From the Editor's Desk

International Association on Electricity Generation, Transmission and Distribution – Afro Asian Region (AARO) is an international forum of experts & organizations engaged in the various technical activities related to the field of Power development in the Afro Asian Region. The association was formed in the year 1990 for the benefit of all the developing countries in the Afro – Asian region, with their mutual help and cooperation.

India is centrally placed in the South Asian region and with cross-border interconnections with neighbouring countries, playing a major role in the effective utilization of regional resources. Due to its unique location as well as sound electricity infrastructure, we must lead in energy cooperation and development of the market in South Asia, regional transmission infrastructure development as well as facilitate efficient utilization of the energy resources for the cross-border entities. Presently, India is connected with Nepal, Bhutan, Bangladesh, and Myanmar. Nepal is interconnected with India at various places through 11kV, 33kV, 132kV, and 220kV lines. For the transfer of bulk power, the interconnection between India and Nepal through Dhalkebar (Nepal) - Muzaffarpur (India) 400kV D/C transmission line has been constructed. A total of about 700 MW of power is being supplied to Nepal through these interconnections. India and Bhutan already are connected through various 400kV, 220kV, and 132kV lines, mainly for the import of about 2000 MW power from Tala HEP (1020MW), Chukha HEP (336MW), Kurichu HEP(60MW) and Mangdechu HEP (720 MW) in Bhutan to India. A high capacity interconnection between India and Bangladesh exists through Baharampur (India) – Bheramara (Bangladesh) 400kV D/C lines along with 2x500 MW HVDC back-to-back terminal at Bheramara. Another 400kV (operated at 132kV) interconnection exits between Surajmaninagar (Tripura) in India to Comilla in Bangladesh. These interconnections cumulatively facilitate the transfer of power of the order of 1160MW to Bangladesh. India is providing about 3 MW of power from Moreh in Manipur (India) to Tamu town in Myanmar through an 11 kV transmission line. Interconnection between India and Sri Lanka is under discussion between the two countries.

Through this journal, we disseminate the technical information and innovations, on the subject of Electricity Generation, Transmission and Distribution amongst the professionals of the power sector.

In this issue, five important articles have been contributed by eminent engineers from the Power Sector such as 'Managing Disaster in Power Utility' which describe the experience of CESC in managing emergencies caused due to natural Disaster in Kolkata. Another two articles on the subject of Renewable Energy i.e. 'Operational Challenges of Large Scale Battery Systems for Grid-Scale Applications' and 'Renewable Energy Integration with the existing grid using Battery Energy Storage and Machine Learning Applications' present in detail the challenges of the large RE integrations in the grid and also about the various technical and commercial challenges of energy storage system implementations in the Indian context with the case study.

Another article on 'Understanding of Grounding & Effective Grounding System for Substations' which covers the details about the importance of grounding system has been included. The paper on 'PD Measurement of Rotating Machine for Condition Monitoring' which explains in detail the results of online PD measurements done on Hydro Generators is also included. This paper discussed the cases of failure of two of the air-cooled generator, with detailed reasons and corrective action.

We hope that the article and information included in this issue of the journal will be of interest to the readers and they will be benefitted. Through this journal, it has been our endeavor to share the experiences of Power Engineers in the field of Generation, Transmission & Distribution. We, therefore, request the readers for sending their contributions in the shape of technical papers, etc. for publications in this journal.

A.K. Dinkar
Secretary General, AARO & Secretary, CBIP

Managing Disaster in Power Utility – CESC's Vision

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1. INTRODUCTION

Every disaster whether natural or human induced poses serious threat to Power Generation & Distribution infrastructure in terms of damage, premature breakdown, fire hazards etc. leading to prolonged supply outages, interruption of various vital services, massive financial loss and unprecedented human sufferings. Damaged distribution plant & equipment, snapped live OH conductors etc. poses serious threat to human life and living creatures in terms of fire hazards, explosion and fatal accidents from electrocution. The scenario is far more severe in metro cities due to high population density, large daily footfall, severe space constraints etc. Present pandemic situation posed serious threat to power utilities to continue operation due to high rate on infection during outdoor operation in maintaining uninterrupted supply. Electricity being the way of life in modern society, every electricity utility is fighting their best to maintain uninterrupted & safe electricity service to its consumer even in severe crisis situation following any disaster. Therefore Disaster management process & protocol for handling emergency situation should be absolutely robust and foolproof for every Power utility so that supply restoration time is optimum and safety of consumers, public including their asset are ensured.

About this Paper

This paper will deal with our experiences of managing emergencies caused due to natural Disaster in Kolkata, few developmental plan and initiatives taken by us to reduce/eliminate disaster risk including prevention of accidents in CESC supply system, our planning towards sustainable developmental goal and initiatives for protecting environment which are the genesis of present Disaster Management plan for Power sector indicated in NDMA national plan as well as in recently published DM Plan for Power sector by CEA.

Brief introduction of CESC Ltd

CESC Ltd, established in the year 1897, is RP-Sanjiv Goenka group company. It is a vertically integrated power utility having generation, transmission and distribution. It serves above 3.26 million LT & MV consumers and 1834 HT consumers within its licensed area of 567 square km covering the twin cities of Kolkata and Howrah and few adjoining areas of Hooghly, 24 Parganas (N&S). The company owns three thermal power plants with an installed capacity of 1125 MW within its licensed area. Haldia Energy Limited (HEL), a RP-SG group company & subsidiary to CESC, generates 600 MW power and entirely feeds to CESC System. The peak demand in CESC's licensed area is 2337 MW clocked on 14.06.2019 and the annual electricity sales amounts to around 9999 MU (FY 2019-20).

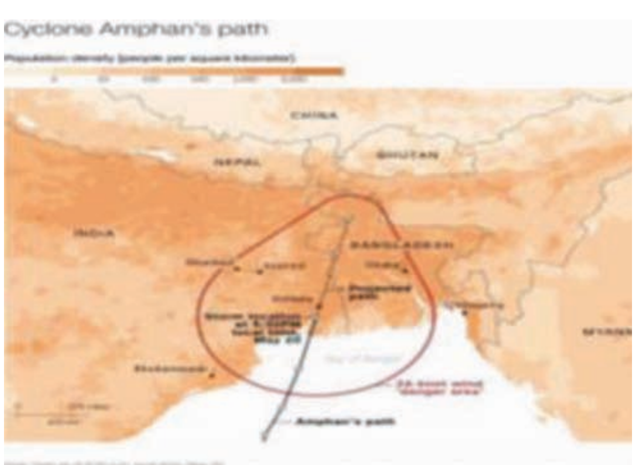
The Company has a robust EHV network which operates at 220/132 kV. There are 21 EHV Substation (220/132 kV) & Switching Station (132 KV), geographically spread within its licensed area for transmission of power. Some of these stations serve as interconnection points with the State Transmission Utility and the Central Transmission Utility for import of power. The power at 220/132 kV is further stepped down to 33 kV at the Substation level for primary distribution through 33 kV network. 33 kV feeders are terminated to around 116 Distribution Stations where it is further stepped down to 11/6 kV for distribution mainly through UG cable. Power to LV & MV consumers are served through approximately 8400 Distribution Transformers via UG cable & limited OH network. All Distribution Transformers are provided with metering for online monitoring of transformer loading, voltage profile, energy advance etc. Ring Main Units (RMU) have been installed at the 6/11 kV network almost after every 2-3 Distribution Transformers for flexibility of network operation during fault isolation, supply restoration etc. Automated RMUs are also used at important Government Offices, Government Hospitals, Drainage Pumping Stations and other critical installations for remote operation during emergency to ensure practically interruption free services.

Modern maintenance practices like condition monitoring and condition based maintenance are in place for ensuring availability of all assets in the network. A 24 x 7 Call Centre is in place for addressing the supply related issues of LV & MV consumers. For better outage management, intelligent meters are installed at Distribution Transformers, HT/LTCT/VVIP consumers for immediate attention. A dedicated Help Desk is available round the clock for addressing power supply related issues of the HT consumers and a Commercial Call Centre is in place for addressing the commercial issues of the consumers.

Dedicated optical fiber (OF) based communication infrastructure is in place at all company establishments to support the voice and data communication requirements within the organization. Power plants, Control Rooms (load dispatch center), Vital Operation centers etc. Breakdown vehicles are provided with VHF and Mobile trunk as back up communication in addition to mobile communication. Satellite phone are recently installed at major Generating plants and load dispatch center as back up when all other communication fails following to any major disaster. Breakdown vans are provided with GPS system for ease of operation and emergency deployment against fire/electrocution hazards.

Major Disasters faced in recent past

We faced the devastation due to deadly super cyclone Amphan on 20th May 2020 which hit our city with maximum average speed of 133 kmph and ransacked many districts of West Bengal including our entire licensed area spread over Kolkata & Howrah city with a part of Hoogly and 24 Parana's (N&S) districts. Its land fall started at around 2.30 pm in Sagar island and continued almost 4 to 5 hours before got diverted to neighboring country, Bangaladesh. Total rainfall recorded during 24 hours till 8 AM on 21st May 2020. was 236 mm.



Amphan Impact

Amphan Path

Impact & Damages in CESC Power infrastructure

There was huge impact followed by several damages in our Generating plants, T&D system few of which are mentioned below

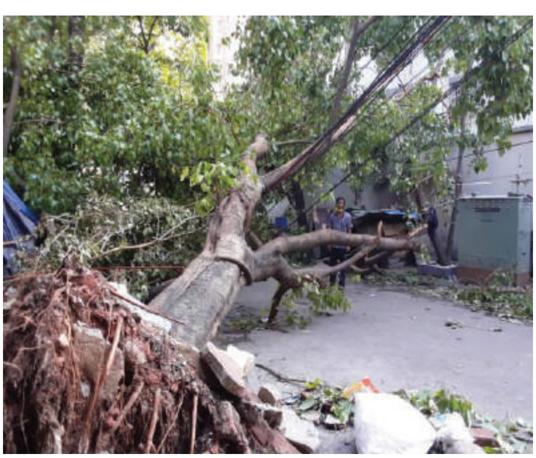
- Sharp fall of System demand noticed, (approx. 295 MW at 19.00 hrs) almost 23.5 % of system demand met on the previous day evening i.e. 19.05.2020
- Complete shutdown of HEL Generation occurred.
- Major evacuation circuits at 220 kV & 132 kV from BBGS plant tripped due to fault but BBGS generation was somehow maintained
- Countless no of trees uprooted damaging OH network, blocking major arterial road & lanes in our licensed areas thereby suspending movement of our breakdown crew, critical supply chain, ash disposal system from thermal plants etc.
- Many sheds in our Power plants & at our various establishments collapsed , side insulating walls of ESP, ID inlet etc. got severely damaged, Chimney aviation light became out of commission.
- One power Transformer and no of 220kV, 132kV Isolators got damaged beside many outages in 33kV, 11 & 6 kV Distribution system
- Around 2000 LT Electric poles and 60 HT poles got grounded and damaged
- Around 3500 LT OH & 2200 LT UG Distributor faults recorded
- Volume of Supply outage complain recorded in call center was more than 2 lakh
- 82 Dist. Transformers and 50 Overground distribution pillar boxes found damaged

ESP Side wall insulation & Cladding damaged

Power Transformer in 33/11 kV Dis. Station

Other major impacts & hardships due to Cyclone

- Accidents due to electrocution which got aggravated due to water logging
- Call centers were simply flooded with supply complain and collapsed (unreachable)
- Huge damage of OF network paralyzed entire voice & data communication
- Collapse of mobile services posed serious threat to our restoration work and other services
- Large no of breakdown w.r.t. available restricted manpower due to COVID 19 situation
- Outsourced manpower could not been deployed without our active supervision due to our specialized OH installation, hybrid network and spot identification issues
- Consumer agitation due to prolonged supply outage raised law & order issues



Huge OH Optical Fiber network damaged

- Inadequate deployment of manpower from external stakeholders delayed tree cutting, road clearance that affected our restoration process, badly.
- Mismatch in demand & supply of Mobile generator within the city created standoff in temporary supply restoration arrangement for providing vital services like water, mobile charging etc.
- Shortage of vital raw materials and spares due to unexpected volume of breakdown

Huge gathering -post Amphan situation

Supply Restoration

Supply restoration was done gradually by providing temporary services and huge outsourced manpower was deployed to make our distribution system up & running as early as possible. Major restoration work took almost seven days. Company incurred huge capital expenditure to manage initial restoration and normalize the system.

Despite of huge breakdown and fault in distribution system, we ensured no power interruption in drainage pumping station, Hospital, COVID centers etc. Large no of small and medium size mobile Diesel Generators were pressed into service to ensure water supply, mobile charging and other essential services in affected localities, lift & pump operation in multi-storied housings etc. till restoration from our distribution system is made.

Restoration work in progress

Actions planned - learning from the Cyclone Amphan

- Speedy changeover from OH to UG LT Distribution in the worst affected areas of the Metro city based on priority and fund availability
- Introduction of Survey and condition based maintenance of LV & MV distribution network & routine vegetation removal
- Detection of alive Pole & over ground distribution equipment with indication & sms generation for public safety
- Use of mechanized tools, tackles and innovative techniques for fighting emergency situation due to any major disaster and enhance faster restoration
- Networking with external vendors for quick mobilization of Manpower, vital spares, DG set etc.
- Conversion of all critical outdoor yards into GIS in phased manner to arrest major plant outage followed by any disaster
- Developing dedicated outsourced manpower to handle similar emergency situation in future
- Conversion of OH to UG OF network and use of more leased bandwidth as alternative communication media for mission critical applications
- Use of Satellite phones, mobile trunk and alternate mobile sims as back up for reliable communication backbone
- Strong focus on consumer safety and dissemination of mass alerts to all consumers using technology and call center infrastructure.

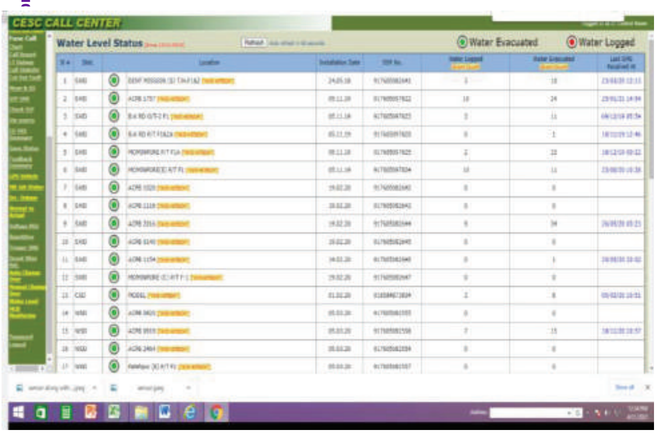
Preemptive actions & Initiatives taken by CESC for Disaster risk reduction including prevention of Accident

1. Consumer Safety

Insulated jacketing of LT metal poles

There are many low lying pockets in Kolkata & Howrah cities that get easily inundated after medium to heavy rainfall. It has been observed that many cases of electrocution and fatal accidents in such areas are due to alive pole resulting from damaged insulator, snapped conductor touching pole etc. Few such poles are now covered with PVC insulated jacket to arrest electrical accident from LT Poles.

Application of Water level sensor in Over head Distribution Pillar Box

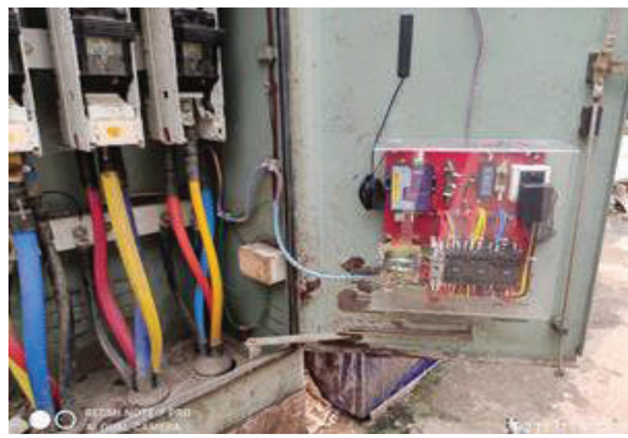


Water level Indicator dashboard

Many of our overhead Distribution pillar boxes are installed in low lying areas. We have installed an electronic water level detector at strategic location inside such Distribution pillar box along with a remote sensing and sms generation device. Soon water level rises following to major rainfall and waterlogging, a sms is received at LT Control room & get populated in water level indication dashboard. We mobilize our team in advance to de-energize such distribution boxes and avoid accidents due to electrocution from the alerts generated in the dashboard. Dashboard data helps us to plan for escalation of plinth level of such vulnerable installation in earliest opportune moment.

Detecting live Pillar box

It has been observed that due to inadvertent touching of alive part of Feeder/Distributor cables with metal body of Distribution pillar boxes or due to waterlogging, overhead distribution pillar boxes become charged and remain alive since fuse rating of incomer from DTR is quite high w.r.t. dead earth fault current generated due to above reason. An electronic voltage sensing detection system is recently being tried with one overhead distribution pillar box in low lying area, as a pilot project to sense potential rise of distribution boxes (metal housing) w.r.t. earth. It triggers a flasher cum indicator for alarming nearby public and send sms to our LT Control room for initiating immediate action. It is provided with a voltage setting facility for its triggering and max voltage setting possible is up to 415V AC. This is under trial and once its effectiveness is proved necessary planning will be made for horizontal deployment in selected areas.



Detection of alive Overground Distribution box box

Indication cum flasher

2. Building reliable LT Distribution network

OH to AB cable and UG conversion in critical densely populated areas within the metro cities

After analysis of damage & breakdown due to recent cyclone Amphan along with difficulty in supply restoration, few localities in south & south west Kolkata are identified for conversion of OH with insulated AB cables. It is found that restoration with AB cable network is much faster w.r.t damaged bare OH lines caused due to any major storm/ cyclone. Work of such conversion program are already under taken based on priority and capex arrangement.

Vegetation Management on OH network

We have experienced major damage of our OH distribution system during recent Amphan due to falling of tree branches. We are applying GIS system to locate growth of vegetation and continuous surveillance of our OH system. Necessary tree trimming and removal of vegetation activities are taken up from such studies which will certainly help in reduction of OH breakdown due to fall of tree branches.

Online detection of vegetation growth on OH Distribution lines

Systematic OH maintenance

It is noticed that damages in OH system is negligible where OH maintenance work was done in recent past. It has been decided to deploy additional budget for enhanced OH maintenance work round the year to reduce disaster risk and building reliable OH distribution system. Arrangement for regular patrolling of LT OH system is also under our active consideration.

CESC OH network after systematic maintenance

3. Disaster Resilient Communication backbone for CESC

Following initiatives are thought of to build back reliable communication infrastructure across CESC so that no impasse is faced due to voice & data communication failure.

OH network with AB Cables

- Conversion of OH to UG Optical fiber cable network as far as possible
- More use of leased bandwidth for mission critical applications as plan – B
- Use of Satellite phone for major power plant, Load dispatch center(System control) and Network operation center
- Venturing for cloud based call center operation
- More use of Mobile trunk & VHF as backup communication in addition to alternate sims

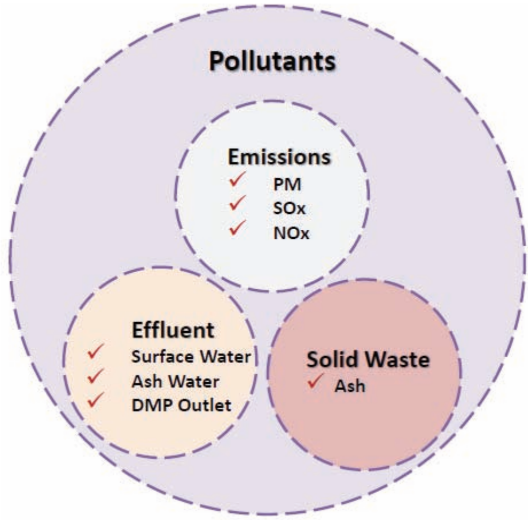
4. Capacity building and networking

Following emphasis are given to strengthen the disaster management process further

- Stress on capacity building for all sections of employees as well as for outsourced employees and contractors.
- Stress on mock drill and table top exercises including resolving of the issues promptly
- Auditing of Disaster management process internally as well as by external experts
- Conducting awareness program for critical customers and public safety
- Communication through alerts/electronic media preempting major disaster
- Close Networking with all external stakeholders through Workshop/meeting
- Benchmark visits with parallel power utilities to adopt their best practices.

5. Protection of environment

Various initiatives are exercised for protecting environment as commitment towards climate change agreement. Effective environment management is practiced at our all Generating plants to control pollutants.



Initiatives for protecting environment-control of Pollutants

Ammonia dosing at ESP inlet reduces Ash resistivity and enhances dust collection. Similarly use of on line monitoring of Coal Gross calorific value ensures proper blending of coal and improves heat rate of Boilers, reduces Cox discharge etc.

Water sprinklers are continuously used in wagon-tripler, coal stack area to suppress dust and suspended particles in air. Remarkable green initiatives have been taken in post Amphan period within the plant for environment protection. Our thermal plants received several accolades & recognition on environment protection from National & International forum towards climate change mission.

Water sprinklers to control suspended coal dust

Green initiatives in Thermal power plant

LIGHT UP YOUR OWN LIFE

BY

LIGHTING UP ANOTHER'S

Operational Challenges of Large Scale Battery Systems for Grid Scale Applications

Chandrakant Shrivastava[1] and Shilpa Shrivastava1

ABSTRACT

Increasing penetration of uncertain and intermittent renewable energy sources can cause various problems in grid such as frequency variations, voltage fluctuations and demand- supply imbalance. India is having an ambitious target of adding 175GW regeneration to the grid by 2022, which may bring more challenges to the grid operators for safe and secure grid opera- tions. However, a fast responding storage device such as Battery energy storage system (Bess) could be used to mitigate these challenges in real time operation of power system through vari- ous grid applications including Frequency regulation, energy time shift and re firming etc. at present, many battery chemistries are available in the market suitable to various grid scale ap- plications. However, each chemistry has its own merits and demerits depending upon its tech- nical characteristics. this paper discusses about various operational challenges of different bat- tery storage systems in real time grid integration applications. real time implementation of li- ion, advanced lead acid battery systems of 1MW capacity has been considered for this study. the study would also provide insights on regulatory and commercial framework to be adopted by regulators in allowing large re integration in Indian grid scenarios.

Keywords *: Battery energy storage system, ancillary services, renewable energy.*

1. INTRODUCTION

The escalation in the grid penetration of intermittent renewable energy sources espe- cially solar and wind constitutes threats to the power system stability. These threats include the failure of balance between the generation and demand while instability can manifest itself in frequency fluctuations. In countries such as India, the attraction towards RE has been increased over couple of years and it has set an ambitious target of adding 175GW RE capacity by 2022 which will be almost 45% of installed generation capacity by that time [1]. The higher quantum of RE may create more challenges for operation and maintenance of the grid which required stringent grid code regulations including effective ancillary services. Energy storage systems are best alternatives to overcome the challenges posed by intermittent RE resources. Battery Energy Storage Systems (BESS) are more viable options compared to other energy storage systems due to its technical merits [2]. Due to its faster response and high ramp rate, battery storage systems works effectively during transient periods of RE generation fluctuations which are not possible with other storage systems. BESS provides self- healing property to the grid by acting as both generator as well as load depending on grid requirement. Hence, the BESS can be used for various applications such as Frequency regulation, Peak shaving, Energy time shift and RE capacity firming etc. [3]. At present, many battery chemistries such as Lithium-ion, Ad- vanced Lead Acid, Sodium Sulphur (NaS), Nickel cadmium and flow batteries are used for grid scale applications. Each of the chemistry has its own merits and demerits in terms of energy densities, response time, lifecycles, Depth of Discharge (DOD), power

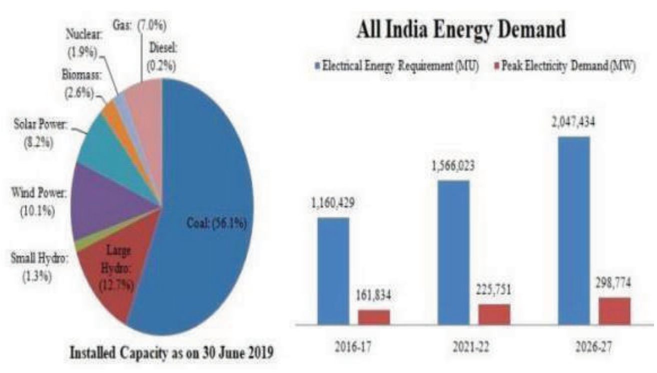


Fig. 1 : Installed capacity and load demand curve in India densities, safety and economical aspects.

Response time of the BESS is one of the critical requirements when it comes to ancillary services support such as frequency regulation, RE firming etc. Based on it's technical merits, these battery systems used for different grid scale applications [4]. Utilization of lithium

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ion group in e-mobility and grid applications increased over couple of years due to its faster response and higher power density compared to other chemistries. The cost of the Li-ion batteries also reduced drastically over last 5 to 7 years due to increase in us- age. Many studies have been presented for the utilization of different battery systems for vari- ous grid applications [5][6]. Usage of various battery systems for primary frequency regulation has been investigated in [7]. The optimal utilization of BESS for wind power integration has been addressed in [8]. Different control strategies have been proposed in [9] for implementation of primary frequency regulation. This paper presents the real time operational challenges of the grid tied battery energy system while executing ancillary services. A real case of installation of Li-ion and Advanced Lead acid battery energy storage systems of 1MW capacity together by POWERGRID at Puducherry has been considered for the study. The studied system is under operation of frequency regulation and energy time shift for nearly two years. Sample of real time field data from the BESS and distribution grid has been considered for the study.

II. BATTERY ENERGY STORAGE SYSTEMS IN POWER SYSTEM APPLICATION

Battery energy storage systems are becoming strong alternatives in the energy market. It offers wide range of benefits due to its higher ramp rate, lower response time, modularity in size, flexibility in transportation and options of different chemistries. Ramp rate and response time of BESS are one of the significant requirements in view of intermittent renewable generation. Due to flexibility in size, it can be installed in any corner of the grid depending on the requirement.

Unlike other energy storage systems, BESS works as both generator as well as load and can change its function momentarily depending on the grid requirement. In case of utilities, BESS are the best alternatives for providing fast responding ancillary services and other power quality services compared to other ESS technologies [10].

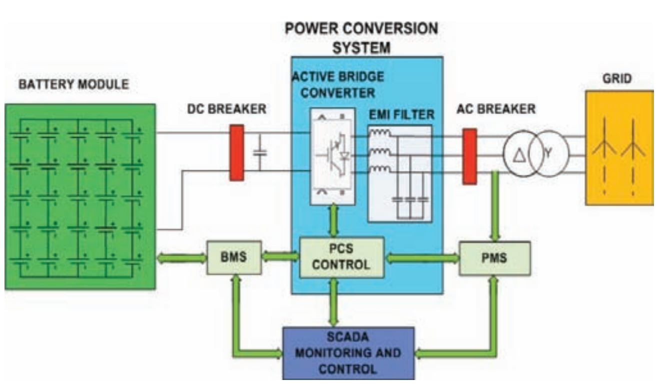

Fig. 2 : Battery Energy Storage System Architecture

Major components of the BESS are:

(i) Battery modules

(ii) Battery Management System (BMS)

(iii) Power Conversion System (PCS)

(iv) Power Management System (PMS).

(v) SCADA for monitoring and control

The capacity of the battery system is determined by the nature of the application. All the battery modules are connected in series and parallel combination to get the required capacity. Depending on its capacity, the battery modules formed into different clusters. All the clusters from the battery system are connected to a common DC bus and further DC bus extended to PCS. BMS monitors the individual battery cell voltage, current, temperature and SOC. BMS also manages the cell balancing by controlling cell temperature and power. Power conversion system converts AC to DC and vice-versa. It basically regulates the charging and discharging power depending on input signal. Power management system is basically control software and all the control logics execute at PMS. It provides input signal to PCS for charge / discharge depending on control logic requirement. Bay Control Unit (BCU) collects all the data through optical fiber to the SCADA servers for real-time monitoring and control.

2. BESS PILOT PROJECT AND APPLICATIONS

The Indian electrical grid is experiencing major challenges from the increasing inte- gration of renewable energy resources in terms of reliability and stability of the grid. A pilot project has been initiated by POWERGRID to test different battery technolo- gies for grid scale applications. 1 MW capacity of two battery systems namely Lithi- um Ion and Advanced Lead Acid has been integrated with 22kV medium voltage distribution system. The main aim of the project is to test the above battery systems for various grid scale applications such as Frequency regulation, Energy Time Shift / peak shaving, RE capacity firming, Voltage support / Reactive power compensation and load levelling etc.

1. Frequency Regulation: Frequency regulation is one of the ancillary services that entail moment-to-moment reconciliation of the difference between supply and de- mand. During frequency regulation, grid frequency shall be maintained in the speci- fied band to maintain stability and reliability of the grid [11]. Here, the performance of the system has been studied for different range of grid frequencies and operational performance of the battery system and its impact has been studied.

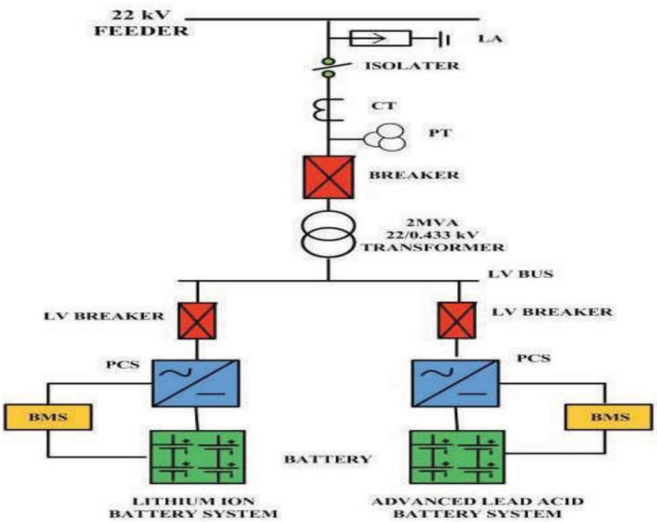

Fig. 3 : Single Line Diagram of proposed BESS connected to Feeder

2. Energy Time Shift: In this operation, Battery system shall be charged form the grid during off- peak hours and same shall be discharged to the grid during peak hours [12]. Based on the load flow studies of the feeder in absence of BESS, different tim- ings for energy time shift (charge/discharge) have been configured. Application con- trol logics under implementation:

Table 1 : Frequency Setting

Sl. No.	Frequency Range	Operation
01	F<49.95 Hz	Discharge Mode
02	49.95<F<50 Hz	SOC Mode
03	F>50 Hz	Charging Mode

3. Renewable Energy Capacity Firming: Uncontrolled variable power generation is major concern for the renewable energy sources especially solar photovoltaic (SPV) and wind power plant. BESS can be used as buffer to absorb or supply the excess or under RE power generation to maintain the constant injection of power in to the grid. So, BESS will be used to make RE source as constant power supply.

4 . Voltage Support/Reactive power support: Keeping the voltage within the speci- fied limit is essential for stable operation of grid. Voltage of the grid varies through- out the operation which requires a fast responding source to deliver/absorb the reac- tive energy quickly. Battery energy storage system (BESS) is one of the best options to fulfil the requirement. BESS can start deliver/absorb the energy within few sec- onds. Also BESS can be used for the reactive power support in order to mitigate the voltage issue in the grid.

5. Load Following: In order to meet the varying load, system operators need to fluctuate the generation. Variation in thermal generation is time and resource inten- sive. BESS system can meet the variation in the demand in much swift way than con- ventional generating system.

6. Dynamic Frequency Regulation: This application provides frequency regulation service support in grid operation, while optimizing the battery response considering the life cycle of the batteries. The history of frequency variations in a grid is used to determine the frequency variation pattern of the particular grid which s used for set- ting the frequency bands for each intervals of time. The number of intervals in a day is fixed and the energy charge or discharge during that particular time interval is also recalculated to cap the overall charge or discharge during the day. BESS can also provide overriding emergency support to the grid.

Table 2 : Technical Specification of the Battery Technologies Included in the Bess Pilot Project Puducherry

Parameter	Li-on Battery	Advanced lead acid Battery
Capacity	250 kWh	250 kWh
Power	500kW for half-hour	500kW for half-hour
Charging rate (from rated DoD to Full Capacity)	3 hrs.	3 hrs.
DC-DC Round-trip efficiency	>90%	>80%
Service Life	10 years	10 years
Life-cycle	4000 cycles	3000 cycles
Status	Under operation	Under operation

3. OPERATIONAL CHALLENGES

Operational challenges of battery energy storage systems can be classified as techno- logical as well as economic challenges. Performance of any BESS depends upon the usage of application. It undergoes detoriation due to the continuous usage in the grid scale applications [13] [14]. The performance efficiency and the life span of the battery depend on the battery technology, DOD, duration of charge / discharge, operating temperature of the cell and the number cycles completed etc [15].

1. Battery life degrades due to the continuous utilization during the grid applica- tions. The end life of the battery is defined as the time when its capacity reaches 80% of the original capacity. The parameters which characterize a battery are State of Charge (SOC), Open Circuit Voltage (OCV), C rate, internal resistance, operating temperature etc. The

stress from the continuous operation of the battery accelerates the aging process and it will reach its end of life before completing the lifetime de- fined by the manufacturers. The charging as well as the discharging process of the batteries is exothermic thereby the temperature of the battery increases and hence the life of the battery decreases.

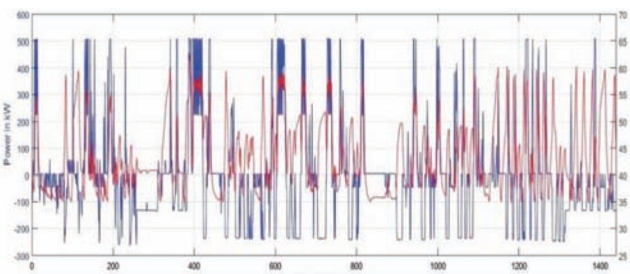

Fig. 4 : Power Vs temperature curve during frequency regulation application

As shown in above figure 4, the average temperature of the system is more than 45oC and some of the individual cell temperature is more than 65oC during FR appli- cation. The average temperature of batteries is high due to increase in temperature during both charging and discharging period which is continuous process. It will af- fect the performance and life of the battery cell, Hence effective cooling is required to enhance the life of the battery system.

2. Each cell has optimal range of operating voltage and temperatures. The response of the individual cell depends upon its internal chemistry. Some weaker cells will not sustain sudden changes in charge / discharge power. Its voltages and temperatures vary momentarily according to power variations. These cells will become faulty after certain period of operation and will not support FR type applications further. The faulty cells need to be replaced with healthy / spare cells. In case of large scale battery systems (MW scale), hundreds of cells used to make the required useful capacity. In such cases, it is most difficult to attend / replace the faulty cells if it fails frequently. Hence, all the cells in the system need to properly designed and packed to operate efficiently.

3. BMS plays key role in entire battery storage system. After continuous operation, SOC levels of individual clusters will vary due to unbalance in charge / discharge power. Proper cell balancing taken care by BMS by monitoring individual cell volt- age, temperature and SOC. Hence effective BMS system is recommended for efficient operation of BESS.

4. If the system operates continuously under ancillary services (FR application), af- ter certain period of time, majority of cells lose its capability of response for sudden change in charge / discharge power. The variations in voltages are more even if it has higher SOC levels. Hence it is recommended to use the same system for peak shaving or load following type of applications where the rate of change of power variations are less to get maximum utilization of the battery system.

5. Pre-estimation of faulty cell is critical requirement as when the BESS operates for critical applications such as ancillary services. If the particular cell fails during ancillary service operation, the entire battery clusters under down condition until re- placement of the faulty cell, which will impact the economic viability of the system. Hence, effective forecasting of cell failure is important for any BESS project.

3.1 Other Technical and Commercial challenges:

6. Poorly defined and categorized systems: The ESS industry is receiving a tre- mendous boost from the increased integration of REs into electric power systems. As the industry expands, defining and standardizing the terminology will become in- creasingly important. Proper defining of the standards and guidelines for the design, installation and maintenance of the battery energy storage systems and the related equipments are very much important.

7. Regulatory guidelines and Licensing Issues: The concept of forecasting and scheduling of renewable energy generators and the commercial settlement was intro- duced in Indian context by CERC through Indian Electricity Grid Code (IEGC), 2010. Considering the recent development of different state regulations, the Deviation Settlement Mechanism (DSM) charges are to be computed on a monthly basis. DSM penalty is calculated according to the frequency deviation in the grid from the allowa- ble frequency band. The tightening of the frequency band and the sign change re- quirements defined by the CERC regulations severely impacts the power manage- ment. In order to satisfy the CERC regulations the BESS can be utilized. The BESS can support the grid for frequency regulation effectively and it can also be used to ensure the required sign changes. The price of the BESS installation is much lesser than the DSM penalty for a whole year. Analyzing the applications of BESS in the electrical grid, it can maintain the grid stability, reduce the losses and also economic benefits. Hence, comprehensive regulations have to be established for effective im- plementation of BESS.

8. Energy storage industry is facing the challenges like lack of policy support, higher manufacturing cost, unclear application value etc. As the battery manufactur- ing companies are under developing in India, the cost of the battery and the cost for the procedure for purchasing the batteries from

international vendors are the main challenge of India. In order to overcome these issues the country should encourage numerous researches and applications of energy storage, establish sustainable devel- opment model and support more capital for the implementation of large scale battery energy storage system projects. For the implementation of large scale systems, the electrical enterprises, researcher, economical organizations, electricity consumers and the social and government organization needs to work together.

4. CONCLUSION

Increasing penetration of uncertain and intermittent renewable energy sources such as solar and wind can cause various problems in grid such as dynamic frequency, volt- age fluctuations and demand-supply imbalance. In countries such as India, where has an ambitious target of adding 175GW RE generation to the grid by 2022, may bring more challenges to the grid operators for sustainable and reliable grid operations. However, a fast responding storage device such as Battery Energy Storage System (BESS) could be used to mitigate these problems in real time operation of power sys- tem by providing various grid applications including Frequency Regulation, Energy time shift and RE firming etc. This paper discussed about real time operational chal- lenges of large scale BESS integrated with grid applications. A real case of installa- tion of 1MW capacity of Li-ion and Advanced Lead Acid batteries initiated by POWERGRID has been considered for the study. Recommendations made based on performance of battery systems and real time system performance. This paper also discussed about various technical and commercial challenges of large scale battery system implementations in Indian context.

5 Acknowledgement

Authors are thankful to the management of POWERGRID for granting permis- sion for presentation of this paper. Views expressed in the paper are of the authors only and need not necessarily be that of the organization in which they belong.

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Renewable Energy Integration with Existing Grid using Battery Energy Storage and Machine Learning Applications

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ABSTRACT

Ambitious goals for meeting the electricity demand and decarbonizing the electricity supply, essentially requires integrating of higher shares of variable renewable energy (VRE) technologies, such as wind and solar PV, in the power systems, however its output is mainly dependent on weather conditions making it extremely variable and uncertain in nature, and thus poses immense challenges of its integration with the existing grid, and having safe and reliable operation. Moreover, non-uniformity of renewable energy resources across the different geographical locations and complexity involve in VRE interface with grid using power electronics devices making it more perplexing. This paper describes the various challenges being encountered for integration of the VRE generation with the existing grid, role of energy storage for which can participate in smooth integration, flexible operation, frequency control and reliable operation of a power system. For solving the problem, suitable reference from data analytics and machine learning were also made for getting the desired results. Thereafter, the progression is ultimately corroborated with certain case studies for better demonstration.

Keywords *– Renewable Energy, Intermittency. Integration, Energy Storage, Power System, Grid, Solar, Battery Energy Storage, Machine Learning*

I. INTRODUCTION

Power systems around the world are undergoing significant change, driven particularly by the increasing availability of low-cost variable renewable energy (VRE), the deployment of distributed energy resources, advances in digitalization and growing opportunities for electrification. These changes require a profound power system transformation. The increasing prominence of VRE is among the most important drivers of power system transformation globally.

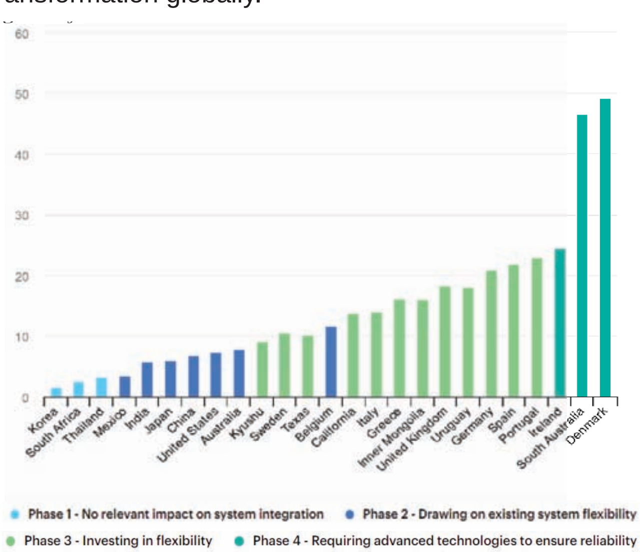

Fig. 1 : Selected countries by integration phase and share of VRE, 2017 [1]

The most prominent Renewable Energy (RE) technologies, wind power and solar power, are extremely intermittent, variable and uncertain in nature, which impose major challenges to power system planning including RE integration. Significant portion of our power generation through these renewable resources is as reliable as the weather. Moreover, the Renewable Energy generating resources are non-uniform across the different geographical locations. Both of the thing, are making the RE generation extremely intermittent in nature and thus poses immense challenges of its integration with the existing grid, and having safe and reliable operation.

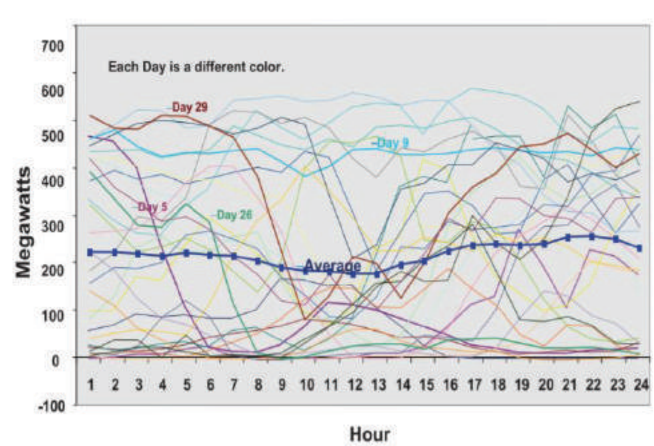

Fig. 2 : hourly wind power output on 29 different days in April 2005 at the Tehachapi wind plant in California [haw06] [2]

The above makes it difficult to hold one important consideration of power systems i.e. balancing, preserving a match between generation and load at all times while safely operating the grid by not overloading its components and operating them within their damage limits. With the increase in shares of fluctuating and non-dispatchable power generation throughout the system, the ability of power transmission from where it is produced to where it is used will become increasingly complex. Emerging technologies on the demand side, such as utility grade batteries and smart grid technology provide new opportunities by offering services which have previously been of limited availability to the electricity sector, energy storage and demand side management.

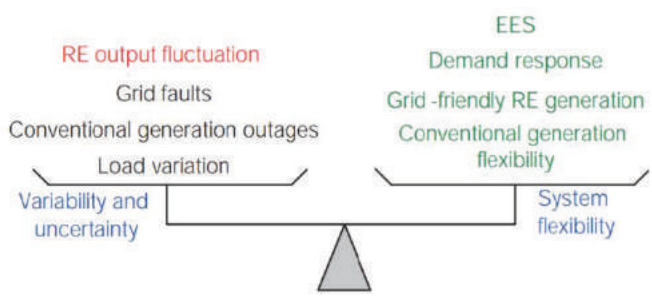

Fig. 3 : System flexibility vs. variability and uncertainty [2]

These days, Energy storage systems (ESS) are commonly being used in power systems where renewable energy sources (RES) are being integrated with the existing grid. ESS can participate in frequency control and also represents a flexible solution for reliable operation of a power system supplying the electricity and meeting the energy demand. Suitable means are being developed in the field of Energy Storage to optimise the investment costs, load shedding costs and generation costs, concomitant with integrating ESS and building new transmission lines if the capacity of the existing ones is not sufficient.

II. VARIOUS PHASES OF VRE INTEGRATION

For VRE system integration with the grid, it is needed to properly manage power system flexibility, which encompasses all system components that facilitate the reliable and cost-effective management of variability and uncertainty in both supply and demand. Maintaining a reliable supply of electricity requires that supply and demand be balanced continuously across all timescales, from sub-seconds to years – it is thus useful to consider flexibility along these timescales.

In response to the recent growth of renewable energy, four phases of VRE integration have been distinguished (see IEA 2017) to describe the progressive stages of VRE penetration in the grid, including its impacts and challenges. As shown in Table 3.1, each phase involves a different set of power system interconnection and operational challenges. The various phases [3] of VRE Integration can be majorly characterized by a specific penetration level along with the other integration issues and challenges, covering technical, regulatory, market and institutional aspects. It is important to note that a variety of system-specific factors influence how much an increase in VRE will affect overall system flexibility. In response to the recent growth of renewable energy, four phases of VRE integration have been distinguished (see IEA 2017) [3] to describe the progressive stages of VRE penetration in the grid, including its impacts and challenges, as:

Phase 1 : The first set of VRE plants are deployed, but they are basically insignificant at the system level; effects are very localised, for example at plants' grid connection points.

Phase 2 : Changes between load and net load become noticeable, but the existing system is flexible enough to achieve system integration.

Phase 3 : Greater swings in the supply-demand balance prompt the need for a systematic increase in power system flexibility beyond what can be relatively easily supplied by existing assets and operational practices.

Phase 4 : VRE output provides the majority of electricity demand in certain periods, requiring both operational and regulatory modifications. Operational changes involve power system stability, determining the way the power system responds following supply or demand disruptions, and regulatory changes may include new rules for VRE to provide system services.

Moving smoothly from one phase to the next requires that measures become increasingly interrelated and complex. Ultimately, a systematic transformation of the electricity system, and the wider energy system overall, is required.

III. INTEGRATION PROCESS

Considering the above challenges, the following functionalities are essential for VRE generation and operation integrated with the grid:

(a) Voltage regulation and reactive power capability

(b) Low- and high-voltage ride-through

(c) Inertial-response (effective inertia as seen from the grid)

(d) Control of power ramp rates and/or curtailing of power output

(e) Frequency control (governor action, automatic generation control, reserve, etc.)

In general, bringing a utility-scale generation resource online can be divided into three major stages [4], each with its own set of required studies:

Stage 1 (Interconnection Studies): Network-wide and project-specific planning encompassing various interconnections studies in addition to project development

Stage 2 (Design Studies): Resource modelling and registration – and, in the case of private VREs, the signing of power purchase agreement (PPA)

Stage 3 (Control Studies): Connection to the grid, commissioning, and testing, followed by commercial operations

Considering that in some countries the grid code may be incomplete or under development, it is important to carry out a comprehensive Interconnection Studies (in stage 1) to analyze the impacts of the new generation supply on the grid and determine any possible adjustments that may need to be made to accommodate the successful integration. At a minimum, the following four studies are usually included in the studies for all generation resources:

(a) Steady-state analysis

(b) Short-circuit study

(c) Dynamic and transient stability analysis

(d) Facilities study

IV. MAJOR CHALLENGES OF RE INTEGRATION

The properties of VRE interact with the broader power system, giving rise to a number of relevant system integration challenges of various categories. These challenges do not appear abruptly, but rather increase over time along with the increase in VRE penetration. Some of the major challenges of respective categories are listed below:

Issue, Description	VRE Constraints
Challenge Category: Power Flow	
More regional voltage excursions	Modularity, Location constraints
Complex protection design	Variability, Location constraints
More short circuit currents	Modularity
Reduced controllability and visibility of VRE generation	Uncertainty, Modularity
Narrow voltage trip limits	Modularity
Increasing transmission distances and Under-utilisation of transmission grid capacity	Variability, Location constraints
Reduced distribution grid capacity	Variability, Location constraints
More volatile flow patterns from lower grid levels	Variability, Location constraints
Challenge Category: Power Quality	
More flicker content and harmonic distortion	Non-synchronous
Prolonged shut-down during faults	Modularity
More local voltage excursions	Modularity, Location constraints
Challenge Category: System Stability	
Inadequate reactive power Support (mainly in case of Wind Power Generation)	Non-synchronous
Decreasing level of inertia	Non-synchronous
Decreasing frequency control reserves	Variability, Uncertainty
Insufficient coordination of frequency trip limits	Modularity
Insufficient coordination of voltage trip limits	Modularity
Challenge Category: Energy Balance	
Inadequate forecasting of VRE generation	Variability
Non-uniformity of renewable energy resources across the different geographical locations	Location constraints
Uncertain short-term and long-term generation	Uncertainty
Inefficient planning for Energy Security	Variability, Uncertainty

There are various Centralised as well as distributed technologies solution available for mitigating the aforesaid constraints. In order to address the increased variability and uncertainty brought about by integrating higher levels of large-capacity RE, the power system must become more flexible so as to maintain a constant balance between generation and load.

Power system flexibility can be achieved from the generation side (both RE generation and conventional generation), from the load side, and through ESS acting as either generation or load. The Energy Storage solution is one of the prominent technology for having the desired interface between VRE generation and grid, and remove / mitigate the associated constraints.

V. UTILISATION OF ENERGY STORAGE

Energy storage, due to its tremendous range of uses and configurations, may assist RE integration in any number of ways. These uses include, inter alia, matching generation to loads through time shifting; balancing the grid through ancillary services, load-following, and load-levelling;

managing uncertainty in RE generation through reserves; and smoothing output from individual RE plants.

The Energy storage technologies, can be classified into the below major categories:

Electrical or mechanical high power EES systems	Mechanical High energy EES systems	Electrochemical EES systems (High Power / Energy Applications)*
Superconductive magnetic energy storage (SMES)	Compressed air energy storage (CAES)	Accumulators with internal storage (e.g. Pb / PbO2, NiCd, Li-ion, NiMH, NaNiCl, NaS)
Super-capacitors / Electrochemical double layer capacitors (EDLCs)	Pumped hydro energy storage (PHS)	Accumulators with external storage (e.g. hydrogen storage system, flow batteries)
Flywheels		

The universe of energy storage applications maps closely to the challenges of integrating RE into the grid. In the same way that RE integration creates needs at a variety of temporal scales, different types of energy storage are suited to different discharge times, from seconds to seasons. The tremendous application range of storage is shown in Figure given below:

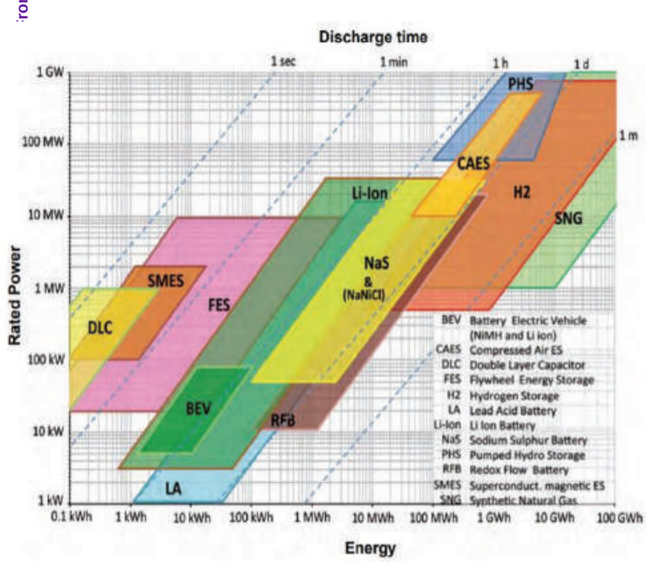

Fig. 4 : Comparison of rated power, energy content and discharge time of different ESS technologies [2]

VI. ROLE OF BATTERY ENERGY STORAGE

The widest range of uses for Electrical Energy Storage (EES) lies in services to the grid operator in providing generation flexibility. These services also represent – from the grid operator's perspective – the optimal use of storage as a tool to mitigate variability and uncertainty for an entire grid, rather than for specific loads or generation assets. The below table describes various grid-side roles of battery energy storage and their relevance to large capacity RE integration challenges, along with some examples of EES technologies currently in use:

Role / Time Scale(s)	Description	Examples of Battery EES technologies
Time shifting / Arbitrage / Load levelling (Hours to days)	EES allows storage of off-peak energy and release during high demand period	NaS batteries
Load following / Ramping (Minutes to hours)	EES follows hourly changes in demand throughout the day	Batteries
Power quality and stability (< 1 second)	Provision of reactive power to the grid to handle voltage spikes, sags and harmonics	LA batteries, NaS batteries
Frequency regulation (Seconds to minutes)	A fast-response increase or decrease in energy output to stabilize frequency	Li-ion batteries, NaS batteries
Efficient use of transmission network (Minutes to hours)	EES can help grid operators defer transmission system upgrades through time-shifting and more efficient operating reserves	Li-ion batteries
Isolated grid support (Seconds to hours)	EES can assist in the integration of RE on small power grids, such as those in use on islands	LA batteries
Emergency power supply / Black start (Minutes to hours)	EES may be used to re-start the power system in the event of a catastrophic failure	LA batteries

VII. VIRTUAL POWER LINES USING ENERGY STORAGE

The increasing share of renewable electricity in power systems, especially from variable sources, requires efficient management of transmission and distribution networks to prevent congestion. The traditional approach to increasing grid capacity is reinforcing the system with additional network components (e.g. adding overhead lines) or by upgrading existing lines or cables to address thermal or voltage constraints.

As an alternative to expensive upgrades to the transmission and distribution infrastructure for VRE grid integration, non-wire alternatives – also called virtual power lines (VPLs) – are being rolled out by International Renewable Energy Agency (IRENA). Instead of reinforcing or building additional transmission and distribution systems, energy storage systems (ESSs) connected at certain points of the grid can support the existing network infrastructure and enhance the performance and reliability of the system. VPLs are a particular application of batteries. In this case, batteries are usually owned and operated by system operators

The synthesis report, "Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables" (IRENA, 2019a), illustrates the need for synergies between different innovations to create actual solutions. Solutions to drive the uptake of solar and wind power span four broad dimensions of innovation: enabling technologies, business models, market design and system operation. It maps the relevant innovations, identifies the synergies and formulates solutions for integrating high shares of variable renewable energy (VRE) into power systems, allow large-scale integration of solar and wind power without grid congestion or redispatch, avoiding any immediate need for large grid infrastructure investments.

VPLs include ESSs connected in at least two locations. The first is on the supply side, close to the renewable generation source, which stores surplus electricity production that cannot be transmitted due to grid congestion.

Such storage averts the need for curtailment. The other on the demand-side, can be charged whenever transmission capacity is available. In this second case, the ESS is used to meet demand during periods when there is insufficient transmission capacity, using batteries charged during previous periods of low demand and free transmission capacity.

Ultimately, a VPL is the application of ESSs to help manage congestion without interfering in the balance between demand and supply. Below figures illustrate the concept of VPLs [5]:

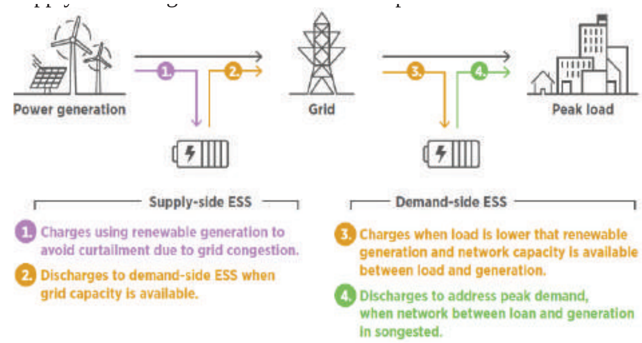

Fig. 5 : Concept of VPL [5]

VIII. CASE STUDIES

The key reference has been made '2x15 MW Solar Power Plant at Zitundo in Mozambique where a 66kV transmission line has been proposed for power evaluation and further to be connected with the national electric network at the Salamanga substation and thus supply power to Mozambique and to the neighbouring country South Africa. During feasibility analysis, suitable assessments were made for integration of the plant to the existing grid with and without Battery Energy Storage facility and prepared Energy Yield Predictions in 4 nos. of different scenarios by using the Metronome 7.2 satellite data/ industry standards and by using simulation software PVSYST 7.0.6 version. The four scenarios considered are described in following table along with estimated energy yield (s) taking into account an annual degradation factor of 0.4% for the first year and for the subsequent years (i.e., between 2-25 years):

Scenario Description	Proposed Capacity	Energy Yield (MWh/year)
1. Grid Interactive Solar Power Plant without storage	15 MW	22,281
2. Grid Interactive Solar Power Plant with 10 MWh storage capacity	15 MW	22,258 + 622.38 (Battery Storage)
3. Grid Interactive Solar Power Plant along with 66/33KV Substation and 66kV transmission line (35km)	15 MW	22354
4. Grid Interactive Solar Power Plant along with 66/33KV Substation and 66kV transmission line (35km) without storage	30 MW	44881

Another reference which were made from the project 'Rural Electrification Project by Solar Photovoltaic Systems in

50 Villages of Dosso, Tahoua, and Tillabery Regions in Republic of Niger' aiming for expanding the network of electricity access, which would assist transformative progress in many dimensions of human development (i.e. education, health care, access to water, communication, and information). The project works involves but not limited to 40 Nos. of Micro Grid connected solar system using Battery Energy Storage (10 each for Schools, Integrated Health Centres, Mosques and Recreation Centres) in 40 numbers of identified villages and Micro power stations of 50 kWp capacities each in 10 Nos. of identified villages. ML techniques ahev been considered both for solar forecasting as well as operational analytics purpose.

IX. MACHINE LEARNING APPLICATIONS

In contemporary times artificial intelligence/machine learning techniques have been in use to utilities for various operational paradigm. Massive data both in real-time basis and historical data provide ample scope of both action and data mining opportunity. Data science being considered as an intersection of CS/IT, Maths/Stats and domain knowledge while Deep learning is being considered as a subset of Machine learning which is again a subset of artificial intelligence as in Fig. 6A&B.

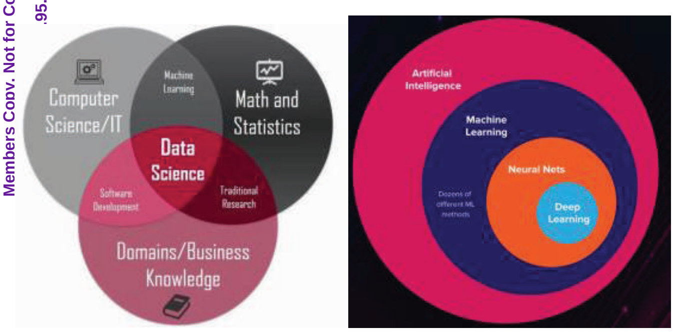

Fig 6A&B : Data Science and AI/ML/DL subset

Data analytics techniques for power system information management considers deployment of machine learning techniques for regression/classification such as Fuzzy logic, genetic algorithm etc while deep learning techniques such as artificial neural network/convolutional neural network (ANN/CNN) which again on a real-time basis monitoring purpose uses big data like Hadoop/ Apache Spark with machine learning libraries and cloud storage system like amazon web service(AWS) /Oracle/ Arduino cloud that integrates with IOT sensors and GNSS UTC time stamped data for application like smart grid applications. Computational capacity increase is also catered by viz. use of Graphical processor unit (GPU) and Google Tensor Processing Unit (TPU) for AI enterprise applications are also commercially available for the domain specific user ecosystem.

ACKNOWLEDGMENTS

The Authors would like to highlight that using the Energy storage system along with the following would result in better exploiting of VRE generation:

If system operating technologies and practices are improved, and based on control shared over wider geographic areas with the support of transmission expansion at higher voltage-level and the power-electronics-based FACTS and DC transmission technologies along with the the development of probabilistic transmission planning methods

RE generation can be made more predictable, controllable and dispatchable, or in other words more grid-friendly, by improving the design, operation and modelling technology at the generating unit, plant and plant cluster level and Suitable consideration of flexibility and capacity of conventional generation for current as well as foreseeable future.

Improvements in operational technologies and practices should be made at each stage in power system operation, namely in scheduling, dispatch and control. Of these, the development of more accurate RE generation forecasting and its incorporation into the scheduling and dispatch tools is the most important.

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[7] advanced utility data management and analytics for improved operation situational awareness of epu operations.

Understanding of Grounding & Effective Grounding System for Substations

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ABSTRACT

The main purpose of grounding electrical systems is to provide a suitably low resistance path for the discharge of fault current which ultimately provide safety to working personnel and costly equipments in the substation. The flow of heavy fault current results in rise of potential in the substation area and with respect to remote ground. There is need to ensure that the ground potential rise, and touch and step voltages are within permissible limit. An accurate soil model is required to design grounding system of the substation that ensures that the resistance of the grounding grid through the earth is sufficiently low. Soil resistivity data is of fundamental importance in performing grounding system analyses. Reliable data is required to achieve good correlation between design and measured grounding system performance. This paper provides overview and importance of grounding system. Besides above key factors for designing of effective grounding systems are also discussed in this paper.

Keywords *: Grounding, Soil Resistivity, Safe Potentials, Ground Resistance, Grounding System*

1. INTRODUCTION

Grounding/ Earthing means making a connection to the general mass of earth. The use of grounding is so widespread in an electric system that at practically every point in the system, from the generators to the consumers" equipment, earth connections are made.

Earlier, the design criterion was to achieve lowest earth resistance, However, the modern design criterion for grounding system is to achieve low earth resistance and also to achieve safe step-potential, touch potential and voltage gradient during an earth fault between conductor and any of the earthed bodies in the substation [1-4].

All component of power system like AIS, GIS, Power cable & overhead transmission system (shown in figure 1,2 and 3 respectively) need proper design of grounding system.

A picture depicting the need of earthing to prevent electric shock is given below in figure 4.

Fig. 1 : Air Insulated Substation

Fig. 2 : Gas Insulated Substation

Fig. 3 : Underground Cable and Over Head Transmission Line

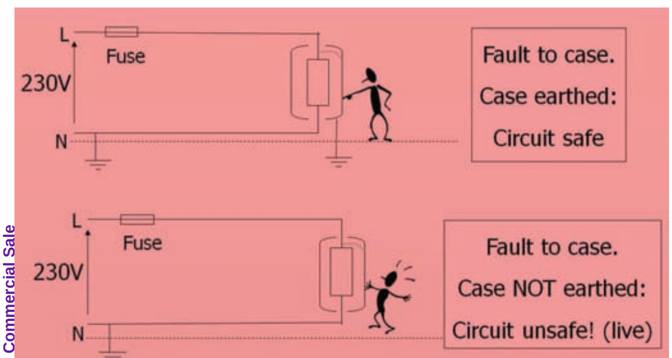

Fig. 4 : Grounding and Human Safety

2. DIFFERENCES BETWEEN BONDING AND GROUNDING

The terms "bonding" and "grounding" are often employed interchangeably as general terms in the electrical industry to imply or mean that a specific piece of electrical equipment, structure, or enclosure is somehow referenced to earth. In fact, "bonding" and "grounding" have completely different meanings and employ different electrical installation methodologies. "Bonding" is a method by which all electrically conductive materials and metallic surfaces of equipment and structures, not normally intended to be energized, are effectively interconnected together via a low-impedance conductive means and path in order to avoid any appreciable potential difference between any separate points. The bonded interconnections of any specific electrically conductive materials, metallic surfaces of enclosures, electrical equipment, pipes, tubes, or structures via a low impedance path are completely independent and unrelated to any intended contact or connection to the Earth.

For example, airplanes do not have any connection to Earth when they are airborne. However, it is extremely important for the safety and welfare of passengers, crew, and aircraft that all metallic parts and structures of an airplane are effectively bonded together. The laboratories and satellites orbiting in space above the planet Earth obviously have no direct connection with the surface of our planet. However, all of the conductive surfaces of these orbiting laboratories and satellites must be effectively bonded together in order to avoid differences of potential from being induced across their surfaces from the countless charged particles and magnetic waves travelling through space.

The common method to effectively bond together different metallic surfaces of enclosures, electrical equipment, pipes, tubes, or structures is with a copper conductor, rated lugs, and the appropriate bolts, fasteners, or screws. Other bonding methods between different metallic parts and pieces might employ brackets, clamps, exothermic bonds, or welds to make effective connections. An illustrative picture showing difference in grounding and bonding is given in figure 5.

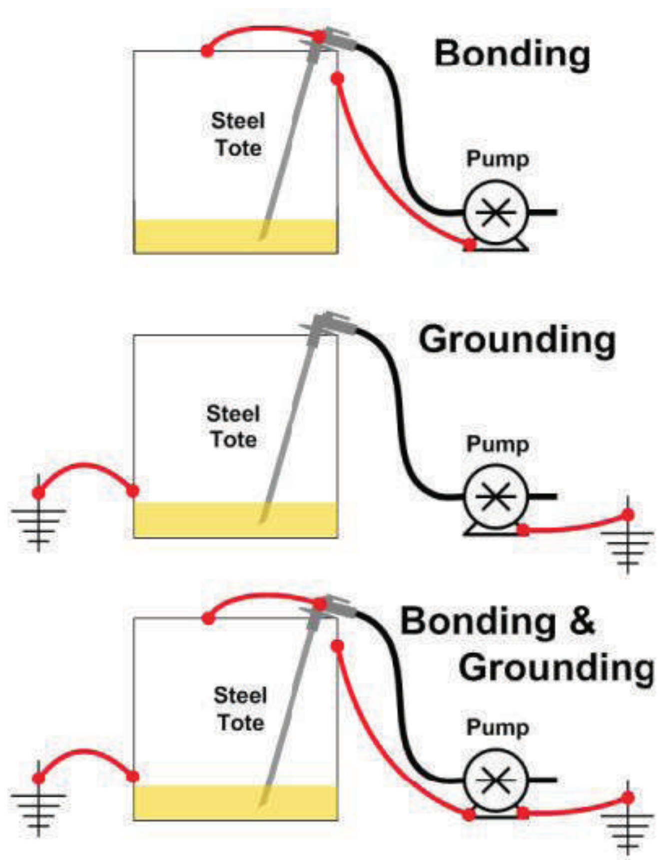

Fig. 5 : Grounding and Bonding

In addition to preventing potential differences that may result in hazards, effectively bonded equipment can also be employed to adequately and safely conduct phase-to-ground fault current, induced currents, surge currents, lightning currents, or transient currents during such abnormal conditions. "Grounding" is a term used to indicate a direct or indirect connection to the planet Earth or to some conducting body that serves in place of the

Earth. The connection(s) to Earth can be intentional or unintentional by an assortment of metallic means. [5]

A designated grounding electrode is the device that is intended to establish the direct electrical connection to the earth. A common designated grounding electrode is often a copper-clad or copper-flashed steel rod. However, the designated grounding electrode might be water pipe, steel columns of a building or structure, concrete encased steel reinforcement rods, buried copper bus, copper tubing, galvanized steel rods. Gas pipes and aluminium rods cannot be employed as grounding electrodes. The grounding electrode conductor is the designed conductor that is employed to connect the grounding electrode(s) to other equipment.

3. UNGROUNDED AND GROUNDED NEUTRAL SYSTEM

Generally earthing of neutral point of the transformer and the generator is called the system earthing. Now, if the neutral point for any system is connected to the earth then it will be called grounded system.[8]

But when the neutral for any system is not connected with the earth then it will be called ungrounded system as shown in figure 6. Connecting the neutral point to the earth through a resistance means resistance earthing and reactance earthing means connecting the neutral point to the earth through a resistance. When the neutral point connected to the earth directly it will call solidly grounded as shown in figure 7.

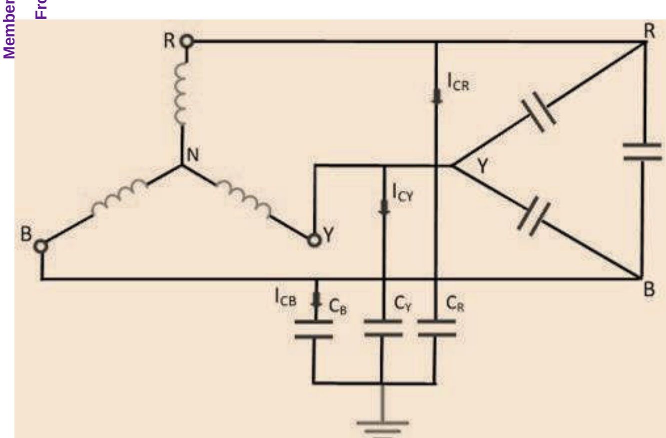

Fig. 6 : Ungrounded Neutral System

3.1 Disadvantage of Ungrounded Neutral Earthing System [8]:

1. *System Voltage Increase* : When the earth fault occurs in line then the potential of the faulty phase becomes equal to ground potential. However, the voltages of the two remaining healthy phases rise from their normal phase voltages to full line value. This may result in insulation breakdown.

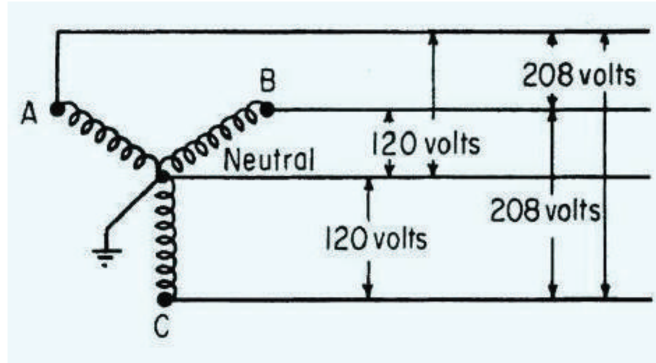

Fig. 7 : Grounded Neutral System

2. *Protection Complicacy* : In this system earth fault is not easy to sense and troubleshoot will become complicated.
3. *Arcing Ground* : Sudden temporary fault can caused by failing of a branch creates an arc between the overload line and the ground. Arc extinguished and can re strike in a repeated regular manner. This is called arcing ground.
4. *Static Induced Voltage* : Over voltage due to the static induced charges are not conducted to the earth.

3.2 Advantage of Grounded Neutral Earthing System:

1. *The System Voltage Will not Increase in Case of Ground Fault* : When the healthy line of a grounded system i.e earthed the voltage of the healthy line will not increase w.r .t earth as in the case of ungrounded earthing system.
2. *Arcing Grounds are Eliminated* : If the neutral point of the system is earthed then the distribute capacitive current from the lines to earth will neutralized by the current from the neutral point to earth and the arcing grounds will eliminated.
3. It will be a stable neutral point.
4. Life of the insulation will increase.
5. It will give general safety to personnel and the equipments due to operation of the fuses.
6. Over voltage due to sudden lightning will discharged to the earth.
7. Earth fault relaying will relatively simple.

3.3 Theory of Arcing Ground in Ungrounded System

Ungrounded System is one where the neutral is not connected to earth. Thus, neutral of ungrounded system is isolated. Arcing Ground is an electrical phenomenon in which the voltage of faulty phase fluctuates due to capacitive charging current. This arcing ground phenomenon is prevalent in three phase ungrounded neutral system. [8]

We know that, a transmission line has shunt capacitance associated. Due to this shunt capacitance, a charging current flows from line to ground under normal operating condition. Let us consider a three phase ungrounded neutral system as shown in figure 8.

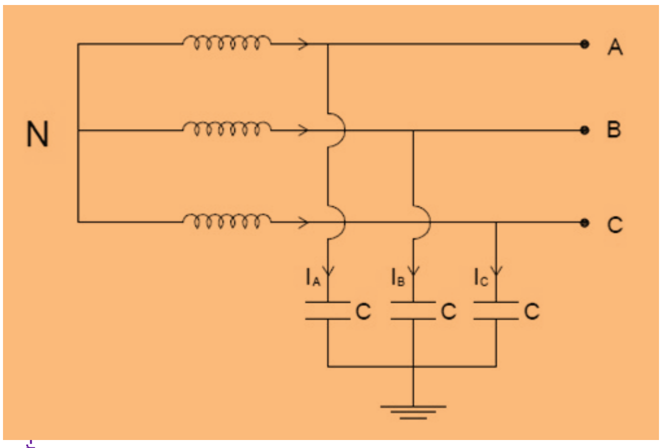

Fig. 8 : Floating (Ungrounded) Neutral of System

As shown in figure above, shunt capacitance for each line is C. I_A, I_B and I_C are the charging current corresponding to three phases A, B and C. Under normal operating condition, these charging currents will lead their corresponding phase voltage by 90°.

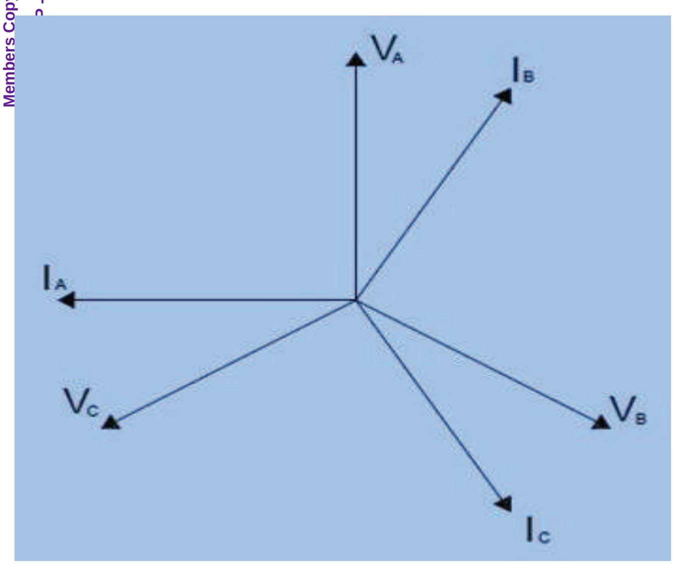

Fig. 9 : Phasor Diagram for Healthy Ungrounded System

Carefully observe that I_A, I_B and I_C are leading phase voltage V_A, V_B and V_C by an angle 90°. But the angles between the three charging currents are maintained 120° (refer figure 9). Thus we can say that, the charging currents are balanced and therefore,

$$I_A+I_B+I_C = 0$$

Thus there will be no flow of current through the neutral. Hence the potential of neutral will be maintained at the ground potential. Let us now consider a fault condition. Suppose a single line to ground fault takes place in C phase as shown in figure 10.

The fault current this case will complete its circuit as shown in figure above. Fault current I_C will be equal to the vector some of I_A and I_B. Therefore,

$$I_C = I_A + I_B$$

Mind here that, I_C in C phase will flow toward the neutral. Therefore we can say that, phase voltage of C phase has reversed its direction. This in turn means that, the voltage of neutral point has shifted from ground potential to phase voltage.

Because of this shifting of neutral voltage, the voltage of healthy phase will become equal to the line voltage (figure 11).

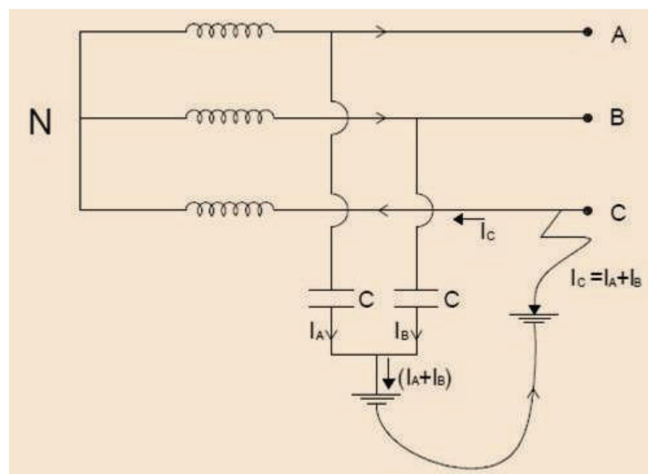

Fig. 10 : Condition of Single Ph-G Fault in Ungrounded System

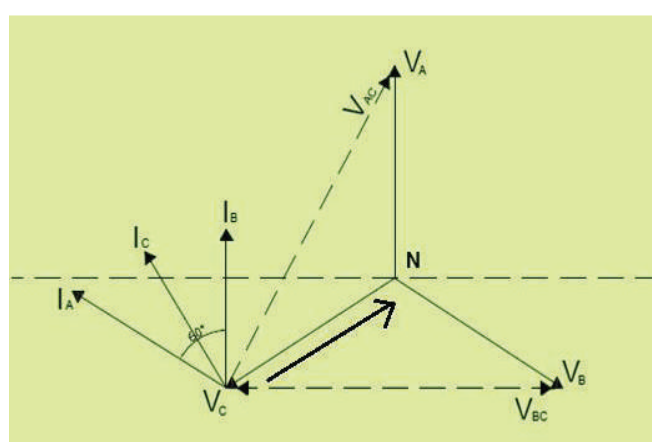

Fig. 11 : Phasor Diagram for Single Ph-G Fault in Ungrounded System

This can be well understood by applying Kirchhof"s voltage law in the current loop of phase A.

$$(V_C - V_N) + (V_N - V_A) + (V_A - V_C) = 0$$

So, $(V_A - V_N) = (V_C - V_N) + (V_A - V_C)$

$$= -V_C + (V_A - 0)$$
$$= -V_C + V_A$$
$$= V_A - V_C = \text{Line Voltage} = V_{AC}$$

But $V_A - V_N$ = Phase Voltage of A phase. Thus we observe that, the voltage of healthy phase rises to line voltage i.e. √3Vph. Due to this raised voltage of healthy phases, charging currents will increase.

$$I_A = \sqrt{3}V_{ph} / X_C$$

and $I_B = \sqrt{3}V_{ph} / X_C$

where X_C is capacitive reactance.

These charging currents will now lead with their respective voltages by 90° as shown in phasor diagram above. But notice that, this time the voltage is line voltage.

Therefore the fault current will be,

$$I_C = I_A + I_B \text{ (vector sum)}$$
$$= 3V_{ph}/X_C$$

From the above expression of fault current, it is clear that charging current in faulted phase is three times that of the normal charging current. Due to this heavy arcing will take place in the faulted phase. This phenomenon of arcing is known as Arcing Ground. Peterson coil is used for the elimination of arcing ground.

4. IMPORTANCE AND PURPOSE OF GROUNDING

The Objectives of Neutral Grounding are :

1. To preserve security of the electric system by ensuring that the potential on each conductor is restricted to such a value as it is consistent with the insulation applied.
2. To ensure efficient and fast operation of protective gear in case of earth faults.

The objectives of General Grounding system include [1-5] :

1. To provides a low resistance return path for fault current which further protect both working staff (freedom from dangerous electric shock voltage) and equipment installed in the substation.
2. To provide current carrying capability, both in magnitude and duration, adequate to accept the earth fault current permitted by the over current protective system without creating a fire or explosive hazard to building or contents.
3. To prevents dangerous GPR with respect to remote ground during fault condition
4. To provides a low resistance path for power system transients such as lightning and over voltages in the system
5. To provide uniform potential bonding /zone of conductive objects within substation to the grounding system to avoid development of any dangerous potential between objects (and earth).
6. To prevent building up of electrostatic charge and discharge within the substation, which may results in sparks.
7. To allow sufficient current to flow safely for satisfactory operation (better performance) of protection system.

5. FLOW CHART OF DESIGNING OF GROUNDING SYSTEM

The algorithm of the steps involved in the designing of the grounding system of Air and Gas insulted substation is given figure 12 [1].

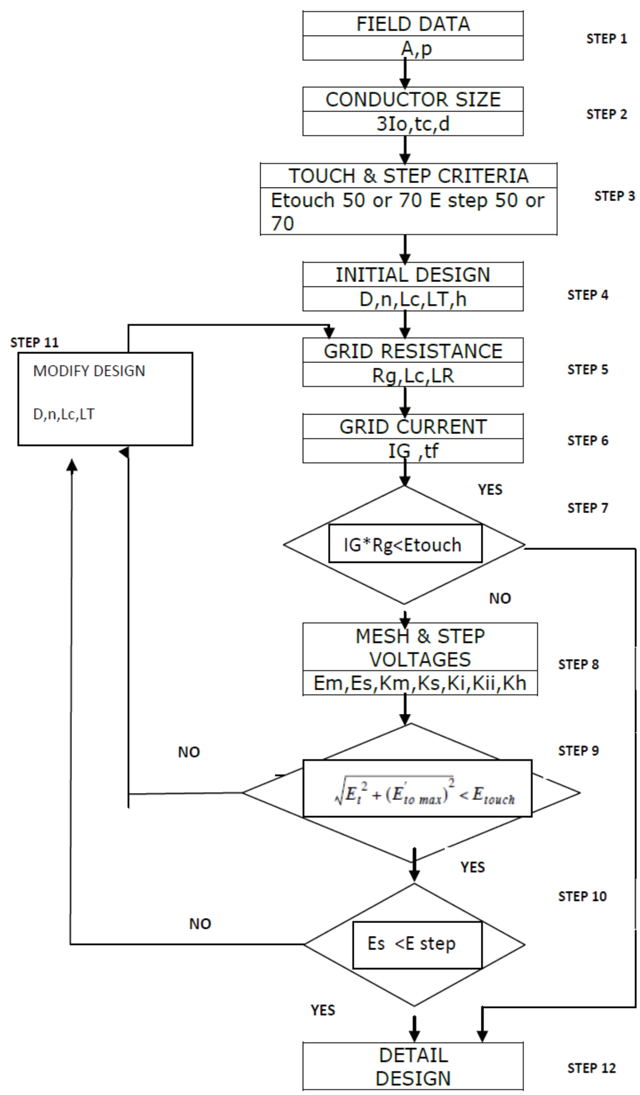

Fig.12 : Algorithm for Design of Grounding System

Six dangerous voltages encountered in the substation are depicted in figure 13 below.

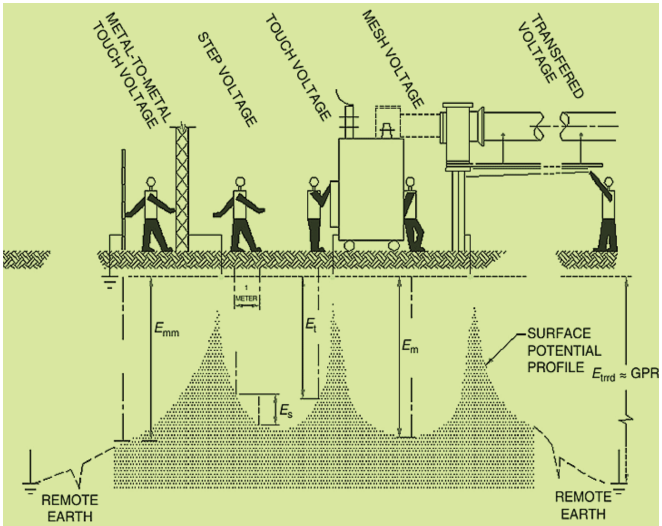

Fig.13 : Six Dangerous Voltages in Substation [1]

Various symbols used in the calculation as per IEEE-80 are given in table 1 below[1]:

Table 1 : Nomenclature Used in Designing of Grounding system

S. No	Description	Symbol	Unit
1.	Soil resistivity	ρ	Ω – m
2.	Surface Gravel layer (crushed rock resistivity)	ρs	Ω – m
3.	Symmetrical fault current in substation	I_f	A
4.	Total area enclosed by ground grid	A	m^2
5.	Surface layer de-rating factor	C_s	
6.	Diameter of grid conductor	d	m
7.	Spacing between parallel conductors	D	m
8.	Attainable Touch Voltage	E_m	V
9.	Attainable Step Voltage	E_s	V
10.	Tolerable step voltage for human with 50 kg body weight	$E_{step\ 50}$	V
11.	Tolerable touch voltage for human with 50 kg body weight	$E_{touch\ 50}$	V
12.	Tolerable step voltage for human with 70 kg body	$E^{step\ 70}$	V
13.	Tolerable touch voltage for human with 70 kg body weight	$E_{step\ 70}$	V
14.	Depth of Burial of earth material	h	m
15.	Surface Gravel layer thickness	h_s	m
16.	Maximum grid current that flows between ground grid and surrounding	I_G	A
17.	Symmetrical grid current	I_g	A
18.	Reflection factor between different resistivity	K	
19.	Corrective weighting factor that emphasizes the effects of grid depth	K_h	
20.	Correction factor for grid geometry	K_i	
21.	Corrective weighting factor that adjusts for the effects of inner conductors	K_{ii}	
22.	Spacing factor for mesh voltage	K_m	
23.	Spacing factor for step voltage	K_s	
24.	Total length of grid conductor	L_c	m
25.	Effective length of $L_c + L_R$ for mesh voltage	L_M	m
26.	Periphery Length of the grounding equivalent area	L_P	m
27.	Total length of ground rods	L_R	m
28.	Length of ground rod at each location	L_r	m
29.	Effective length of $L_c + L_R$ for step voltage	L_S	m
30.	Total effective length of grounding system conductor, including grid conductor	L_T	m
31.	Maximum length of grid conductor in x direction	$L = L_x$	m
32.	Maximum length of grid conductors in y direction	$W = L_y$	m
33.	Geometric factor composed of factors n_a, n_b, n_c and n_d	n	
34.	Number of rod in switchyard	N_r	
35.	Resistance of grounding system	R_g	Ω
36.	Duration of shock for determining allowable body current	t_s	s

6. KEY FACTORS FOR DESIGNING OF GROUNDING SYSTEM [1-4]

A. Soil Resistivity : A piece of land which is being used for construction of substation may have multiple soil layers with different soil resistivity. Resistivity may vary vertically or horizontally in the substation. A soil model is derived from the site measurement which may or may not be accurate always. In uniform soil model the average of all measured values of resistivity is selected as resistivity of soil. However it has been proved that the two- layer model of soil gives good approximation of real soil condition than uniform soil model. Soil resistivity plays crucial role in designing of grounding system of substation.

B. Resistivity of Surface Material (Gravel) : The resistivity of surface material over the grounding grid mat plays important in enhancing the safe touch and step potential of the operation and maintenance staff (refer fig. 14). Thus by using good quality of the surface material, value of safe potentials can be raised.

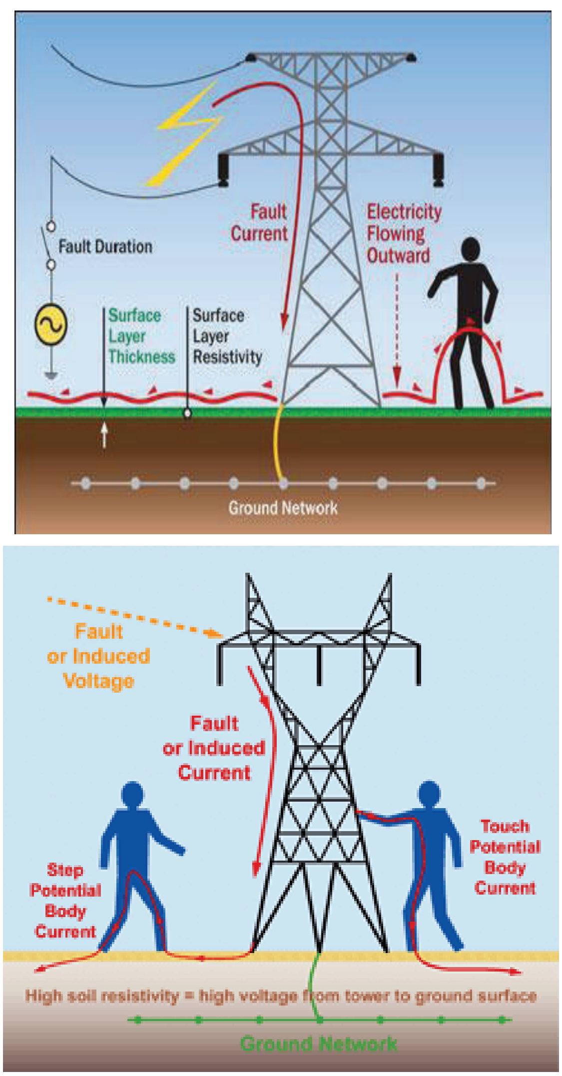

Fig.14 : Step and Touch Potential During Fault

C. Height of Surface Material (Gravel) : The height of the surface material also helps in enhancing the safe touch and step potentials of the operation and maintenance staff.

D. Depth of Burial of Grounding Grid : There is great impact of decrease or increase in depth of burial grounding grid on the touch and step potential. Depth of burial of grounding grid changes the mesh potential i.e. it may results in increase or decrease depending upon the initial depth. But step potential always decreases with depth of burial of grounding grid.

E. Conductor Spacing : Reduction in conductor spacing increases the total number of conductors of the grounding grid. Mesh potential can be controlled by reducing the conductor spacing to some extent as too much reduction may results in rise in step potential in the substation.

F. Vertical Ground Rods : Penetrations of the vertical ground rods deep in the soil enhance the performance of grounding system in both uniform and two layer soil model as these rods help in easy discharge of fault current. Thus GPR, touch and step potentials can be controlled to safe limits as compared to grounding grid with vertical ground rods. Vertical ground rods are usually placed at the corners or periphery of the grounding grid as maximum potentials are experienced in this area.

G. Fault Level of Substation : With the increase in the fault level of the substation GPR, touch and step potential of the substation increases. So, accurate determination of fault level plays important role in accurate designing of the grounding grid of the substation.

The maximum grid current is the worst case earth fault current that would flow via the grounding grid back to remote earth. To calculate the maximum grid current, there is need to calculate the worst case symmetrical earth fault current at the facility that would have a return path through remote earth (IF). The concept of grid current is illustrated in the figure 15.

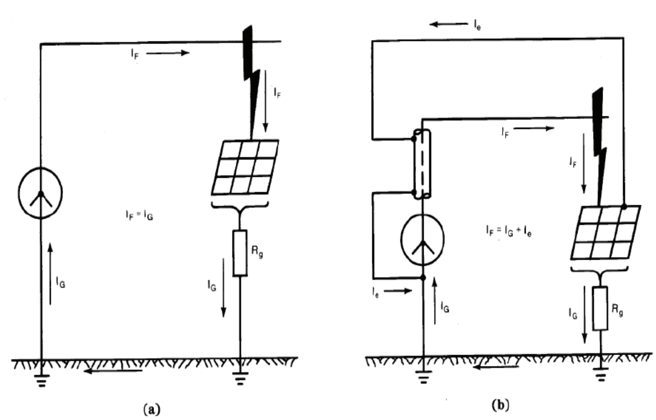

Fig.15 : Fault Current and Max Grid Current in Substation [1]

H. Current Division : Factor Not all of the earth fault current will flow back through remote earth. A portion of the earth fault current may have local return paths (e.g. local generation) or there could be alternative return paths other than remote earth (e.g. overhead earth return cables, buried pipes and cables, etc). Therefore a current division factor must be applied to account for the proportion of the fault current flowing back through remote earth . In the most conservative case, a current division factor of one can be applied, meaning that 100% of earth fault current flows back through remote earth. The symmetrical grid current is calculated by:

$I_g = I_F S_f$ …… Equation (1)

Split factor for substation (in terms of actual grid current) may be understood with the help of figure 16 and 17 respectively.

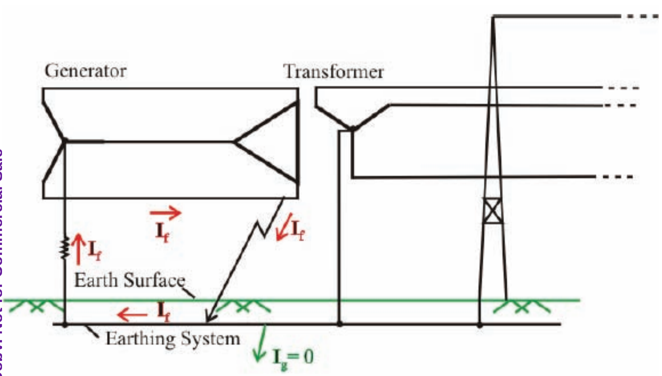

Fig.16 : Grid Current for Fault within Substation

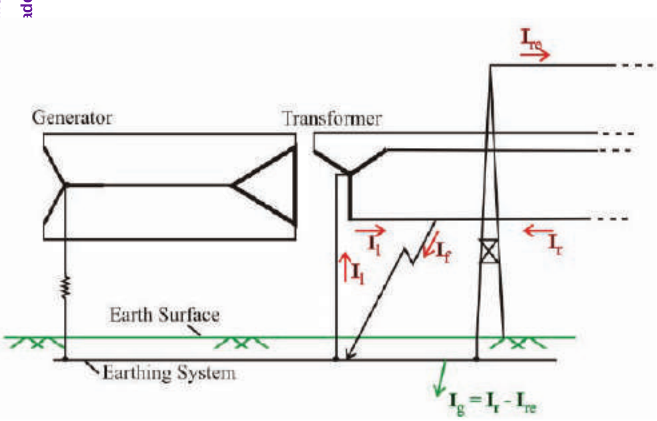

Fig.17 : Grid Current for Fault Outside Substation

I. Decrement Factor (D_f) : The symmetrical grid current is not the maximum grid current because of asymmetry in short circuits, namely a dc current offset. This is captured by the decrement factor as below:

$$D_f = \sqrt{1 + \frac{T_a}{t_f}\left(1 - e^{\frac{-2t_f}{T_a}}\right)} \quad \text{…… Equation (2)}$$

Where D_f is the decrement factor

t_f is the duration of the fault (s)

T_a is the dc time offset constant

$$T_A = \frac{X}{R} \cdot \frac{1}{2\pi f}$$

Where $\frac{X}{R}$ is the X/R ratio at the fault location

f is the system frequency (Hz)

Otherwise the table 2 of IEEE 80 may be used for getting value of D_f.

Refer figure 18 to get clear picture of short circuit current and decrement factor.

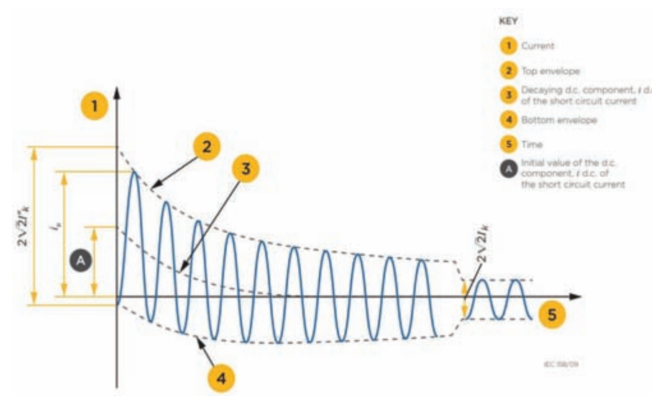

Fig.18 : Concept of Short Circuit Current (SCC)

Table 2 : Fault Duration Vs Decrement Factor [1]

Fault duration, t_f		Decrement factor, D_f			
Seconds	Cycles at 60 Hz	X/R = 10	X/R = 20	X/R = 30	X/R = 40
0.008 33	0.5	1.576	1.648	1.675	1.688
0.05	3	1.232	1.378	1.462	1.515
0.10	6	1.125	1.232	1.316	1.378
0.20	12	1.064	1.125	1.181	1.232
0.30	18	1.043	1.085	1.125	1.163
0.40	24	1.033	1.064	1.095	1.125
0.50	30	1.026	1.052	1.077	1.101
0.75	45	1.018	1.035	1.052	1.068
1.00	60	1.013	1.026	1.039	1.052

The maximum grid current is lastly calculated by:

$I_G = I_g D_f$ …… Equation (3)

The maximum GPR is calculated by:

$GPR = I_G R_g$ …… Equation (4)

Where *GPR* is the maximum ground potential rise (V)

I_G is the maximum grid current

R_g is the grounding grid resistance

7. CONCLUSION

It is very important for an electrical engineer to understand the fundamental and importance of grounding system of substation for the safety of staff and installed equipments in the substations. Soil resistivity and proper measurement of resistivity & interpretation of results are prime factors for accurate designing of grounding system. Other important factors are fault current, grid current, surface material resistivity and type of protection system play crucial roles in the effective designing of grounding system of substation.

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The Greatest thing in the world is not so much where we are, but in what direction we are moving

Oliver Wondell Holmes

PD Measurement of Rotating Machine for Condition Monitoring

Sanjay K PRASAD, Imran ALI and Chhaya R BHONSLAY

The Tata Power Company Limited

ABSTRACT

A Generator in power system is an extremely critical equipment and availability of this to be maintained at highest reliability. Online PD measurement of rotating machine is a good and evolving condition monitoring technique apart from well establish offline testing technique. This paper discusses the results of online PD measurements done on Hydro Generators, with different type of coupling capacitors (80 pF & 2 nF). PD measured in absolute values pC (Pico-coulombs) and analysis of PRPD are also briefed for results. Cases of failure of two other thermal VPI generator are discussed. Case studies about failure of air-cooled generator were discussed, with detail reason and corrective action. PD confirmation by capacitance and Tan Delta Measurement of rotating machines was also explored in this paper.

***Keywords** : Partial Discharge (PD), Phase Resolved Partial Discharge (PRPD), VPI (Vacuum Pressure Impregnation), Coupling Capacitor (CC), Bus Coupler Matching Unit (BCMU)*

INTRODUCTION

The Tata Power Company limited (TPC) is the largest integrated private sector utility in the business of Power Generation, Transmission and Distribution in India. It has installed capacity of Generation of 10757 MW as on date. There is variety of Generators based on different parameter

(a) MW and Voltage rating- 1.5 to 830 MW, 11 kV to 26 kV,

(b) Rotor: Salient pole (375 to 750 RPM) & cylindrical pole (3000 to 5000 RPM),

(c) Cooling: Air cooled, Water Cooled, Hydrogen cooled

(d) Insulation: Resin Rich, Global VPI (Vacuum Pressure Impregnation), VPI conductor

(e) Application: Hydro station (vertical & Horizontal), Thermal station (Coal, Flue Gas, Natural Gas (Gas turbine)

Offline condition monitoring techniques are less feasible due to outages requirements and economic reasons. These are established techniques, but don't give true condition of stator insulation, being performed in stationary condition. Insulation Resistance (IR), Polarization Index (PI), Capacitance & Tan Delta, PDCA (Polarization Depolarization Current Analysis), DC Resistance are some offline condition monitoring techniques. These Offline techniques cannot measure effect of temperature, motion and voltage related stress on insulation and defects may remain undetected. Temperature, vibration and electrical parameter are some widely used online conditioning monitoring techniques for generators. High Temperature may indicate deterioration of insulation sometimes but cannot accurately pinpoint the problem. Electrical PD (Partial Discharge) in the insulation are generated because of various failure mechanisms subjected to operational electrical stresses while Generator is in normal service. PD themselves may not be a sole cause of problem but an important symptom of an underlying cause. Improper design and manufacturing, unequal thermal expansion, abrupt load changes, electromagnetic forces, mechanical vibration can also cause stress to insulations.

Partial Discharge (PD) is an electrical discharge (millions of Spark) that partially bridge the insulation and are measured in terms of charge Q in pC (pico-coulombs), when voltage cross inception voltage (Vi) [2,4]. For rotating machine, PD sensing by contact method (Electrical coupling) is more established compare to non-contact type (Acoustics Emission, Ultrasound, RFI, UV light). PD measurements can help diagnose and prioritize problems within the generator's complex and distributed insulation system. Measurement of magnitude of the PD (pC) alone is not adequate to judge the condition of insulation and more meaningful information can be gained by evaluation of the PRPD (Phase Resolved Pattern PD, IEC 60034-27) as a fingerprint which is trended over time. Offline and Online PD measurement of rotating machines are a good and evolving condition monitoring technique.

At Tata power, offline PD measurement for rotating machine started with motors and then practiced for generator. For Hydrogen cooled generator, PD is not monitored due to known varying behaviour with and without hydrogen. For PD measurement many kits are available in India, which vary in their capability, output, resolution, pulse, super-positioning, error handling, dynamic ranges, noise rejection, signal processing methods and sensitivities. Online PD measurement have advantages over offline methodology are detailed in IEC 60034-27, Appendix-A. For gaining condition monitoring experience with online PD measurements, coupling capacitors were installed in some air-cooled generators in 2009. Learnings and Case studies based of this are detailed below.

1. Case Study 1 : Measurement of PD by different coupling capacitor

At one of the Hydro stations there are 7 Generator, 6 number of 25 MW having 80 pF CC (Installed in 2009) and 7th Generator of 150 MW have 1 nF CC (installed in 2015). The machines have already completed more than 90 years and are still an important source during peak demand hours and in monsoon. The Generator stator and stator insulations were altered twice for maximizing the MW generation and prime mover (runner/turbine) were also upgraded two times.

Initial measurements with these couplers from 2009 to 2012 did not indicated any problem and the measurement was stopped. In year 2017 again the PD measurement was done, with different instrument and set up to gain knowledge on PD of machine. The sequence followed are briefed below.

1. Gain factor of PD measurement system
2. The PD measurement was done at no load and rated load conditions.
3. For Generator-1, 2, 3, 4 and 6, the PD measurement was done with existing 80 pF CC and for unit-7 existing 1 nF CC was used. For Unit-5, the PD measurement was done with existing 80 pF as well as by 2 nF CC.

Following are the Summary of measurement

1. High frequency Capacitor Couplers (HFCC, 80 pF) offers frequency measurement bandwidth of 40MHz to 350MHz and they are prone to very high level of signal attenuation because of generator stator system impedance as compared to IEC frequency range (100-500 kHz), which is of great interest as far as assessing the condition of stator insulation is concerned. To mitigate the attenuation problem a BCMU (Bus Coupler Matching Unit) [3] was used which facilitated the measurement from the same 80pF PD coupler already installed on the machine.
2. Signal amplitude of measured PD signal from each phase winding are given in Table 1.
3. Generator-1,2,3,4 and 6 (80 pF CC): The PD magnitude from each phase was 3 to 6 nC and PRPD analysis helped to characterize it as noise originating from AVR system and no meaningful activity from the stator windings. (Figure 1).

Table 1 : Results of online PD measurement

Machine	CC	Max PD	PRPD interpretation
Gen-1	80 pF	3 nC	Discharge by AVR, No meaningful PD detected which would originate from stator insulation system
Gen -2	80 pF	4 nC	
Gen -3	80 pF	6 nC	
Gen -4	80 pF	5 nC	
Gen -5	80 pF	3 nC	Discharge by AVR, surface discharge activity, near phase terminations
	2 nF	50 nC	Discharge by AVR, surface discharge activity deep in winding
Gen 6	80 pF	4 nC	Discharge by AVR, No meaningful PD detected which would originate from stator insulation system
Gen -7	1 nF	5-7 nC	Discharge by AVR, low void type discharge

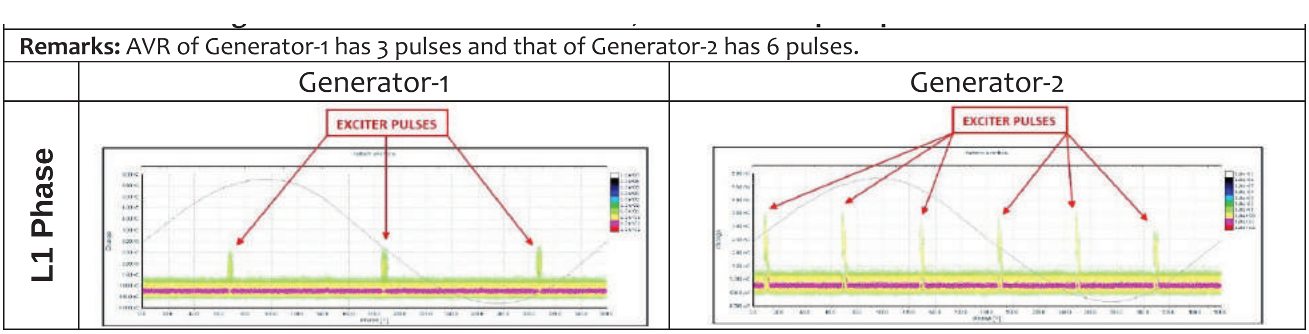


Fig. 1 : Generator-1 & Generator-2, PRPD with 80 pF Capacitor and BCMU

4. For Generator-5, PRPD indicated surface discharge activity in the windings (Figure 2). Surface discharge activity can often cause the signal amplitude of very high order with occurrence of discharge cycle at rise in voltage i.e. generally between 0 and 90 degrees electrical. Moreover, the discharge activity as seen in PRPD pattern show multiple event clusters (in the shape of humps) and can be attributable to cross-coupling of discharge activity from the neighbouring phase or a possibility of inter-winding discharge activity.
5. Measurements from 80 pF couplers and 2nF couplers were observed to have different magnitude of same discharge activity occurring in the generator (Figure 2). The PD measurements performed in IEC frequency range of 100 kHz to 500 kHz but with different characteristics of PD coupler. The measurement presented in the report clearly exhibits the differences in sensitivities offered by each type of sensor and PD signal decoupling characteristics. Significant attenuation was seen in case of PD signals obtained from 80pF couplers and it potentially understates the intensity of discharge activity occurring in the stator insulation. Such scenario often leads of existence of problem conditions but lack of information availability during PD measurements [1].
6. For Unit-7, PD measurement was carried out in IEC frequency range as well as outside the IEC frequency range to identify, far field activity as well as noise elimination from AVR system (Figure 3). PRPD indicate, presence of void type discharge as well as AVR noise in IEC frequency range (100-500 kHz). In 1-2 MHz range PRPD don't show the AVR as well as void type discharges. The results show usefulness low frequency measurement with high CC. It is not uncommon for such a large generator to have void type discharges of lower magnitude. Present test data do not show alarmingly high discharge activity.

Inferences from these measurements are

1. HFCC (80 pF) offers frequency measurement bandwidth of 40MHz to 350MHz and are prone to very high level of signal attenuation because of generator complex stator system impedance as compared to LFCC (Low Frequency capacitor coupler: 100-500 kHz).

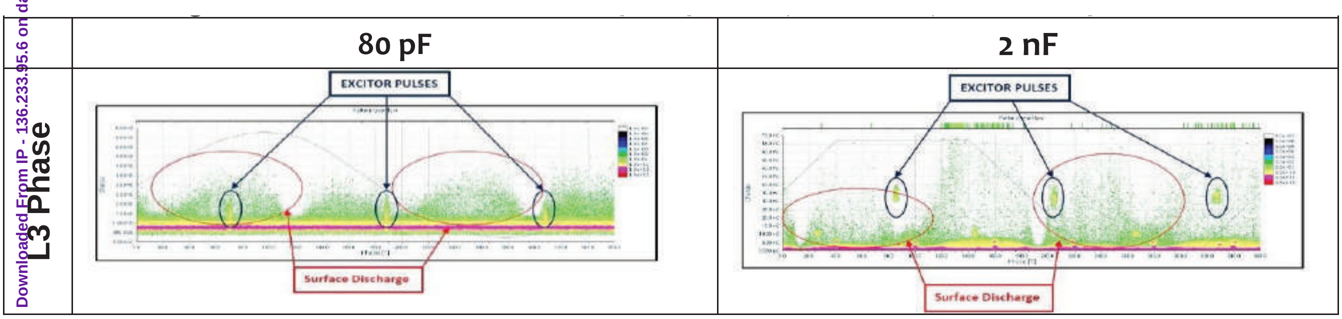


Fig. 2 : Generator-4, PRPD with 80 pF Capacitor (with BCMU) and 2 nF Capacitor

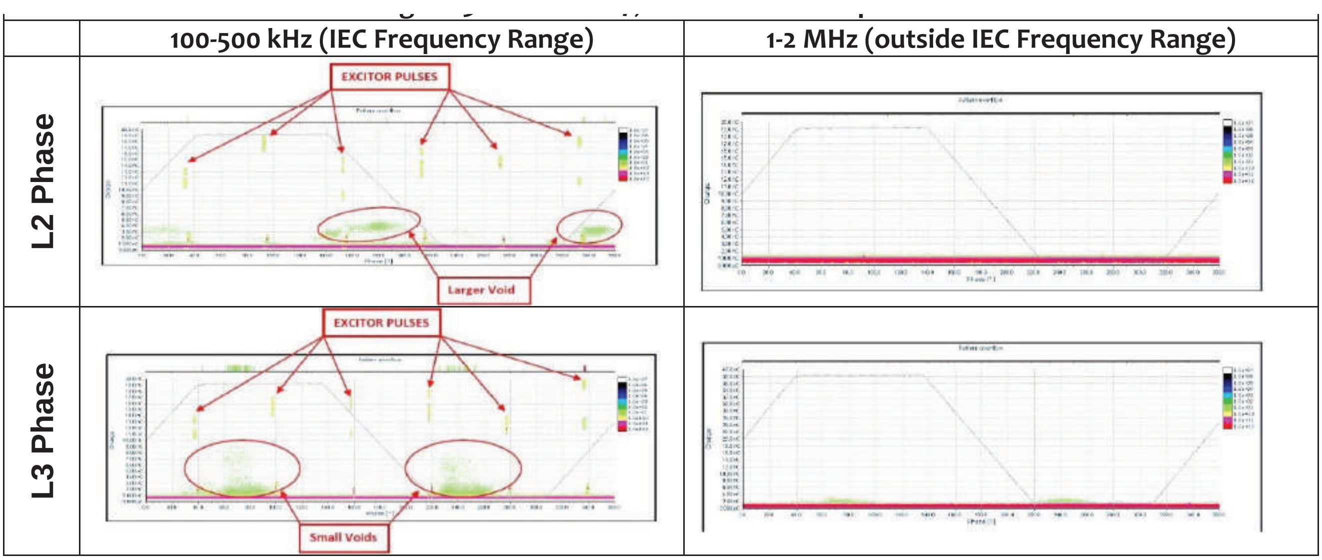


Fig. 3 : Generator-7, PRPD with 1nF Capacitor

2. To mitigate the attenuation problem to some extend a BCMU can be used with 80 pF CC.
3. Measurements from 80 pF couplers and 2nF couplers were observed to have different magnitude of same discharge activity occurring in the generator. Due to higher Sensitivity with higher Capacitive couplers, PD occurring deeper into the stator coils could be measured.
4. The standards suggest, use of LF range for off-line PD tests on coils and windings. However, the choice of LF verses HF PD testing is not so clear for on-line PD testing of rotating machines. LF may detect more PD in the winding, but with a risk of false indications due to noise, when compared to HF testing. Standards should clearly specify the values of CC for On-Line PD testing [9].

2. Case-2: Failure of 150 MVA, Air Cooled Generators

In 2018, Two 150 MVA generator (Gen-6:9 years & Gen-4: 13 years) stator failed, one in January and other in April. Both were Global VPI machine commissioned at same thermal plant, of same make, by same OEM. Generator-4 failed top conductor in slot-1 was replaced at site by VPI bar and for Generator-6, both top and bottom conductor has failed in slot-1, so the complete stator was replaced. The location of failure for Gen-4 is given below, same was the case for Generator 6.

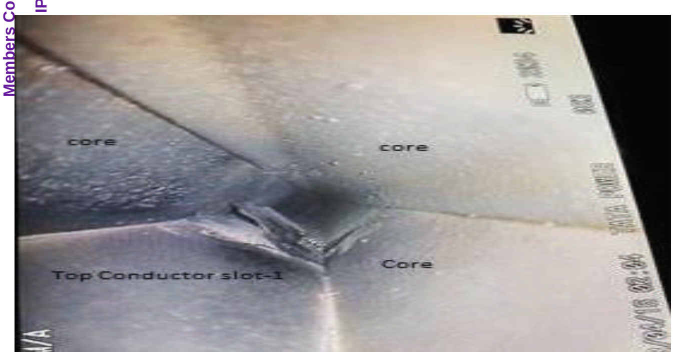


Fig. 4 : Image of Burn insulation with borescope

Fig. 5 : Smoke observed from Slot no. 1, having L1 phase conductor at top and bottom

1. The location of fault was, top conductor in slot-1 (54 slot machine) at wedge-8 (total 14 wedges) at conductor transposition location in the middle portion.
2. Stator conductor design: The stator bar consists of 78 number of separately insulated strands which are transposed by 360° (Roebel bar transposition). The strands are of small rectangular cross-section and are provided with a braided glass fiber insulation and arranged side by side over the slot width. The individual layers are insulated from each other by a vertical separator. The stator bars are provided with high voltage insulation which consists of the specified number of half overlapped, continuous layers of dry mica tape applied from end to end on the stator bars. A semiconducting tape applied as a final wrapping in the slot section provides for a good electrical contact with the grounded parts via the stator core (Figures 8 & 9). Specially treated tapes are applied to the bar portions just outside the slot to provide a corona grading system which ensures uniform control of the electric field without corona discharges.
3. Excess heating was observed on copper strip, near to burnt insulation i.e. at transposing location at the bottom side of slot. Reason for excess heating could be :
   (a) Partial discharge: Not observed in offline and Online PD test
   (b) Hot spot: Blocking of cooling vents are not seen around this area
   (c) Sharp edges: During bending of strip for transposition, sharp edges may have created. This has created corona over 13 years of operation and resulted into failure
   (d) Excess vibration of conductor at 8th wedge in slot-1: the wedge was found semi-lose in 2011 testing by ABB by wedge knocking test.

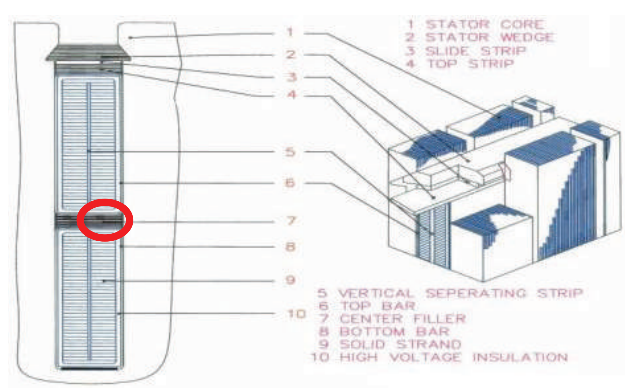


Fig. 6 : Two conductor in one slot, with insulation and wedges

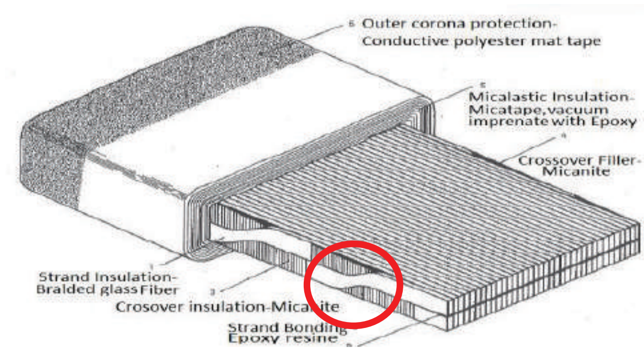


Fig. 7 : Transposing scheme of strips in one conductor, separated by insulation, red circle is fault location

Fig. 8 : Transposing impression in insulation

Fig. 9 : Damaged insulation (outside View) at bottom side of top conductor at 8th wedge location

Fig. 10 : Zoom in View of Damaged insulation, at Transposing location

Fig. 11 : Damaged filler insulation (paper & Micalite filler) top & bottom view

4. The PD measurement for Generator-4 are given below and did not indicated any abnormality. The Online PD measurement was done just 2 months prior to failure and indicated no abnormality. Discussions with OEM and other PD experts remained inconclusive for the fault which was of ground wall delamination type. Generator-6 did have CC for online measurement. (Table 2)

5. The fault being of similar nature in two generator, system surge studies were also conducted, to understand the effect of surges producing at 132 kv side on 11 kV generator windings. With healthy and adequately designed SA (Surge Arresters) at 132 kv of GT (Generator Transformer) and SA and Surge Capacitor at 11 KV Generator terminals, there is no possibility that lighting or switching surges to cause damage to the Generator coils.

   Subsequently, diagnostic testing report of five generator having identical rating and design from same OEM, but slightly different operating condition were studied, and results are given in Table 4. The PD measurement is Offline measurement with same instrument, with same coupler at different times. The extent of problem in generator could not be assessed with certainty. Some observations were

   (a) The capacitance of 5 generators (Global VPI) was same, but the measured Tan δ values are different (9% to 0.5%), indicating change in material or the manufacturing process. Residuals of not fully cured “pools” of resin can cause issues with test parameters such as DF, and Tip-Up [8].

   (b) The measured PD in terms of nano-coulombs is varying from 1.5 to 20 nC.

   (c) The PD activity were separated in slot discharges due to deterioration of Insulation corona protection shield, slot-End / Surface discharge due deterioration of Insulation of stress grading system and De-lamination/void discharges in ground walls insulations.

(d) New Generator-6 and Generator-2 shows higher PD activity and higher void contents (calculated from variations in the tan delta and capacitance measured), but exact corrective actions are not possible, being Global VPI design, as discussed with OEM. Thorough cleaning (cryogenic) and surface varnishing will be done. (Table 3)

Table 2 : Comparison of Off-line and Online PD results for Generator-4

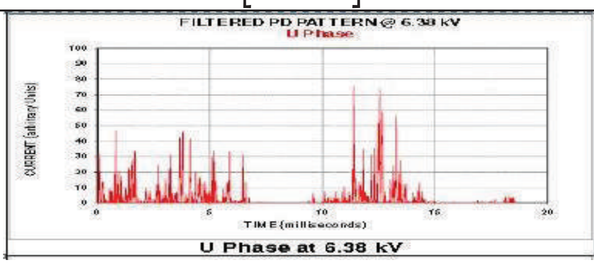
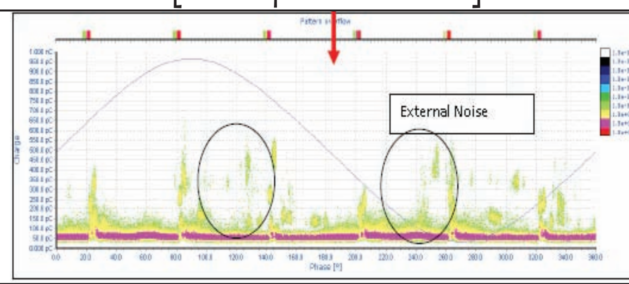
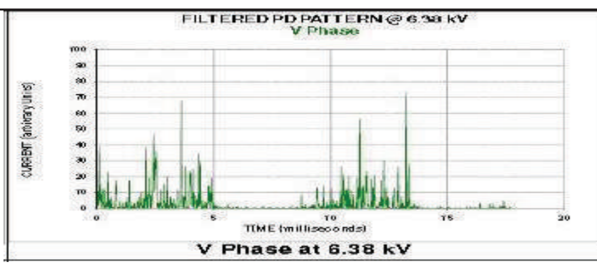
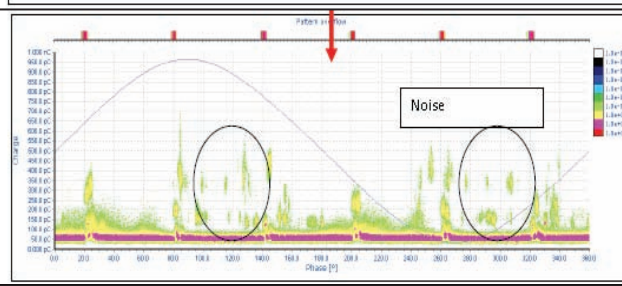
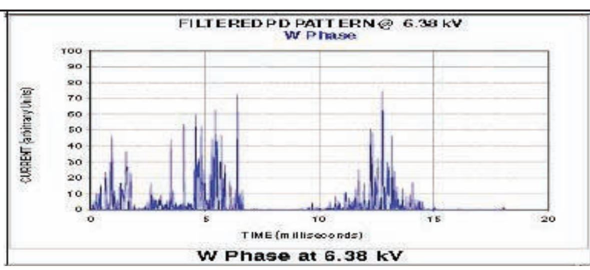
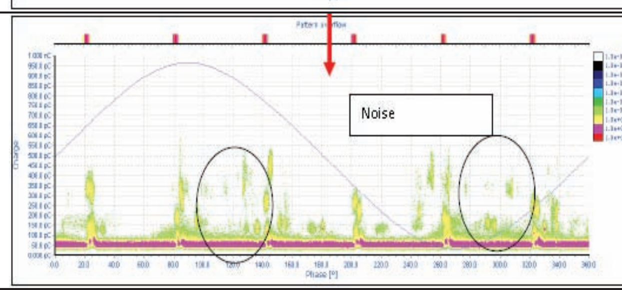
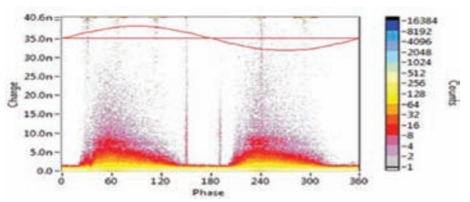
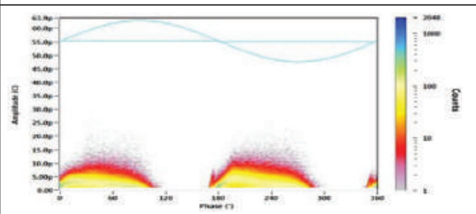
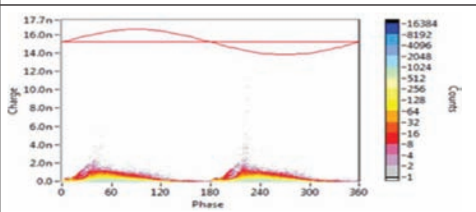
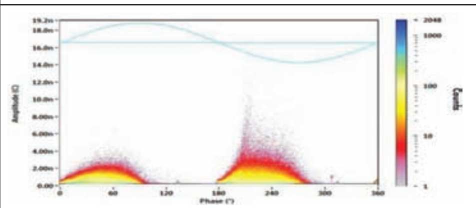
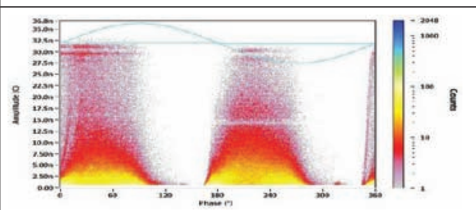
Table-2: Comparison of Off-line and Online PD results for Generator-4	
Off Line PD test by Kit-X, in 2011 [CC-1 nF]	**ON Line PD test by Kit-Y in Feb-2018** [CC-80 pF with BCMU]
	
	
	
L1, L2 & L3 Measurement	L1, L2 & L3 Measurement
• *No damage/ deterioration to the corona protection shield, stress grading system at the slot ends and de-lamination/voids in the ground wall insulation.* • *PRPD indicate insignificant discharging in internal voids/de-laminations.*	*PD measurement on Gen-4 exhibited values of up to 6.5 nC when measured in IEC frequency band of 100 KHz to 500 KHz. The evaluation of Partial Discharge in phase resolved pattern did not showed any internal PD discharge activity in the stator winding insulation.*

Table 3 : Comparison of Test reports of 5 generators

	PRPD of U phase	nC	Cap. & Tan δ	IR (MΩ)	PI	Year of Mfg
Gen-2		**Avg- 10, Max- 25** Dominant discharges in Slot, Slot-End, Surface and De-lamination in ground wall. Void contents are high.	508600 pF 9.514 %	6311	3.23	2000
Gen-3		**Avg-10 nC, Max-15 nC** Dominant discharges in Slot, Slot-End, Surface and De-lamination in ground wall. Void contents are high.	509300 pF 4.274 %	6502	2.91	2000
Gen-4		**Avg-1.5 nC, Max-2 nC** Non-dominant Delamination in the ground wall insulation. No Slot or surface discharges. Void contents are low.	519000 pF 1.328%	739	3.24	2004
Gen-5		**Avg-4 nC, Max-9 nC** De-lamination in the ground wall insul^n. Slot end discharges from the predominance of -ive cycle. Void Contents are High	490900 pF 0.501%	8737	5.32	2008
Gen-6		**Avg-20 nC, Max-32 nC** Dominant discharges in Slot, Slot-End, Surface and non-significant De-lamination in ground wall. Void contents are lower.	479800 pF 0.874%	8930	5.38	2017

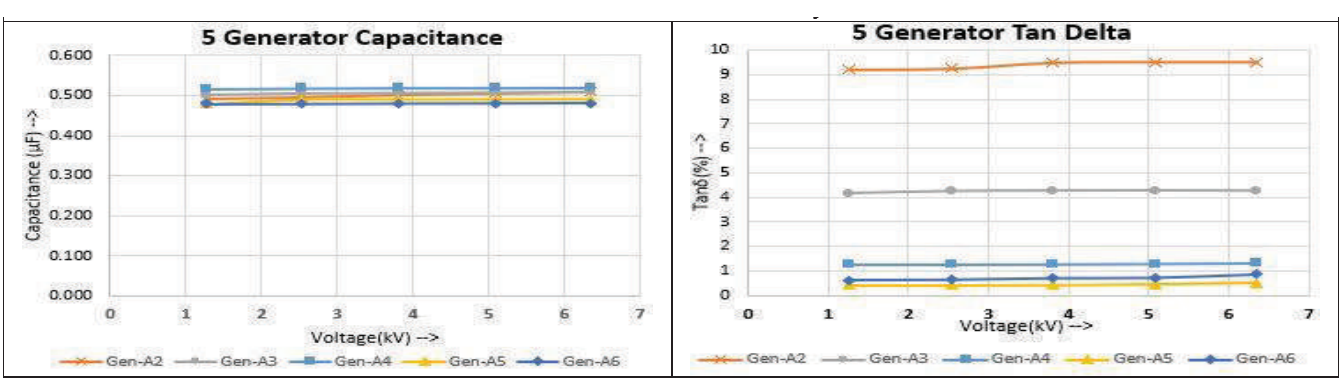


Figure 13 : Capacitance and Tanδ of Five 150 MVA, 11 kV, Generators stator (Global VPI) by same OEM, manufactured in different year

Inferences from this failure are

1. Both VPI machine, failed due prolonged heating of insulation at transposing area of slot-1 top conductor, due to suspected sharp edges and subsequent PD, created during bending of strip.
2. Offline as well as On-line PD test could not detect the problem, with accuracy well in advance.
3. Machine of identical rating from same OEM, operating at same condition have different PD, PRPD and Tan delta values. The variation could be due to insulation material change or non-curing of resin during VPI processing or change in the VPI process itself.
4. Corrective action for global VPI machine, with high PD is difficult to workout. Spare VPI conductor (single bar replacement) or complete stator is the only option available with utility. IEC should create working group to study these variations and to release guideline for PD in Global VPI machines with recommended actions.

3. Case 3: PD assessment through Tan Delta test

For complete assembled rotating machines overall limit for Tanδ are not available in standards, though same is available for single coil and conductor [10 & IS 13508]. In India OEM don't specify limits for complete assembled machines, so the condition monitoring must start with values obtained during Factory testing.

All machine has semi-conductive grading/paint (SCG) (Silicon carbide) at end conductor, when exiting from core slot. This semi conductive paint causes a defined reduction (i.e. uniform distribution of electric field) of the high-voltage potential from the HV conductor to the grounded laminated core. Without Semi-conductive grading high electrical field gradients would appear at the laminated core, causing high discharges and subsequent puncturing of insulation. The electrical property of SCG is like varistor (at higher voltage it becomes more conductive), so Tanδ and Capacitance values start increasing at higher voltage. This increase should not be interpreted as PD as applicable to other equipments. Guard measurement for single conductor can decrease the effect this SCG paint but is not possible for complete wound machine.

During Capacitance and Tanδ measurement following, parameters analysed are

(a) Tanδ at lowest and highest voltage

(b) Tanδ tip up values and increasing curve

We can also perform capacitance and Tanδ hysteresis by increasing and then decreasing the voltage in steps of 10% of rated voltage. Tanδ hysteresis indicates PD-activity in the ground wall insulation [7] and can be used as initial signature for further trending. This can be confirmed by PD measurement. Capacitance and Tanδ is relatively simpler measurement with simple setup and don't require intensive calibration. The interpretation of test results required lower competencies and can be basis for detail investigation of equipment.

We started Tanδ hysteresis measurement for new 6.6 kV Motor received from factory. All result had noticeable hysteresis in Tanδ, but no hysteresis in capacitance. Same time we got opportunity to perform this test in one of reputed machine manufacture i.e 67 MW, 11 kV Generators. No Tanδ hysteresis was observed, only increase of Tanδ as expected was seen. This we are in discussing to put in SQP (Standard Quality Plan) for acceptance of machine and is good condition monitoring tool

Inferences from this failure are

1. Tanδ hysteresis in increasing and decreasing voltage will be used for knowing the PD activity on rotating machine.
2. This initial signature can be used later for knowing the extend to deterioration of insulation in stator.

CONCLUSIONS

PD measurement in rotating machine is being practice since 2000 in our organisation. Rich guidelines are available for Static instrument like transformer, Instrument trf, etc. but for rotating machine these lacks. Development and improvements in PD measurement and new criteria like PRPD are gaining popularity over charge (Q) or mV (milli volt) methodolgy, but the real challenge is to interpret the result, pin point the problem and take corrective/ preventive action. Decision making also difficult, since stator insulation design is very complex being customised design, specific for site condition. The Coupling capacitor for online PD measurement are not part of standards and test Kit manufactures are not aligning to common specification. This is causing unpopularity of PD as condition monitoring tool. Offline and Online PD measurement was unable to detect failure in two 150 MVA generators last year. Comparison of PD and PRPD of identical designed machine are indicating problem (case-2), but in absence of limiting value in Standards, OEM don't empathise with this. In case they accept the problem in design (mostly VPI), corrective action cannot be planned, hardly any case study exists. The PD measurement/indications through simplified test like Tanδ can be practiced for gaining knowledge in PD behaviour in complex stator insulation of Rotating machine.

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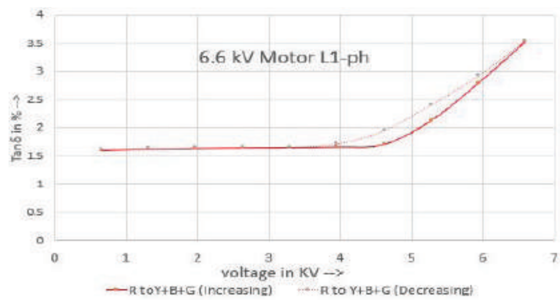

Fig. 14a : Tanδ hysteresis in 6.6 kV, 350 kW, VPI Motor

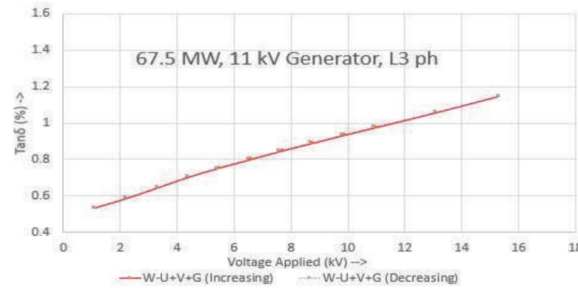

Fig. 14b: Tanδ hysteresis in 11 kV, 67.5 MW, VPI Generator

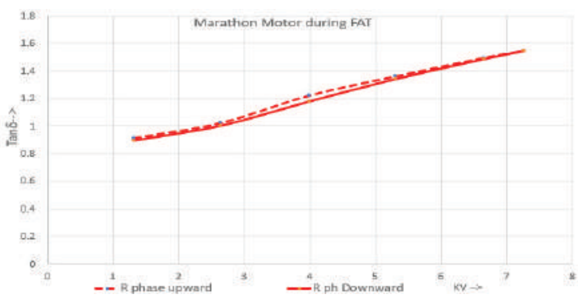

Fig. 14c: Tanδ hysteresis in 6.6 kV, 1.8 MW, VPI Motor

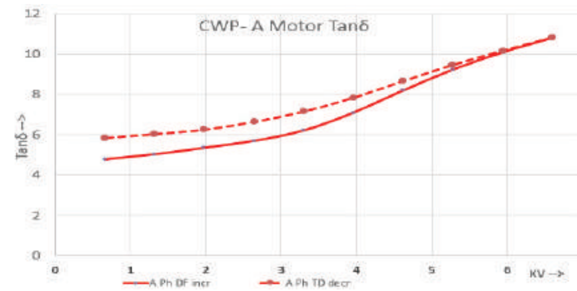

Fig. 14d : Tanδ hysteresis in 6.6 kV, 710 kW, VPI Motor

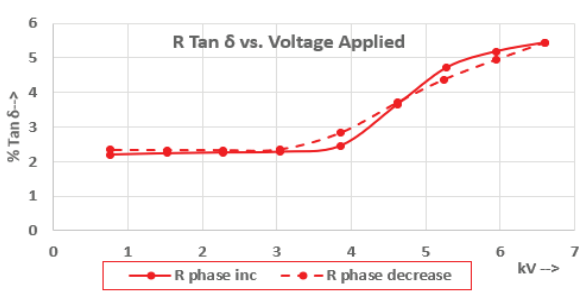

Fig. 14e : Tanδ hysteresis in 6.6 kV, 275 kW, VPI Motor

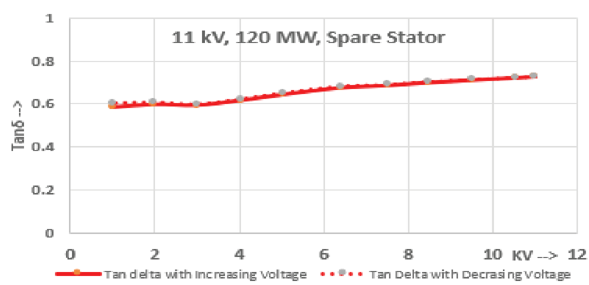

Fig. 14f : Tanδ hysteresis in 11 kV, 120 MW, VPI, Generator Stator

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