in adhering to proper safety guidelines and in the process reducing the tedious effort of theauditor. Archiving the critical documents will guide in the future to prepare a better blueprint in reducing the network redundancy which will lead to sustainable management of the distribution system in the long run.

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Auto Sequential Operation of EHV Lines

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Abstract
The Tata Power Company (TPC) is one of the largest integrated private sector utilities in the business of Power Generation, Transmission and Distribution in India. It has majorsignificance in Mumbai region with 25 Number of Receiving stations connected with 94 Number of EHV lines to Cater the load demand of Mumbai and its suburb. Power Transmission lines needs to be cut out for its scheduled maintenance and project jobs. Since EHV transmission lines are part of grid, completion of scheduled activities within allotted timelines is necessary. Conventionally to carry out line outages and taking back into service, operation team has to travel to remote station from its base station to perform operations. Travel time is contributing to additional line outage hours in addition to time required for actual work. Hence to overcome above mentioned issue, customized logic is designed in Supervisory Control and Data Acquisition System (SCADA) to automate existing manual process of line outage and taking back into service by internal expertise. Operational area CCTV features being used to getfeedback of remote places for confirmation of grounding forsafety of personal and equipment. In our proposed method, all the operational sequence are carried out automatically through SCADA with required safety interlocks. This will help in opti- mizing total EHV line outage duration improving reliability of supply to the customers.

INTRODUCTION

The Power Transmission Network generally consists of Receiving Stations, Substations and Transmission lines. AtTata Power, the Transmission network system is divided into various nodes, each containing one base station and othersatellite stations. Generally, the operation and maintenancecrew are available at the Base station. Until now, we haverelied mainly on manual isolation of EHV lines. During outages of lines connected to the satellite station operation team used to travel to a remote station from its base station to perform operations. Travel time by the team contributes to additional line outage hours in addition to the time requiredfor actual work. Moreover, whenever the work is carried out manually, it is prone to the risk of errors and wrong operations,which could further result in severe accidents and damage to equipment.

In this work, we propose a novel SCADA-based [1] methodto automate the existing manual process of line outage and bring it back into service through internal expertise where the current process of line outage and bringing back into serviceis converted into the logical sequence in SCADA (in the form of Script), and a simple method is provided on the SCADA screen to operate. Supervisory Control and Data Acquisition (SCADA) systems are commonly used in electrical power gen-eration, distribution and transmission. They are very powerful tools that are used to carry out and perform a wide varietyof functions that are essential to the daily running of theelectrical, utility. These functions include automatic generation and transmission control [3], load management, identifyingand isolating faults and restoring service [4], to name a few.[5] The rest of the paper is organized as follows, in Section II, we discuss the transmission network model and problemformulation, and in section III, we discuss the performanceof our developed SCADA-based method over the existing method. Finally, we end the paper with conclusions.

2. Network Model

We consider the Tata Power Transmission network as de- scribed in the Fig.1 consisting of 25 Receiving and substations.The network is divided into eight nodes, each consisting ofone base station and other satellite stations. The operationteams are located at each base station of the node. For every remote operation, an operation crew must travel from the base station to the satellite stations to perform the operations. For example, the Kalyan node consists of Kalyan as a base station and Waghivali, Bhokarpada, Ambernath, Panvel and Karanjadeas satellite stations. Shift maintenance crew (SMC) needs to travel from Kalyan to five remote stations for operations. Similarly, SMC travels from its base to a remote satellitestation for other Nodes. In this work, we aim to reduce the time delay required to perform the line outage with manual isolation. Thus, we employ the SCADA-based technique and automize line outage procedures for that purpose.

Programmable SCADA Controls (PSC) is a customized application built on .Net Framework that enables users tocreate and edit groups of executable commands (referred toas macros) for controlling the SCADA points in the system. These macros perform a variety of tasks, such as calculations, controls, alarms, or data entry. As a user, you can start, stop, and pause macros and individual commands contained within macros from the Programmable SCADA Controls display.

The commands are set up to run in a specified sequenceand can be triggered to run automatically based on monitored information, or users can manually execute them. In addition to monitoring and control functions, a number of macro- control functions (such as Pause to delay command execution and jump to go to another command line in the macro) are available.

PSC consists of a display that permits control at both the macro level (upper half of the PSC window) and command level (lower half of the PSC window). The Programmable

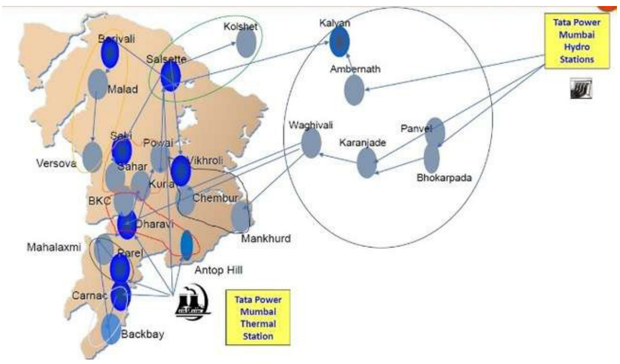

Fig. 1: Tata Power Transmission network

SCADA Controls display shows a list of all available macros. From this display, users can execute or stop or reset individual macros, or select a macro to edit. The bottom gridof this display lists the SCADA commands assigned to each macro. Users can create and modify new macros. Macros are modified by adding or deleting commands; users can also edit commands within each macro. Prior to executing a macro, it can be checked for valid syntax. Users can view the real-time execution status of macros as each command is highlighted as it is activated.

In our work, we enlist the sequencing procedure of outages for identified transmission line and then code them in the formsof macros in PCS. For example, the Outage sequence of 220 kV Salsette Sahar line is described below.

III. Outage sequence of 220 kV Salsette Sahar line

1. Open breaker of 220 KV Salsette-Sahar at Sahar end.
2. Ask for operator to confirm system condition.
3. Confirm line MW (active power) has gone to zero from Salsette end.
4. Open breaker of 220 KV Salsette-Sahar at Salsette end.
5. Open line side isolator (QL3) of 220 KV Salsette-Sahar at Salsette end.

6. Salsette: Ensure QL4 of 220 KV Salsette-Sahar is open.
7. Open line side isolator (QL3) of 220 KV Salsette-Sahar at Sahar end.
8. Check that line voltages are zero (Ensure that there will be no voltage on line. * Considering line CVT's / IVT's are used for taking line voltages in SCADA *)
9. Close earthing isolator (QE3) of 220 KV Salsette-Sahar at Sahar end.
10. Close earthing isolator (QE3) of 220 KV Salsette-Sahar at Salsette end.

Note. *If any of the step-in above sequence is not executed, further operation should be abandoned, and alarm shouldcome on SCADA.*

Similarly, we enlist the steps and code in PCS to bring back the transmission line to service.

IV. Taking back 220KV Salsette Sahar Line into Service

Note. 1) *Line Lock out should be in reset condition at bothends.*
2) *No Release / operating permit tag is present online at either end.*

V. Prerequisite for the operation.

1. Salsette and Sahar end breakers are in open condition.
2. Salsette and Sahar: QE1 and QE2 are in open condition.
3. Salsette and Sahar: either one of the conditions is satis-fied.
4. QL1 is closed and QL2 is open.
5. QL2 is closed and QL1 is open.
6. Salsette: QL4 of 220 KV Salsette-Sahar line is open.
7. Ask for operator to confirm there is no permit / tag persist on 220kV Salsette Sahar line / line breaker at either end.

VI. Operations

1. Open earthing isolator (QE3) of 220 KV Salsette- Saharat Salsette end.
2. Open earthing isolator (QE3) of 220 KV Salsette- Saharat Sahar end.
3. Close line side isolator (QL3) of 220 KV Salsette- Saharat Sahar end.
4. Close line side isolator (QL3) of 220 KV Salsette- Saharat Salsette end.
5. Close breaker of 220 KV Salsette- Sahar at Salsette end.
6. Confirm all three phase voltages are showing on SCADAat Sahar end.
7. Sahar end synchro scope will check line voltages, fre-quency and phase sequence
8. Close breaker of 220 KV Salsette-Sahar at Sahar end.

Note. *If any of the step-in sequence is not executed, further operation should be abandon and alarm should come on SCADA.*

Similarly, we followed the same procedure for different transmission lines. In the next section, we discussed the impactof our developed auto-sequential method on time saved and economic aspects.

VI. Experimental results

This section discusses the proposed method's performance over the existing one. The bar graphs in Fig. 2 show thetotal time required to finish the operation (in Hrs.) throughto the proposed method (auto sequential operation of lines) compared to the earlier mode of operation for the period ofone year. From the bar graphs, we can observe that thereis a significant reduction in the time required to finish thetask with the developed method. For instance, in the case of 220KV Salsette Sahar Line, earlier, it used to take 45 Mins to complete one set of operations. However, it takes 10 Mins to complete the same job after implementing the new SCADA- based method. Similarly, gain in terms of time can also be seen in other cases.

We further evaluate the performance of our developed method in terms of key performance indicators such as trans- mission grid availability and discuss their economic im- pact. In India, Power Transmission is a regulated business, andutilities are entitled to collect annual Transmission charges, which consist of various components. Return on Equity capital(ROE) is one of the components. As per the regulations of the Maharashtra Electricity Regulatory Commission (MERC) [6],

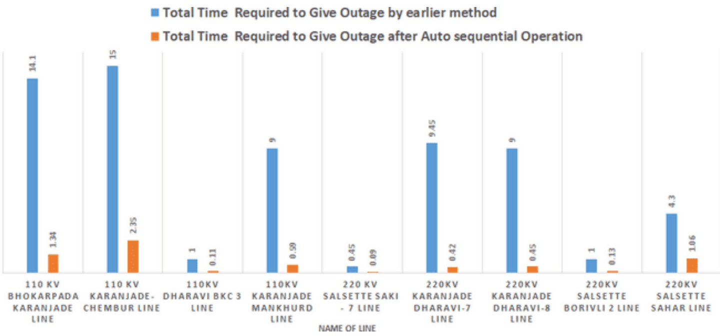

Fig. 2: Total time required to finish operation (in Hrs.) due toauto Sequential operation of lines Vs Earlier method of operation

we calculate the impact of each line on Grid Availabilitywith the outage of 24 Hrs. and its co-relation with ROE* (return on equity) ; it depends on voltage level, line lengthand SIL of the line. Table I and II describe the details,where ROE is calculated on 30% of the allowable equity of total capitalized value. Transmission Licensees shall get full recovery of Annual Transmission charges by achieving 98% Grid Availability for the AC system. For the additional rateof return on Equity consideration, Grid availability should be above 99%. For every 0.5% over-achievement in transmission availability up to transmission availability of 99.50%. Forevery 0.25% over-achievement in transmission availability above 99.50% rate of return shall be increased by 0.75%subject to a ceiling of an additional rate of return on equityof 1.50%.

TABLE I: Details of Transmission Lines, ROE loss withrespect to non-Availability

Voltage Level	Name	Length in km	Non-Availability %	ROE Loss (Rs Lakhs)
220 KV	Karanjade Dharavi 7	35.350	0.0077	27.8
220 KV	Karanjade Dharavi 8	35.310	0.0077	27.8
220 KV	Salsette Borivali 2	11.070	0.0024	8.7
220 KV	Salsette Sahar	10.780	0.0024	8.5
220 KV	Salsette Saki 7	9.816	0.0021	7.7
110 KV	Karanjade Mankhurd	21.780	0.0014	4.8

110 KV	Dharavi BKC	5.403	0.0003	1.2

TABLE II: Illustration of ROE considering Capitalization of1000 Rs. Crores

Availability %	Capitalization (Rs. Crores).	Allowable Equity (Rs. Crores)	Applicable Base ROE %	ROE (Rs. Crores)
99.00	1000.00	300.00	14.00	42
99.50	1000.00	300.00	14.75	44.25
99.70	1000.00	300.00	15.35	46.05
99.75	1000.00	300.00	15.50	46.50

Conclusion

In this paper, we have proposed the SCADA-based auto-mated operation method for the transmission line outage. In the proposed method, we have enlisted sequential steps that areperformed manually while taking an outage to the line and areencoded in the form of macros in PCS. Our observation showsthat the implication of the proposed method helps reduce the time required to provide an outage to the transmission lineand

bring it back to service, which is economically efficient over the existing traditional manual labour-based methods.Moreover, it reduces exposure to accidents and equipmentdamage, which might be the case with manual labour dueto operating errors.

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BOT Based Power Management

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Abstract

For any of the Distribution Utilities, Power Purchase cost is approximately 80% of the total cost of supply and is outside the direct control of the Distribution Utilities. Hence, PP cost reduction forms the strategic priority for almost all the utilities. Currently in Maharashtra, all power industries are under DSM (Deviation Settlement Mechanism) regime. DSM is a regulatory mechanism by which grid stability is achieved by imposing penalty and incentives for over drawl/injection or under drawl/injection from the schedule. The objective of the proposed strategy is to reduce PP cost by minimizing DSM charges and avoiding Additional DSM penalties which is directly impacting to bottom line of company. Real Time Power Management is defined systematic processes which is the backbone of organization. RPA (Robotic Process Automation) is an emerging tool of automation technology based on notion of software robots or Artificial Intelligence (AI). When robot is at work, it performs tasks just like a human would: logging in, operating applications, entering data, performing complex calculations, and logging out. The use of robot helps us to automate power management process in a relatively short amount of time.

Index Terms

Deviation Settlement Mechanism, Additional DSM penalties, Power management, Power purchase cost, Robotics Power Management.

1. Introduction

Tata Power Company's vision of Empowering a billion lives through sustainable, affordable, and innovative energy solutions is specifically addressed. The project targets reduction in electricity tariff for entire customer base of Tata Power DISCOM Mumbai license area benefitting approx. 7 Lakh internal & external customers. Power purchase cost contributes around 80% of the total supply cost hence the reduction in the purchase cost reduces average cost of supply to the consumers.

This project solves the hurdle to reduce Power purchase cost for forecasted demand on Day ahead and Real time basis by ensuring an optimization of all available resources in the portfolio (Long term / Bilateral Contracted Generation, Variable Renewable Generation, Demand Response Solutions, Battery Storage and Energy Markets). Each day comprises of 96-blocks (15-min each) & solution for every block is defined within stipulated time frame by collecting & validating data from multiple sources, computing shortage/surplus, putting power exchange bids and uploading/downloading schedules which was earlier entirely manual and person dependent process.

Main challenge to of power management process is Demand Estimation and commercial with in stipulated time frame.

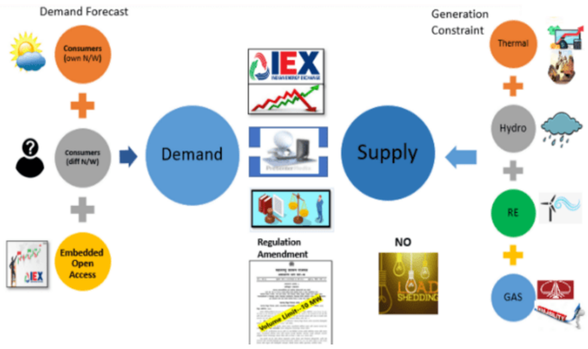


Fig 1.1 Demand Estimation and Commercial Challenges

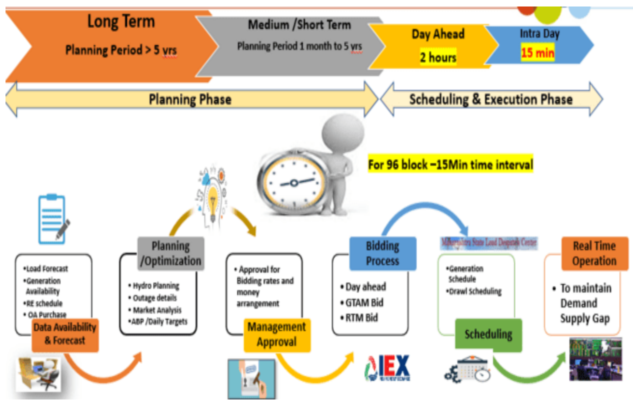


Fig 1.2 Block Diagram of Power Management Process

Entire Power Management process is divided in two phases, one is Planning Phase and second is Scheduling and Execution Phase.

The project is intended to achieve an optimized Power Purchase cost ensuring proper Supply Demand balance in every 15 Min interval thus ensuring No Penalties as per DSM regulations as well as no shortage or curtailment of power at any time The solution overcame the problem which was not available in market as a single product.

Hence, we have developed Inhouse BOT based power management, End to End solution which can be used by any of the utilities with respect to their regulations and mechanism with plug and play smart characteristics. The BOT will behave as an assistant and help in DSM features by addressing any system variation with respect to day ahead planning.

2. Methodology

Power Management process follows by Forecast, Optimization and scheduling in broad way AI/ML based forecasting tool is used for different types of forecasting. For optimization, the Power Management Optimization Module comprises in the stages:

Real time Data Integration

- Version update for schedule updates by SLDC
- Updates < 5 mins to facilitate decision making at block level schedule update
- Integration of platform with demand schedule (open access, direct consumers

Linear Programming based Optimization

- Buy vs Generation decision based on cost optimization
- Rescheduling of Forecast vs Demand changes & intraday contingency transactions
- Identify margin to drop & pickup, identify shortfall and surplus

Our proposed algorithm solves problems of the form

$$\begin{aligned} \min \quad & f(x), \\ \text{s.t.} \quad & g_j(x) \leqslant 0,\ j = 1, \ldots, m_i, \\ & h_r(x) = 0,\ r = 1, \ldots, m_e, \\ & x \in R^n, \end{aligned} \qquad (NLP) \qquad (1)$$

where the functions $f : R^n \to R$, $g_j : R^n \to R, j = 1, \ldots, m_i$ and $h_r : R^n \to R, r = 1, \ldots, m_e$ are continuously differentiable over R^n. Contrary to [19], the objective or constraints are not assumed to be convex. It is assumed that the constraints $g_j(x) \leqslant 0, j = 1, \ldots, m_i$ include linear constraints defining a bounded region X.

It is also assumed that the extended Mangasarian–Fromovitz constraint qualification (EMFCQ) holds for any $x \in R^n$. The constraint qualification holds at $x \in R^n$ when $\nabla h_r(x)$, $r = 1, \ldots, m_e$ are linearly independent and there exists a $z \in R^n$ such that

$$\nabla g_j(x)^T z < 0,\ j \in J_+(x) \cup J_0(x),$$
$$\nabla h_r(x)^T z = 0,\ r = 1, \ldots, m_e,$$

where J_+ is an index set denoting the violated constraints g_j,

$$J_+(x) := \{j : g_j(x) > 0\},$$

and J_0 is an index set denoting the active constraints g_j,

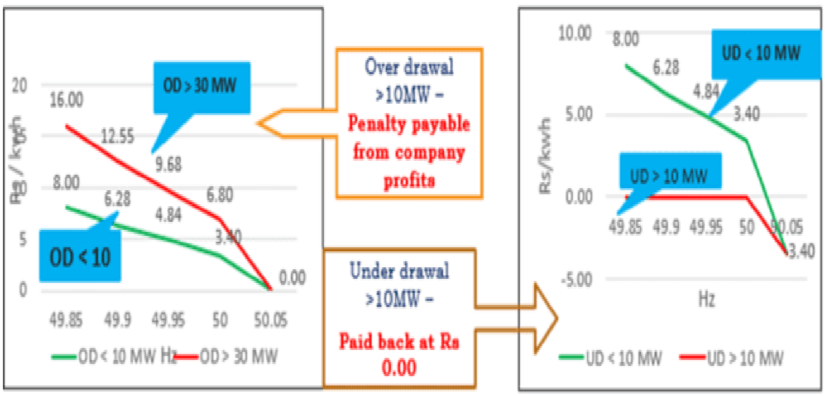
$$J_0(x) := \{j : g_j(x) = 0\}.$$

The EMFCQ and its relation to exact penalty functions are considered in [15]. In the context of this algorithm, the constraint qualification guarantees that one can, for any infeasible point, find a search direction such that the constraint infeasibilities are reduced.

Fig 1.3 Linear Programming based Optimization

Energy Exchange Bid

- Comparative reports with past version submitted
- Monitoring intraday block wise pricing changes & decision support for auction bids, based on DSM and ADSM penalties.



- Real time management module for bid format-based exports

The design:

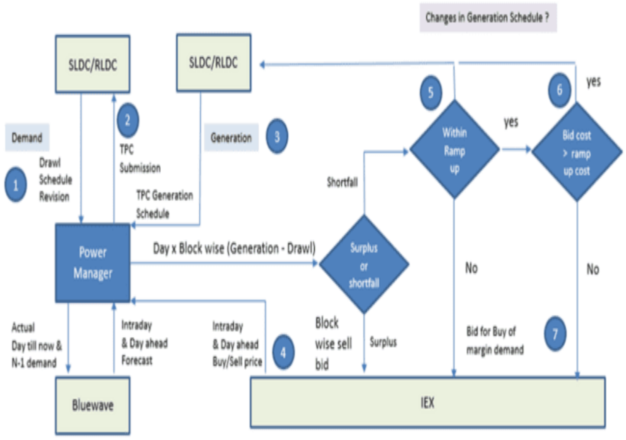


Fig 1.5 Forecast for No load day/holiday in summer

High Level Architecture

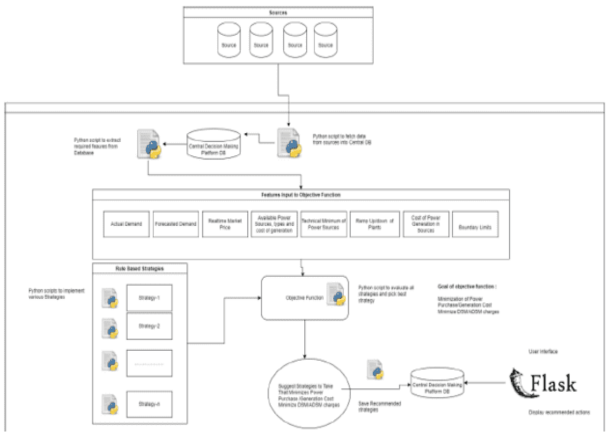


Fig 1.6 Forecast for No load day/holiday in summer

Manual Process Vs Robotic Process Automation

The following diagram depicts the manual process of providing the user with access to an application.

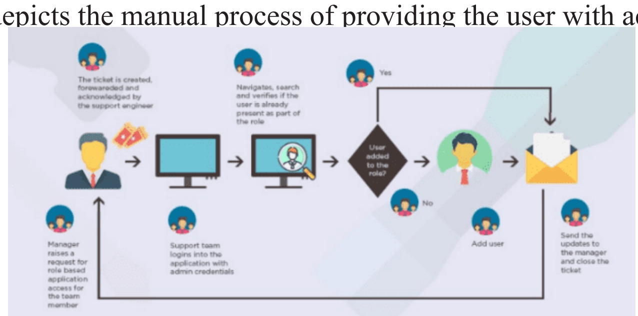


Fig 1.7 Forecast for No load day/holiday in summer

It is a labor-intensive process. In this approach, the employees are involved in the mundane routine task. As it highly relies on the action of the employee, it increases the chance of errors due to fatigue or lack of concentration.

In the contrast, implementing RPA tool in this process can benefit the support team to capture or record the routine activities performed and replay them.

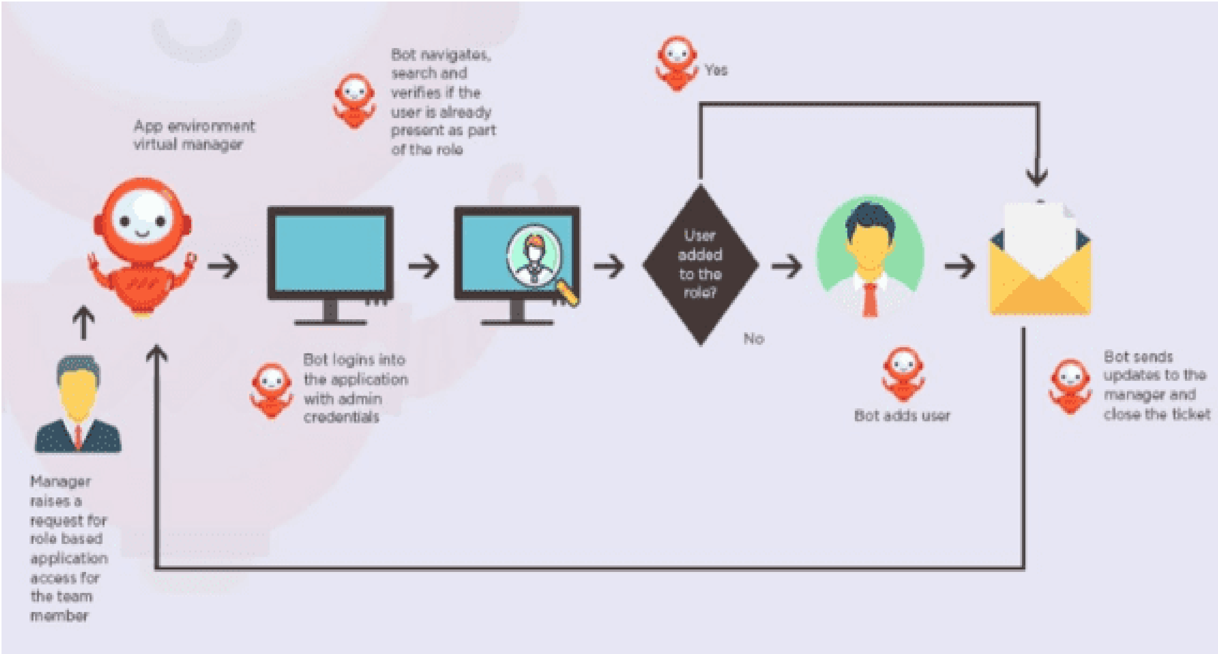


Fig 1.8 Forecast for No load day/holiday in summer

Here, the entire manual actions are recorded, scheduled, and activated by a robot when required.

When it comes to robotics and automation, people usually think of it as robots or devices. However, RPA stands for virtual or invisible robots, which sits inside the systems, moving between various applications, checking, inputting, updating, and processing more promptly that a human could. Therefore, RPA robotics is different from other direct types of automation. As like human user, RA interacts with different systems at the level of GUI or presentation layer. Hence, existing software systems can function together more efficiently; since, RA completes some tasks far faster and reliable than human do. This logical software tool shifts manual effort away from repetitive processing functions towards optimizing business processes. A major benefit is it connects existing system without re-engineering them. Today's RPA systems are more flexible and accurate than humans are - they enhance compliance and are available 24/7.

Output Analysis

As the whole process of power management is time dependent starting from N-1-day activities up to real time actions. Hence, time becomes the driver and on-time delivery of all actions are bound to be taken within critically. The BOT based End to End Smart Solution for Power Management achieves data quality improvisation by integration with various servers. The auto reminders & alerts characteristics covers up the accuracy level and error free operation. The product has boosted the morale of the operators by reducing the manual effort to minimal and provides them decision making suggestions and alerts. The critical live SCADA data is fetched from firewall protected PI system to avoid any direct linkages with the main monitoring system and runs parallelly with data validation.

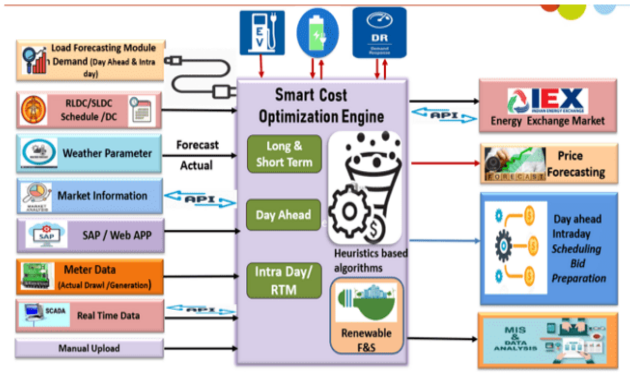


Fig 1.9 Forecast for Full Load Day in summer

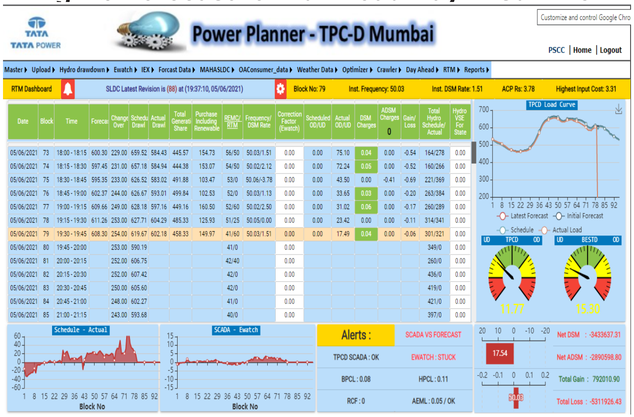


Fig 1.10 Real Time Monitoring output based on DSM regulation and rule-based instruction to BOT

RESULT:

This has resulted into efficient power tie up during high demand periods. Power was procured in advance through tendering process. Resulting in accurate power planning for summer months and during unit outages. Thus, power purchase cost reduced considerably, thereby lowering tariff of consumers (lowering FAC)

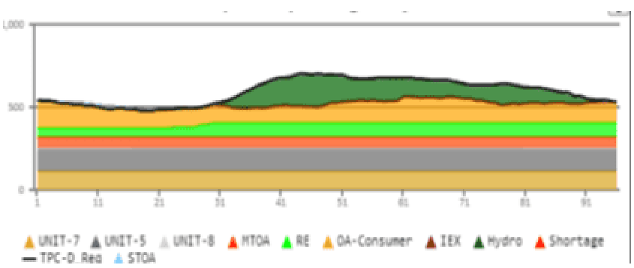


Fig 1.11 Accurate and timely Power scheduling for TPC-D.

A. **Ease of Use**

Complex, manual process is replaced by simplified, BOT based process.

Module output can also be used for the infrastructure enhancement and Long term asset planning.

Work accuracy is improvised.

Abbreviations and Acronyms

TPC-D: Tata power Company - Distribution

DISCOM: Distribution Company

DSM: Deviation Settlement Mechanism
ADSM: Additional Deviation Settlement Mechanism
MU's: Million Units,

C. Units

MW: means the electrical power, being the product of root mean square (rms) voltage, root mean square (rms) current and cosine of the phase angle between the voltage and current vectors and measured in units of 'Watt' (W).
Time Blocks: 15 minutes blocks accounting for complete day (Total of 96 Blocks)

D. Benefits

This idea has helped in optimizing the cost benefit with respect to available generation, Day ahead, Real time market & Green Power Term ahead market rates.
Quick and correct solution for cost optimization which has reduced PP cost for TPC-D by @ 10 Paisa Per Unit thus saving @Rs 21 Crores
Tangible benefits: -
Savings due to Day ahead IEX purchase as suggested by model -@ 11.9 Crores
Savings due to Real Time IEX purchase as suggested by model -@ 7 Crores
Savings due to Hydro and Thermal generation Optimization as suggested by model -@ 1.1 Crores
Savings on UI charges due to auto crawling and monitoring of RE revisions -@ 1.7 Crores
Savings due to Inhouse metering software integration @ 0.1 Crores
Reduction in high-cost State Pool purchase.
Improvement in forecast accuracy by external agency by 2%
Avoided scheduling of High-rate bilateral contracted power.
Intangible benefits: - Ease of data handling, Reduction in manual interface, Cycle time reduction, Manhours savings, Digitalization of power purchase process, Sustainable Green solution. Meeting RE Obligation.

E. **Future Scope and Planning**

Robotic Process Automation has grown exponentially over the past few years. The demand for RPA is increasing in the RPA market as it promises to replace repetitive, rule-based, mundane, manual digital tasks with software robots. It also ensures organizations to make their operational processes error-free.

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Energy Trading Solution for Infirm OA Consumers

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Abstract

With the limitation on power banking arrangement, In-firm open access consumer faces the issue of lapsed energy or curtailment. This is a commercial loss to the consumer. This solution enables embedded infirm open access consumer to transact excess energy on day ahead and real-time basis, as per the agreed contracts on 'Blockchain' based Digital Platform. Now, consumers can utilize their untapped source of electricity resulting in maximum renewable adoption thereby increasing green portfolio with power purchase cost optimization.

1. BACKGROUND

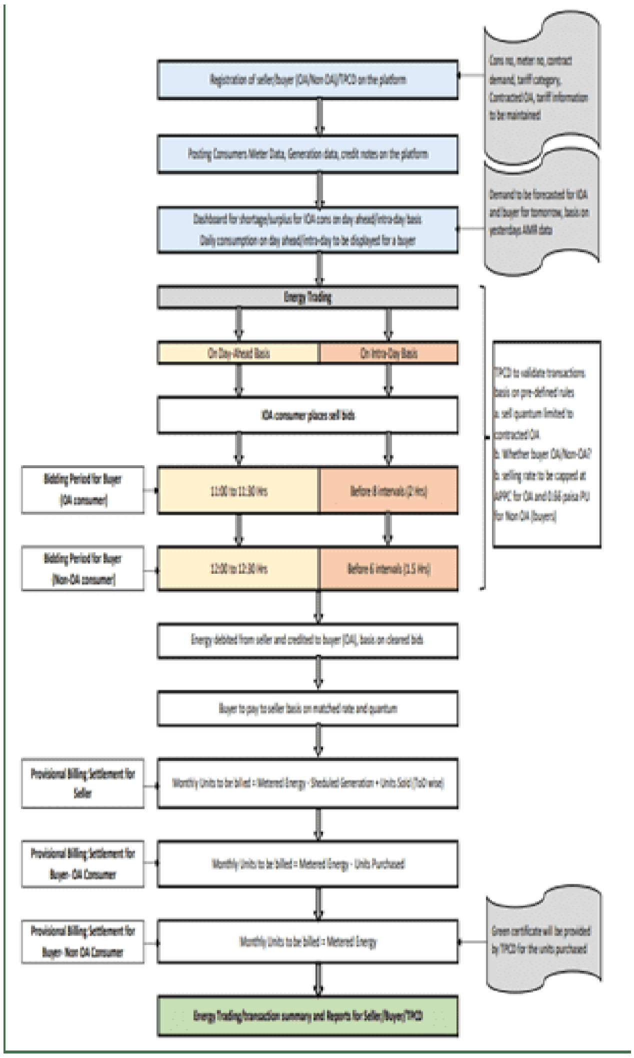
Consumers having contract demand of 1MW and above have the facility of sourcing their power through open access. Consumers sourcing their power from solar and wind (renewable) are called as Infirm open access consumers. As per the present regulation in Maharashtra state, excess monthly energy beyond 10% of generation is lapsed and this is a commercial loss to open access consumer. Therefore, this excess energy is very important parameter for consumers to decide on open access quantum to be tied-up. Presently, infirm open access consumer is billed on monthly basis and credit is passed after the credit note is received (indicating generation units) from relevant authority, generally after 2-3 months. Excess units, if any, limited to 10% of the generation is purchased by DISCOM on monthly basis. It is observed that, the quantum of lapsed energy is substantial and one of the major hindrance for consumers while going for 100% green portfolio.

2. Proposed solution

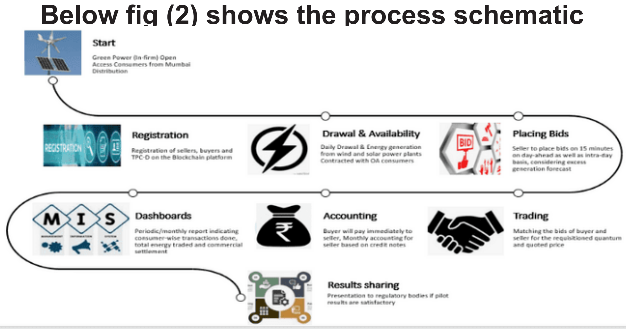
As a pilot project, 'Blockchain' based digital platform is developed to enable In-firm open access consumers in TPCD Mumbai distribution area to sell excess/unutilized power to other embedded consumers on agreed terms and conditions.

Blockchain based platform is used to facilitate power purchase/sale transactions by embedded TPCD consumers and to generate financial and settlement reports accordingly. Trading rules and process flow was discussed and finalized keeping in line with the existing billing settlement practice for open access consumers. During pilot period, all transactions, (energy/commercial) are kept virtual, without impacting the existing practice of billing of consumers.

Below **fig (1)** shows the process flow for trading



Below fig (2) shows the process schematic



3. Integration & trading rules

Platform is integrated with the existing smart metering system to capture actual demand of consumers (buyers and sellers). Daily scheduled generation from the contracted generators is captured from power management platform, being used for daily power management. Consumer specific, trading rules were defined, for maximum allowed power to bid and the corresponding bid rate. Similarly, buyers were segregated into open access and non-open access categories and trading rules were set accordingly. Blockchain based platform designed to handle trading on day ahead and intra-day basis, with specific timelines. Consumer is empowered to take decisions whether to sell and in which interval. Buyers to participate as per the offered quantum and rates and if the rate matches, energy exchange happens. As the trading platform is being tried on pilot basis, no integration with the billing system is done and the actual practice of billing remained separate from these transactions. Provisional monthly billing settlement is done basis on actual metered consumption, scheduled generation and the quantum of energy traded for the period.

Below fig (3) shows indicative platform snapshot.

4. Benefits to stakeholders

This platform makes great commercial sense to infirm open access consumers, as it enables them to sell excess energy, reducing energy wastage due to monthly banking restrictions. It actually helps them to earn up to 10-15% additional revenue by selling surplus power. It supports 100% RE vision as consumers can aggressively contract RE power as there would be virtually no risk of lapsed energy.

This is also beneficial to embedded consumers who wants green power cheaper than the DISCOMs retail tariff. With the new regulation coming, which allows consumers having demand more than 100kW to have open access, such platform is expected to help them to go for green portfolio optimally.

There are benefits to DISCOM also. Some of them are reduction in losses, defer system investments, balancing demand and generation locally and it will open new revenue streams by applying transaction fees on such trading.

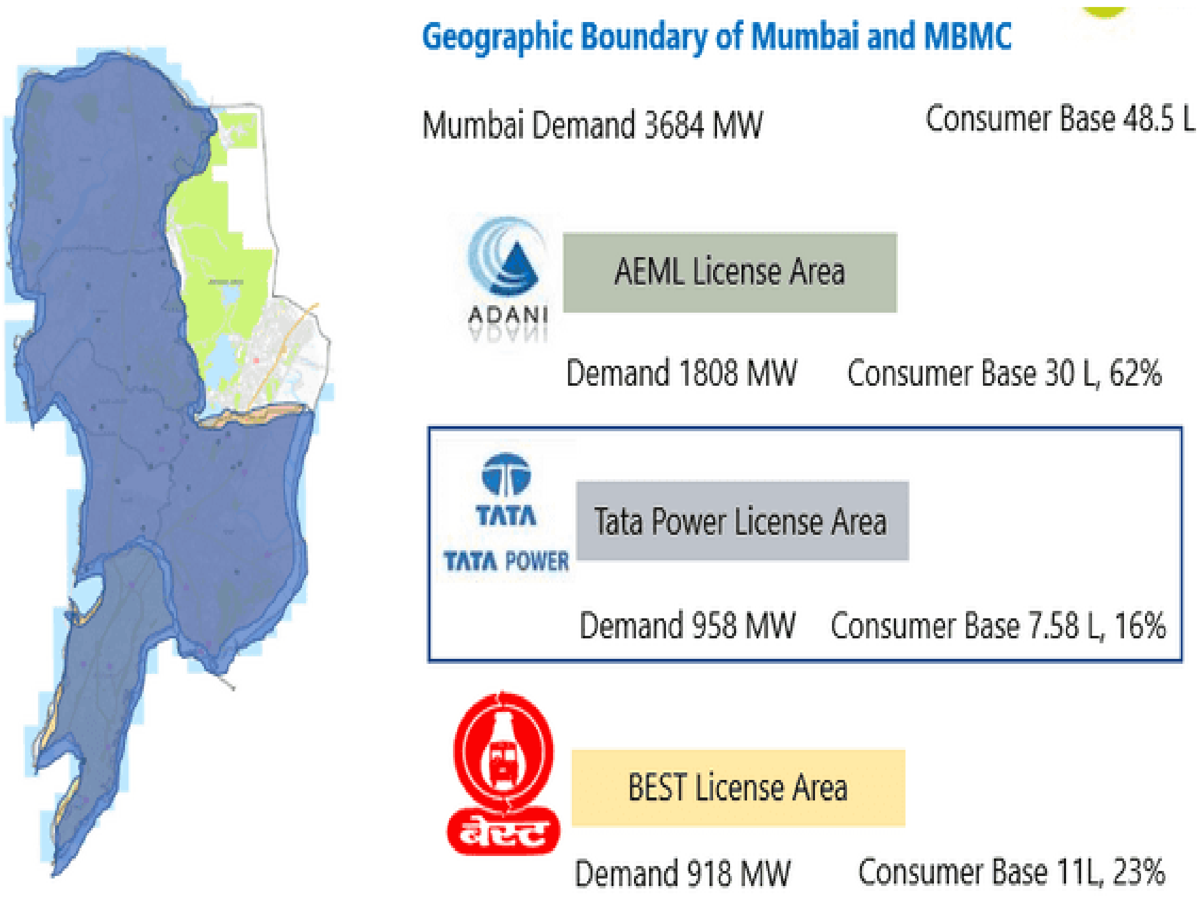
5. WAY forward

It is planned to observe pilot results for another 2-3 months and compile all involved stakeholders' experiences, before presenting the same to the relevant authorities/regulators

Revolutionizing Customer Service

Roopesh Srivastava

Mumbai operates in a unique and competitive power distribution model. There are 4 parallel licensees, and we ensure the city, and its consumers receive efficient and reliable power supply 24x7. A power consumer in Mumbai, enjoys being wooed by power service providers, giving him/her the option to choose between various tariffs and this is something no other city in India enjoys. With a legacy of 107+ years in the power business, ***'Keeping the Customer at the Centre of All We Do'*** has and will always be Tata Power's core Mission statement. The key to excellence in business operations is taking 'CARE' of its stakeholders. Team Tata Power has always aimed to deliver the best-in-class customer service for Mumbai consumers not only with efficient and reliable operations 24*7, but also by introducing new and innovative customer care solutions. Tata Power acknowledges the privilege bestowed on it by Mumbai consumers. The recent unprecedented pandemic has made it imperative to go contact-less in almost all customer transactions. As a service provider offering innovative solutions, a dual purpose of customer affection and sustainable living is accomplished when innovative solutions are introduced.

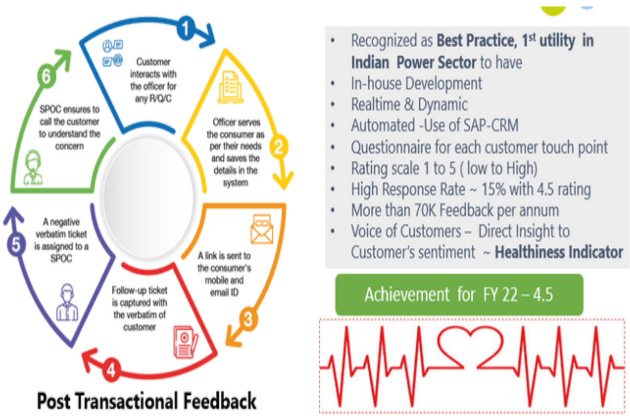


With tariff being regulated by Maharashtra Electricity Regulatory Commission – differential customer services laced with ethical code of business conduct becomes the primary foundation for customer acquisition as well as retention of the customers. Various solutions which are aligned to Tata Power's business goals have been undertaken. For a brand which is synonymous with Care and Trust, listening to consumer feedback is also taken very seriously and there is always a lookout for improvement in services through such voices. Aligning the two 'V's – VOICES from consumers and VISION

of the organization in becoming the 'Utility of the Future' has motivated Team Tata Power in offering below mentioned solutions.

1. **Introduction of Paperless CRCs** – believing 'Sustainable is Attainable' all customer verification documents are scanned and attached with the applications and tagged with service requests. Collection of physical documents completely stopped across CRCs. This introduction has led to consumers feeling safe in not giving away some of the identification documents in paper format. It sets their mind at ease. The benefit for the organization has led to savings in costs in storing documents along with beating the burden of providing space for storage and maintenance of paper documents.
2. **Introduction of Bill on WhatsApp** – It is the company's vision to promote digitalization in a big way and switch at least 90% of its consumer base to E-Bill. Being an E-Bill consumer is incentivized by MERC which has mandated a Rs.10/- credit to an E-Bill consumer every month in his power supply bill. Understanding that WhatsApp communication has a tremendous reach with customers and enjoys higher engagement w.r.t. customer, Bill on WhatsApp was introduced. The benefits of E-Bill are also extended to such customers. Customers while registering for Bill on WhatsApp also enjoy the benefits of receiving bill the day of generation and can accordingly enjoy benefits of payments by discount date, receipt of bill on time, and the incentive of Rs10/-. This has led to an increase in the E-Bill consumer base of Tata Power, and it is anticipated that at least 50% of the present consumer base of 7.5 Lakhs in Mumbai will be on E-Bills at the end of the current FY.

3. **Extensive promotion of consumers on E-Bill and Digital Payments** – With an aim to promote a digital lifestyle, Tata Power has introduced 'Go Digi, Get Lucky' rewards scheme for its Mumbai consumers from 15th August 2022 till 26th January 2023. The intent of the scheme is to create awareness on the benefits of E-Bill and making payments digitally along with an aim to increase the E-Bill and Digital transactions. There are around 1000+ prizes planned to be rewarded to the lucky participants. Mega prizes like LED TVs, Smart Phones, OTGs etc. are planned. Apart from this dedicated programmed, there are also MILAN customer connect sessions held regularly, wherein Team Tata Power visits residential societies on weekends to impart digital literacy and assist in E-Bill conversions and addressing concerns at the doorstep of a residential consumer. Various social media posts, IVRs at Call Centre, Taglines in customer email responses are other channels used to promote and drive E-Bill and Digital Payments.



1. **In-house developed Post Transactional Feedback (PTF) system** – LISTENING to consumer is the most important tool for service excellence. Consumer voice in verbal and nonverbal tone can serve as a cue to improvement in service and further strengthening customer affection. Tata Power has deployed the PTF survey across 3 customer touch points viz., Call Centre, Customer Relation Centers, and E-Care. Once a transaction is completed, an SMS link is sent to the consumer through SAP CRM to the customer for a rating on a 5-point scale. The feedback collected is analyzed & corrective/preventive measures adopted to enhance customer delight.
2. **AI/ML – Artificial Intelligence and Machine Learning** tools used for analyzing content and auto allocation of emails. – An adversity always leads to an opportunity of learning. The unprecedented global pandemic prodded Customer E-Care service function to look to AI/ML tools to handle the huge influx of emails during the pandemic due to billing issues. With all onsite meter reading activities halted, and billing methodology adopted on estimated basis, there was a perception of high billing, mistrust etc. with a huge influx in email concerns coupled with escalations to senior leadership. The tools enabled identification of sentiments and auto allocation of emails on the basis of most used words in emails. Manual intervention of allocation of emails to agents which was time consuming became redundant with the adoption of such tools and resulting in quicker resolutions to consumer queries.

TINA (Tata Interactive Assistance) - empowers consumers to seek quick resolutions through a chatbot deployed in customer portal https://cp.tatapower.com/ for concerns viz., billing query, outstanding amount, power failure registrations, E-Bill registration, online payment query, etc.

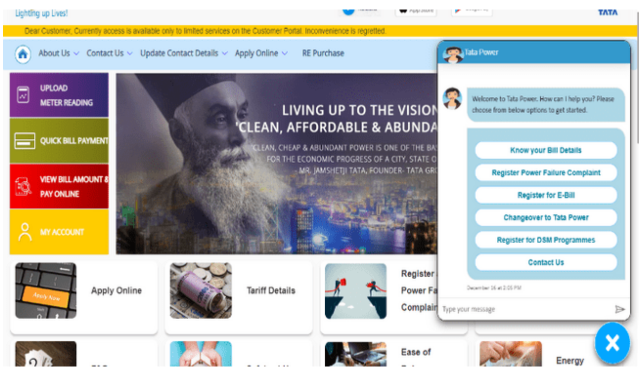
WAY FORWARD

1. **Dedicated Counters at all the Customer Relation Centers for Senior Citizens and Specially Abled -** Understanding the need for special dedicated counters to assist our family of senior citizens and specially abled, counters are being introduced across our 10 Centers to cater to the needs. Dedicated service with minimum hassle is the aim while also encouraging them to go digital. Centers which have already started such services received very good feedback which encouraged Tata Power to also plan a center completed served **by** Specially Abled **for** the Specially Abled.

2. **Jan Jangruti – We Care, Beyond Business –** Tata Power undertakes pre-monsoon safety awareness sessions to educate Mumbaikars on the need of observing electrical safety especially during floods, heavy rainfall, etc. Taking the concept further of caring beyond business, such sessions will be held twice a year. During November-December, the teams will reach out to slum pockets and share general safety tips to be observed around open trenches, electrical poles, feeder pillars, etc.

A delighted customer becomes an organization's brand ambassador. In a competitive power distribution scenario like

Mumbai, Value-Added-Services and serving the customer with delight becomes crucial to the service excellence journey. Team Tata Power is constantly endeavoring to preserve its rich legacy of serving Mumbaikars and enjoying heightened customer affection while marching to become the 'Utility of the Future.'



Augmented Operator Advisor (AOA)

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Abstract

Tata Power, a pioneer in providing reliable and uninterrupted power supply to Residential, Commercial & Industrial customers in Mumbai City & suburbs of Mumbai city. Tata Power is committed & lead adopter of latest technologies. Considering the safety & customer satisfaction, a pilot project was done by implementing “Augmented Operation Advisor”, which gives Operation & Maintenance crew the ability to superimpose real-time data and virtual objects on to the real equipment condition in substation. With this capability, the “augmented operator” minimizes equipment downtime and increases efficiency in maintenance and repair activities.

1. Introduction

Augmented Operator Advisor (AOA) is the solution based on Augmented Reality Concept, which gives Operation & Maintenance crew the ability to superimpose real-time data and virtual objects on to real operating environment. With this capability, the AOA minimizes downtime of Equipment and increases efficiency in maintenance and repair activities. AOA guides the operators to perform operations seamlessly and effortlessly. AOA puts real-time and relevant information at users’ fingertips, whenever and wherever it is needed. The user points a tablet at the site or equipment to be monitored. AOA uses special image comparison techniques to match the scene visible in the field of view of the tablet camera with previously stored photographs. When a match is made, markers called Points of Interest (POI) are overlaid on the live scene visible on the tablet. The user taps the POI markers to display information. A wide variety of information can be displayed in form of documents, images, videos, procedures, relevant parameters etc.

2. Challenges faced by O&M Team

As a utility there is mix of equipment from various OEM. The operating procedures are different, for various types of equipment’s and with varying specifications. Depicted below are image of different equipment’s & challenges faced by the team.

Fig. 1

- Human errors during complex Operations leading to safety concern.
- Increased co-ordination required between various O&M Personnel within team during emergencies.
- Equipment operation know-how is person specific and dependency on key person(s)/ OEM during emergency.
- Availability of information in time of need and safe preservation of all document/information.
- Holistic view of real time process information, condition of equipment is not always available on field.
- Absence of centralized information due to multiple OEM legacy equipment.
- Internal component view of live equipment not available for trouble shooting leading to increased downtime of the equipment.

3. Need of project

As Tata Power is working towards customer delight and satisfaction. Safety being the core value, for enhancing all the above parameters mentioned it was necessary to implement technological interventions for overcoming the challenges. The solution worked out was AOA.
Following are the key objectives of AOA.

- To minimize human error during equipment operations.
- To enhance ease of operations, maintenance & troubleshooting during emergency situations without the help of OEM or Domain Experts.

4. Project Scope

The main objective of AOA application is to scan equipment located in substation. During station rounds, O&M engineer has access to virtual views, all important technical documents, operational videos, procedures, email facility, digital checklist, and crucial TATA Power apps like GIS & Saamarthya.

AOA application provides holistic real time information at fingertips. Data collected from condition monitoring checklist during station round is stored in central repository and can be used for future analytics.

5. Architecture of Project

The architecture of AOA is an application that runs on an Android, iOS, or Windows tablet. A cloud-based architecture where AOA runtime server is installed in virtual machine. The AOA project built is deployed in runtime server which is connected to the User Tablet through internet connection on secured port 443. The solution is made cyber-secured by installing SSL certificate both in server and user tablet.

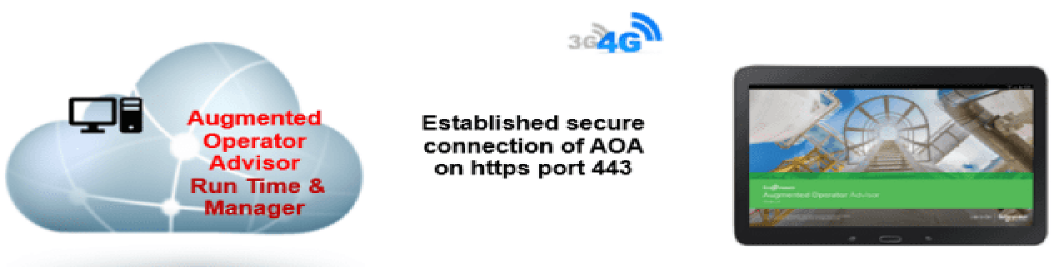

Fig.2

6. Development of Application

Collating of all required data of the Equipment from OEM manuals, condition monitoring checklist, routine maintenance records, failure reports, vital data related to SF6 leakage, oil related parameters, relay settings information, protection information etc. during implementation stage of AOA application. Post which all data was saved and incorporated in AOA application through programming. This data was made easily accessible to end user for future use of AOA application.

7. Working of Application

The working principles of the application designed are:

- Identify the equipment.
- Point camera of Tablet on target equipment.
- AOA application will give augmented view/information about the equipment.
- Point of information includes virtual view, important documents like electrical drawings, manuals, SLD & reports, operating procedures, operational videos, digital checklist for condition monitoring & email-facility.
- Filling the checklist of condition monitoring by manual entry or through voice operated assistance.
- Logs of collated data stored at central repository and can be viewed by nodal head/team.

8. Functioning of AOA Application

After logging in application, Tablet Camera must be pointed towards Equipment. Post which home screen appears on Screen. In Home Screen click on camera icon.

- After scanning the equipment, POI gets popped up on the scanned image. User has to click on snowflake symbol. (Refer Fig. 3)

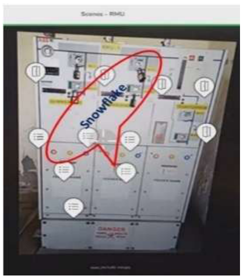

Fig.3

- By clicking on appropriate snowflake symbols required data can be fetched. (Refer Fig. 4)

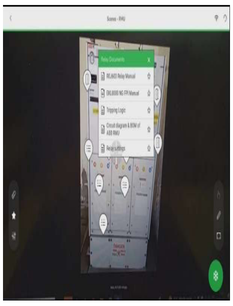

Fig. 4

3. Document can be viewed in pdf format where user can utilize all pdf features. Similarly rest of POI can be viewed. (Refer Fig. 5)

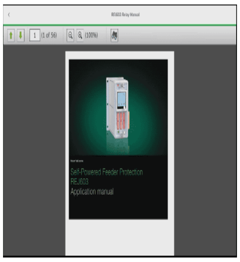

Fig. 5

- Apart from PDF format, videos can also be attached for sharing operational procedures, maintenance practices and defect troubleshooting. (Refer Fig. 6)

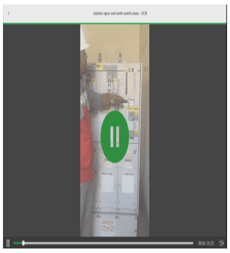

Fig. 6

AOA natively supports TATA Power inhouse application with seamless integration. (Refer Fig. 7)

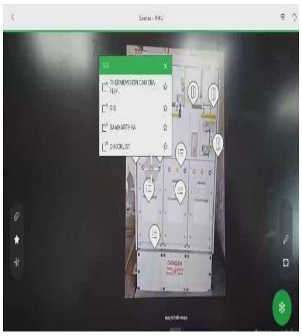

Fig. 7

- Conditional Monitoring Checklist can also be accessed with historical Logs. (Refer Fig. 8)

Fig. 8

The virtual view of the application helps O&M Teams & user to understand equipment with latest information of condition monitoring and historical records of the defects, problems, and routine maintenance records of the equipment. This helps O&M Teams & users to take appropriate decisions within time.

9. AOA Enhanced Benefits

- Point of interest (POI): Wide selection of information: Real-time data from Data Acquisition system, technical documents, images, web pages, notes & labels.
- Access hidden parts: Possibility to have virtual internal view of an electrical & mechanical component.
- Image freeze: AOA can freeze the image and the user can continue working on the equipment hands free.
- Notes: AOA can create information alerts.
- Procedures: AOA provided Step by step guide for user. It is available in both training & launch mode.
- Screenshot: AOA helps take a screenshot of the scene which can be attached to notes.
- Digital checklist: AOA is used for condition monitoring and checking the healthiness of equipment during station rounds.
- Expert connect: AOA helps to connect to an expert via video call.

10. AOA Disadvantages

As Pilot project was implemented at one Substation, the cost of the project was ₹ 9 Lakhs inclusive of software and Tablet. Thus, there is cost implication for adding further Substations. Moreover, further updation of any data needs programming support from AOA developer with cost implication

11. Conclusion

As a pilot project AOA was implemented and tested for various scenarios. It is a helpful application supporting Operation Engineers, O&M Engineers as the data available is in real time and the dependency on OEM or Domain Experts is reduced or negligible. Also, this can be used as a simulator training tool for new entrants & Trainees.

Transformer LT Cable Box Health Monitoring System

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Abstract

Traditional way of monitoring LT (Low Tension) cable box is availing outage before and after monsoon to check for abnormalities which has direct impacts grid availability. In order to bring down the outage requirement a monitoring system was required for assessing the Transformer cable box condition. A customized device was developed in house, which consist of Thermal imaging sensors, temperature sensors, humidity sensors and wide-angle camera with flash light. The device is also compact enough to fix inside a cable box.

1. Introduction

The Transformer LT (Low Tension) cable box is closed chamber which consist of cable terminations, LT Bus, and LT bushings. The cause of failure inside cable box is due to moisture and condensation. It is impossible to open and check the LT cable box when transformer is in service. Separate outage may be required to check and inspect Transformer cable box which can impact grid availability.

It was proposed to develop a monitoring system by which user can monitor the cable box from remote. The proposed system has Thermal imaging, camera, temperature sensor, humidity sensor which gives live data.

Fig.1: Transformer LT Cable Box

Trigger for Improvement

Transformer shutdown due to LT cable box failure is a major contributor for Transformer shutdowns. The major contributor of Transformer tripping related to cable box is listed below

1. Dust, Moisture ingress, Condensation
2. Surface Tracking
3. Mechanical load on cable termination
4. Partial Discharge
5. Ageing of Gasket
6. Hotspot at bus bar bolts
7. Oil Leakage

The non-availability of condition monitoring system to assess the condition of Transformer cable box was major setback which lead to development of a health monitoring system for Transformer cable box.

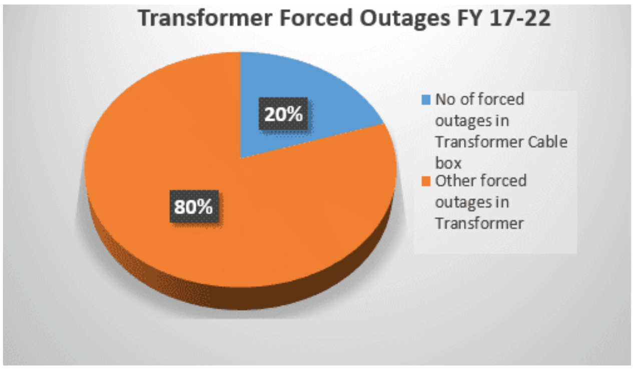

Fig.2: Five years data indicating Transformer shutdown in Tata Power Transmission

2. Idea Development

The idea was proposed to develop a compact system which can fit inside the Transformer cable box The thermal camera and digital camera are installed in such a way that there is sufficient clearance from the live parts and it also covers all the parts sections the box

- The Transformer Cable box health monitoring system consists of Thermal sensors, Humidity sensor, temperature sensor and a wide-angle camera with flash light.
- The system is integrated to fit inside the Transformer cable box.
- The configuration can be customized based on the user's requirement.
- The data is live streamed in control room where the user can see real time data.
- The temperature humidity and thermal data is stored in the background can be used to provide alert to user when there is an abnormality.

Key Benefits of Transformer Health monitoring system Units

- Real time Thermal scanning of Transformer LT cable terminations
- Live feed of Cable box view is available by which abnormality like moisture ingress condensation can be detected early
- Immediate actions can be taken if any abnormality observed by user there by avoiding forced outages

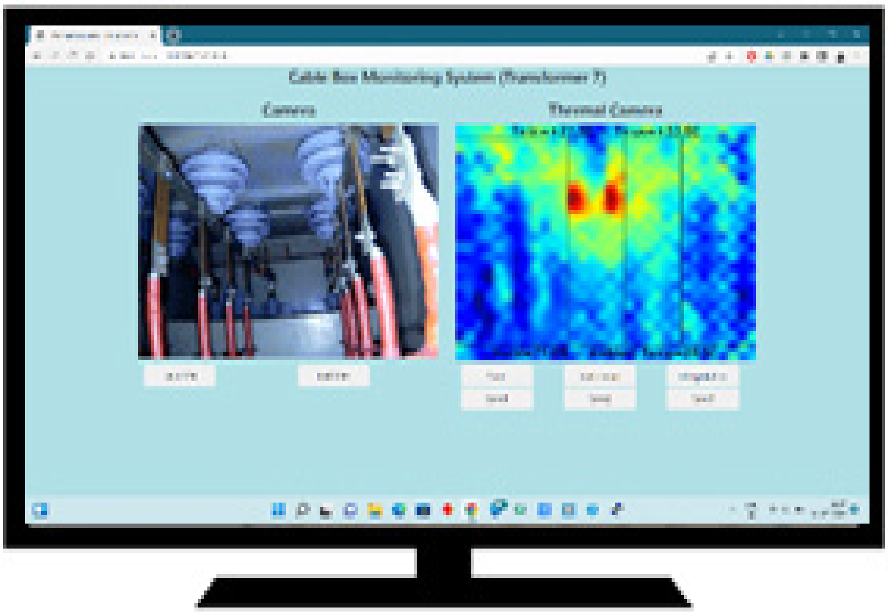

Fig.3: Remote Monitoring

- 24/7 Live data is available in control room for user to monitor
- Data of Thermal, humidity and Temperature sensor are captured which can be used to provide Notification alert to users in case of deviations.

3. Proposed actions and way ahead

The thermal temperature, cable box temperature and humidity data inside cable box is stored in the background.

The data will be configured to generate notification alert to user if any data is exceeding the limit. The notification alert will be sent through mobile and user can check the live data for any abnormality. Outage may be taken based on the data.

		Thermal #1		Thermal #1	
Date	**Time**	**Min**	**Max**	**Min**	**Max**
07/23/22	12:46:13	37.35943	52.96537	37.03099	55.78284
07/23/22	13:16:13	38.26886	51.17469	37.77102	54.12726
07/23/22	13:46:13	37.29969	46.96196	37.54579	54.51636
07/23/22	14:16:13	37.59496	48.49083	37.17042	55.09619
07/23/22	14:46:14	37.9631	47.32397	37.37419	54.01282
07/23/22	15:16:14	36.90204	45.82303	36.69851	54.59265
07/23/22	15:46:15	36.89395	46.33152	36.15153	55.47003
07/23/22	16:16:15	33.31871	42.74525	35.31497	58.07166

Used cases of Live Tracking App for EHV/HV Cable Safeguarding Sites to Ensure Uninterrupted Power Supply and Fast Restoration of Supply

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Abstract

There are 100 of excavations daily on Mumbai roads due to infrastructure activities by Other Utilities/Authorities. Tata Power is having huge underground network of HV and EHV Cables under Mumbai Roads.

These cables are lifeline of Mumbai supplying/transmitting supply to major Power Distributors like M/s BEST and M/s Adani in addition to the Tata Power own network. Any damage to these cables can result into shutdown to EHV Receiving stations, Distribution substations and Consumers and due to which High pockets of Mumbai areas can be under black-out. Also repair cost of these cables are in the range of Crores of rupees.

To monitor excavation and to avoid damage to cables during excavations Site supervisors are posted at sites. Earlier there was no live tracking of sites and supervisors, due to which there were external damages to Cables resulting into interruption in power supply, revenue loss and increase in cable repair cost. So, to reduce no. of external damage to cables Live tracking mobile app is developed

This app shows the all-site persons live on the Geographic Map. Sites are allotted to site persons through mobile app and site periphery can also be fixed through mobile app. If any site person leaves the allotted site's periphery, then alarm generates and message goes to Engineer. In case of any tripping of any cable in system then one alarm is generated through app and it goes to all site persons and they have to respond the alarm otherwise alarm will beep in every 5 minutes. Site persons have to respond alarm by responding that there is damage to cable at their site or not. This help in fast isolation of faulty cable section from cable ring network so faster restoration of supply can be done. Similarly other features are there like automatic calculation of attendance, automatic Patrolling efficiency calculation and there is two-way communication with certain logics etc. This app is helping in great way in reduction of external damages to cables which save crores of Rupees annually and help in maintaining the reliability and availability of the Network.

1. Introduction

In present time we are seeing many digital interventions which are helping in cost effective management of operation and maintenance activities. In this paper we are discussing the used cases of Live Tracking App for EHV/HV Cable safeguarding sites to ensure uninterrupted power supply and fast restoration of supply. First, we will discuss the challenges which triggered for development of this Live tracking mobile app. Then we will se the used cases of Live tracking of mobile app. Then we will discuss the benefits of Live tracking app. In brief this mobile app is helping in reduction of cycle time of restoration of power supply during cable faults and automatic monitoring of Site Person and Foot Patrolman. which is associated with many tangible and intangible benefits

2. Challenges

In earlier system there were many challenges which triggered to create this mobile app few of them are discussed below.

A. ***Cycle Time in restoration of Power Supply***

Generally, Power utilities have their network in Ring system. Ring system means that if there are 5 Consumer Substations then there will be a ring system between these consumer substations. Source A will feed to consumer substation 1. Consumer substation 1 will feed to consumer substation 2. Consumer substation 2 will feed to consumer substation 3 and similar way consumer substation 3 will feed to consumer substation 4 and consumer substation 4 will feed to consumer substation 5. Consumer substation 5 will also have a second source B. So, in case of fault in any cable between two consumer substations supply can be restored by other source. In below Image- 1 Ring Network System is Shown.

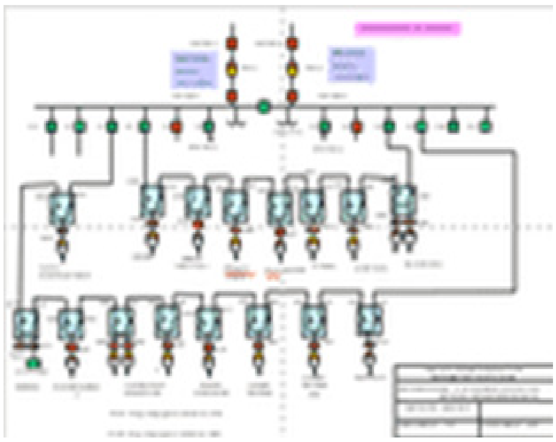

Image 1- Ring Network System

So, in above example if any underground cable between two consumer substations will be damaged in utilities excavation work, then Source A will be tripped and all the 5-consumer substation will be under shutdown. Operation engineer will do the Insulation Resistance Testing of each cable section between all consumer substation to identify the faulty cable and then he will isolate the faulty cable section and will restore the supply. This may take 2 hours to many hours to restore the supply in bigger ring network systems. So, restoration of supply was a big challenge. We were looking to find the solution for early restoration of supply in external damage cases.

B. ***Cost reduction in repair of cable faults***

Repair cost of 1 HV External damage Cable fault is approx. 1.5 Lacs and for EHV it is in crores of Rupees. Site Persons who are appointed for safeguarding of cables are responsible for avoiding the external damage cable fault to HVand EHV cables. Earlier there was no tracking of these site persons. Many damages were happening when site persons were not present at site. So, to reduce the cost it was necessary to monitor and control the site persons. So, this challenge was also a trigger point for creation of this app.

C. **Physical visit to sites to monitor the Site Persons and Foot Patrolmen**

Earlier Engineer was visiting sites to verify the sites if Site persons are present at their site or not or Foot patrolmen are doing patrolling or not. This was increasing manpower workload as one engineer has to do multiple jobs. So, to avoid travelling for monitoring purpose one mobile app was required.

1. **Used cases of Live tracking app**

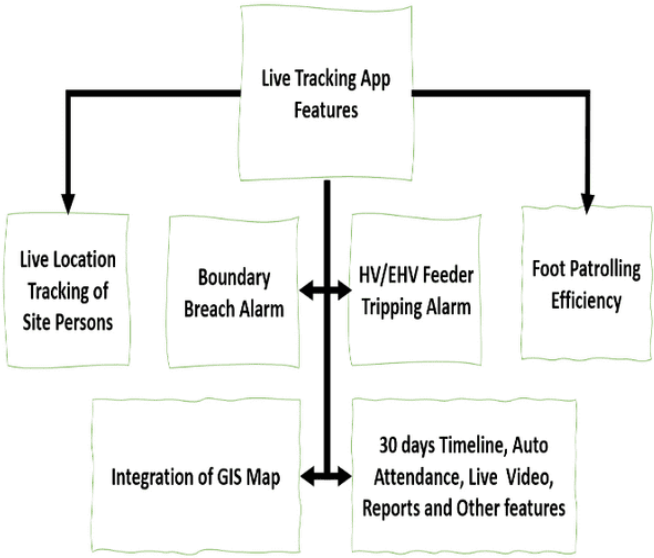

Image 2- Features of Live Tracking App

We can see in above image 2 block diagram of main features of Live tracking app. These features are Live location tracking of site persons, Boundary Breach Alarm, HV/EHV Feeder Tripping Alarm, Foot Patrolling Efficiency, Integration of GIS

cable network Map and other features like 30 days' timeline, auto attendance, live video, and various reports. We will see each feature with used case in details in below points.

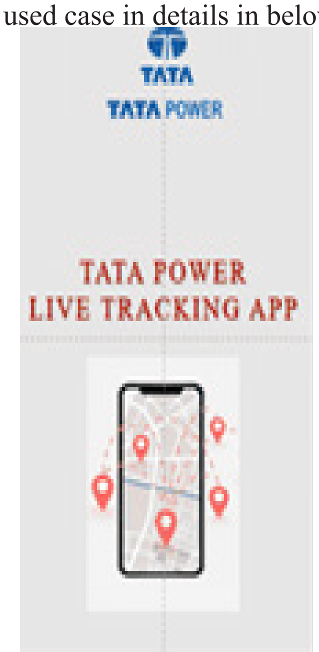

Image 3- Live Tracking App

We have developed live tracking app which is shown in Image 3. This app is using different logics for managing the site persons, sites, foot patrolman and other patrolling team members. Below are the used cases.

A. **Live Location Tracking of Site Persons**

Image 4 - Live Location of Site Persons

In image- 4 we can see that all the posting persons belonging to respective zonal boundary can be seen on google map in a single screen. If In emergency situations if Engineer wants one person to do the site visit at a location, then he can see the live location of all persons on app and can call to that site person who is very near to that location. This will save time as nearby person will reach at that site early.

In another case if any site has become critical and urgently few more persons are required to be deputed there then immediately Engineer or supervisor can see the live location of nearby persons and can send them at that location. So, site management is being done in faster way.

Image 5 - Live Site Detail

In above image- 5 Engineer has clicked on one site person location and he can see in image- 5, his name, photo, mobile no., current location. Engineer can directly call him from this window. So, this is helping in great way in monitoring and communicating with site persons.

2. Boundary Breach Alarm

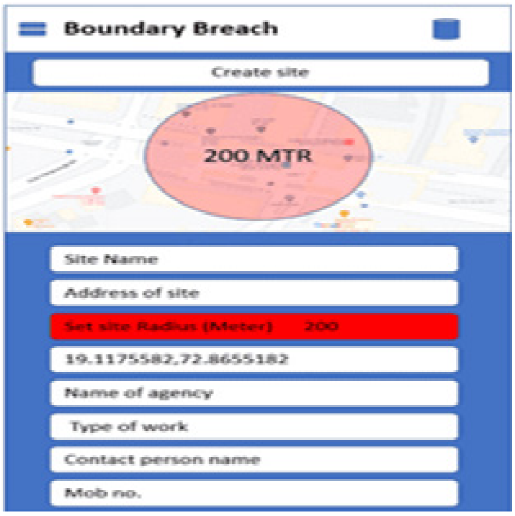

Image 6 - Creation of Boundary in site person app

Image 7 - List of breach boundaries in Supervisor App

In above Image 6, Boundary Breach screen is shown. As the site person reach at site, he login into the app. After login he must create the site by entering the site details in Mobile app form. He will also get the option for setting his site radius which is by default given 200 meters. If he set his site radius different to 200 meters for example 100 meter then a notification will go to engineer and he has to approve the change in radius and even engineer himself can reset the site radius through mobile app. In above example site radius is 200 meters.

After creation of site, the site person must be present at that site within the set radius. If site person will breach the radius of site, then Engineer will get the notification for boundary breach as shown in above image 6.

In above image 7, Boundary breach data of Metro zone for 10 oct 2022 is shown. Mr. Naaz the site person has breached the site at 12:10 and he is currently inside the site radius. Mr. Dhiru has breached the site at 17:30 and he is currently outside of site radius. This report is also being daily sent in mail to concerned engineer so that he can take necessary action. So, in this way site persons monitoring is being done effectively.

c. Tripping Alarm

Image 8 - Tripping Alarm Creation in Supervisor App

Image 9 - Tripping Alarm Response in Site Person App

Generally, Power utilities have their network in Ring system. Ring system means that if there are 5 Consumer Substations then there will be a ring system between these consumer substations.

Source A will feed to consumer substation 1. Consumer substation 1 will feed consumer substation 2. Consumer substation 2 will feed to consumer substation 3 and similar way consumer substation 3 will feed to consumer substation 4 and consumer substation 4 will feed to consumer substation 5. Consumer substation 5 will also have a second source B. So, in case of fault in any cable between two consumer substations supply can be restored by other source.

So, in above example if any cable between two consumer substations will be damaged in utilities excavation work, then Source A will be tripped and all the 5 consumer substations will be under shutdown. Operation engineer will do the Insulation Resistance Testing of each cable section between all consumer substation to identify and isolate the faulty cable and then will restore the supply. This may take 1 hour to many hours to restore the supply in few typical cases. So, restoration of supply was a big challenge. We were looking to find the solution for early restoration of supply in external damage cases.

In above image 8 as soon Engineer will get message of tripping of any HV/EHV Feeder he will create a tripping alarm in his Live tracking app. He will select the zone, google location, and will write the name of tripping and create the alarm.

After creating the alarm all 20 or more site persons of that zone will receive an alarm ring in their mobile and they have to respond by clicking on reject or accept. Until they will not click either of the button alarm will continuously ring. After clicking on button for example clicking on accept button, they have to select the option like Damaged or issue not found. If they will not respond then after 5-minute alarm will ring again. So, in any situation Site person has to respond.

So, within five minutes Engineer will receive the response from all 20 or more site persons and he will get the exact location of damage to cable. Engineer will immediately inform to Operation engineer about the location of fault. After confirming the cable network from GIS mapping data Operation Engineer can isolate the faulty section immediately without checking all cables with Insulation Resistance Tester. So, this is reducing the time of restoration of power supply from approx. 2 hours to 15 minutes i in bigger ring network systems.

D. Foot Patrollinig Efficiency

Image 10- Foot Patrolling of 220 KV Cable route by Foot Patrolman

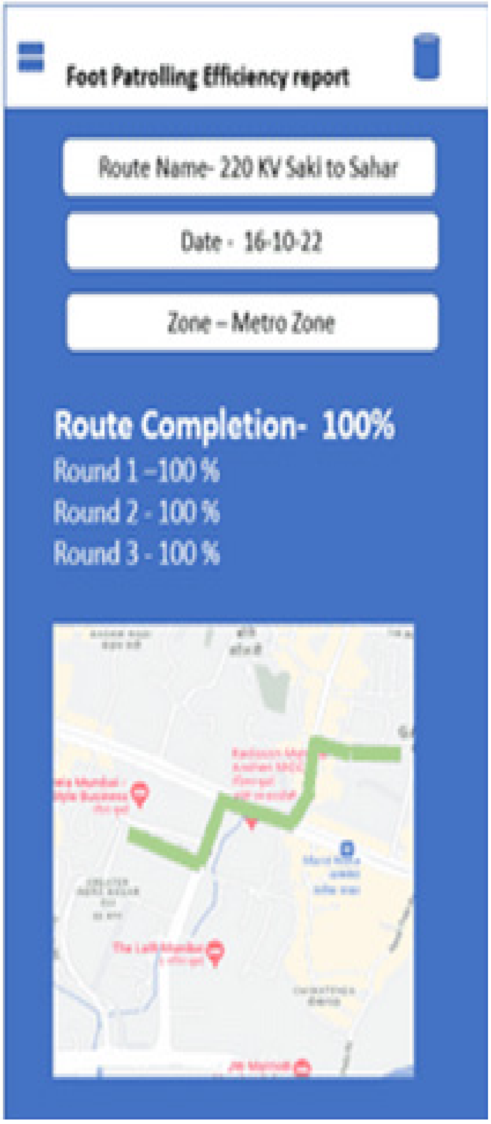

Image 11- Foot Patrolling Tracking of 220 KV Cable route by Site Supervisor

Foot Patrolling activity is walking on road above EHV underground cable routes and reporting if any excavation work happens on roads. Generally, one Foot Patrolman walk approx. 10 KM during day above cable routes. He covers one route of 5 KM two times a day.

Earlier there was no method to track the Foot patrolman other than physical surprise site visit by Engineers at cable routes. This was creating extra work load on engineers to visit the site and increasing convenience expenses of vehicle.

There are around 30 no. of persons who walk on defined routes on roads. These roads are having 110/220 KV cables. These Cable goes from different Receiving stations to other stations length ranging from 200 meter to 10 KM or more. There should be tracking of route coverage. Live tracking App send daily mail mentioning foot patrolling efficiency. Suppose if a route is having 5 Km length and it was covered for 2.5 KM then it generate = 2.5/5*100= 50 % efficiency. So, Foot patrolling efficiency is being shared daily in mail as given in below image 12.

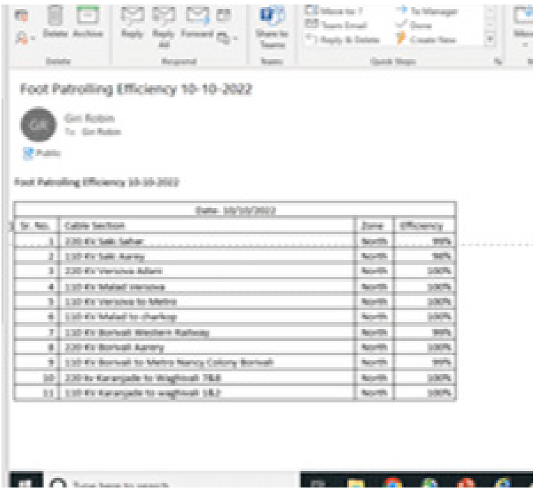

Image 12- Daily foot patrolling mail

We can see in above image 10, which is of Foot Patrolman mobile screen. At top cable route name 220 KV Saki to Sahar is mentioned and below that percentage of cable route covered is shown. In this screen one line is marked in green and yellow color on google map. This line is showing the 220 KV cable route alignment. Green color is representing the cable route which is covered and remaining red color is the route which is yet to be covered.

Image 11, is showing the screen of Engineer's mobile app. To check the Foot Patrolling efficiency report first Engineer must select the Cable route name, in image 11, it is selected 220 KV Saki to Sahar. Then engineer has to select the date. We can see in image 11 that Route completion is 100 %. Three rounds are taken by Foot patrolman and every round is covered 100%.

After deployment of Live Tracking app, now there is no need to physical surprise visit to sites and automatically Foot Patrolman monitoring is happening through Live tracking app.

Integration of GIS Map for HV/EHV Network

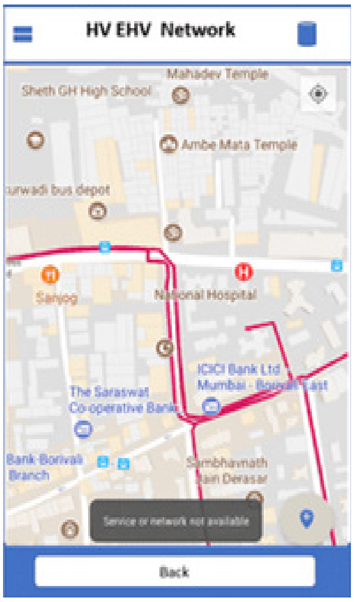

Image 13 - Cable route integrated with Google Map

Whenever Site Person or Foot Patrolman observe any excavation work near to cable route, he has to take necessary precautions so that no damage to underground cables happen during excavation work. First, they have to check the cable route alignment in excavation area. Earlier they required to go to Office to collect the cable route drawing and then they were taking necessary precautions. It was taking 1 day to collect the drawing from office. During this delay damages to cables were happening as excavation utility was not getting any confirmation about cable route timely. To avoid this delay one mobile app was required which should have readily available drawing in it so that Site Person can immediately show the drawing to Excavation Utilities.

We can see in above image 13 that HV/EHV Cable route GIS map is integrated with Live tracking app. red color line is showing the underground cable route network alignment on google map. Now with the help of live tracking app Site Person or Foot Patrolman immediately shows the cable route alignment to Excavation Utilities. This is reducing external damages to cables during excavation work and improving overall reliability of network. This app has also reduced the cycle time of drawing sharing from 24 hours to 5 minutes.

F. 30 days' timeline data of site persons

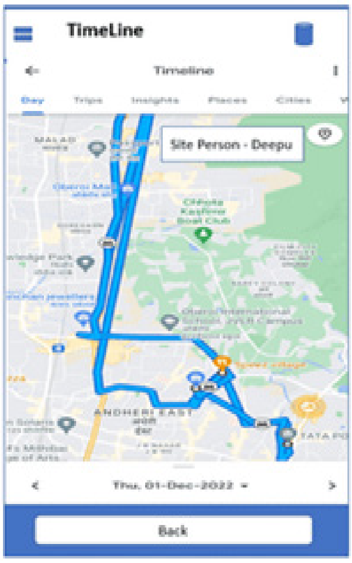

Image 14- Timeline of site person

In above image 14, time line of Site person is shown on date 1st Dec 2022. In similar way timeline of all Site Persons and Foot Patrolman can be seen for last 30 days. This help in cross verify the Site Persons and Foot Patrolmen locations during external damage to cables. For example, suppose if any external damage happened to cable then engineer can check the Site Person's location on time line and can ensure if he was present at site or not. For another case suppose if Engineer has received the Site Person's boundary breach notification, then Engineer can check his timeline and can decide course of action as per investigated reasons.

B. **Auto Attendance Calculation of site manpower**

This app generates auto attendance monthly for all Site Persons and Foot Patrolmen. This report has Site Person's daily presence duration in hours at site. Site Person's login time, logout time, boundary breach time etc. are generated in the report. This reduces effort of manual calculation and monitoring of site persons.

C. **Group Chat, Live Video**

Image 15- Group Chat Live Video

This Live tracking app is having chatting, voice calling and video calling features. All Site Persons, Foot Patrolman, Supervisors and Engineers are added and mapped zone wise through admin application. Individual Team member can connect to any one in his zone. Zone wise groups are also formed for sharing important information. Photos and videos can be shared with this app. Live streaming from sites can be done with the help of this app.

benefits

B. **Cycle Time reduction in restoration of Power Supply**

As we have seen above that power utilities have their network in Ring system. Ring system means that if there are 5 Consumer Substations then there will be a ring system between these consumer substations. Source A will feed to consumer substation 1. Consumer substation 1 will feed to consumer substation 2. Consumer substation 2 will feed to consumer substation 3 and similar way consumer substation 3 will feed to consumer substation 4 and consumer substation 4 will feed to consumer substation 5. Consumer substation 5 will also have a second source B. So, in case of fault in any cable between two consumer substations supply can be restored by other source.

So, in above example if any cable gets damaged in utilities excavation work the Source A will be tripped and all the 5-consumer substation will be under shutdown. Operation engineer will do the Insulation Resistance Testing of each cable section and will isolate the faulty cable section to restore the power supply. This may take 2 hours to many hours to restore the supply in bigger ring network systems.

With the help of this App Engineer create the alarm which go to mobile of all 20 or more site persons of that zone who are monitoring the excavations at site. This alarm continuously rings till the site person respond to alarm. Site person must select the option if damage happened at his site or not. So, within five minutes Engineer will get the location of damage to cable and he will immediately inform to Operation engineer about the location of fault.

After confirming the cable network from GIS mapping data Operation Engineer can isolate the faulty section immediately without checking all cables with Insulation Resistance Tester. So, this is reducing the time of restoration of power supply from approx. 2 hours to 15 minutes i in bigger ring network systems

C. **Cycle Time reduction in drawing sharing**

We can see in above image 13 that HV/EHV Cable route GIS map is integrated with Live tracking app. red color line is showing the underground cable route network alignment on google map. Now with the help of live tracking app Site Person or Foot Patrolman immediately shows the cable route alignment to Excavation Utilities. This is reducing external damages to cables during excavation work and improving overall reliability of network. This app reduced the cycle time of drawing sharing from 24 hours to 5 minutes.

D. **Customer satisfaction by Fast restoration of power supply**

As we have seen above that monitoring of site persons who are safeguarding the cables from external damage cable faults is improved so the no. of external damages to cables also reduced by approx. 20 % so power interruptions to consumer is also reduced. This is improving the consumer satisfaction.

As mentioned in above benefit A, those cases where external damage cable faults are happening to cables in those cases with the help of tripping alarm restoration of power supply is happening in approx. $1/8^{th}$ cycle time. So even after getting interruptions consumers supply is being restored in approx. $1/8^{th}$ time. So, consumer satisfaction is Improving.

E. **Network Reliability Improvement SAIDI, CAIDI, SAFI Index Improvement**

Network Performance indices generally depends on no. of interruptions, duration of interruption and volume of consumers. As we have seen above that with the help of this Live Tracking App No. of interruptions have decreased and duration of interruption has also decreased so overall system performance indices have improved.

F. **Cost reduction in repair of cable faults**

Repair cost of 1 HV External damage Cable fault is approx. 1.5 Lacs and for EHV it is in crores of Rupees. Site Persons who are appointed for safeguarding of cables are responsible for avoiding the external damage cable fault to HV and EHV cables. Earlier there was no tracking of these site persons. Many damages were happening when site person was not present at site. With the help of this app monitoring of site persons have strengthened and site persons presence at site has been ensured to 100 %. This is helping in reduction of external damages to cables by approx. 20 %. So, Cost of repair of external damages is reduced by 20 % which is more than 20 Lacs.

G. **Cost reduction in convenience charges**

Earlier there was no method to track the Foot patrolman other than physical surprise site visit by Engineers at cable routes. This was creating extra work load on engineers to visit the site and increasing convenience expenses of vehicle.

So, after deployment of Live tracking app now there is no need to physical surprise visit to sites and automatically Foot Patrolman monitoring is happening through Live tracking app

H. **Environmental Benefit by Reduction in Carbon Emission**

As all site persons can be monitored remotely through mobile app and site can also be seen with live video streaming through this app so there will be no requirement of routine physical visit at sites. This will reduce daily 500 km running of vehicles for 5 vehicles in 5 patrolling zones which will further reduce carbon emission. Co2 Carbon emission for diesel vehicle is 2.68 kg per liter. If Total diesel consumed in a year is calculated then it comes out to be 36,00 liter if car mileage is 10 km per liter. So, carbon emission 9648 kg would be reduced by 70 % with use of this app which will improve our environment condition.

I. **Social Benefits**

Due to reduction in use of vehicle this will contribute for reduction in traffic jams.
Reduction in damages to cables will improve power supply reliability which will help in smooth running of public services like hospital etc.

J. Safety to society

Damages to power and gas lines can create flash over and fire which can cause injury to nearby passing persons. Thus, reduction in damages to power cables will improve safety to public.

K. **Revenue through uninterrupted service**

If damages to utilities will reduce then tripping in utility services like power, gas, telecom, water will reduce. Uninterrupted service will provide more revenue to utilities

Acknowledgment

Thus, in this paper we have discussed the used cases of Live Tracking App for EHV/HV Cable safeguarding sites to ensure uninterrupted power supply and fast restoration of supply. First, we have discussed the challenges which triggered for development of this Live tracking mobile app. Then we have discussed the used cases of Live tracking of mobile app. Then we have discussed the benefits of Live tracking app. In brief this mobile app is helping in reduction of cycle time of restoration of power supply in cable fault condition and automatic monitoring of Site Person and Foot Patrolman which is associated with many tangible and intangible benefits

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Compendium of Technical Paper isuw. 2023

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India Smart Grid Forum (ISGF) , (CBIP) Building
Malcha Marg , New Delhi , Delhi 110021

Woodhead Publishing India Pvt Ltd
ISBN :-978-81-968480-6-4
9 7 8 - 8 1 - 9 6 8 4 8 0 - 6 - 4