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SMART GRID

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PREFACE

The importance of **Smart Grid** is well known in various engineering fields. Overwhelming response to our books on various subjects inspired us to write this book. The book is structured to cover the key aspects of the subject **Smart Grid.**

The book uses plain, lucid language to explain fundamentals of this subject. The book provides logical method of explaining various complicated concepts and stepwise methods to explain the important topics. Each chapter is well supported with necessary illustrations, practical examples and solved problems. All the chapters in the book are arranged in a proper sequence that permits each topic to build upon earlier studies. All care has been taken to make students comfortable in understanding the basic concepts of the subject.

The book not only covers the entire scope of the subject but explains the philosophy of the subject. This makes the understanding of this subject more clear and makes it more interesting. The book will be very useful not only to the students but also to the subject teachers. The students have to omit nothing and possibly have to cover nothing more.

We wish to express our profound thanks to all those who helped in making this book a reality. Much needed moral support and encouragement is provided on numerous occasions by our whole family. We wish to thank the **Publisher** and the entire team of **Technical Publications** who have taken immense pain to get this book in time with quality printing.

Any suggestion for the improvement of the book will be acknowledged and well appreciated.

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Dedicated to God

Syllabus

Smart Grid - (EE8019)

UNIT I INTRODUCTION TO SMART GRID

Evolution of Electric Grid, Concept, Definitions and Need for Smart Grid, Smart grid drivers, functions, opportunities, challenges and benefits, Difference between conventional & Smart Grid, National and International Initiatives in Smart Grid. **(Chapter - 1)**

UNIT II SMART GRID TECHNOLOGIES

Technology Drivers, Smart energy resources, Smart substations, Substation Automation, Feeder Automation ,Transmission systems : EMS, FACTS and HVDC, Wide area monitoring, Protection and control, Distribution systems : DMS, Volt/VAR control, Fault Detection, Isolation and service restoration, Outage management, High-Efficiency Distribution Transformers, Phase Shifting Transformers, Plugin Hybrid Electric Vehicles(PHEV). **(Chapter - 2)**

UNIT III SMART METERS AND ADVANCED METERING INFRASTRUCTURE

Introduction to Smart Meters, Advanced Metering Infrastructure (AMI) drivers and benefits, AMI protocols, standards and initiatives, AMI needs in the smart grid, Phasor Measurement Unit (PMU), Intelligent Electronic Devices (IED) & their application for monitoring & protection. **(Chapter - 3)**

UNIT IV POWER QUALITY MANAGEMENT IN SMART GRID

Power Quality & EMC in Smart Grid, Power Quality issues of Grid connected Renewable Energy Sources, Power Quality Conditioners for Smart Grid, Web based Power Quality monitoring, Power Quality Audit. **(Chapter - 4)**

UNIT V HIGH PERFORMANCE COMPUTING FOR SMART GRID APPLICATIONS

Local Area Network(LAN), House Area Network (HAN), Wide Area Network (WAN), Broad band over Power line (BPL), IP based Protocols, Basics of Web Service and CLOUD Computing to make Smart Grids smarter, Cyber Security for Smart Grid. **(Chapter - 5)**

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UNIT - I

1 Introduction to Smart Grid

Syllabus

Evolution of Electric Grid, Concept, Definitions and Need for Smart Grid, Smart grid drivers, functions, opportunities, challenges and benefits, Difference between conventional and Smart Grid, National Initiatives in Smart Grid.

Contents

1.0 Electrical Grid

- Current transmission and distribution grids were designed with smart grid for developing an autonomous monitoring and controlling in power grid. Cost-effectiveness, rapid electrification of developing economies was the criteria used for the development of grid. The requirements of smart grid are quite different, and, therefore, the reengineering of the current grid is in pipeline. Enhancements and extensions to the existing grid, inspection and maintenance activities, preparation for distributed generation and storage, and the development and deployment of an extensive two-way communications system are the various works to be made in the existing grid.
- The electric delivery system of transmission lines, distribution feeders, switches, breakers, and transformers carries heavy metal wires and this will remain the core of the utility transmission and distribution infrastructure. To overcome the problems in existing grid, slight modification may be introduced, namely usage of amorphous metal in transformers to reduce losses. To make the system smart, the following works are to be carried.
- To improve the grid infrastructure, advancement in the monitoring, control, and protection of the grid component have become essential. The enhancement in the operation and maintenance of the transmission and distribution network can be implemented by the introduction of microprocessor-based monitoring, control, protection, and data acquisition devices. However, changes for deployment of smart grid with the existing system will create significant challenges.
- The greatest changes in the utility industry have been driven not by innovation, since the invention of electric power technology and the establishment of centralized generation facilities. To this unchanged system, a new technology to be introduced will be a great challenge. Currently, generation is matched to supply consumer load plus a reserve margin, and often expensive generating plants are used to satisfy peak demand or supply reserve energy in the case of contingencies. Today, consumer demand management to control the use of demand resources that are located behind-the-meter, enabled by the smart grid.
- Consumer demand management and new dispatch model could significantly improve the optimization of the electric system by enabling smart grid. This can create new markets, and establish new consumer participation in the energy industries. The capability to dispatch consumer demand and alternative energy resources integration in the grid could also pull down pressure on the wholesale price of electricity

1.1 Concepts of Smart Grid

- An electrical grid is an interconnected network for delivering electrical energy from the generating end to customer end. This interconnected network is also referred as electric grid or power grid. The network contains four important modules namely, generating station, substation, transmission system and distribution system. The electrical power produced at generating station is transmitted via high voltage transmission system. This system carries power towards demand side where substation steps up electrical voltage for transmission, or steps down electrical voltage for distribution. The last module of electrical grid connects customer with the grid through distribution lines. The size of electrical grid varies based on the coverage capability. Often, power generating stations connected to grids are located near energy resources. This makes the grid to effectively use the source of fuel or to take advantage of renewable energy resources.
- A smart grid can be termed as a modern grid. This modern grid enables a bidirectional flow of energy and uses two-way cyber-secure information and communication technologies. To attain a sustainable and secured system, this grid is integrated in a fashion across electricity generation, transmission, substations, distribution and consumption. The smart grid co-ordinates needs of all generators, grid operators, end-users and electricity market stakeholders for ensuring an effective operation. A smart grid is defined as the integration of information and communications technology into electric transmission and distribution networks. The smart grid delivers electricity to consumers using two-way digital technology, where the customers can effectively manage the load and avoid demand imbalance. Smart grid can detect faults automatically that improves service quality, enhances reliability, and reduces costs.
- In order to realize this modern grid model, National Institute of Standards and Technology (NIST) provided a conceptual model. The smart grid framework 1.0 was proposed by NIST during January 2010.There are seven domains presented in that model which are based on the different roles performed by smart grid. To get a clear understanding, a conceptual model of smart grid has been shown in the Fig. 1.1.1. The various domains in conceptual model are generation, transmission, distribution, operation, service provider, market and customer.

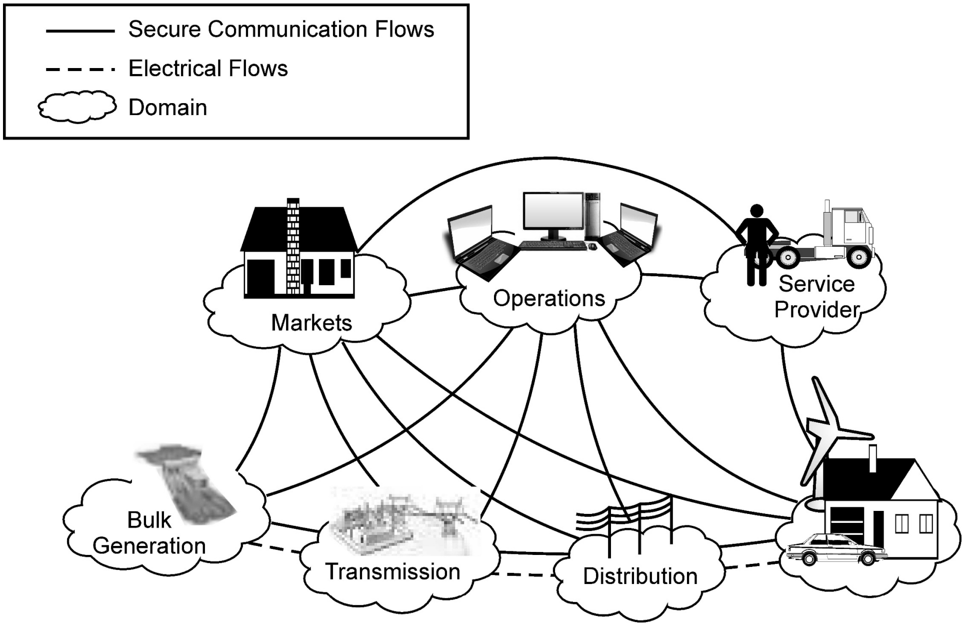

Fig. 1.1.1 : Conceptual model of Smart Grid

➥ 1.1.1 Bulk Generation Domain

The bulk generation domain generates electricity in bulk quantities (more than 300 MW). Generation domain is a location where power plants convert mechanical energy of turbine into electrical energy. There are few exceptional cases like solar power generation and wind power generation involved in bulk generation domain.

➥ 1.1.2 Transmission Domain

The domain carries bulk electricity over long distances via transmission cables or power lines. The generation domain get exit at transmission domain, where the generated power is stepped up for transmission. The increase in voltage is done to reduce transmission loss. The power generation needs to be transported from generation end to customer end have several hundred Kilometer distance separation. Under such condition, an inevitable resistance loss occurs in power lines. Thus, high voltage transmission can minimize the loss due to transportation. This domain needs to maintain stability on the electric grid by balancing energy generation with energy demand across the transmission network.

➥ 1.1.3 Distribution Domain

The generated electricity is provided to customer based on their demand. The distribution of electricity is initiated with distribution substations. It contains step-down transformers, which reduces the high voltage transported from the generator side. Such voltage reduction ensures safety of power utilization. The customers can be either large industries or small homes. The demand of industries and residential customers are satisfied by this domain.

1.1.4 Operations Domain

The flow of electricity is managed in this domain, where a supervisory network topology is deployed. The role of this topology is to provide the status of circuit breaker, switches and other control equipment's loading condition. By using this domain, real time data analysis can be performed. Such analysis can reveal the system efficiency and reliability. It can also be used for analyzing the faulty occurrence in the system.. Such faulty analysis provides information about faulty location, identification, isolation and system restoration.

1.1.5 Service Provider Domain

The domain is used for supporting the business related data of a power system. It is used for providing services to electrical customers and utilities. The system ensures the customer service enhancement. This domain executes the billing and customer account management, monitoring and controlling of energy use and energy generation, etc.

1.1.6 Markets Domain

This domain is a place where grid assets are bought and sold. In this domain, the operator balances the supply and demand within the power system.

1.1.7 Customer Domain

The customers are end users of this conceptual model. The customer store, and manage the use of energy.

1.2 Need for Smart Grid

- A Smart Grid can also be referred as a digital technology that accomplishes two-way communication between the utility and its customers. To the quickly varying electrical demand, these technologies will respond fast. These responds work with the electrical grid, which are digital response.
- The Smart Grid has made the energy industry to move into a new era of reliability. There are several reasons for this transition in energy industry. The following discussion will enumerate the need for smart grid in reality.

1.2.1 Curtail Power Theft

Every moment an increase in global energy crises is observed. It is also observed that a great attention towards energy production and its effective utilization. Even after such high level of attention, several losses occur in the system. These losses are categorized as technical and non technical. With the support of mathematical modeling, computation of technical losses has become simple. But, evaluating the non technical losses have become complex. One such non technical loss is power theft. In country like India, quite a common problem is power theft. To address this problem, a high security, best efficiency system is highly demanded. One way to curtail power theft is to have grid accounting, where the power flow can be easily tracked.

1.2.2 Enhancement of Power Reliability

- The reliability of power defines the capability of customer to access the electricity without any disruption. Still in many countries, accessing electricity is to be improved. The access of electricity is restricted to a particular time only. Thus, power reliability has been reduced.
- The power flow can be made continuous by grid load balancing and distribution automation services. The services offered may also alert utilities from blackout. This supports to react quickly to reduction in the voltage of commercially supplied power. Thus, grids are made smarter.

1.2.3 Lack of Infrastructure

The growth of power sector can be made highly realistic only with a good infrastructure. Such betterment in infrastructure can make power sectors to be highly manageable and reliable. Additionally, existing power systems is becoming obsolete and no longer can address the sustainability, security and economic requirements of today's population. This demands improvement in grid infrastructure.

1.2.4 Satisfying Power Demand

The increasing population has triggered power shortage challenges. In country like India, there could get double within a decade. Such increase in power demand can be smartly managed by the smart grid technologies.

1.2.5 Integrating Clean Power

Fossil fuels will exhaust in next six decades which will lead to power shortage. So, it has become essential to use renewable energy based power resources rather conventional power plants The addition of renewable energy to existing grid have to address few issues. Smart grid will address the issues related to integration of renewable energy sources to the existing grid.

1.2.6 Environmental Impact

Global warming has turned out as an alarming issue in this current century. Fossil fuel based power plants has become a largest source of carbon emission. To move towards zero emission system it has become mandatory to deploy renewable energy source integration to existing grid.

1.3 Smart Grid Drivers

- For enabling a sustainable future, the smart grid is essential. For modernizing the existing grid, all stakeholders must be aligned together in attaining the common goals. The electric power delivery infrastructure needs to provide adequate, affordable energy to homes, businesses, and factories. To achieve these, there is an urgent need for major improvements in the world's existing power delivery system. A number of converging factors will drive the energy industry to modernize the electric grid.
- Smart grid drivers are the forces that have emphasized the need for smart grid for overcoming the challenges faced by power sectors. The challenges with existing grid have increased the need for reinvention of energy sector. The deployment of smart grid is based on important factors, namely inexorable increase in energy demand, global warming, empowering customer, economic competitiveness, energy reliability and security. For addressing these issues smart grid drivers are required. Since, these factors are major driving factors; they are also referred as Global drivers of smart grid

1.3.1 Economic Competitiveness

By including alternative energy sources, a new business models can be created to alleviate the challenge of a drain of technical resources in an aging workforce. The energy reliability can be increased through decreased outage duration. By replacing manual meter reading and field maintenance, labour cost can be reduced. Transmission and distribution system delivery losses can be minimized by improved system planning and asset management. Such grid management can prevent power theft and fraud, which may provide better billing and protect revenues of energy sectors.

1.3.2 Customer Empowerment

Without compromising the individual's life styles, an effective utilization of energy usage by customer can be triggered. Empowering customer so that they have more control over their energy utilization. To satisfy the customers energy demand and provide an uninterruptible power.

1.3.3 Inexorable Increases in Electricity Demand

The growth in population and technological advancement has escalated the demand for electricity. The tremendous growth in industrial sectors for providing goods and services has still increased the demand for electricity. As per world energy outlook 2014 datasheet, world electricity demand increases by almost 80% over the period 2012-2040. For satisfying such hike in energy demand, smart grid has become highly essential.

1.3.4 Global Warming

By considering the environmental impact, addressing global warming related issues have become vital. A major source of carbon emission is fossil fuel based power plant. To protect the world from global warming issues, a search for alternative fuel for energy production has become essential. Renewable energy based energy generation has become a good choice of energy production, where low carbon emission and high sustainability can be attained. To the existing system, integrating renewable energy source can be managed effectively by smart grid. Hence deployment of smart grid can create an ecology friendly energy production system.

1.4 Smart Grid Functions

Real time load management can be done by real time load measurement and its transfer. With the support of automation, automated connection and reconnection during fault occurrence is possible. Smart grid reacts to critical issues in a safe and secured manner. The entire process of smart grid can be managed and monitored under a single system called Wide Area Network. The following section will discuss the important functions of Smart grid.

1.4.1 Fault Current Limiting

With the deployment of sensor based technology, fault current limiting can be achieved. High degree network coordination will prevent the excessive damage under fault currents. The system reconfiguration will protect the excessive damage of system due to fault current. A special device called Fault Current Limiter is employed for fault current limiting. Such special devices can automatically limit high through currents that occur during faults.

1.4.2 Improved Fault Protection

Fault protection is defined as the process of identifying fault, its location for providing isolation and service restoration. Such process must be speed enough to provide better fault protection. Various types of faults have been categorized using sensor based technologies.

1.4.3 Diagnosis and Notification of Equipment Condition

To protect the system from fault condition, it has become mandatory to analysis the system or equipment working condition. Diagnosis and notification of equipment condition is defined as on-line monitoring and analysis of equipment. Such analysis reveals the equipment performance, and operating environment. Equipment abnormality namely excessive vibration, heat dissipation can be easily detected using diagnosis and notification of equipment condition. Diagnosis and notification of equipment condition supports in accurate fault identification and service restoration automatically.

1.4.4 Wide Area Monitoring, Visualization and Control

- As the grid is too wide, monitoring its performance manually is highly impossible. So, a monitoring and visualization requires time synchronized sensors called Phasor Measurement Units (PMUs), communications, information processing and actuators. Wide area monitoring and control can provide real time protective action to be made.
- Automated voltage and VAR control requires coordinated operation of reactive power resources such as capacitor banks, voltage regulators, transformer load-tap changers, and Distributed Generation (DG) with sensors, controls, and communications systems. These devices could operate autonomously in response to local events or in response to signals from a central control system.

1.4.5 Power Flow Control

By using tools such as Flexible AC Transmission Systems (FACTS), Phase Angle Regulating Transformers (PARs), series capacitors, and very low impedance superconductors, power flow control can be easily attained. Flow control requires techniques that are applied at transmission and distribution levels to influence the path that power (real and reactive) travels.

1.4.6 Dynamic Capability Rating

Dynamic capability rating is defined as the ability to carry load based on electrical and environmental conditions. The real-time load carrying determination of line, transformer in presence of line tension, temperature, wind speed can be considered as dynamic capability rating in a smart grid.

1.4.7 Adaptive Protection

The signals from local sensor or central control room are used to provide an adjustable protective relay setting. Such settings are considered to be the response for real time signal generated from sensor. Adaptive protection is useful for feeder transfer and two way flow issues associated with high distributed energy resources (DER) penetration.

1.4.8 Automated Feeder and Line Switching

Automatic isolation and reconfiguration of faulted segments of distribution feeders or transmission lines via sensors, controls, switches, and communications systems can be realized using automated feeder and line switching. An autonomous operation of smart grid can be observed in response to local events or in response to signals from a central control system. Real-time load transfer is achieved through real-time feeder reconfiguration and optimization to relieve load on equipment, improve asset utilization, improve distribution system efficiency, and enhance system performance.

1.4.9 Automated Islanding and Reconnection

Automated islanding and reconnection is achieved by automated separation and subsequent reconnection (autonomous synchronization) of an independently operated portion of the T&D system (i.e., microgrid) from the interconnected electric grid. A microgrid is an integrated energy system consisting of interconnected loads and distributed energy resources which, as an integrated system, can operate in parallel with the grid or as an island.

1.4.10 Real-Time Load Measurement and Management

Advanced Metering Infrastructure (AMI) is a system that contains smart meters, two-way communications and embedded appliance controllers. Such infrastructures provide information to customers regarding their energy use decisions via real-time price signals, Time-Of-Use (TOU) rates, and service options. Hence in a smart grid, a real time measurement of energy consumption and load management by customers are communicated. It is possible by customers, when they are provided with information to make educated decisions about their electricity use. The cost, reliability, convenience, and environmental impact are the various factors that are needed to be optimized. This can be achieved by real time information sharing to customer.

1.5 Opportunities for Smart Grid in India

- The smart grid concept is not confined to utilities only; it involves every stage of the electricity cycle, from the utility through electricity markets to customers' applications. The emerging vision of the smart grid encompasses a broad set of applications, including software, hardware, and technologies that enable utilities to integrate, interface with, and intelligently control innovations. In country like India, deployment of such modern grid provides more opportunities in the field of energy sector.

- As a technology, the smart grid is proving to be very reliable and having multiple benefits. Smart grid is being considered the future for power grids across the globe. The deployment of smart grid technology at the earliest can help reduce commercial losses. In particular, losses due to theft by installing tamper proof smart meters provide better monitoring.
- Apart from this, minimizing transmission or technical losses by proper grid optimization and improving the grid infrastructure can also be obtained. Currently, India is under a lot of pressure to move towards zero emission system as imposed by international regulatory organizations. Reduction in carbon emission can be attained through integration of renewable energy sources via smart grid. Thus, environmental impact of existing grid can be overcome by smart grid.

1.5.1 Smart Grid Drivers in India

- India has few drivers' very similar to global drivers of smart grid. The adoption of the smart grid in India can improve the economic status of energy sectors. Shortfall in power, reduction of losses, automation, integration of clean energy and satisfying peak load demand are few smart grid drivers in India. The technological advancement and increasing affordability of household appliances is adding to the burden on the grid. It is estimated that India's demand shortfall are 12 % for total energy and 16 % for peak demand. Managing growth and ensuring supply is a major driver of Indian power sector.
- India's aggregate technical and commercial losses are thought to be about 25-30 %. The lack of transparency in metering may still have an increase in technical losses. India's supply shortfalls are expected to persist for many years. A smart grid would allow more intelligent load control. Such measures would help mitigate the supply-demand gap. Integrating customer relations management (CRM) and advanced metering infrastructure (AMI) data will be a key enabler in India, as it will help to attain the benefits of optimized capacity utilization and system performance.

1.6 Challenges for Smart Grids

- The smart grids technology platform has identified following key challenges that impact on the delivery of the mandated targets for utilization of renewable energy, increasing efficiency, minimizing costs, carbon emission and environmental impacts while maximizing system reliability, resilience and stability by 2020 and 2050.

  1. **Government support :** The utility industry is capital-intensive, but has been sustaining excessive losses due to thefts and subsidization. So, without the support of Government the industry may not have the financial capacity to fund new technologies. Incentives for investments are to be done through Government support.

2. **Lack of policy and regulation :** Since smart grid is a new technology, there are no defined standards and guidelines available for the regulation of smart grid initiatives in India.

3. **Compatible equipment :** The compatibility issues between existing equipment with smart grid technologies must be addressed. The replacement of older equipment with intelligent electronics devices is highly demanded.

4. **Capacity to absorb advanced technology :** The deployment of information and communication technology in the grid faces problems due to limited experience and skill in managing smart grid component.

5. **Consumer awareness :** The deployment of smart grid technology won't be beneficial without creating customer awareness. The end user must be educated with the importance and benefits of advanced metering and two-way communication. Else the features and benefits of a smart grid will not be achieved.

1.7 Smart Grid Implementation Challenges in India

Smart grid implementation means a transition towards the next generation grid through automation. In the current situation, monetary issues are found in power utilities. Inspite of this, there is a need to deploy basic automation systems for upgrading existing to an advanced level. The implementation of smart grid is not an easy task as the Indian power sector poses a number of issues such as minimizing losses, power theft, inadequate grid infrastructure, low metering efficiency and lack of awareness. By analyzing the growing power demand and market competence, this is the only way for domestic power industry.

1.7.1 Power Theft

In country like India, power theft has grown as major issues in power sector industries. Several techniques are needed to be adopted for preventing such power theft. Usually, power theft of energy happens through hooking lines. Insulated overhead lines, replacement of LT overhead wires with insulated cables are few methodologies to prevent power theft. Apart from these, solutions to eradicate power theft are replacement of conventional energy meters with digital tamper proof meters and deployment of prepaid card for energy utilization.

1.7.2 Inadequate Grid Infrastructure

India can provide a stable environment for investments in electric infrastructure, which is a prerequisite for fixing the fundamental problems with the existing grid. To build a modern, intelligent grid, Government has to provide funds for establishing this new technology.

1.7.3 Low Metering Efficiency

By improving metering efficiency, proper energy accounting & auditing can reduce commercial losses while increasing smart grid efficiency. Usually, low metering efficiency, theft and pilferage are reasons for commercial losses in a grid.

1.7.4 Lack of Awareness

In many developing countries, a major obstruction in deployment of new technologies is lack of awareness among users. End users have only a minimal knowledge on the way power to them. With a deployment of new technology, it has become mandatory to educate end users regarding benefits of smart grid. Consumers should be made aware about their energy consumption pattern at home, office etc. Utilities need to focus on the overall capabilities of Smart Grids rather than mere implementation of smart meters. Policy makers and regulators must be very clear about the future prospects of smart grids.

1.8 Smart Grid Benefits

- The smart grid presents a wide range of potential benefits, including optimizing the value of existing production and transmission capacity, incorporating more renewable energy sources, enhancement in energy efficiency, enabling zero emission system, improving load delivery efficiency, increased operational efficiency. The following discussion will highlight the benefits of smart grid implementation.

  1. Reliability of the system increases by deploying smart grid. The monitoring and management technologies enhance the reliability of smart grid. Smart grid will self-heal by redirecting energy during power outages to provide more reliable service. Self-healing of grid is defined as automatic detection of faults and response to routine problems. Such response can quickly recover the fault while minimizing financial loss. The measure of reliability is observed through higher customer satisfaction during brownouts, blackouts and surges
  2. Improvement in reliability can provide monetary benefit to customers, society, utilities and government. In particular power theft is reduced.
  3. The information and control over the grid will allow operators to draw energy supply from more efficient, renewable resources and optimize the grid assets. The technical and non technical losses of the grid can be reduced, which supports to improve smart grid efficiency. The reduction of transmission congestion, peak load and energy consumption can extend the life of system.

4. The smart grid is necessary for the efficient integration of renewable energy. The problems related to greenhouse gas emissions and reduced use of peak energy generators has increased need for renewable energy integration to smart grid.
5. A smart grid offers benefits to various consumers namely industrial, commercial, and residential. The consumers have the option of choosing demand based on real time pricing of energy.

1.9 Difference between Conventional and Smart Grid Traditional Grid

Whenever a new technology is introduced to the existing, its potential can be known only when a comparative study is done. The benefits of smart grid can be highlighted by performing a comparative analysis between traditional grid and smart grid.

1.9.1 Traditional-Grid

Traditional utility grid is a centralized system where power flows in one direction. The power flows from generation resources through the transmission-distribution system to the customer. The power generation station may or may not be located in the same geographic area as the load being served. This often requires transmission from distant locations. Existing utility grids may or may not include Supervisory Control and Data Acquisition (SCADA) sensors, computing, and communications to monitor grid performance. Thus, there requires a need for performing a separate periodical studies and reporting system. Here customer satisfaction is often restricted. Customers, generally receive information related to the periodic bill for their service.

1.9.2 Smart Grid

When compared to the traditional grid, here decentralized system is found. Thus, power flows in both direction, from generation resources through the transmission-distribution system to the customer and vice-versa are observed. In smart grid, power flow and information flow are enabled in the system. The grid allows power sources to be located closer to their point of use. This leads to minimization of investment in transmission and distribution system. Also reduction in energy losses is observed. Implementation of small generating resources can expand supply. Such measures can reduce risks of major outages, and improves overall reliability. Sensors provide the information for better understanding of grid operation, while control devices provide options for better management of system operation. Automation in fault detection and its restoration have made smart grid to be highly reliable. Smart metering installation has increase the energy economics. Smart appliances with embedded price, event-sensing and energy management capability are implemented.

1.9.3 Comparison between Conventional Grid and Smart Grid

Traditional grid	Smart grid
One-way communication	Two-way communication
Centralized generation	Distributed generation
Hierarchical structure	Network type structure
Low level of automation	High level of automation
High losses	Losses are minimized
Low efficiency and reliability	High efficiency and reliability
Low customer satisfaction	High customer satisfaction

1.10 Questions with Answers

1.10.1 Short Answered Questions

Q.1 Define electrical grid.

▣ **Ans. :** An electrical grid, electric grid or power grid, is an interconnected network for delivering electricity from producers to consumers. It consists of: generating stations that produce electric power.

Q.2 What is meant by smart grid ?

▣ **Ans. :** Smart grid is an electrical grid with automation, Communication and IT systems that can monitor power flows from points of generation to points of consumption (even down to appliances level) and control the power flow or curtail the load to match generation in real time or near real time.

Q.3 Compare traditional grid with smart grid.

▣ **Ans. :**

Traditional Grid	Smart Grid
One-way communication	Two-way communication
Centralized generation	Distributed generation
Hierarchical structure	Network type structure
Low level of automation	High level of automation
High losses	Losses are minimized
Low efficiency and reliability	High efficiency and reliability
Low customer satisfaction	High customer satisfaction

Q.4 What are smart grid drivers ?

▣ **Ans. :** Smart grid drivers are the forces that have emphasized the need for smart grid for overcoming the challenges faced by power sectors.

Q.5 What are global drivers of smart grid driver ?

▣ **Ans. :** The challenges with existing grid have increased the need for reinvention of energy sector. The deployment of smart grid is based on three important factors, namely inexorable increase in energy demand, global warming, empowering customer, economic competitiveness, energy reliability and security. For addressing these issues smart grid drivers are required. Since, these factors are major driving factors; they are also referred as global drivers of smart grid.

Q.6 State the need of improving smart grid awareness.

▣ **Ans. :** In many developing countries, a major obstruction in deployment of new technologies is lack of awareness among users. End users have only a minimal knowledge on the way power to them. With a deployment of new technology, it has become mandatory to educate end users regarding benefits of smart grid. Consumers should be made aware about their energy consumption pattern at home, office etc. Utilities need to focus on the overall capabilities of Smart Grids rather than mere implementation of smart meters. Policy makers and regulators must be very clear about the future prospects of smart grids.

Q.7 List out the benefits of smart grid.

▣ **Ans. :** The smart grid presents a wide range of potential benefits, including :

- Optimizing the value of existing production and transmission capacity
- Incorporating more renewable energy
- Enabling step-function improvements in energy efficiency
- Enabling broader penetration and use of energy storage options
- Reducing carbon emissions by increasing system, load and delivery efficiencies
- Improving power quality
- Improving a utility's power reliability, operational performance, asset management and overall productivity
- Enabling informed participation by consumers for empowering them to manage their energy usage.

Q.8 Define dynamic capability rating.

▣ **Ans. :** Dynamic capability rating is defined as the ability to carry load based on electrical and environmental conditions. The real-time load carrying determination of line, transformer in presence of line tension, temperature, wind speed can be considered as dynamic capability rating in a smart grid.

Q.9 In what way smart meter implementation will improve smart grid efficiency ?

▣ **Ans. :** Reliability of the system increases by deploying smart grid. The monitoring and management technologies enhance the reliability of smart grid. Smart grid will self-heal by redirecting energy during power outages to provide more reliable service. Self-healing of grid is defined as automatic detection of faults and response to routine problems. Such response can quickly recover the fault while minimizing financial loss. The measure of reliability is observed through higher customer satisfaction during brownouts, blackouts and surges.

Q.10 Give the various domains of smart grid.

▣ **Ans. :** The various domains in conceptual model are generation, transmission, distribution, operation, service provider, market and customer.

Q.11 What are the needs for smart grid ?

▣ **Ans. :** The following are needs for smart grid :

- To stop power theft
- To improve reliability of power
- Lack of infrastructure
- To fulfill power demand
- To integrate renewable power
- Environmental impact

Q.12 What are the four components of electric grid ?

▣ **Ans. :** The grid has four major components: electricity generators, transmission lines, distribution networks, and consumer use.

Q.13 Why smart grid is highly essential ?

▣ **Ans. :** A smart grid can help utilities conserve energy, reduce costs, increase reliability and transparency, and make processes more efficient. The increasing use of IT-based electric power systems, however, increases cyber security vulnerabilities, which increases cyber security's importance.

Q.14 What are the key features of smart grid ?

▣ **Ans. :** Features of Smart Grid are :

- Real time monitoring.
- Automated outage management and faster restoration.
- Dynamic pricing mechanisms.
- Incentive to consumers for alters the usage during different times of day based on pricing signals.
- Better energy management.

Q.15 What are the key characteristics of smart grid ?

▣ **Ans. :** The key characteristics of smart grid are :

- Self-healing
- Empowers and incorporates the consumer
- Tolerant of attack
- Accommodates a wide variety of supply and demand
- Fully enables and is supported by competitive electricity markets.

Q.16 Name few technologies that enable smart grid deployment.

▣ **Ans. :** Some of the enabling technologies that make smart grid deployments possible are :

- Meters
- Storage devices
- Distributed generation
- Renewable energy
- Energy efficiency
- Demand response
- Security
- Integrated communications systems

Q.17 Name environmental improvements attained through smart grids.

▣ **Ans. :** Smart grid can bring several environmental improvements by :

- Managing peak load through demand response rather than spinning reserves.
- Reducing transmission losses through better management of transmission and distribution networks.

- Monitoring equipment in real time
- Increasing transparency in electricity prices
- Reducing new infrastructure construction
- Integrating more renewable energy sources and energy storage

Q.18 What are challenges of smart grid implementation ?

▣ **Ans. :** The major challenges to be faced during smart grid implementation are :

- Government Support
- Lack of policy and regulation
- Speed of technology development
- Compatible equipment
- Capacity to absorb advanced technology
- Consumer awareness

Q.19 Specify the important functions of smart grid.

▣ **Ans. :** The following are the important functions of smart grid :

- Fault current limiting
- Improved fault protection
- Diagnosis and notification of equipment condition
- Wide area monitoring, visualization and control
- Power flow control
- Dynamic capability rating
- Adaptive protection
- Automated feeder and line switching
- Automated islanding and reconnection
- Real-time load measurement and management

Q.20 Define power theft.

▣ **Ans. :** In country like India, power theft has grown as major issues in power sector industries. Several techniques are needed to be adopted for preventing such power theft. Usually, power theft of energy happens through hooking lines. Insulated overhead lines, replacement of LT overhead wires with insulated cables are few methodologies to prevent power theft. Apart from these, solutions to eradicate power theft are replacement of conventional energy meters with digital tamper proof meters and deployment of prepaid card for energy utilization.

1.10.2 Long Answered Questions

Q.1 Discuss the conceptual model of smart grid with relevant diagram. **[Refer section 1.1]**

Q.2 Explain the need for smart grid. **[Refer section 1.2]**

Q.3 Define smart grid and discuss the various function executed by smart grid.

Smart Grid is an Electrical Grid with Automation, Communication and IT systems that can monitor power flows from points of generation to points of consumption (even down to appliances level) and control the power flow or curtail the load to match generation in real time or near real time.

For smart grid function **[Refer section 1.4]**

Q.4 Summarize the smart driver role in India. **[Refer sections 1.5 and 1.5.1]**

Q.5 Brief the challenges of smart grid. **[Refer section 1.7]**

Q.6 Enumerate the benefits of smart grid. **[Refer section 1.8]**

Q.7 Outline the features of smart grid by comparing it with conventional grid. **[Refer section 1.9]**

Q.8 What is an electrical grid? State the reasons for adopting smart grid. **[Refer section 1.1]**

Q.9 Discuss the role of automation in smart grid implementation. **[Refer sections 1.4.4, 1.4.5, 1.4.7 to 1.4.10]**

Q.10 How renewable energies are integrated into smart grid? **[Refer sections 1.2.5, 1.2.6, 1.3.4]**

1.10.3 Multiple Choice Questions

Q.1 In a traditional grid which of the below mentioned is/are true?

a One-way communication
b Centralized generation
c Hierarchical structure
d All the above

Q.2 An electrical grid is an interconnected network for delivering electricity from producers to consumers.

a True
b False

Q.3 In a smart grid ____________ can be accomplished.

a high reliability
b high loss
c unidirectional communication
d none of the above

Q.4 ______________________ is the benefit of smart grid

a Information hacking
b Delivers low efficiency
c Increasing carbon emissions
d Improving power quality

Q.5 In smart grid _______________________ needed.

a to stop power theft
b to improve reliability of power
c lack of infrastructure
d all the mentioned

Q.6 Real time monitoring can be done in ________________.

a traditional grid
b smart grid
c both a & b
d none of the above

Q.7 _______________ is the feature of smart grid.

a Automated outage management and faster restoration.
b Static pricing mechanism
c Poor energy management
d Offline monitoring

Q.8 The major challenge to be faced during smart grid implementation is ___________.

a lack of technology advancement
b lack of policy and regulation
c incompatible equipment
d consumer satisfaction

Q.9 Mark the functions of smart grid.

a Improved fault protection
b Diagnosis and notification of equipment condition
c Wide area monitoring, visualization and Control
d All of the mentioned

Q.10 Power theft happens due to __________________.

a hooking lines
b insulated overhead lines
c replacement of LT overhead wires with insulated cables
d smart meter

Q.11 Self-Healing of grid is defined as ______________.

[a] response to routine problems
[b] automatic detection of faults
[c] both a and b
[d] smoothening of power quality

Q.12 The implementation of smart grid is not an easy task as the Indian power sector poses ________________.

[a] power theft
[b] inadequate grid infrastructure
[c] low metering efficiency
[d] all of the mentioned

Q.13 India's aggregate technical and commercial losses are ___________.

[a] 25-30%
[b] 35-40%
[c] 15-20%
[d] 10-25%

Q.14 The smart grid co-ordinates needs of ___________________ for ensuring an effective operation.

[a] generators
[b] grid operators and end-users
[c] electricity market stakeholders
[d] all the mentioned

Q.15 _________ domain executes the billing and customer account management, monitoring and controlling of energy use.

[a] Customer
[b] Market
[c] Service provider
[d] Distribution

Q.16 The flow of electricity is managed in __________ domain.

[a] transmission
[b] distribution
[c] service provider
[d] operation

Q.17 Existing power systems can't address ____________

[a] sustainability
[b] security
[c] economic requirements of today's population
[d] all the mentioned

Q.18 What is the role of cloud in smart grid architecture of IoT ?

[a] Store data
[b] Manage data
[c] Collect data
[d] Security

Q.19 A major source of carbon emission is ____________ based power plant.

[a] solar [b] wind [c] fossil fuel [d] biomass

Q.20 The entire process of smart grid can be managed and monitored under a single system called ______________.

[a] LAN [b] HAN [c] WAN [d] None of the mentioned

❒ Answer Keys for Multiple Choice Questions

Q.1	d	**Q.2**	a	**Q.3**	a	**Q.4**	d
Q.5	d	**Q.6**	b	**Q.7**	a	**Q.8**	b
Q.9	d	**Q.10**	a	**Q.11**	c	**Q.12**	d
Q.13	a	**Q.14**	d	**Q.15**	c	**Q.16**	d
Q.17	d	**Q.18**	b	**Q.19**	a	**Q.20**	c

❑❑❑

Notes

UNIT - II

2 Smart Grid Technologies

Syllabus

Technology Drivers, Smart Energy Resources, Smart Substation, Substation Automation, Feeder Automation, Transmission Systems: EMS, FACTS and HVDC, Wide Area Monitoring, Protection and Control, Distribution Systems: DMS, Volt/VAR Control, Fault Detection, Isolation and Service Restoration, Outage Management, High Efficiency Distribution Transformers, Phase Shifting Transformers, Plugin Hybrid Electric Vehicles(PHEV).

Contents

2.1 Technology Drivers

2.1.1 Introduction

- Today's electric power distribution network is highly complex and not suited to the needs of the 21st century. The various deficiencies include lacking in automated analysis, slow response caused by mechanical switches, ignorance of situational awareness, to mention the few. In the smart grid, trustworthy and online information becomes the key factor of continuous delivery of power from the generating units to the end-users. The impact of equipment failures, capacity constraints, and natural catastrophes, which cause unexpected outages, can be largely avoided by online power system condition monitoring, diagnostics and protection.
- In the past decades, to increase the quality of supply and incorporate more distributed generation, automation of distributed system has gone up. The revolution in communication systems has caused the idea of distribution automation. The distribution network which once was passive is becoming active management these days. But due to the connection of distributed generation network voltage changes and fault level increases. Without active management of network, the connection of distributed generation will not be economical. The operation performance, efficiency, reliability and quality of service is enhanced by automation distribution.

2.1.2 An Overview of Technology Drives Required for the Smart Grid

- To satisfy the multiple requirements of the Smart Grid, the following technology drivers must be developed and implemented:
  1. Information and communications technologies.
  2. Control and automation technologies which includes sensing and measurement.
  3. Power electronics and energy storage technologies.
  4. Demand-Side Management (DSM).

2.1.3 Information and Communications Technologies

- Information and communications technologies include :
  1. Communication technologies that will operate in two ways which is able to provide connectivity between different elements in the power system and loads.
  2. Broad constructions for plug-and-play of home devices and electric vehicles and micro-generation.

3. Communications systems with important software and hardware to warn customers with accurate information. They also help customers to trade in energy markets and enable customers to provide DSM (Demand-Side Management).
4. Software to make sure and maintain the security information and standards to give scalability and interoperability of information and communication systems.

➥ 2.1.4 Control and Automation Technologies which Includes Sensing and Measurement

- Sensing, measurement, control and automation technologies include :

1. Intelligent Electronic Devices (IED) to build advanced protection devices, measurements, fault data and event records for the power system.
2. Phasor Measurement Units (PMU) and Wide Area Monitoring, Protection and Control (WAMPAC) to enhance the power system security.
3. Control and automation systems, integrated sensors, measurements, and communication technologies to correctly identify the problem and to take timely corrective action in various parts of the power system. These will support the enhanced asset management and effective operation of power system components. They will relieve congestion in transmission and distribution circuits and prevent or reduce potential outages and enable working autonomously when conditions require quick resolution.
4. Smart appliances, communication, controls and monitors help to increase safety, comfort, convenience, and energy savings.
5. Smart meters, communication, displays and relevant software will give access to customers to exercise correct choice and control over electricity and gas usage. They will provide consumers with accurate bills. They will operate faster. They provide consumers trustworthy real-time information on their electricity and gas use and other related information. They enable demand management and demand side participation.

➥ 2.1.5 Power Electronics and Energy Storage Technologies

- Power electronics and energy storage technologies include :

1. High Voltage DC (HVDC) transmission and Flexible AC Transmission Systems (FACTS) to make possible long distance transmission with the integration of renewable energy sources.
2. Various power electronic interfaces and advanced IED supporting devices will offer efficient integration of renewable energy sources and energy storage devices.

3. Unified Power Flow Controllers (UPFC), series capacitors, and other FACTS devices will offer excellent control over power flows in the AC grid.
4. HVDC, FACTS and active filters combined with integrated communication system that gives control over greater system flexibility, supply reliability and power quality.
5. Interfacing power electronic devices and integrated communication systems will result in better performance by controlling renewable energy sources, consumer loads and energy storage.
6. Increase in energy storage which will result in greater flexibility and reliability of the power system.

➥ 2.1.6 Demand-Side Management (DSM)

Demand-Side Management (DSM) is the modification of consumer demand for energy through different methods like financial incentives and behavioral change by means of education. Usually, the aim of demand-side management is to motivate the consumer to utilize lesser energy during peak hours, or to move the time of energy use to off-peak times such as nighttime and weekends. Peak demand management does not deal with decrease in total energy consumption, but it reduces the need for investments in networks and/or power plants for meeting peak demands. The use of energy storage units to store energy during off-peak hours and discharge them during peak hours is the best example. The application for DSM is to help the grid operators for balancing intermittent generation from wind and solar units, especially when the timing and magnitude of energy demand does not coincide with the renewable generation. The electric power industry is dependent on foreign energy imports, whether in the form of consumable electricity or fossil fuels that was then used to produce electricity. Nowadays, DSM technologies are feasible due to the integration of information and communications technology with the power system. New terms such as integrated demand-side management (IDSM), Energy demand management is none other than the modification of consumer demand for energy through various methods such as financial incentives and behavioral change through education.

➥ 2.1.7 Categories of DSM

DSM is classified into three categories as follows :

❐ 1. Direct control of load :

This makes use of communication system like power line carrier to transmit control from the utility side to the customer. The goal is to have direct control of load, generators and storage.

❒ 2. Local load control option :

This authorizes customers to self-adjust loads to limit peak demand, e.g., demand-activated breakers, load interlock, timers, thermostats, occupancy sensors, cogeneration heating, cooling storage, etc.

❒ 3. Distribution load control :

The utility controls the customer loads by sending real time prices.

2.1.8 Constraints of DSM

The following are the constraints of DSM :

❒ 1. Technological constraints :

They are dependent upon the use of modern communication for remote metering, billing and local controls, and management of power.

❒ 2. Economic constraints :

These constraints involve financial advantages, investment commitments in network expansion and properties. They provide an incentive for utilities so that business operations are diversified.

❒ 3. Social constraints :

These constraints deal with environmental objectives. This provides excellent energy efficient operation. DSM options are controlled by utility's energy cost cutting.

❒ 4. Political and institutional constraints :

These constraints are dependent upon the government, equipment manufacturing companies and institutional support.

2.2 Smart Energy Resources

- The operation and planning of the grid is a complex process that will ensure the dynamic balance of the supply and demand of the electrical grid. Utilities will make sure that there is sufficient margin of supply under outages and contingencies in the generation supply, changes in the transmission and distribution grid configuration. Utilities will schedule and dispatch generators so that cost is reduced and efficiency is maximized providing security of supply. In the past, the load on the grid depended on individual consumer energy usage levels. Particularly, Utilities part was less visible with the loading patterns at the distribution feeder or individual consumer level. Implementation of more advanced technologies is also made possible with the help of utilities which in turn balance the supply-demand equation, such as adding distributed generation to the grid, and changing consumer load behaviors through energy pricing options or real-time pricing signals.

- Smart Energy Resources are defined as the new set of resources available to utilities balance the supply-demand equation-renewable generation, energy storage, and consumer demand management. The challenge is dependent on the long-term planning and new resources implementation. Smart Energy Resources directly affects the real-time operation and management of the supply-demand equation, which in turn operates an open access market.

➥ 2.2.1 Types of Smart Energy Sources

- Renewable sources of electrical energy vary in their varieties. The renewable energy sources differ from other conventional energy sources in such a way that renewable give energy that is cleaner and free of pollution.
- When generating power will not deplete natural resources. The very important point is that renewables can be measured to the correct size from single-house applications to large-scale renewables, which is able to supply power to thousands of homes.
- Some of the most common renewable energy resources are as follows :

1. Solar PV
2. Solar thermal energy
3. Wind energy
4. Bio mass and Bio gas
5. Geo thermal power
6. Hydro power
7. Fuel cells
8. Tidal power

➥ 2.2.2 Advantages of Using Renewable Energy

1. Great reduction in emissions of greenhouse gases.
2. Significant reduction in demand for peak electrical generation.
3. Substituting investment in generation, transmission, or distribution assets.
4. Improving the reliable operation of the electrical transmission or distribution grid.

2.2.3 Solar PV

Solar PV generation has experienced an enormous growth in recent decades because of increasing demand for renewable energy sources. In PV generation, when solar panels are being exposed to light they will generate electric power. Power generated is dependent on the conversion of the energy of the radiation of sun. When a solar cell is exposed to light electrons transfer between different bands inside the material. This, in turn, results in a potential difference between two electrodes, which causes Direct Current (DC) to flow. There are many main PV applications, such as solar farms, building, and supportive power supply in transportation utilities, stand-alone utilities, and satellites. Utilities globally have already incorporated solar farms into their generation during the last decade. To integrate solar farms into utility grids, Alternating-Current / Direct-Current (AC/ DC) converters are needed, as well as the associated control and protection systems. The chief issue with PVs is its discontinuous way of power production. Since PV is a variable power source which cannot be predicted accurately, many efforts have been undertaken to increase the easy dispatch of PV power. Successful approaches have included adding battery storage to store the PV energy during off-peak hours or low demand, and then discharging the batteries during peak usage periods. The issues of intermittency can be reduced to some extent when PV is combined with other generating technologies. In the present generation, solar PV represents lesser than 0.5 % of total global power generation capacity. Anyhow, in some areas of the world, the implementation of PV is increasing to a greater extent (e.g., states in Australia such as South Australia and Queensland). PV growth is currently realized in both the deployment of centralized power plants, as well as small customer-owned DG, bringing electrical challenges not only to the large transmission power systems but also at the distribution level.

2.2.4 Solar Thermal Energy

Solar Thermal Energy (STE) converts solar energy into thermal energy (heat). There are three types of collector levels used in this technology. Based upon the temperature levels they are categorized as low, medium, and high. Practically, low-temperature collectors will be located on flat plates to heat swimming pools. Whereas, medium-temperature collectors are placed on flat plates. Water is heated using these flat plates. Electric power is produced using these temperature collectors. Thermal energy is measured by the intensity of heat. As the sun rays hits the surface of the object, heat energy is gathered from it. Then, heat is transmitted by either conduction or convection. Even in cloudy days when insulated thermal storage is used it will produce electrical energy in a lower measure. However the efficiency of STE will be very low which comes closer to 30 % for solar dish engine technology.

2.2.5 Wind Energy

- Wind power is harnessed by means of wind turbines to convert the energy of the wind into electricity. Wind energy is the mostly preferred renewable energy source because it is the leading clean technology and does not produce greenhouse gas emissions. The main disadvantage of wind power is its discontinuous nature and the impact on the environment namely visual, noise, and wildlife. Under regular operating days, the power produced by the wind turbine will be completely utilized as long as it is available.
- The wind turbine will be stopped, if the power from the wind turbine is not used. Also the excess power generated may be used to charge an energy storage system. Due to the discontinuous nature or variability of the wind speed, power output from wind turbines is not consistent. Discontinuous production of power by wind turbines is the disturbing reason why wind farms cannot be used in a utility's base-load generation portfolio without the addition of energy storage. The wind turbine capacity factor ranges from 20 % to 40 %.

2.2.6 Biomass and Biogas

Biomass energy production refers to power production from dead trees, wood chips, plant or animal matters which are used for production of chemical or heat. Technologies linked with biomass conversion to electrical energy consist of utilizing energy in the form of heat or the converting them in to other forms like combustible biogas or liquid biofuel. The disadvantage of biomass as a fuel is its tendency for increased air pollution. The biomass industry has recently experienced a growth and increase in the level of electricity production in all over the world.

2.2.7 Geo Thermal Power

Geothermal power is derived from the earth through natural processes. Some of the technologies that are used today include such as binary cycle power plants, flash steam power plants, and dry steam power plants. Geo thermal power plants offer very low thermal efficiency. But the capacity factor will be close to 95 %. Geothermal plants can be varying in size. Geothermal power is trustworthy and economical due to no fuel costs, but initial capital costs associated with deep drilling as well as earth exploration which are the limiting factors from higher penetration of geothermal resources.

2.2.8 Hydro Power

Hydropower plants utilize the energy of the moving water as the main source for electric power production. When the falling water hits the blades on the rotor, this will cause the rotor to turn, thus producing electricity. Often times, hydropower plants are constructed in water abundant places. Also, when water movement is found to be fast like valleys and mountains, there also hydro power plant is erected.

2.2.9 Fuel Cells

A fuel cell uses the chemical energy of hydrogen or another fuel to produce electricity which is clean and efficient. When hydrogen is the fuel, water, heat, and electricity are the only products. Fuel cells work like batteries, but they do not run down or need recharging. They produce electric power and heat as long as fuel is given as input. A fuel cell consists of a negative electrode (or cathode) and a positive electrode (or anode) which is sandwiched around an electrolyte. Fuel cells can convert the chemical energy in the fuel to electrical energy with efficiencies of up to 60 %.

2.2.10 Tidal Power

Tidal power harnesses the energy of tides into electricity. The widely used tidal power technologies are tidal stream generators and tidal barrages. Under water tidal stream rotates and generates electricity using the kinetic energy of tidal streams. Tidal barrage makes use of a dam constructed across the wide river at the place where it joins the sea (tidal estuary) to produce electricity using the potential energy of water. The turbine blades move depending upon the tide movement. When the tide is high, water flows into the barrage and when it is low, water is released to move the turbines. Advanced technologies such as dynamic tidal power are under development in recent years. This technology takes advantage of both kinetic and potential energy of tides.

2.2.11 Renewable Energy in the Smart Grid

- To integrate renewable energy generation at high penetration levels, several planning and working guidelines must be followed.
- A smart grid strategy is necessary to achieve high renewable penetration should include the following :

1. Generation must integrate and utilize various alternative resources.

2. Advanced smart grid transmission facilities, including fast responsive energy storage, Flexible AC Transmission Systems (FACTS), HVDC (high-voltage direct current), Wide Area Monitoring, Protection and Control (WAMPAC), etc., must be incorporated
3. Smart grid applications on distribution networks including distribution automation, Fast Demand Response (FDR), including Distributed Resources (DRs) on the distribution feeders, distributed energy storage, Plug-in Electric Vehicles(PEVs) charging control, demand-side management (DSM), etc., must be taken into account.

- Additional transmission planning is needed to identify facilities and storage options to integrate these high levels of renewable energy sources.

2.3 Smart Substations

- An electrical substation is the central point of an electric power generation, transmission, and distribution system where the voltage is transformed from high to low or reverse using transformers. Electric power flows through several substations between generating plants and consumer load points. Usually voltage is changed in several steps. There are different kinds of substations, such as transmission substations, sub-transmission substations, and distribution substations.
- The general functions of a substation include the following :
  1. Transformation of voltage level
  2. Transmission and distribution power lines connecting point
  3. Configuration of switchyard for electrical transmission and distribution system
  4. Monitoring point for the control center
  5. Protection of power lines and other apparatus
  6. Reliable communication with other substations and regional control centers

2.3.1 The Role of Substation in Smart Grid

- Substations in a smart grid will move beyond basic protection and conventional automation schemes to bring complexity around distributed functional structures, communications architectures, and data management. There will be a movement of intelligence from the traditional centralized functions and decisions at the energy management and DMS (Distribution Management System) level to the substations which in turn enhances reliability, security, and responsiveness of the transmission and distribution system. The project system applications will become tough to coordinate as it becomes more complicated. When large scale of new generation is integrated with the active load technologies into the electric grid, this introduces real-time system control and operational challenges around reliability and security of the power supply. Improper maintenance of these technologies will result in degradation of service, diminished asset service life, and unexpected grid failures. Finally, the financial performance of the utility's business operations and public relationship will be affected. If these challenges are properly met, then effective optimal solutions can be brought into picture by the utility to maximize return on investments in advanced technologies.

- Some challenges must be addressed to achieve these needs :

  1. Very high numbers of operating contingencies different from expected system design.
  2. The impact of discontinuous renewable and distributed energy resources with their present characteristic.
  3. Voltage and frequency variation like power quality issues which cannot be immediately addressed by traditional solutions.
  4. Effective and highly distributed, advanced control and operations logic.
  5. When disturbance and corresponding response gap is large.
  6. Integration of advanced protection methods to rapidly changing operational behavior due to the discontinuous nature of renewable and DER (Distributed Energy Resources).

➥ 2.3.2 Types of Substations

- One of the main parts of power system is substations. They transform voltages from high tension to low tension and vice versa at correct frequency and power factor. They transmit power from generating stations to consuming centers depending upon the demands of various loads. They can be subcategorized into three major types.

  1. Transmission substation
  2. Sub-transmission substation
  3. Distribution substation

➥ 2.3.3 Transmission Substation

This type of substation connects generating station with industrial types of loads. It will be having many parallel interconnections in the transmission system. They transmit power over longer distances. Generally, transmission lines operate at voltages above 138 kV. Transmission substation operation includes transformation of one voltage level to another without changing the power to be transmitted.

2.3.4 Sub-Transmission Substation

- This type of substation lies between transmission substation and distribution substation.
- Mostly it is used in radial feeders. It operates between 34 kV to 138 kV. Big industries will be consuming bulk power that act as loads for these types of substations.

2.3.5 Distribution Substation

This type of substation comes between sub-transmission substation and retail consumers. It directly energizes small scale industries and residential consumers without compromising power quality. Distribution feeders will transmit electric power in larger area by using distribution transformers. The voltage level ranges between 2.4 kV to 34 kV.

2.3.6 Objectives of Smart Substation

- The following are the objectives of smart substation :
  1. The real time testing of intelligent distribution with highest reliability and control this will drive the underlying grid.
  2. Ensuring automatic energy saving concepts and systems for the satisfaction and convenience of consumers.
  3. Providing a reasonable, reliable and affordable electricity supply to consumers.

2.3.7 Smart Substation Layout

- The idea of smart substation is nothing but to build an absolute intelligent substation where all devices will work and collaborate in a systematic way to achieve excellent outcome. Excellent controllability and increased automation is made possible by Intelligent Electronic Devices (IED). It empowers remote using and managing of system devices using remote control commands. Some of the features of smart substation are reliability, economy, simple operation, intelligent control and low environmental impact. It must also include measures to expand with new future technological advances.
- Fig. 2.3.1 illustrates the typical layout of smart substation with its essential components. This network-based architecture in many ways also gives a significant response time while accessing quickly the important data, and minimizing system time management with lesser configuration. These benefits are obtained with higher bandwidth connections to the relays in line with the utility's interest. To illustrate with an example, SCADA systems that have been widely utilized in the past. These were largely hardwired control systems with

excellent remote monitoring schemes exchanging data over low speed communications links. In recent years, the application of microprocessor-based IEDs has increased. So effective communication between RTU, IEDs, data concentrator and other substation components has become possible.

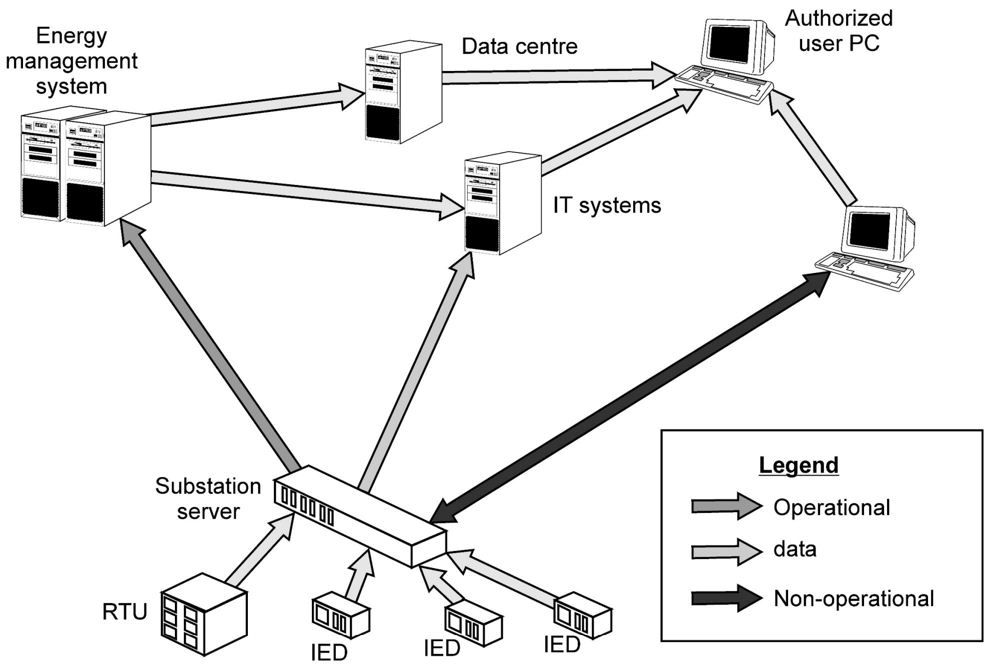

Fig. 2.3.1 : Smart substation layout

- When the installed number of IEDs increases in substations, it will become easy to integrate the protection, control, and data acquisition functionality. The past information which is extracted from RTU will be available now for the present operations from the IEDs. But it is not possible for the master station to communicate with all IEDs from all substations. But to have efficient data flow, advanced devices will be used.
- A substation server communicates with all the IEDs at the substation. When all the information is collected by substation server form IEDs, it will communicate back to the master substation. The IEDs at the substation invokes many different communications protocols. The substation server should have the ability to communicate via these protocols, as well as the master station's communications protocol. The SCADA system will have access to information from IEDs when substation server gives permission. The substation server will have access to all IEDs and RTU. Now, IEDs and RTUs with network connections are polled over the substation LAN (Local area network). The substation server polls serially the IEDS which are having serial connection. The SCADA system

performance will be improved by substation server while the communication process occurs. This increases the availability of IED more in measure. The master station will have its communication links only with the substation server. Many RTUs and IEDs are not directly communicated by the master station. The communication ability of the substation will always be superior than that of the IEDs. This will result in connection of less number of devices directly to with the master station. Because of this significant reduction in connection numbers, the communication performance will increase in greater measure.

- Substations will be having two kinds of data. The one is operational or real-time data and the other is non-operational data. The real time data which are needed to operate the utility systems is known as operational data. They are very much important in performing energy management system (EMS) software applications like Automatic Generation Control (AGC). EMS applications will store these data. They are available as historical data. Non-operational data are historical, real-time, and file type data. They are used for analysis, maintenance, planning, and other utility applications. A large amount of information is stored in modern IEDs. This information will have the data relevant to advanced metering system and relay protection. As said already, many advanced and intelligent devices store thousands of data points available. But the master station will not process this huge volume of data directly. This valuable information will be useful to utilities and customers. To extract and apply these data, special mechanism is developed. This mechanism will operate independent of the master station. Normally the operational data will connect EMS and substation. Non-operational data will be transferred from the substation to various utilities through another path of information technology (IT) systems. These networks are handled by individual departments in many utilities, and in general, physical limitations exist between the networks at control centers and substation.
- The following are the advantages of this network based control strategy :

  1. There is an excellent improvement in speed and connectivity. The communication bandwidth is enlarged by an Ethernet-based Local Area Network (LAN). A direct link is formed by the network layer protocol. It offers connection to devices from anywhere in the network.
  2. Anytime availability of logical channels increases. Network protocols support multiple logical channels across multiple devices.
  3. Integration of data from new sources significantly increases. Unique protocol will be activated by IED. This protocol will help to transfer data without disturbing other processes.

2.3.8 Features of Smart Substation

The following are considered as features of smart substation :

1. Gathering information about power flows and stabilizing it in the medium and low voltage networks.
2. Incorporating intelligent devices for all kind of operations.
3. Ensuring whether all control and protection devices have been networked properly.
4. Maintaining the voltage levels of all networks efficiently.
5. Minimizing power shortages and identifying power theft.
6. Reducing power quality problems such as harmonics, sudden voltage drops and flicker.
7. Ensuring the formation of micro grids and increasing their autonomous operation.

2.4 Substation Automation (SA)

- Most of the substations are rated 220 KV and above in India with ageing more than 40 years. It requires multiple stages of building in order to realize a substation for distribution purposes. The maintenance and operation of substation cost is usually higher. The electric utility substation is very strategic to operations and business. Compared to other electric utility network, the substation has the highest density of valuable information needed to operate and manage a smart grid. The design of primary equipment plays a vital role in substation automation. It must be environmental friendly and have low operation and maintenance cost.
- Substation Automation (SA) assures to give more efficient way of delivering and consuming power. In essence, substation automation is a data communication network allied with power grid. The grid operators will collect and analyze the data about power generation, transmission and distribution in real time application. Smart grid communication technology gives predictive information which will command the utilities, suppliers and customers to manage the power in a better way. To reach this goal, a better power grid communication infrastructure is much needed. With the evolution of modern communication systems from telephone modems to IP networks, many utilities are still using modem access and serial bus technology for communication purposes.
- The present supervisory control and data acquisition (SCADA), remote terminal unit (RTU) systems placed inside the substation cannot completely measure up to support the emerging next generation intelligence. So intelligent electronics devices (IED) are more widely used to transform their communications from serial to internet protocol (IP) based

communications. Conventionally, the secondary of circuit breakers, isolators, current and voltage transformers are soldered to relays. Relays are connected to station computer through serial links for monitoring and controlling purpose. The real time substation automation is already depicted in the Fig. 2.4.1.

- Substation automation (SA) thoroughly integrates IEDs for improved visibility, situational awareness, remote monitoring. Real-time control and automation functions are improved using supervisory control and data acquisition (SCADA) in a substation. This will facilitate improved reliability and condition-based asset management. The most effective way to approach SA is to develop a business case that makes costs and benefits transparent before a project is undertaken. This will result in cost benefits which will support company business drivers. Monetary benefits mean ROI (Return on Investment) measured in years, while strategic benefits are not directly quantifiable, such as a reduction in customer outages.

➥ 2.4.1 Configuration of Substation Automation

The configuration of modern substation automation consists of three levels of equipment function :

❒ 1. The station level function :

This includes the substation computer, the human-machine interface (HMI) and the gateway to control center which informs the status of station equipment. The message specification network acts as a communication link between SCADA, control center and IEDs at bay level and station level. In order to achieve high reliability, excess networks are used in this state level function.

❒ 2. The bay level function :

This comprises of all the controllers and intelligent electronic devices as shown in the Fig. 2.4.1. The main function of these devices is to provide protection for different utilities. Also they carry out a real time evaluation of the distribution network. The IEDs will fully operate in pace with the internet protocol (IP). The phasor measurement unit (PMU) will take care of the measurement of synchronous phasor. In wide area power system monitoring and control, PMUs are mostly used. The inter operation between various IEDs is achieved by GOOSE networks. Generic Object Oriented Substation Events (GOOSE) is a controlled model mechanism or network in which any format of data (status, value) is grouped into a data set and transmitted within a time period of 4 milliseconds.

❒ 3. The process level function :

- In this level of operation optical voltage and current sensors are used instead of conventional transformers. It comprises of switchgear control and monitoring, current transformers (CTs), potential transformers (PTs) and sensors. The merging unit (MU) will consist of all these utilities. Analog signal are received from CTs and PTs which will be converted into optical signals by merging unit. These signals are transferred to protection and control devices via optical fibres. One of the chief advantages of this way of transfer is transformer insulation requirement reduces. It will also mitigate the interference present in the analog signal transmission. Intelligent control units act like intermediate link for circuit breakers interfacing. It converts analog signal from circuit breakers and switches which are primary devices into digital signals.

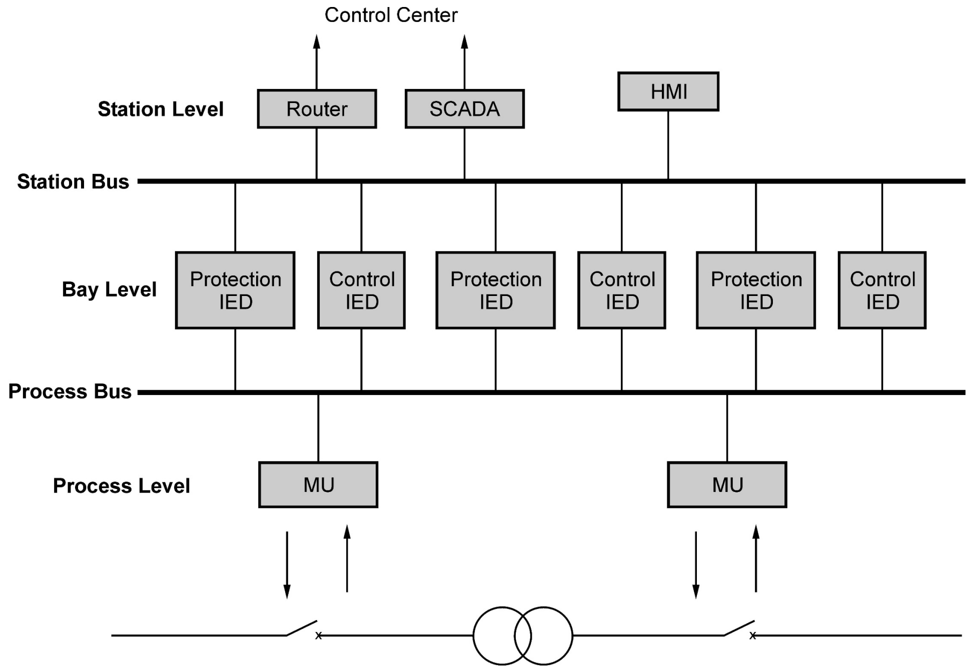

Fig. 2.4.1 : Substation automation configurations

- The protection and control unit receives the converted signal through process bus. The tripping and reclosing commands issued by protection and control unit will be converted into analog signals. Then, the switchyard provides controlling action of the primary equipment. Optical fibres effectively replace a large quantity of copper wires that usually lies between IEDs and primary devices in the conventional substations. Traditional substations use hardwire for long distances through ducts and cable trays. This unfortunately increases the cost and design inflexibility. These shortcomings are completely overcome by smart substations.

2.5 Feeder Automation (FA)

- Feeder automation normally involves installation of sectionalizing devices, and switches, along the feeder. When there is a problem or crisis in the feeder, data will be fed back to the substation or control center for analysis. Once the problem is identified, an expert can remotely activate the switch to segregate the segment causing the trouble and reroute service to sections on either side of the problem, or this process may be done automatically. Many other services related to power quality are incorporated by automating the feeder, like voltage improvement to manage load and capacitor placement and reactive power control to reduce losses.
- The challenges faced by feeder automation are numerous and are spread over large geographic areas. This makes the installation and maintenance of two-way communication an expensive proposition. As a result, feeder automation is often limited to the 10 or 15 worst performing feeders. By paying attention on problem causing feeders, utilities spend less money which will guarantee their automation investment that pay off in reduced duration and frequency of outages. This approach for targeted feeder automation is likely to remain standard procedure in distribution automation projects. Three utilities are involved in feeder automation. The typical feeder automation layout is shown in Fig. 2.5.1.

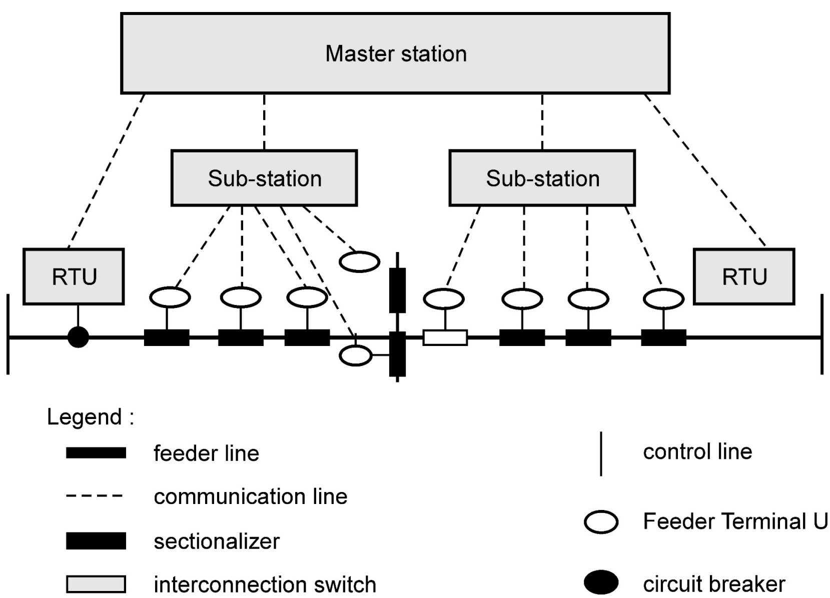

Fig. 2.5.1 : Feeder automation layouts

- The first one is voltage control. Utilities can have effective control of the load which can be achieved by controlling the voltage at the feeders. This is done on peak times for peak load reduction as well as it can be achieved during off peak-times to lessen electricity consumption. But usually voltage control is carried out at peak periods because it brings down the requirement to deploy peaking production plants which are costly.

- The second utility for feeder automation is reactive power control. Reactive power is very important entity in electric system. In order to achieve near unity power factor, which means large transfer of real power, the reactive power must be very low. It can be achieved by using automation technologies. This technology will provide an improvement in power factor which will reduce losses. The third utility is knows as Fault Detection Isolation Restoration (FDIR). It is used to ensure the reliability of the system. This technology automatically detects the disturbance that occurs in the distribution network and locates it. The system will disconnect the faulted segment by opening the switches on either side of the fault point. Importantly, it will continue the service excluding the fault point which will ensure the reliability of the electric system. With respect to consumer's point of view, improvement in reliability is a very important one. The performance of utilities is frequently reported to the power pools which they are a part. Any utility that under performs become well known to consumers.

2.5.1 Feeder Automation Functions

The following are the chief functions of feeder automation :

1. Fault identification, faulty part isolation and service restoration
2. Network reconfiguration
3. Load management / demand response
4. Active and reactive power control
5. Power factor control
6. Short-term load forecasting
7. Three-phase unbalanced power flow
8. Interface to Customer Information Systems (CIS)
9. Interface to Geographical Information Systems (GIS)
10. Trouble call management and interface to Outage Management Systems (OMS)

2.6 Transmission Systems

- The transmission systems are automated all over the world. However, due to the ever increasing power demand with the networks getting larger, the complexity of operation is challenging. The distances between bulk generation and load centers are widening, and at the same time the challenges of integrating large-scale renewables has added additional constraints to the transmission system. Coordinating with generating stations to reach power balance is the responsibility of the transmission control centers. However, the recent blackouts in many parts of the world demands more focus on the transmission control centers and the way the monitoring and control are implemented. This indicates that SCADA systems are not enough for effective monitoring in times of worst contingencies. So the focus is turned on Phasor Measurement Units (PMU) and the Broader Wide-Area Monitoring and Control Systems (WAMS). Because they ensure security and allow the transmission network to operate closest to its capacity. Smart transmission has become the integrated part of smart grid technology.

- With the invention of more advanced technologies, such as FACTS and HVDC, transmission system will have efficient power flow control and enhanced stability. The changes in the generation mix will likely require substantial new transmission growth over the coming years. Transmission network expansion projects will concentrate on renewable generation to densely populated regions of the country. This will help the nation to use its existing generation more fully while providing path for further investment in additional renewable capacity. Also monitoring and control requirements for the distribution system will increase.
- When data exchange happens between Smarter Distribution Field Devices (SDFD) and enterprise applications, the efficiency of integrated smart grid architecture will be enhanced. While considering the grid-edge, substations in a smart grid will update itself beyond basic protection and traditional automation schemes to give way to complexity around distributed functional and communications architectures. This will result in enhancement of advanced local analytics. Also management of huge volume of data increases.
- The centralized functions and decisions are available at the Energy Management System (EMS) and Distribution Management System (DMS). From there (EMS, DMS) data moves to substations and feeders. This significantly improves responding nature of the transmission and distribution system. System operation applications will become more advanced and will be able coordinate with other devices. To ensure system-wide reliability, efficiency, and security, the distributed intelligence in the substations and feeders in the field operate in line with each other. As the number of sensors increase, smart grid technologies will lead to a huge volume of real-time and operational data to be managed effectively. Intelligent devices carry out real-time pricing and consumer demand management. This kind of advanced data analytics and forecasting of the electricity will help the consumers to have real time consumption of electric power.

2.7 Energy Management System (EMS)

- The energy management system is a very important function necessary to increase energy efficiency and to provide the excellent coordination between multiple energy sources. It also plays a very important role in smoothening the problems related to power quality, grid failure, and plugged integration of hybrid vehicle. To solve inherent problems in providing an uninterrupted supply of quality power, energy storage can be utilized effectively.
- Typically an EMS should have the following :
  1. Monitoring and controlling of complete system including the parameters of the power system with its interconnections is absolutely necessary.
  2. Capturing the real-time analog and digital data from the field quickly.
  3. Measured data must be validated properly.
  4. The capability to run the necessary EMS software functions to supervise the key system performance indicators.
  5. Control commands should be sent to the field devices and other associated systems whenever the need arises.
  6. The capability to display the relevant measured and computed data to assist the operator to make quick and appropriate decisions.
  7. Operating the system within safe limits by tracking the instantaneous load-generation balance and ensuring system security.
  8. Ability to take preventive action with the awareness of potential risks.
  9. The ability to start restoration after an emergency in the system or a state change.
- Thus, the objective of EMS is to provide stable, reliable, secure, and optimal power to consumers efficiently and economically. Generally generation and transmission automation systems operate under the name of SCADA/EMS systems in which, the data acquisition and control are SCADA-specific functions. The EMS framework is shown in the Fig. 2.7.1 which includes the transmission operation management in coordination with generation operation management. The necessary simulation tools and energy services are helped by the data acquisition and control systems. Every major energy control center will have a dispatcher training simulator as depicted in Fig. 2.7.1. Here the operators will analyze past disturbances and generate real-life scenarios for study purposes.

Each subsystem in EMS has the functionalities :

Generation operation management

1. Load forecasting (LF)
2. Unit commitment (UC)
3. Hydrothermal coordination (HTC)
4. Real-time economic dispatch and reserve monitoring (ED)
5. Real-time automatic generation control (AGC)

- **Transmission operations management: real time :**

1. Network configuration / Topology Processor (TP)
2. State Estimation (SE)
3. Contingency Analysis (CA)
4. Optimal Power Flow and Security Constrained Optimal Power Flow (OPF, SCOPF)
5. Islanding of power systems

- **Study mode simulations**

1. Power Flow (PF)
2. Short-Circuit analysis (SC)
3. Network modeling

- **Energy services and event analysis**

1. Event analysis
2. Energy scheduling and accounting
3. Energy service providers

- **Dispatcher Training Simulator (DTS)**

❒ 1. Dispatch of information

- One of the ways of classifying EMS functionality is to see the time frame in which the simulations are required. The power system operations are performed in three time frames. The real-time operations are the most critical ones. In this the operator is assisted by the EMS functionalities to take appropriate control actions. Anyhow, to arrive at an appropriate operating plan, a series of important functions must be performed before the real-time operations.

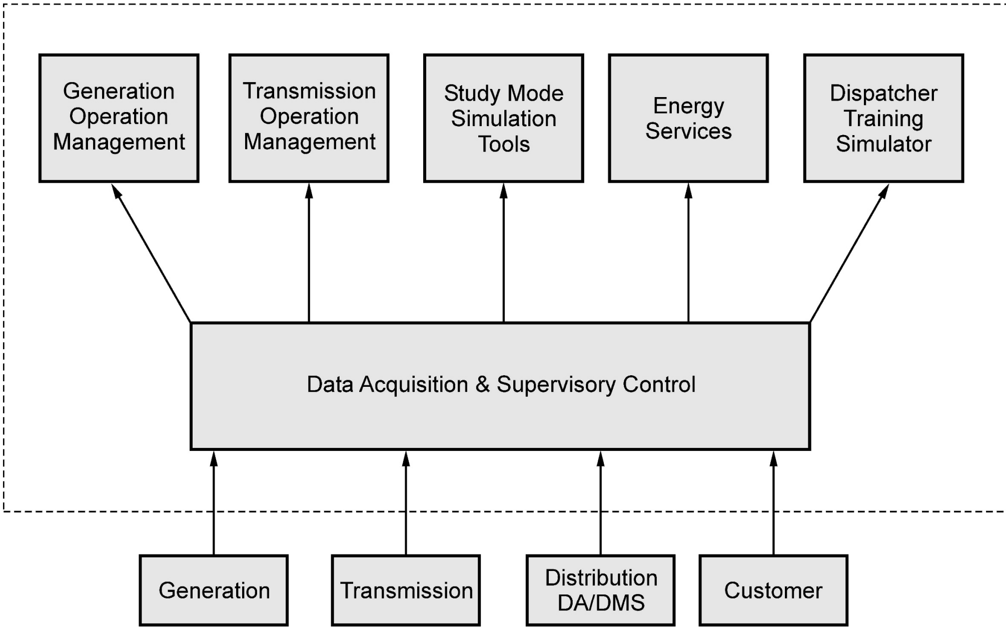

Fig. 2.7.1 : Energy management system frameworks

- A series of post-event analyses are done to calculate the energy transactions and cost of production. This will help to assess the causes of system contingencies. These important functionalities will be classified in three time frames namely real-time operations, pre-real-time and post-real-time analysis. It is to be noted that some of the EMS functionalities are performed offline in study mode, as well as in real time mode like contingency analysis, power flow analysis, and optimal power flow to help the operator.

2.8 FACTS and HVDC

- One of the basic functions of electric power generation is to satisfy the power balance in networks. It is nothing but the amount of power produced at any given moment must equal the amount of power consumed. A transmission utility must be able to change the electrical system response to a given condition. Then it is considered as a useful element in creating a smarter grid. Optimizing the grid for effective operation involves optimal flow of real and reactive power, constant voltage and frequency control. These operations govern the smart grid performance.
- The devices used are :
  - o Synchronous condensers
  - o FACTS's (Flexible AC Transmission Systems) devices
  - o HVDC (High-Voltage Direct Current)

- These devices are capable of exercising excellent and smart control under normal, steady-state operating conditions. Also they will automatically prevent or speed up the recovery from fault situations under transient or fault events depending on their speed of response. Problems arising in heavily loaded power system can be minimized by using a category of high-voltage power electronics devices. FACTS devices come under various combinations of thyristor devices. They enhance the transmission capacity and system stability very effectively and help in preventing cascading disturbances or black outs. Flexibility, accessibility, reliability, and cost effectiveness are the salient features of a future smart grid. Smart grid will help achieve a sustainable development.
- FACTS and HVDC applications will play a significant role in the future development of smart power systems. This will result in trustworthy, efficient, and low-loss AC / DC hybrid grids. The maximum power transferability and controllability rises significantly because of FACTS devices. A super grid with bulk power transmission by means of AC and DC ultrahigh-power transmission technologies can be realized by integrating smart grid consisting of a number of highly flexible microgrids. They are fully suitable for a secure and sustainable access to huge renewable energy resources such as hydro, solar, and wind.

➥ 2.8.1 FACTS (Flexible AC Transmission Systems)

- Reactive power compensation has been considered as a fundamental problem in achieving efficient and economical electric power delivery system. Reactive compensation is subdivided into series compensation, shunt compensation, and combined compensation. They are subdivided based upon how they have been connected in the power circuit. The reactive power-producing devices may be connected in series or in parallel depending upon the compensation required by the power system. The required flexibility will be achieved with dynamically controlled compensation. It supplies the required amount of compensating reactive power precisely and promptly. FACTS devices are well known for their application in power flow control. Reactive power can be controlled and compensated by means of power electronics based FACTS technology.
- Power flow in transmission line is normally carried out at high voltage levels. The magnitude of current flow in a transmission line can be easily calculated once voltage and line impedance are known. This current flow may be more due to overloaded condition or less due to less loaded condition. A transmission utility that is having the potential to modify the electrical system response for a stated condition will be much more useful in establishing a smart grid. While incorporating this device may enhance the system performance, this alone will not help to construct a smart grid.

- Advanced measuring devices and software programs that results in optimal solutions are only helpful to the extent that something can be done about the situation. The balance and control that exists between real and reactive power flow in the transmission system is one of the key factors that decides the ability of the smart grid. It is the main driving force that helps to establish the smart grid to have a grip control not only over on power flow but also on voltage and frequency.
- FACTS and HVDC also have an important role to play in the large-scale integration of transmission line connected wind farms and solar fields into a smart transmission grid. These connections are provided for both offshore and land-based wind and solar energy production. FACTS and HVDC technologies are crucial for transmission lines to proceed with offshore wind power production. Also interconnections of long offshore cables with offshore wind farms are made possible because of FACTS and HVDC. Several factors come into picture when a high level of wind power integration into the AC grid is considered. These may include voltage ride-through, mitigating transient and voltage stability problems, regulating power flows, and compensating for harmonic and reactive power in the long cables.

2.8.2 Types of FACTS Devices

The following are the widely used FACTS devices in transmission systems. Their corresponding representative diagram is shown in the Fig. 2.8.1.

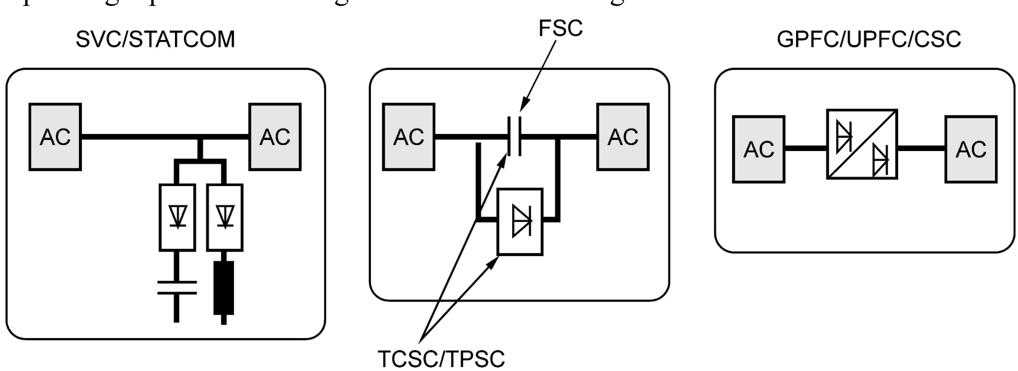

Fig. 2.8.1 : Various FACTS devices representation

SVC	-	Static VAR Compensator
STATCOM	-	Static Synchronous Compensator, with VSC
FSC	-	Fixed Series Compensation
TCSC	-	Thyristor Controlled Series Compensation
TPSC	-	Thyristor Protected Series Compensation

UPFC	-	Unified Power Flow Controller
CSC	-	Convertible Synchronous Compensator
GPFC	-	Grid Power Flow Controller (FACTS-B2B)

➥ 2.8.3 Series Compensation

- Series compensation is carried out by using series capacitors. When series capacitors are installed in series with the transmission lines, this will reduce the total inductive reactance. In this way, reactive power compensation is achieved. As shown in the Fig. 2.8.2, the series-capacitor compensation equipment consists of series-capacitor banks, incorporated in the line terminals or in the middle of the line.

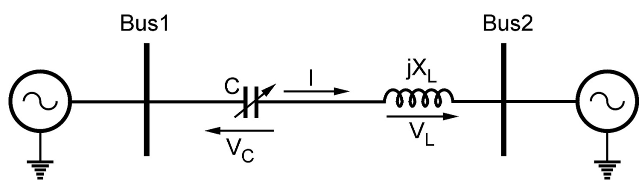

Fig. 2.8.2 : Series compensation

- Capacitor bank can also be placed in the overvoltage protection circuit for compensation. The dynamic stability and steady state stability of the power system is significantly improved by installing series capacitors in reactive power sensitive locations. When transient stability improvement and long distance power transmission is crucial and deciding factor in the transmission system, series compensation plays a vital role. The maximum power that can be transferred through a transmission line is inversely proportional to the series inductive reactance of the line. So, compensating the series inductive reactance from a range 25 % to 70 % with the help of series capacitors will result in higher value of real power transfer with excellent transmission line efficiency.
- Besides this will increase the transmission line efficiency and improve the system performance. In recent years, it has been found that voltage stability in shorter transmission lines can be increased by using series capacitors.
- Series compensation in transmission systems has the following significant advantages :
  - Dynamic stability of power system is enhanced
  - Desirable load division among parallel lines
  - Voltage regulation is improved significantly with decent reactive power balance
  - Overall network power losses is reduced

- The Thyristor-Controlled Series Compensation (TCSC) is a modification of conventional series compensation techniques. It provides further flexibility of series compensation in transmission applications.

➥ 2.8.4 Shunt Compensation

- The SVC is a regulated source of leading or lagging reactive power. SVC has the capability to maintain constant voltage under all conditions when its reactive power output is changed with respect to the demand of an automatic voltage regulator, When SVC is connected in a network, it controls the reactive power flow to such an extent that it is able to maintain almost constant voltage at the point in the network to which it is connected.
- SVC consists of standard inductive and capacitive branches which are controlled by thyristor valves as shown in Fig. 2.8.3. They are connected in parallel with the transmission line through a step-up transformer. SVC has the characteristics of variable shunt susceptance because of the presence of controllable thyristors. It is one of the most widely used SVC configurations for reactive power compensation in electric power systems. It consists of a TCR, Metal Oxide Variator (MOV).

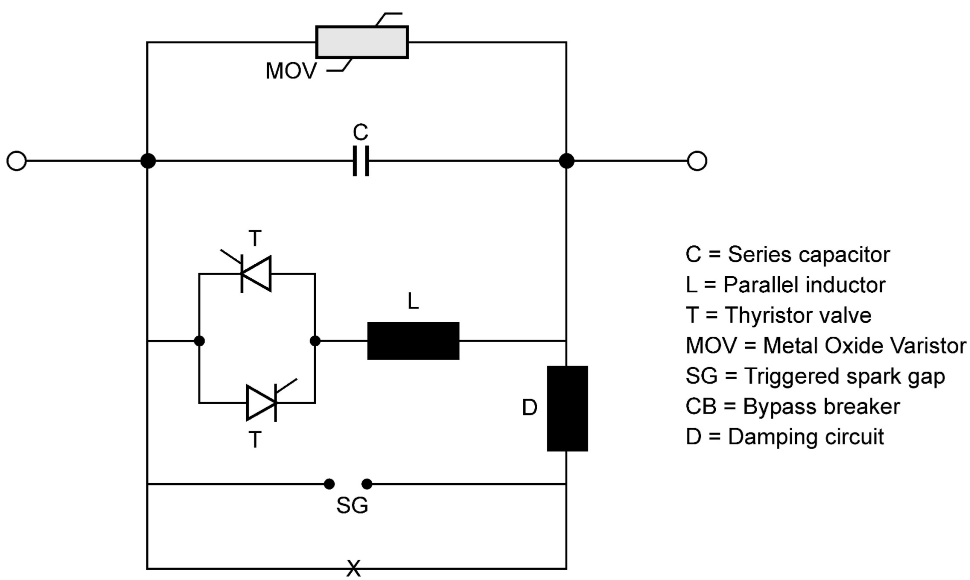

Fig. 2.8.3 : Shunt compensation

- For example, with the TCR / TSC configuration is illustrated in Fig. 2.8.4 (i), wide range and excellent reactive power compensation can be obtained by properly switching of TSCs and minutely controlling of TCR. At the same time, full inductive rating of the TCR to the full capacitive rating of the TSCs and the FC can be obtained by TCR / TSC / FC combination as shown in Fig. 2.8.4 (ii). The SVC is a predominantly used technology and has reached its advanced level now a day for transmission applications with varied combination like TCR / FC / MSC as shown in the Fig. 2.8.4 (iii). These combinations will provide robust voltage support when the power system undergoes severe disturbances. When heavy loads in industries fluctuate, the balance between reactive power demand and voltage will be severely affected in the transmission line. Under such circumstances, this configuration can be located in the midpoint of transmission interconnections or in load areas.

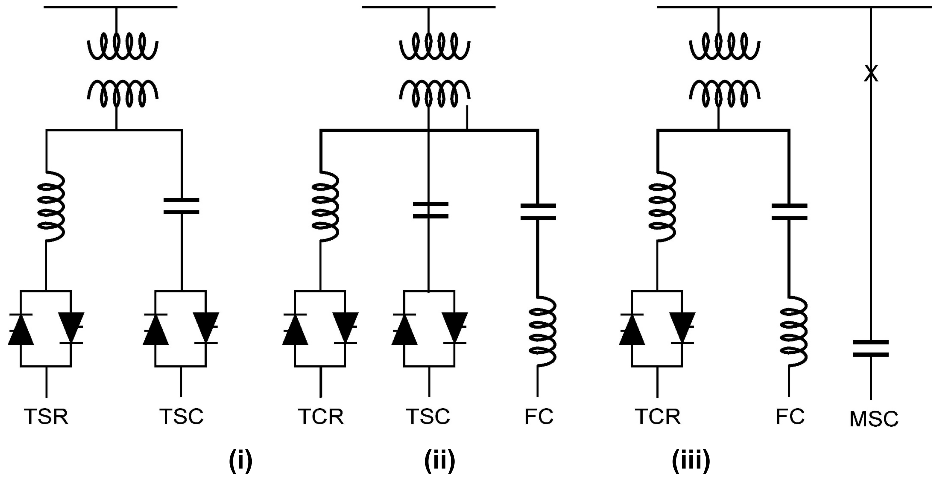

Fig. 2.8.4 : (i) TCR / TSC (ii) TCR / TSC / FC (iii) TCR / TSC/MSC

- In general, the main benefits of applying SVC technology in power transmission systems include the following :
  - Voltage profile of the system is improved significantly
  - Reduced network power losses
  - Voltage stability will increase in weak areas
  - Power delivering capacity is enhanced
  - Oscillations during real power flow is minimized

2.8.5 STATCOM (Static Synchronous Compensator)

- The STATCOM technology is based on power electronic concept of voltage-source conversion. The shunt connected Voltage-Source Converter (VSC) consists of solid state switching components with excellent turn-off capability with diodes connected in opposite directions.
- The performance characteristics of STATCOM resemble a three phase synchronous machine which generates balanced sinusoidal voltages at the fundamental frequency with controllable amplitude and phase angle. However, STATCOM does not have inertia and does not contribute to the short circuit capacity. The STATCOM consists of a VSC operating as an inverter with a capacitor as the DC energy source as depicted in Fig. 2.8.5.

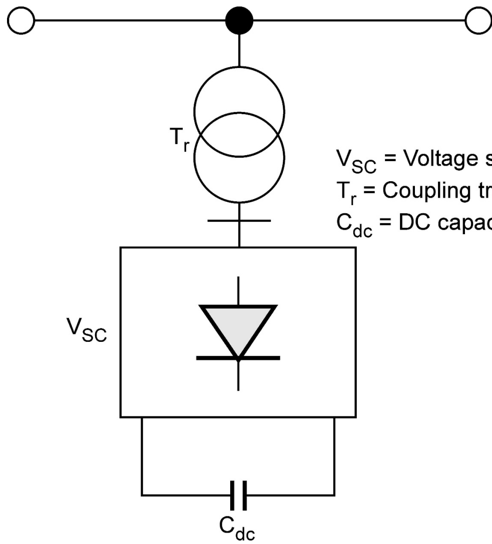

Fig. 2.8.5 : STATCOM main circuit diagram

- It is operated to regulate the voltage in much the same way as the SVC. A coupling transformer is used to connect to the transmission voltage level. In the use of STATCOM, only the voltage magnitude is controlled, not phase angle. The reactive power magnitude and direction is regulated by having a control over the converter output voltage with respect to the system voltage. Reactive power is absorbed whenever the VSC output voltage is lesser than the system voltage. On the other hand, reactive power is produced whenever the VSC output voltage is greater than the system voltage.
- When compared with each other, STATCOM and SVC function almost the same manner in a transmission network. Both of them support enhancement of steady-state, dynamic stability and power system damping. Also they help to improve voltage stability and regulation. They enhance synchronous stability and transfer capability. In addition, STATCOM is also installed for power quality applications.
- These include the following :
  - o Dynamic load balancing is significantly improved
  - o Flicker control is enhanced
  - o Load compensation becomes faster

➥ 2.8.6 Combined and Other Devices

By combining series and shunt devices, more advanced systems to control power flow in transmission lines can be created. The STATCOM described in the previous section is a shunt-connected voltage source device that can control reactive power flow by injecting reactive current. It also regulates voltage at the point of connection efficiently. The static synchronous series compensator (SSSC) is one of the FACTS devices, which is similar to the STATCOM. When it is placed in series connection, independent of the current in the line, it controls the magnitude and phase of an injected voltage. When a STATCOM and SSSC are combined and located on a transmission line as shown in Fig. 2.8.6, it forms the unified power flow controller (UPFC) configuration. The UPFC is able to regulate both real power and reactive power in a line and offers very quick voltage support and power flow control. To con configuration. UPFC two converters are connected in back to back fashion (B2B).They will make use of the same DC capacitor similar to that of a HVDC link. The Interline Power Flow Controller (IPFC) is another configuration of the combined VSCs as depicted in the Fig. 2.8.7. In this configuration two converters are installed at different transmission lines. Two SSSC converters constitute IPFC. In this configuration, both real and reactive power control is optimized excellently through power exchange by means of the DC link that has been connected between different transmission lines. Thus the IPFC operates in both lines i – j and i – k and enhances stability of the power system.

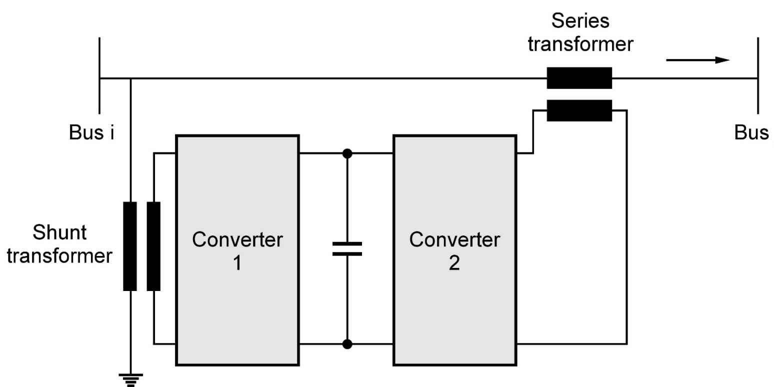

Fig. 2.8.6 : UPFC representation

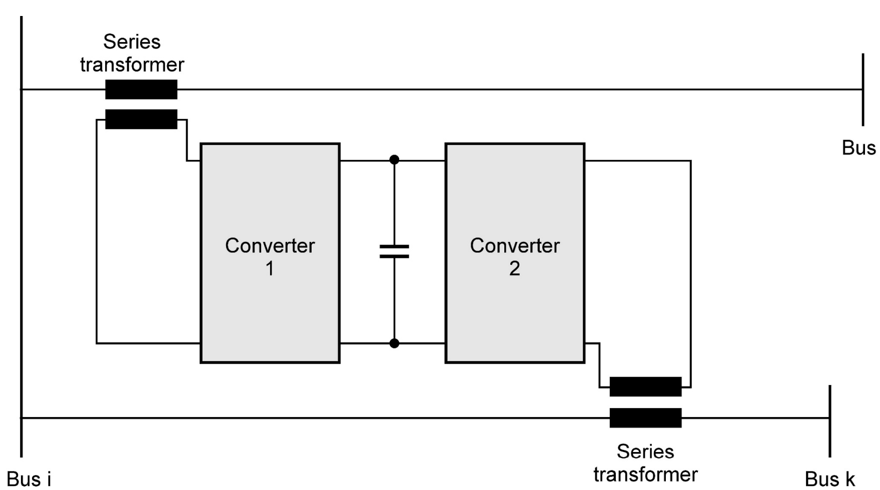

Fig. 2.8.7 : IPFC representation

2.8.7 HVDC (High Voltage Direct Current) Systems

- HVDC transmission system heavily makes use of power electronics systems to control power flow within or between networks. Thyristors are used as the controlling devices in the modern HVDC systems. It is impossible to realize smart grid without the HVDC system. It is considered to be such an essential component of the smart grid.
- HVDC transmission systems have lot of advantages over their HVAC counterparts, including the following :
  1. Power flow direction and magnitude can be controlled excellently in both directions. This is achieved by means of manual action or through automation.
  2. When two separate AC systems are operated, voltage and frequency in these two AC networks can be controlled independently of each other, again either through manual action or through automation.
  3. The HVDC link can be used to assist one of the AC networks in responding to disturbances like power swing damping. This can be achieved by modulation of the transmitted power. This happens in a fully automated mode, since the operator is unable to respond in this timescale.
- Additionally, the use of an HVDC link instead of AC interconnection results in the following advantages :
  1. Power system stability margins improves significantly due to the ability of rapidly changing power transfer.
  2. The short circuit level of the power system remains stable.
  3. No transfer of faults across the interconnected systems.

2.8.8 Types of HVDC Systems

- There are mainly three types of HVDC systems used for transmission purposes.
- They are as following :

  1. Monopolar link 2. Bipolar link 3. Homopolar link

2.8.9 Monopolar Link

As depicted in the Fig. 2.8.8, the Monopolar system will have only one conductor with ground as return conductor. Usually the conductor will have negative polarity and it is very suitable for submarine systems.

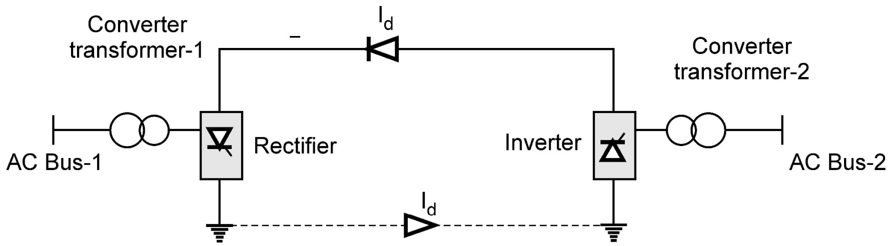

Fig. 2.8.8 : Monopolar system

2.8.10 Bipolar Link

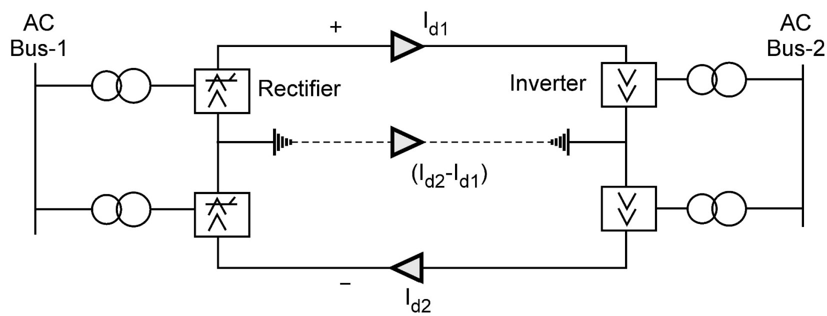

Fig. 2.8.9 : Bipolar system

As shown in the Fig. 2.8.9, the bipolar link will have two conductors. One is positive and the other one is negative. The ground point is maintained at mid potential. Both poles will operate with equal currents under normal operation. Under faulty condition, one DC link may be used along with ground return to meet half of the rated load.

2.8.11 Homopolar Link

As shown in the Fig. 2.8.10, two conductors having the same polarity can be operated with ground return. In the face of fault in one conductor, the whole converter can be connected to working pole and half the rated power can be transmitted. When continuous ground currents are unavoidable, homopolar system is highly preferred.

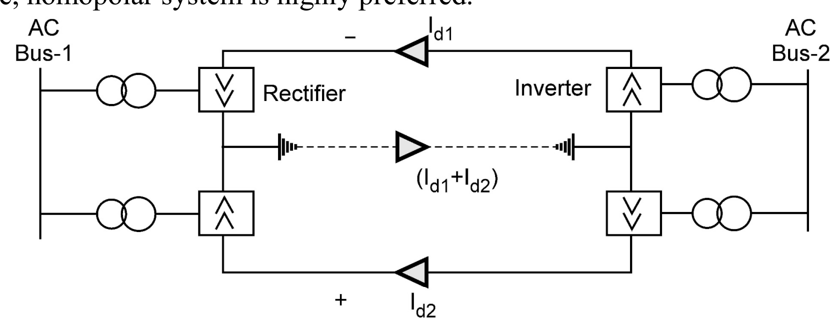

Fig. 2.8.10 : Homopolar system

2.8.12 Technical Advantages of HVDC

- The following are the main advantages of HVDC transmission :
  1. Reactive power stations are not required
  2. System stability increases significantly
  3. Provides independent control of AC system
  4. Energy flow changes in a fast manner
  5. Corona loss is minimized
  6. Radio interference is minimized
  7. Provides greater reliability
  8. Transmission of power is not limited by distance
  9. Power flow direction can be changed instantly
  10. Cost is lower

2.9 Wide Area Monitoring Protection and Control (WAMPAC)

- Wide Area Monitoring, Protection and Control (WAMPAC) is defined as a system that is based on Synchronized Measurement Technology represented by Phasor Measurement Units (PMUs) which is an important part of the solution. The typical layout of WAMPAC with many PDCs (Phasor Data Concentrator) is shown in the Fig. 2.9.1.

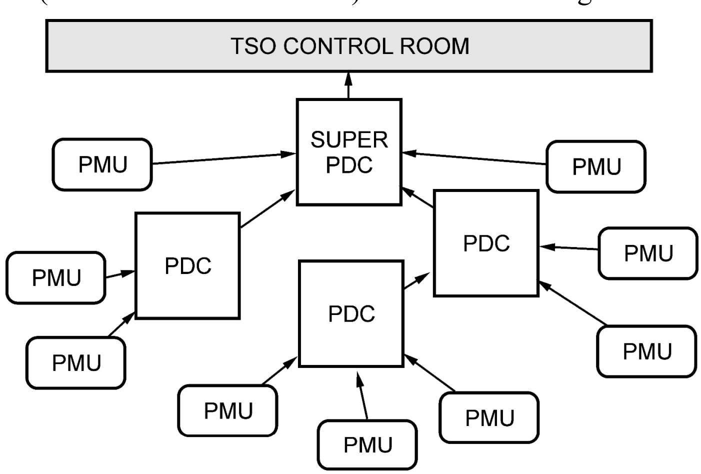

Fig. 2.9.1 : Typical layout of WAMPAC

- The key feature of wide area monitoring, protection and control system is nothing but time-synchronized measurements. Their locations are completely scattered and over spread in an electric power grid. WAMPAC systems are configured upon the synchronized sampling of power system currents and voltage signals as shown in Fig. 2.9.2. A common timing signal which originates from GPS synchronizes them with the power grid. The sampled signals are converted into phasor or vector representations of the grid's voltage and current measurements at fundamental frequency. An accurate GPS time reference compares these synchronized signals effectively and thoroughly across the electrically connected power system. Bus voltage and current phasor indicate the state of an electric power grid in real time. All the processed information's are finally given to TSO (Transmission System Operator) as input for necessary action.

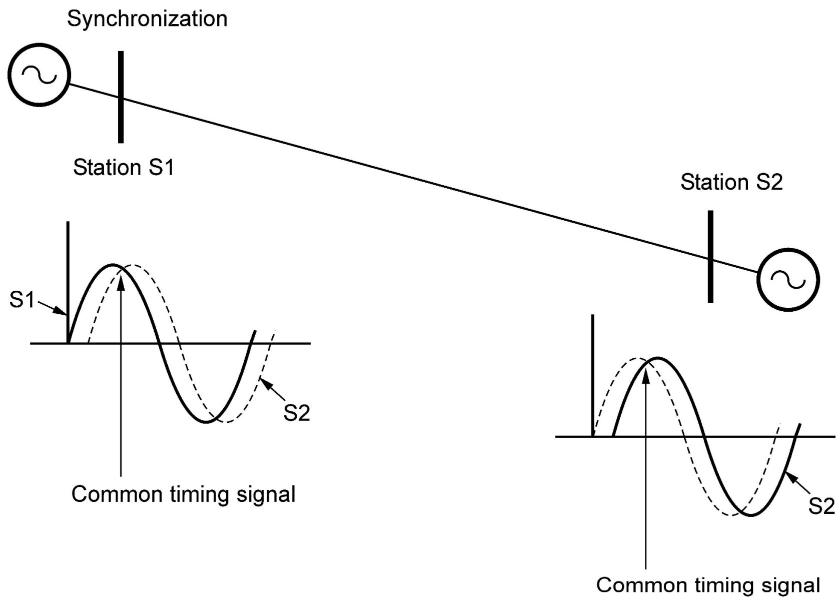

Fig. 2.9.2 : Synchronized sampling of power system signals

➥ 2.9.1 Phasor Measurement Unit (PMU)

- The PMU is also known as a synchrophasor. It is the basic building block of a WAMPAC system. The diagrammatic representation of PMU is shown in the Fig. 2.9.3. The power system signals are obtained from voltage and current sensors. These signals are sampled by the PMU and converted into phasors. These phasors are complex number representations of the sampled signals. They are generally used in the design, control and protection of power systems for bulk power transmission. When the timing pulse is obtained from the GPS, then the phasor is time tagged and then streamed into the wide area communications network as fast as one phasor per cycle of the power system frequency.

- GPS timing pulse interrelates with the phasor angle information. Because of this interrelationship, the information will be having physical significance. It must be compared with other phasor angle measurements from the same system. The condition of the system and other valuable information like oscillatory disturbances will be informed by the difference in the phasor angle. Modern-day PMUs have excellent accuracy and capable of measuring a bigger set of phasors in a substation. Many of the PMUs output will have binary modules for transmitting binary signals.

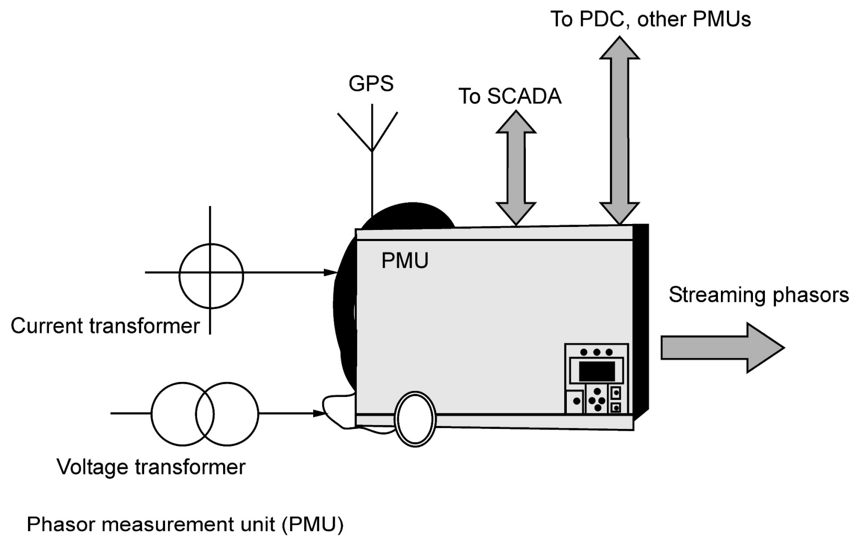

Fig. 2.9.3 : Phasor measurement unit (PMU)

- These binary signals are nothing but trip signals to open a circuit breaker.

➥ 2.9.2 Time Synchronization

- Time synchronization is the heart of WAMPAC-based applications. WAMPAC application is dependent upon a precise time scale transmitted with the help of each PMU. Information about the details of protection, controlling and monitoring the electrical network will be taken care by each PMU. Normally, it takes nanoseconds to microseconds for time synchronization requirements. This is an extremely important function for every component of the smart grid system. This demands the crucial need for highly reliable and available time synchronization. The typical time synchronization is depicted in Fig. 2.9.4. Time synchronization is achieved by so many ways.

- A common source clock signal controls all methods across the network. This control action is carried out by satellite through the communications network or using synchronization networks that operate independently. A systematic use of clock with an excellent quality along with high accuracy is expressed in PPM (parts per million). Because of this temporary loss of the synchronization signal is totally avoided in the signal transmission processes.

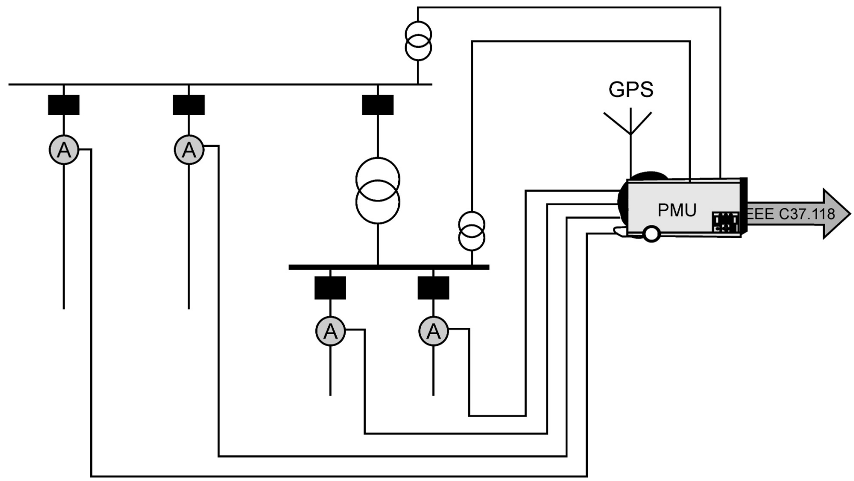

Fig. 2.9.4 : Time synchronization

➥ 2.9.3 Phasor Data Concentrator (PDC)

- A phasor data concentrator collects phasor data from multiple PMUs or other PDCs and aligns the data by time tag. It formulates a synchronized dataset, and then transfers the data to applications processors. For applications that process PMU data from the grid, it is essential that the measurements are time aligned and grounded on their original time tag to create a system-wide, synchronized snapshot of grid conditions. Normally delay time arises in the communication process when individual PMUs deliver data. To overcome this problem PDCs are designed to buffer data streams from the input. So delay time in communication process is efficiently handled by giving certain wait time in this buffering action. A PDC also performs data quality checks that will ensure the integrity or completeness of the data. Also it flags all the missing or problematic data. Levels of PDC operation is shown in the Fig. 2.9.5.

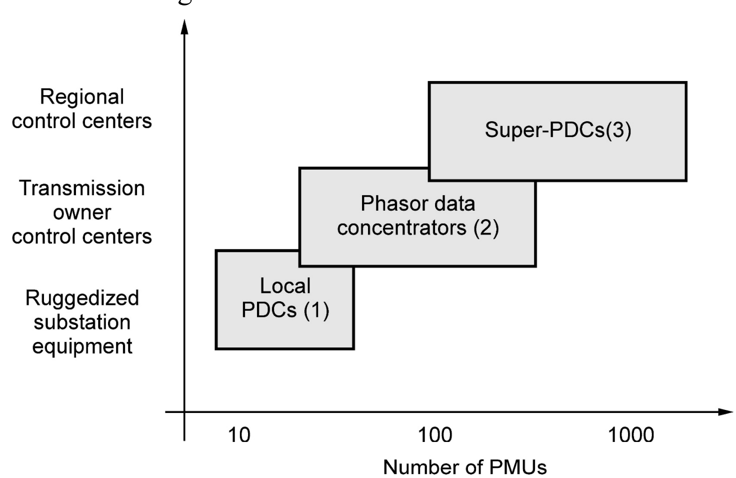

Fig. 2.9.5 : Levels of PDCs

- There are levels of PDC :
  1. Local or substation PDC level
  2. Control center PDC level
  3. Super PDC level
- PMUs make use of various data formats, data rates, and communications protocols for streaming data to the PDC. The PDC supports such kind of different formats in the input side. In addition to that, it must be able to sample the input streams to a standard reporting rate and process the different datasets into a general format output stream.
- Multiple users may also be accessing the data. Hence the PDC should have the capability to distribute received data to multiple users simultaneously, each of which may have different data requirements that may have specific application. The operating nature of PDC will be differing based upon its place of installation. Normally they are placed between the source PMUs and the point of applications. Generally speaking, the functions of PDCs are subdivided into three levels which can be explained as follows :

❒ 1. Local or substation PDC

A local PDC is generally placed near the substation. It communicates with various PMUs to collect and manage information within the substation or other substations which are located closely with each other. The collected information is time synchronized dataset. This dataset will be sent to higher-level concentrators at the control center. Since the local PDC is situated nearer to the PMU source, it is typically designed to have less delay time. It is also widely used for local substation control operations. Protection against communication network failures will be tackled by local PDCs. An additional short-term data storage system will be readily available in PDC helps to avoid communications network failures. A local PDC is generally a hardware device that requires less maintenance and having the capability to operate independently if it loses communications with the rest of the communications network.

❒ 2. Control center PDC

The PDC which is in the control center works only within the range of its environment allocation. It collects data from individual utility's PMUs and substation PDCs. If needed, it also collects data from neighboring utility PDCs. In a time synchronized manner they will be sending multiple output streams to different applications like visualization, alarms, storage, and EMS applications. The data rate requirements of these applications are self-specified in nature. Control center PDC architectures are generally more in numbers. This is an important requirement that helps to handle future loads. It also satisfies high-availability needs of the system**.** The space for new protocols is organized by PDC which are highly adaptable in nature. They also accommodate interfaces with new applications in addition to managing new protocols and output formats.

❒ 3. Super-PDC

A Super-PDC works on a larger, regional scale. It takes the responsibility for collecting and correlating phasor measurements from several hundreds of PMUs and multiple substations and/or control center PDCs. It additionally takes responsibility to exchange data between utilities by channeling the PMU. Not only it supports applications such as EMS, visualization, wide area monitoring system (WAMS), and SCADA applications, but also it collects enormous amount of data, normally several Terabytes per day. Super-PDC has a significant storage property. Generally they operate on enterprise-level software systems working on clustered server hardware. They will accommodate the scalability to meet the growing PMU configuration and needs of the utility.

➡ 2.9.4 Needs and Significance of WAMPAC in a Smart Grid

- In the face of power disturbance the smart grid must have the self-healing ability. The significant operational feature of smart grid is that it must have the ability to understand the specific needs of WAMPAC in relation to the transmission systems. Events often cause failure or isolation of transmission lines and generation sources that could potentially lead to grid collapse. A smart grid must be in a position to tackle a huge number of renewable sources from solar, electric vehicles, wind, and other renewable energy sources. It must be able to maintain excellent level of power quality even after integrating these resources. There is also a justifiable expectation that smart grids will be more efficient in their transmission of power. With an increasing number of discontinuous renewable generation sources, the reliability and efficient transmission capacity of electricity is not a trivial task. Smart grid is dependent upon utilities coordinating and interoperating with each other in a large measure. Communication and exchange of essential data at proper time scale is solely governed by the level of interaction happens between the devices. PMU data are time controlled. Systems that are interoperating WAMPAC must include time synchronization. For example, network management systems which enable improved disturbance visualization into the control center will interoperate with WAMPAC.
- The following are the chief advantages of WAMPAC :
  1. Reliability, stability and security is maintained against large disturbances.
  2. Large numbers of intermittent generating sources like solar, wind, etc., are managed properly.
  3. Power quality is maintained to better level.
  4. Transmission efficiency is increased.

- The main works carried out by WAMPAC are the following :
  1. Monitoring of voltage phase angle difference
  2. Monitoring of thermal limits of the line
  3. Voltage stability monitoring
  4. Monitoring of power system damping
  5. When predefined critical levels are exceeded enabling intelligent alarming
  6. Online monitoring of system loading

2.10 Distribution Systems

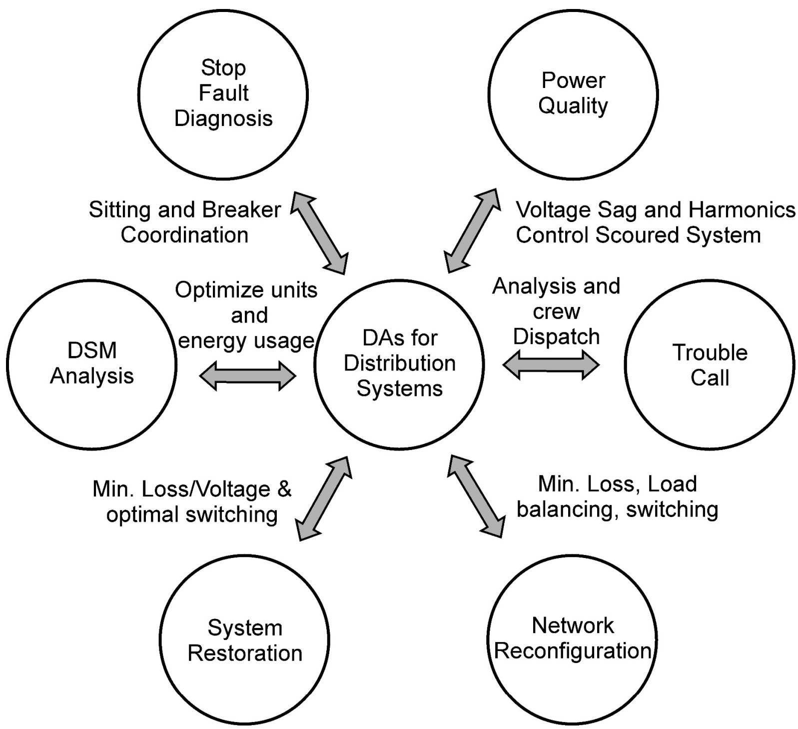

Fig. 2.10.1 : Distribution automation for distribution systems

- The distribution system is the last stage in the transmission of power to end users. Primary feeders at this voltage level meet the power need of small industrial customers. Secondary distribution feeders meet the power need of commercial and residential customers. Fig. 2.10.1 shows the distribution automation schemes for distribution systems. At the distribution level, intelligent supporting methodologies will be monitoring closely distributional level activities. These activities include ability to use automation with the help of smart meters, various modes of communication between consumers and utility control, components of energy management, and AMI (Advanced Metering Infrastructure). It is usual that the automation function has been well equipped with self-learning capability. This energizes the automation function to carryout fault detection, voltage optimization, load transfer, restoration and feeder reconfiguration, real-time pricing, and automatic billing. Distribution automation and control ensures the delivery of energy to customers.

- The chief goal of smart distribution solutions is to minimize energy losses, bring down power disruptions, and optimize the use of distributed smart grid components. This includes alternative energy sources, and Plug in hybrid electric vehicles (PHEV) charging infrastructure. There is also access to bigger pools of available generation and this may also be important to the reliable integration of large-scale variable generation. As the level of variable generation increases in a balancing area, this will result in imbalance with its existing sources of generation. So this must be monitored closely to maintain balance. Base load generation must be frequently cycled in response to these varying conditions. This new situation will introduce the system engineer to reliability concerns along with its economic consequences. These outworking will help to address minimum load demands of conventional generation and contribute to the effective use of off-peak, energy-limited resources.

➥ 2.10.1 Distribution System Topology

- When critical outages are considered, the option of distribution system topologies are the first line of defense in power system.
- Distribution system can be categorized as follows :
  1. Secondary-selective 'Main-Tie-Main' topology
  2. Main-Tie-Main topology
  3. Ring bus topology
  4. Primary loop topology
  5. Composite primary loop/secondary selective topology

➥ 2.10.2 Secondary-Selective 'Main-Tie-Main' Topology

The most widely used arrangement of Secondary-selective 'Main-Tie-Main' topology is shown in the Fig. 2.10.2. As illustrated in Fig. 2.10.2, in this topology there are two buses, each will meet approximately fifty percent of the load, but are designed to carry the entire load. This means that each transformer, secondary main circuit breaker, and bus is designed to carry the full load.

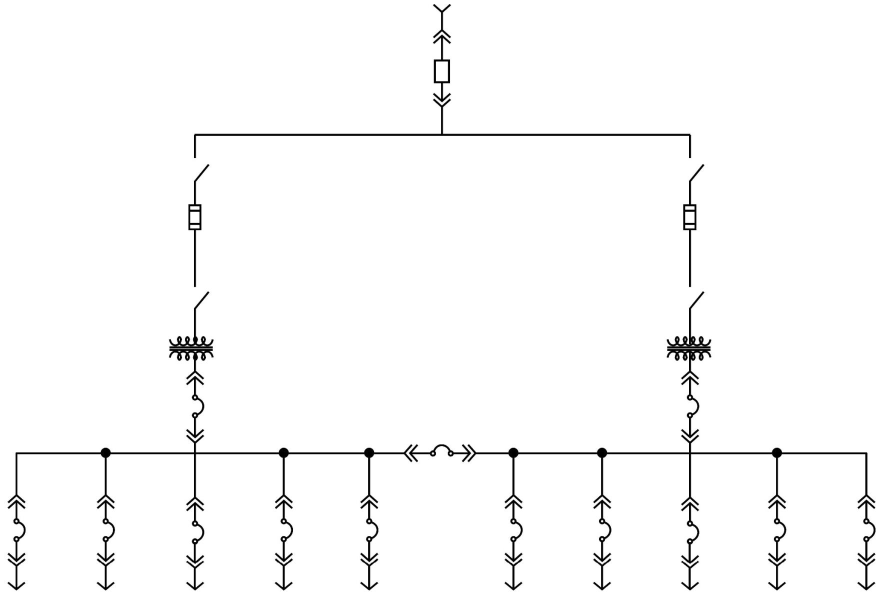

Fig. 2.10.2 : Secondary-selective 'main-tie-main' topology

➥ 2.10.3 Main-Tie-Main Topology

The Main-tie-Main topology omits the bus tie circuit breaker and directly have the secondary buses connected all the time. This is a significant variation obtained from the previous secondary selective topology which will have two secondary buses separated into two different pieces of equipment. As shown in the Fig. 2.10.3, in this topology single power source carries the total load. Other sources will act as standby sources and operate only the main source fails.

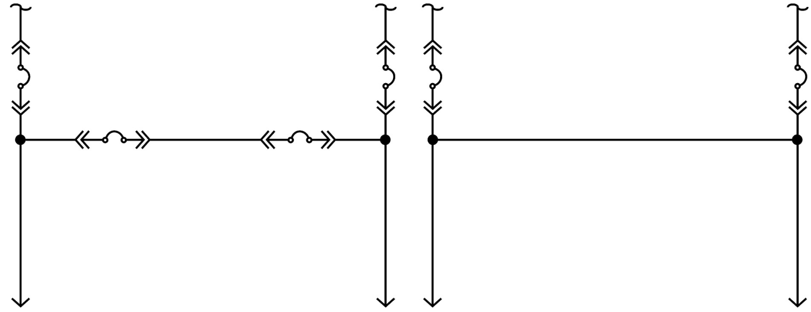

Fig. 2.10.3 : Main-tie-main topology

➥ 2.10.4 Ring Bus Topology

Ring bus topology is also widely used in distribution systems. It is highly flexible in supplying multiple loads by ring bus arrangement and multiple buses as shown in the Fig. 2.10.4. For medium voltage level distribution it is often used. Usually it is in a closed loop arrangement.

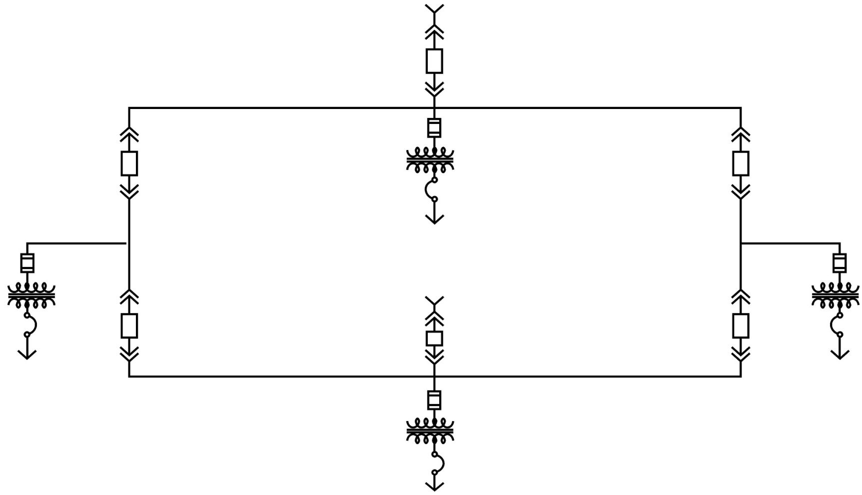

Fig. 2.10.4 : Ring bus topology

➥ 2.10.5 Primary Loop Topology

The typical arrangement of primary loop topology is shown in the Fig. 2.10.5. In this topology load interrupting switches are used for switching on the loop. It is more economical and justifiable than ring distribution system. Usually the loop is operated under open loop way but will be able to supply all loads.

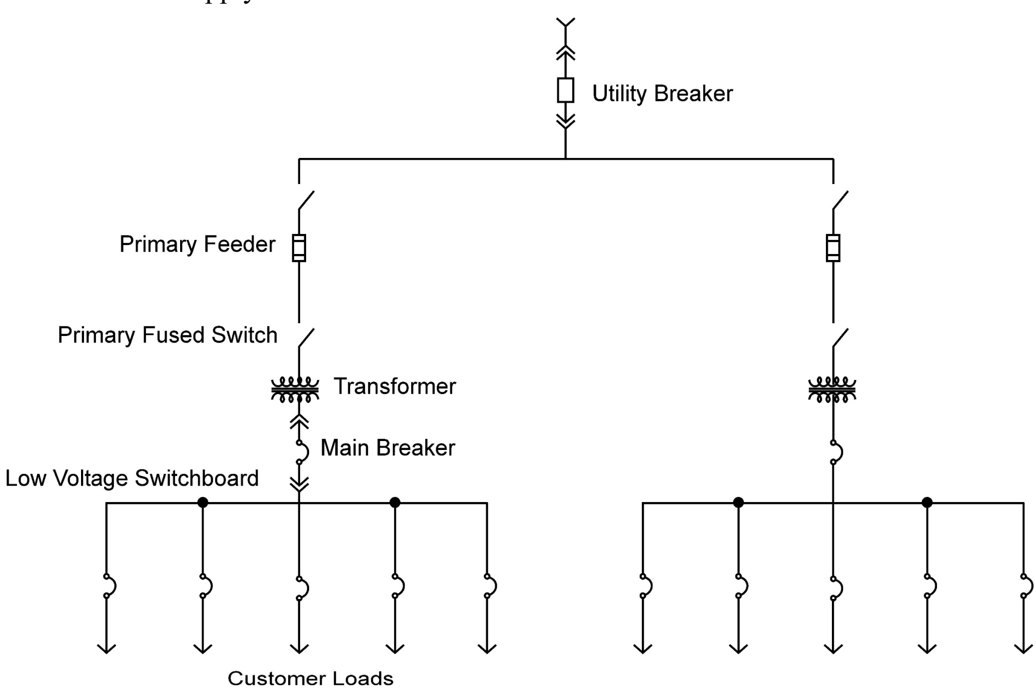

Fig. 2.10.5 : Primary loop topology

2.10.6 Composite Primary Loop / Secondary Selective Topology

Composite topologies offer excellent flexibility and highest level of reliability. A typical depiction of this topology is shown in the Fig. 2.10.6. Depending upon the configuration, cost, and service quality distribution system may be radial or ring, mesh or the combination of both.

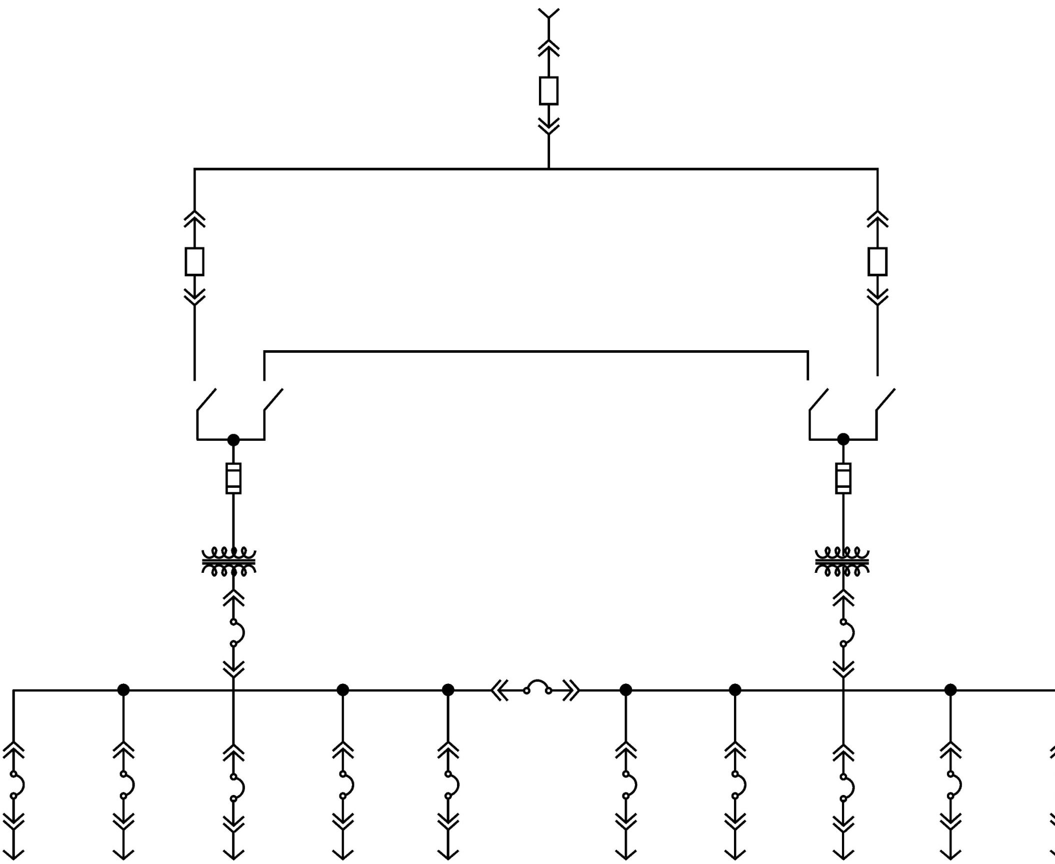

Fig. 2.10.6 : Composite primary loop / secondary selective topology

2.11 Distribution Management System (DMS)

A DMS is a collection of applications incorporated to monitor and control the whole distribution network efficiently and reliably. It works as a decision support system to help the control room and field operating engineers with the monitoring and control of the electric distribution system. It helps to enhance the reliability and quality of service in terms of reducing outages. While minimizing outage time, it maintains acceptable frequency and voltage levels. These are the key achievements of a DMS. In order to support proper decision making activities, DMS shall have the following functions :

2.11.1 Network Connectivity Analysis (NCA)

- Distribution network normally encompasses over a large area and serves power to different customers at different voltage levels. So identifying required sources and loads on a larger GIS / Operator interface is often very hard task. Network connectivity analysis is an operator dependent functionality which helps the operator to fix or locate the preferred network or component in a quicker way. NCA does the necessary investigation and provides display of the feed point of different network loads.
- The network is modeled depending upon the condition of all the switching devices such as circuit breaker (CB), Ring Main Unit (RMU) and isolator. After that the prevailing network topology is determined. In addition to that the NCA further helps the operator to know the operating state of the distribution network which indicates the loops and parallels in the network.

2.11.2 State Estimation (SE)

- Power system state estimation is a method where data are telemetered from network measuring points to a central computer which can be formed into a set of reliable data for control and recording purposes. It permits the calculation of margins to operating limits, equipment health and necessary operator actions with high accuracy despite of measurements that are corrupted by noise or could be missing or inaccurate.
- In power networks, state estimation absorbs observable data from the field and gives a model of what is actually happening. It is achieved by processing the data to indicate inaccurate readings or to estimate missing data. In a distribution network, the data quality that is telemetered will be imperfect because of the presence of noise. Problems in electronic devices and in the communications networks suggest that prior to conducting an analysis, preprocessing of data is compulsory to eliminate the bad data points. This will help to resolve any non-telemetered points and stabilize the telemetry systems.

2.11.3 Load Flow Applications (LFA)

- Load flow study is an essential tool which involves application of numerical analysis to the power system. The chief aim of power flow study is to obtain the details of voltage magnitude, phase angle, real power and reactive power information for each bus in the power system for specified load conditions. After getting this information, real and reactive power flow on each branch as well as generator reactive power output can also be found analytically.

- Load flow is highly nonlinear problem with a lot of constraints. So numerical methods are applied to obtain a solution which lies within acceptable tolerance. It uses customer type, profile of different loads and other necessary information to correctly distribute the load to each individual distribution transformer. Load flow or Power flow studies are significant for future planning and expansion of power systems as well as in determining the optimal operation of existing systems.

➥ 2.11.4 Volt / VAR Control (VVC)

Volt / VAR Control or VVC implies the process of balancing voltage levels and reactive power (VAR) throughout the power distribution systems. In power system there will be always loads that has reactive components like capacitors and inductors like AC electric motors. This will put additional stress on the grid. It is the reactive nature of the load which will cause them to draw more current than what is actually required. The over drawn current will result in both over-voltage and under-voltage violations. Besides that this will be leading to excessive heating up of equipment like transformers, motors, and conductors. This will unnecessarily demand resizing of equipment to carry the total current. The power system must be able to control reactive power by fixing the limits of reactive power production, absorption and its flow at all levels in the system. A VVC application is very much helpful for the operator to soften such conditions by suggesting required action plans. This plan includes setting of correct tap position and capacitor switching to stabilize the voltage and thus optimize Volt/VAR control function for the utility.

➥ 2.11.5 Load Shedding Application (LSA)

Power system is characterized by its long stretches of transmission line and injection points at multiple locations. This complex structure of power system will lead to instabilities and critical failure or unpredicted system conditions. The instabilities usually come into picture because of power system oscillations generated due to faults, peak deficit and protection failures. Distribution load shedding and restoration schemes plays a significant role in control and emergency operation in any utility. It not only reveals the emergency situation but also performs necessary predefined control actions, like opening, closing of noncritical feeders. It determines the sources of injections and performs a tap control at transformer. Generally distribution network is complex and has large area under its control. So, the emergency actions taken will reduce a lot of burden of the distribution network. In a manually controlled system, operator's awareness of system conditions is extremely important. The operators must have the ability to respond to the changing situation. This will mitigate stress level of the system. If the decisions are not fast enough, the problem will grow exponentially and will cause major catastrophic failure. Automated load shedding and restoration application instructions will be given by DMS for any utility. These instructions must cover various activities like Under Frequency Load Shedding, checking of limit violation and time of day based load shedding schemes which are manually performed by the operator.

2.11.6 Fault Management and System Restoration (FMSR)

Reliability and quality of power supply are the deciding parameters which must be ensured by any utility. When the outage time gets reduced, this will improve the overall reliability of any utility and increase the FMSR indices. FMSR is well known for automated switching applications under fault condition which plays an important role in power system stability and reliability. FMSR usually requires two important features. They are switching management and suggested switching plan. The DMS application will receive information about faults from the SCADA system. It processes the information for fault identification and running switching management application. The results are converted to action plans by the applications. The action plan can be authenticated in study mode which is provided by the functionality. The switching management can be either manual or automatic depending on the configuration.

2.11.7 Load Balancing Via Feeder Reconfiguration (LBFR)

Load balancing via feeder reconfiguration is an important application for utilities where they have multiple feeders feeding a congested area. The operator rearranges the loads to other neighboring parts of the network in order to balance the loads on a network. The Feeder Load Management (FLM) is required to permit the operator to manage energy delivery in the electric distribution system and identify problem sensitive areas. The FLM observes the vital signs of the distribution system and indicates areas of concern so that the distribution operator is warned in advance and can effectively focus his attention where it is most needed. It permits for quicker correction of existing problems and makes possibilities for problem avoidance. This will result in both improved reliability and excellent energy delivery. Many times feeder reconfiguration is also used for loss minimization. Because of many network and operational limitations utility network may be operated to its maximum capability without knowing its consequences of losses occurring. The overall energy losses and losses in revenue due to these operations can be reduced for effective operation. The DMS application utilizes switching management application for this very purpose. The loss minimization problem will be solved by optimal power flow algorithm.

2.11.8 Distribution Load Forecasting (DLF)

Distribution Load Forecasting (DLF) offers a structured interface for creating, managing and analyzing load forecasts. It is designed to provide both top-down and bottom-up forecasting methodologies. These actions are carried out in the same environment without giving any restrictions on the types of models available. It supports short-term, medium-term, as well as, long-term forecasting. DLF provides data aggregation and forecasting capabilities that is created not only to address today's requirements but also to address future requirements. DLF has the capability to produce repeatable and accurate forecasts.

2.12 Volt / Var Control (VVC)

VVC governs two important objectives namely distribution substation switching and feeder voltage regulation equipment with the help of capacitor banks. The first one is to reduce the VAR flow on the distribution system and the second one is to maintain voltage at the customer delivery point within required limits. For an effective VVC application in power system it has to be coordinated and combined to optimize the control of both VAR flow and customer voltage. Components of VVC are as follows :

2.12.1 VAR Control, VAR Compensation, Power Factor Correction

Substation and distribution feeder capacitor banks are utilized to reduce the VAR flow which will improve the power factor on the distribution feeder during all load levels. The distribution system losses are reduced because of optimal VAR flow. Ultimately, this reduces load losses on the substation and distribution feeders.

2.12.2 Conservation Voltage Reduction (CVR)

The distribution feeder voltage regulators and substation transformer load tap changers (LTC) are controlled by CVR. Because of this customer delivery voltage is minimized within specified and safe margins point during peak periods of load at the customer service. So there will be a considerable reduction in load on the substation and distribution feeder is made possible. Sometimes during base loading period CVR may also be incorporated to enhance voltage stability.

2.12.3 Integrated Volt / VAR Control (IVVC)

IVVC is the integration of VAR flow and CVR to minimize losses in the distribution feeder. It also controls the voltage profile of feeder. This will reduce system losses and may improve the quality of voltage supplied to the customer. Other additional benefits may include frequency of capacitor bank maintenance is reduced and capacitor bank troubleshooting is minimized.

2.12.4 Volt / VAR Optimization (VVO)

VVO deals with the capability to optimize the objectives of VAR loss minimization and reduction in load with voltage constraints by means of optimization algorithms and well-crafted control objectives. These objectives are restrained by various constraints through decision making process either in a centralized way or decentralized way. In the coming years, with the increase in distributed generation, smaller plants that are placed nearer to the end customer will help to reduce electrical losses. At every level of the transmission and distribution system electrical losses cannot be avoided due to the presence of electrical impedance which includes both resistance and reactance of the equipment. So electrical losses occur starting from the step-up transformers which are located at the power plants and the transmission and distribution grid down to the delivery points where customer are connected. Generally VAR flow happens in the system due to flow of current through equipment on the system which is inductive in nature, such as transformers and transmission lines, and also by the nature of load. To reduce the VAR flow in the system, capacitance in the form of capacitor banks are connected to the system.

2.12.5 Volt / VAR Optimization and the Smart Grid

- As the power system is faced by complexities differing radically, VVO helps the distribution organizations to function their systems within their limits. These complexities include increase in renewable generation placed at distribution voltage levels. The essential data sharing between the enterprise applications is enabled by smart grid. For example, customer revenue meters will inform about voltage readings from AMI systems will be shared with a centralized master VVC. This will benefit the customer by monitoring the lowest customer service point voltages and make sure that the voltage profile from the substation to the customer is as stable as possible.
- With the presence of distributed energy sources (DER) and the incorporation of consumer demand management, the combination of VVO with the control and optimization of these resources in the distribution system is becoming a new challenge in smart grid. The very fast growth of renewable generation and energy storage system in the future years with smart grids will introduce huge challenges. But it will also provide opportunities for VVO in a greater extent. Nondispatchable distributed renewable energy resources like wind and PV are discontinuous and hard to predict in their operation. The tendency to reach overvoltage conditions will increase because of them in the distribution system. This means that the controllable voltage and VAR resources on the distribution system must be controlled as often as possible and with more accuracy in order to equal the varying output profile of the renewable energy sources.

2.13 Fault Detection, Isolation and Service Restoration

- Fault Detection Identification and Restoration (FDIR) is one of the important technologies whose aim is to identify the fault occurrence, record the occurrence, and determine the fault location. Finally it helps in the restoration process. It is an integration of advanced DMS and OMS systems, as well as a close combination of feeder level assets with the DMS. FDIR systems will also use automated switching like reclosers, sectionalizers and switches.

This will help to reduce the number of customers affected by a fault. The FDIR system is tightly connected with the DMS so that measured values from the shunt capacitors, reclosers, and sectionalizers are available to find the location of the fault. In addition to that, automatic operation of switches, reclosers, and sectionalizers is made possible which further reduces the time length of the outage. The result is that the system operates with reclosers and sectionalizers in the face of fault occurrence and the time required to identify and locate the fault is reduced by 30 %.

- From the analysis of FDIR the following conclusions and observations can be made :

  1. The chief benefit of the incorporated FDIR is power system reliability increases. The peak load or annual energy consumption is not affected.
  2. When the FDIR is coordinated with reclosers, sectionalizers, DMS and OMS, it becomes one of the most fruitful ways to increase the reliability of a distribution feeder.
  3. Only when the power system is having low reliability, coordination of FDIR is mandatory.

- Generally, two technology components are needed to provide FDIR capabilities. These are software algorithms and field devices. Field devices have sensors and switches. The sensors search for issues on the network, while switches are utilized to control the power flow in the network. Algorithms are the mathematical tools that guide the switching operations when isolating equipment on the network. Switching operations proposed by software algorithms must be applied by an automatic system or human operator. Fig. 2.13.1(a) shows a typical 11 KV distribution network. When there is a fault on the network at the location shown in the Fig. 2.13.1 (a), CB1is opened by the over - current protection element in IED1.This opening action will bring an outage at loads L1 to L5. Since there are no automated operations of components in the network, this demands human intervention for supply restoration. Supply restoration is normally started by receiving phone calls from affected customers in the area where outage has occurred. Now, the electricity supplier is reported about the loss of power supply to the customer. After receiving these calls, a restoration crew is dispatched to the area. But it will take more time for the crew to locate the fault and manually isolate it by opening SD3 and SD4. Now CB1 is closed to restore the supply to L1, L2 and L3. The normally open point (NOP) is closed to restore the supply to L5. Load L4 will not have supply until the fault is cleared.

- A larger degree of automation may be introduced by making use of reclosers with RTUs, with communication infrastructure between them as shown in the Fig. 2.13.1 (b). In this scheme, an agent is brought into picture who gathers data from all the intelligent devices in the system. During normal operation, the Agent surveys all the RTUs and IEDs to stabilize the system status. When there is a fault at the location shown, IED1 senses the fault current, opens the CB and give information to the Agent. The Agent, in turn sends instructions to RTU1 to RTU4 (i.e., remote terminal units extending till NOP) to open them and requests current and voltage data from them in real time.

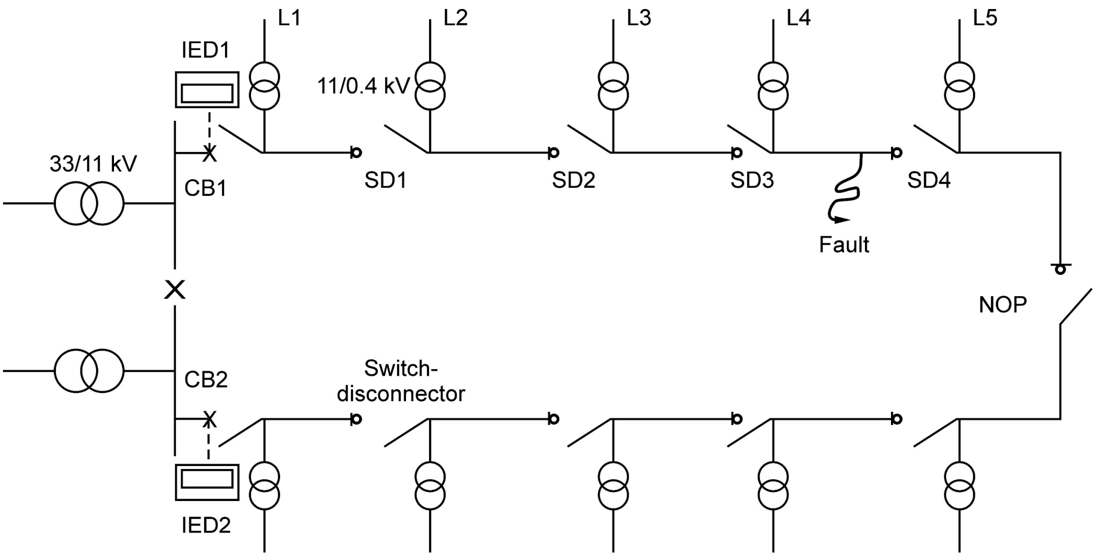

Fig. 2.13.1 (a) : 11 KV distribution network

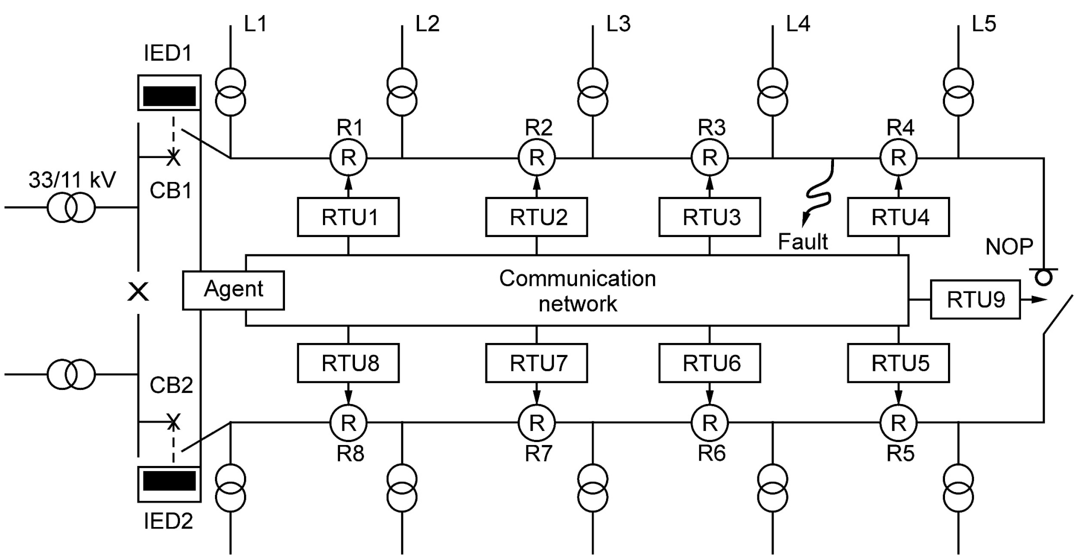

Fig. 2.13.1 (b) : 11 KV distribution network with reclosers and sectionalizers

- A possible automatic restoration method works as follows :

  1. A command is sent to IED1 to close CB1.
  2. Next level command is sent to RTU1 to reclose R1. If the fault current exceeds, a trip is initiated but as there is no fault current, R1 remains closed. Similarly a set of commands sent to RTU2, 3 and 4 to reclose R2, R3 and R4. When R3 is closed, fault current flows, thus causing R3 to trip and lock-out.
  3. Then a command is sent to RTU9 to close the normally open point.
  4. Finally, a command is sent to RTU4 to close R4. As the fault current flows, a trip command is initiated for R4. R3 and R4 thus isolate the fault and supply is restored to loads L1, L2, L3 and L5.

2.14 Outage Management System (OMS)

- Conventional outage happens because of bad weather and heat, excavations, defects in the power station, power lines damages and defects in the distribution system. Other reasons for outage may include a short circuit in the line, the overloading of electricity mains, equipment failures, or vehicles hitting utility poles. The solution to manage power outages effectively depend upon implementing outage management system (OMS) or upgrading the existing system.
- Recent computer-based OMS makes use of connectivity models and graphical user interfaces. This includes operations like trouble call handling, outage analysis and prediction, working crew management, and reliability reporting. The distribution system connectivity helps operators with the outage management system which will result in detection of nested outages and inclusion of partial restoration of the system. Outage management was initially carried out by receiving calls from the customers and did not have a connectivity model of the system. This will include the connection points of all customers. In the past, use of paper maps and manual data recording were very common to estimate the location of outages. With the invention of modern OMS, system connectivity information is usually stored in the GIS (Geographic Information System).
- A typical OMS is shown in the Fig. 2.14.1. Network data from GIS are given to the OMS database by means of a network data interface. This interface gets data from GIS and designs a data model conversion which depends upon business rules and data model mapping. The interface first generates the database with all network data. This will include connectivity information, system components, protection and switching device types and their locations, and information about distribution transformers. This is called as the bulk network data load or bulk load. The interface will be periodically run to exchange the subset of data that has changed since the last update. This process is called as the

incremental network data update or incremental update. Outage Management Systems are usually integrated with SCADA systems which will automatically report the monitoring of circuit breakers operation. In recent years, mobile data system is just another system that is usually integrated with an outage management system. This integration enhances the ability for outage predictions and it sends information to working crews in the field automatically for necessary actions. This will reduce estimated restoration times without demanding radio communication with the control center.

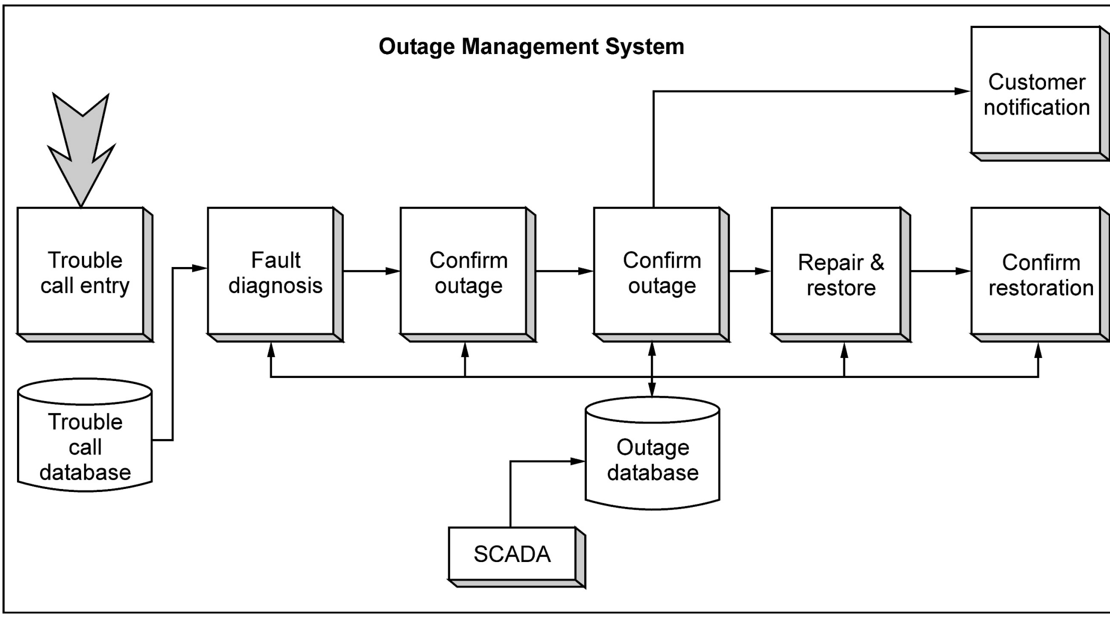

Fig. 2.14.1 : Information flows of OMS

➥ 2.14.1 OMS Benefits

- The OMS benefits can be listed as below :
  1. Outage duration is reduced due to faster restoration based upon outage location predictions.
  2. Reduced outage duration minimizes due to prioritizing of outage clearing.
  3. Customer satisfaction is improved due to increase in awareness of outage restoration progress to the customers.
  4. Media relations are improved by providing accurate outage and restoration information.
  5. Number of complaints is reduced due to ability to prioritize restoration of emergency facilities and other critical customers.
  6. Frequent occurring of outage is reduced due to efficient outage management.

2.15 High-Efficiency Distribution Transformers

- India is currently experiencing 23 percentage transmission and distribution losses. We struggle to reduce these losses which are made possible by incorporating energy efficient equipment.

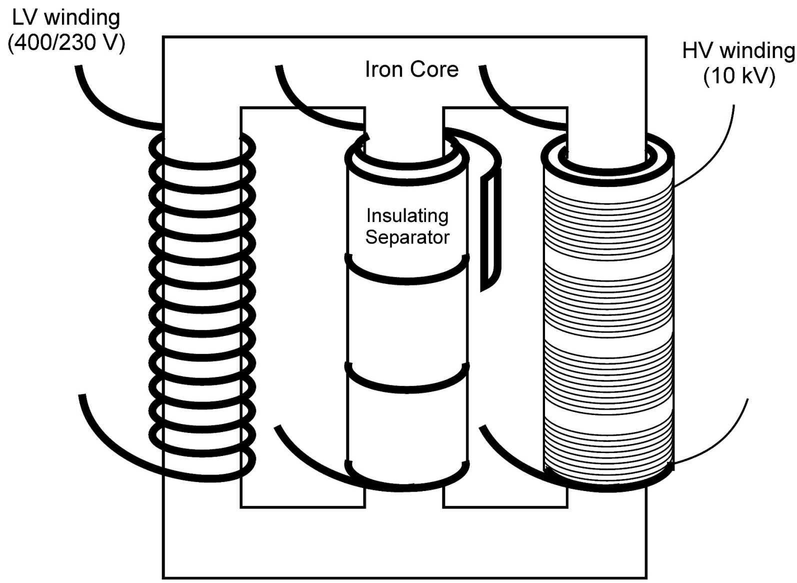

Fig. 2.15.1 : High efficiency distribution transformer

- Because of the presence of a large number of distribution transformers in electric power system and their long lifetime, even small increase in the efficiency of these units will end up in very good energy savings. The representational diagram of the high efficiency distribution transformer and its amorphous core is shown in the Figs. 2.15.1 and 2.15.2 respectively. A significant increase in energy efficiency of distribution transformers is obtained by minimizing no-load loss (iron or core loss) of the transformer. The use of amorphous metal in distribution transformers has an advantage of allowing both liquid filled and dry type transformers with highly reduced no-load loss.

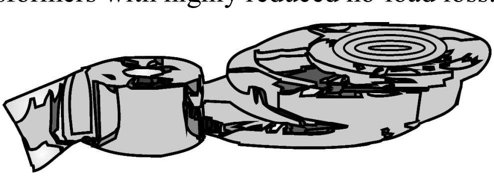

Fig. 2.15.2 : Amorphous Ribbon or core

- Fig. 2.15.3 depicts the efficiency level of high efficiency distribution transformer with respect to international standard HD 428 types of load testing with amorphous core materials. It can be easily observed from the picture that these transformers give an efficiency ranging from 97.98 to 99.58 even under 50 % of loading.

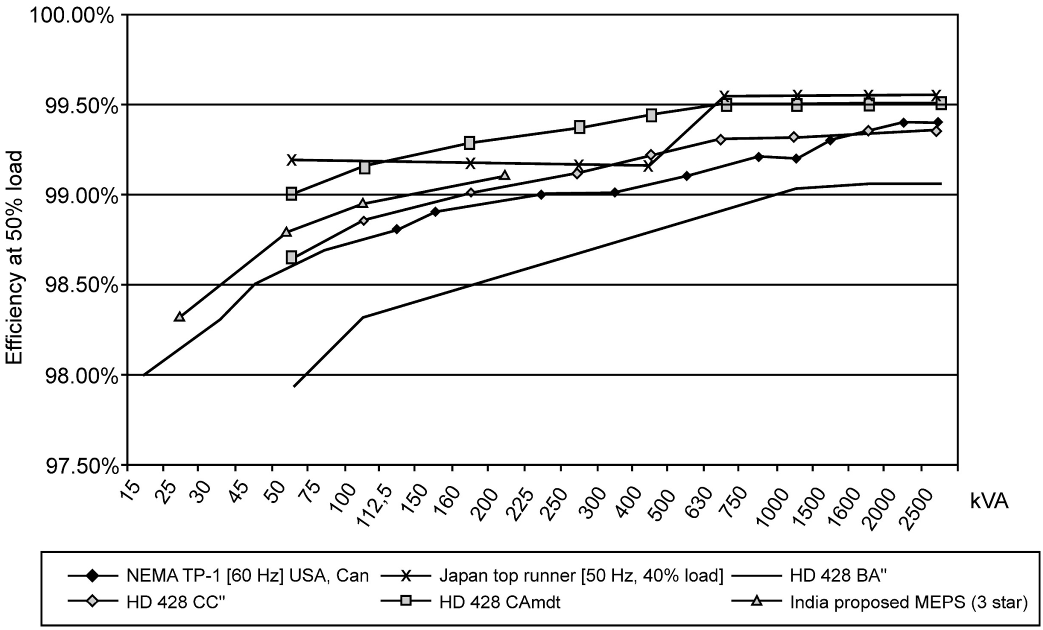

Fig. 2.15.3 : Comparison of international standard efficiencies at 50 % of load. 'C-AMDT' refers to an amorphous-core transformer with HD 428 C-class of load losses

2.15.1 No Load Losses of Amorphous Ribbon or Core

1. Hysteresis Loss :

When a magnetic field is applied, the random molecular structure of amorphous metal produces less friction than silicon steel. This unique property of amorphous materials allows ease of magnetization and demagnetization. This will significantly lessen hysteresis losses.

2. Eddy Current Loss :

Amorphous metals are of very thin laminations and have high resistivity. This will reduce the eddy current losses as compared to silicon steel. When compared with standard liquid filled transformers, the amorphous metal core transformers have a significant no-load loss reduction up to 70 %. An amorphous metal transformer (AMT) is a unique kind of energy efficient transformer installed on electric grids. The magnetic core of this transformer is constructed with a ferromagnetic amorphous metal. The unique material is an alloy of iron with boron, silicon, and phosphorus combination and having a foil thickness of 25 μm. The magnetic susceptibility of these materials is very high and it has very low coercivity and high electrical resistance. The high resistance and thin foils will produce low losses by eddy currents when subjected to alternating magnetic fields. The only downside of amorphous alloys is that they have a lower saturation induction and give a stronger magnetostriction compared to conventional iron-silicon electrical steel.

2.15.2 Amorphous Metal Transformer Benefits

- The following are the benefits of amorphous ribbon core transformers :
  1. Energy saving can be improved up to 75 % over conventional silicone steel core
  2. CO, SO emission of hazardous gasses is reduced significantly
  3. Fossil fuel consumption is reduced.
  4. Fast and easy repair due to modular construction
  5. Temperature rise in the core is reduced
  6. Overloading capacity is higher because of lesser heat generation due to lower losses.

2.16 Phase Shifting Transformer (PST)

- Phase shifters are largely used in power systems for controlling the magnitude and direction of the active power flow. The typical representation of PST is shown in the Fig. 2.16.1. By injecting a voltage in series with the line the control of the magnitude and direction of real power flow on the line is achieved. This will also change the phase angle of the receiving end voltage. A variable series voltage is obtained by a tap changer which acts on the regulating winding. It is then injected by the booster winding across the series winding.

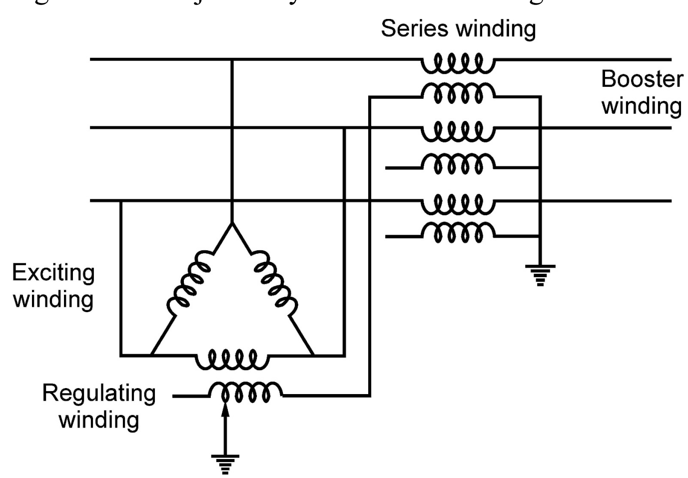

Fig. 2.16.1 : Phase shifting transformer

- A typical PST will be capable of providing variable phase angle shift up to 20°. However, changing the phase angle of the injected voltage through the taps takes time because of the slowly operating nature of phase shifting transformers. When PST uses mechanical taps, this can only be applied for very limited works with slow requirements under steady state system conditions. Quadrature booster is a unique form of transformer used to control the real power flow on three-phase electricity transmission networks. It is shown in the Fig. 2.16.2. For an alternating current transmission line, power flow through the line is directly proportional to the sine of the phase angle difference between sending and receiving end voltages.

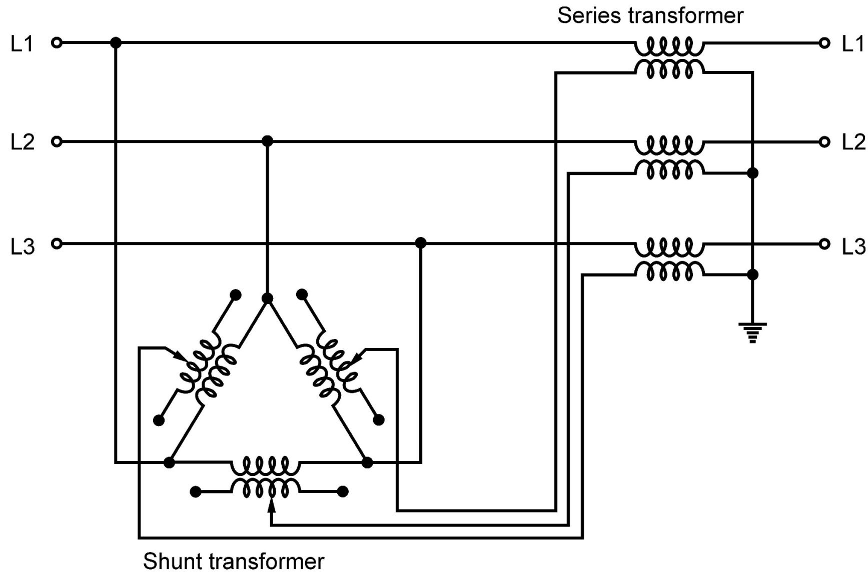

Fig. 2.16.2 : Quadrature booster transformer (PST)

- Where parallel circuits with varying capacity is installed between two points in a transmission grid whether an overhead line and an underground cable, direct handling of the phase angle permits control of the division of power flow between the paths, while preventing overload. Quadrature boosters thus help to relieve overloads on heavily loaded circuits and changing the power flow paths through more favorable paths.
- A phase shifting transformer usually consists of two separate transformers. A shunt unit and a series unit. The shunt unit windings will be connected across the phases. If its output voltage is proportional to, and in phase with, the primary-side phase voltage then series transformer will produce a change in voltage magnitude. On the other hand, shunt transformer can be installed so that its output voltages proportional to the primary-side phase-to-phase voltage. The output voltage phasor diagram of PST is shown in the Fig. 2.16.3. Since the line voltage between two phases in a three-phase system is always in quadrature with the voltage of third phase, the series transformer will bring a negligible change in voltage magnitude but a large change in voltage angle.

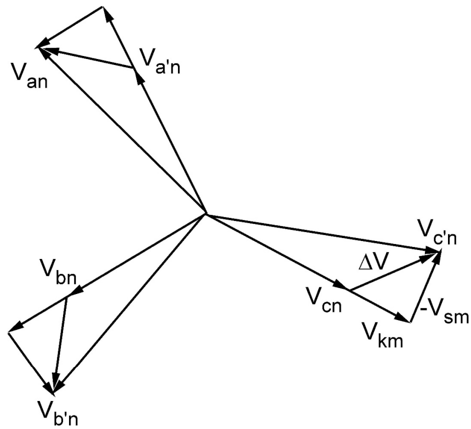

Fig. 2.16.3 : Output voltage phasor of PST

2.17 Plug-In Hybrid Electric Vehicles (PHEV)

One of the serious challenges this world is facing is environmental concern regarding the consumption of fossil fuels. Consequently, consumption of more renewable resources and promotion of a clean transport system such as the use of Plug in Hybrid Electric Vehicles (PHEVs) has become the forefront of the new energy policies. However, the invention of PHEVs in the automobile industries raises concerns about power system stability in the network. The typical representation of PHEV is shown in the Fig. 2.17.1. A series of PHEV studies in UK with respect to the aggregate load profile of PHEVs energy consumption resulted in different price scenarios. The results indicate that under the fixed rate and time of use in the current grid, the extra load of the PHEV increases the consumption profile and also generates new critical points. So, excess standby capacity becomes mandatory to satisfy the peak demand even for a short period of time. Alternatively, when the consumers do not pay the price depending on the true cost of supply, then those who utilize less in peak hours will subsidize the ones who utilize more. This is a critical point in the use of PHEV with respect to regulatory issues. However, smart grids can cope up with PHEVs without raising technical and regulatory problems. This positive consequence is the outcome of demand response to the real time pricing. When analyzed with respect to technical issues, PHEVs load can be shifted to the late evening and the hours of minimum demand. When welfare analysis is considered, real time pricing generates no deadweight losses. Because of this the demand response will limit the spot market clearing price.

2.17.1 Vehicle-To-Grid Technology (V2G)

Because of smart grid, the Vehicle-to-Grid (V2G) concept has become reality. The V2G incorporation permits PHEVs to act as resources to the grid. There are several potential applications for V2G technology. During peak hours if the demand for power in the grid exceeds the supply, then PHEVs will be able to supply peak power. There are also many applications in which the vehicles help to balance the power in feed prediction error of renewable energy generators. Even PHEVs sometimes provide ancillary services to the power grid in order to stabilize the network.

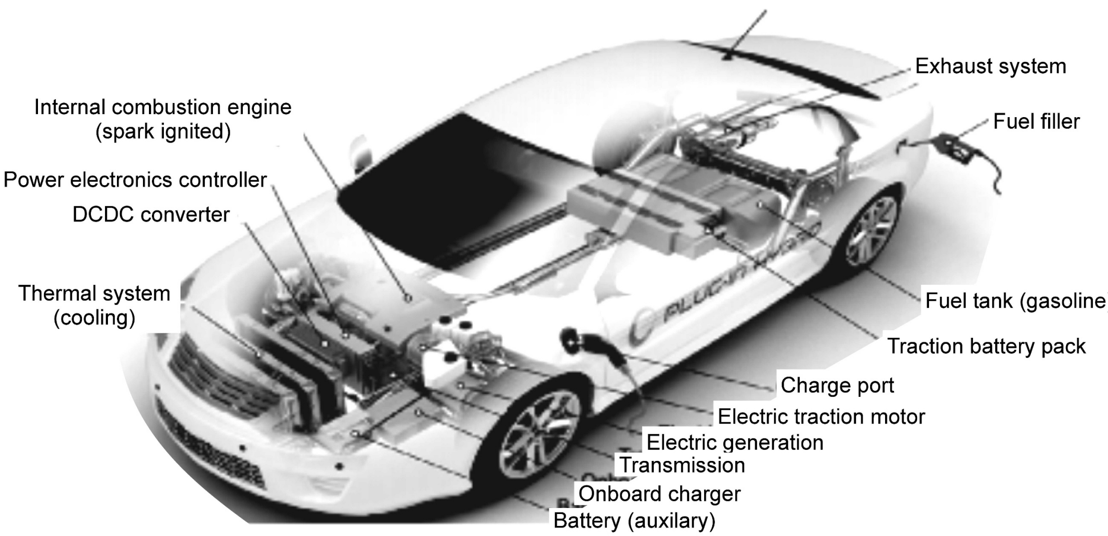

Fig. 2.17.1 : Ford Class B - PHEV

2.17.2 Merits of Plug-In Hybrid Electric Vehicle

- The following are considered as the advantages of PHEV :
  1. The fuel consumption is reduced from 30% to 60%, reduces fuel consumption.
  2. Due to the application of battery and charging abilities of PHEV, greenhouse gases produced by the vehicle are minimized.
  3. Since battery is largely used for the movement of the vehicle, fuel consumption cost is reduced. Even though initial cost of buying is relatively higher, in the long run compared to regular cars PHEV is economical.
  4. PHEV has several energy generators and motors which are smaller in size and lesser in weight. Therefore this reduces fuel consumption without interfering with the performance of the vehicle.

2.18 Questions with Answers

2.18.1 Short Answered Questions

Q.1 Name the technology drivers that build the smart grid.

Ans. :

- Information and communications technologies.
- Sensing, measurement, control and automation technologies.
- Power electronics and energy storage technologies.
- Demand-Side Management (DSM).

Q.2 What is Information and communications technology driver ?

Ans. : Information and communications technologies include :

- Two-way communication technologies which is able to provide connectivity between various elements in the power system and loads.
- Open architectures for plug-and-play of home appliances and electric vehicles and micro-generation.
- Communications systems with the necessary software and hardware to alert customers with accurate information. Helping customers to trade in energy markets and enabling customers to provide DSM (Demand-Side Management).
- Software to make sure and maintain the security information and standards to give scalability and interoperability of information and communication systems.

Q.3 What is sensing, measurement, control and automation technology driver?

Ans. : Sensing, measurement, control and automation technologies include :

- Intelligent Electronic Devices (IED) to offer advanced protective relaying, measurements, fault records and event records for the power system.
- Phasor Measurement Units (PMU) and Wide Area Monitoring, Protection and Control (WAMPAC) to make sure the power system security.
- Integrated sensors, measurements, control and automation systems and information and communication technologies to give rapid diagnosis and timely response to any event in various parts of the power system. These will support enhanced asset management and effective operation of power system components. They will relieve congestion in transmission and distribution circuits and to prevent or reduce potential outages and enable working autonomously when conditions require quick resolution.

- Smart appliances, communication, controls and monitors help to increase safety, comfort, convenience, and energy savings.
- Smart meters, communication, displays and associated software will permit customers to exercise wide choice and control over electricity and gas use. They will provide consumers with accurate bills. They will operate faster. They provide consumers trustworthy real-time information on their electricity and gas use and other related information and to enable demand management and demand side participation.

Q.4 What is power electronics and energy storage technology driver?

▣ **Ans. :**

- High Voltage DC (HVDC) transmission and various schemes and Flexible AC Transmission Systems (FACTS) to provide long distance transport with the integration of renewable energy sources.
- Different power electronic interfaces and advanced electronic supporting devices to offer efficient integration of renewable energy sources and energy storage devices.
- Series capacitors, Unified Power Flow Controllers (UPFC) and other FACTS devices to offer excellent control over power flows in the AC grid.
- HVDC, FACTS and active filters combined with integrated communication system that gives control over greater system flexibility, supply reliability and power quality.
- Power electronic interfaces and integrated communication systems offer better performance by controlling renewable energy sources, energy storage and consumer loads.
- Energy storage to increase greater flexibility and reliability of the power system.

Q.5 Illustrate Demand-Side Management.

▣ **Ans. :** Demand-Side management (DSM) is the modification of consumer demand for energy through different methods like financial incentives and behavioral change by means of education.

Q.6 List out the categories of DSM.

▣ **Ans. :** DSM is classified into three categories as follows :

- Direct control of load
- Local load control option
- Distribution load control

Q.7 What are the constraints of DSM ?

▣ **Ans. :**

1. Technological constraints
2. Economic constraints
3. Social constraints
4. Political and institutional constraints

Q.8 Define Smart energy resource.

▣ **Ans. :** Smart Energy Resources are defined as the new set of resources available to utilities to balance the supply-demand equation—renewable generation, energy storage, and consumer demand management.

Q.9 List out the types of smart energy resources ?

▣ **Ans. :** Some of the most common renewable energy resources are solar PV, Solar Thermal Energy, Wind energy, Bio mass and Bio gas, Geo thermal power, Hydro power, Fuel cells, Tidal power.

Q.10 State the advantages of renewable energy sources.

▣ **Ans. :**

- Great reduction in emissions of greenhouse gases
- Significant reduction in demand for peak electrical generation
- Substituting investment in generation, transmission, or distribution assets
- Improving the reliable operation of the electrical transmission or distribution grid

Q.11 What is solar PV generation ?

▣ **Ans. :** PV represents a method of generating electric power in solar panels that are being exposed to light. Power generated is dependent on the conversion of the energy of the radiation of sun. When a solar cell is exposed to light electrons transfer between different bands inside the material. This, in turn, results in a potential difference between two electrodes, which caused direct current (DC) to flow.

Q.12 What is solar thermal energy ?

▣ **Ans. :** Solar thermal energy (STE) is a technology that converts solar energy into thermal energy (heat). Heat gain is gathered from the sun rays hitting the surface of the object. Then, heat is transferred by either conduction or convection. And high- temperature collectors are used for electric power production.

Q.13 How biomass energy is harnessed ?

▣ **Ans. :** Biomass energy production refers to power production from dead trees, wood chips, plant or animal matters which are used for production of chemical or heat. Technologies linked with biomass conversion to electrical energy include releasing energy in the form of heat which in turn is used for the electric power production.

Q.14 What is hydro power production ?

▣ **Ans. :** Hydropower plants utilize the energy of the moving water as the main source for electric power production. The water fall and gravitational force of this falling water hit the blades on the rotor which will cause the rotor to turn, thus producing electricity.

Q.15 What is fuel cell ?

▣ **Ans. :** A fuel cell is an electrochemical cell that uses the chemical energy of hydrogen or another fuel to produce electricity which is clean and efficient.

Q.16 How tidal power is harnessed ?

▣ **Ans. :** Tidal power harnesses the energy of tides into electricity. Water flows into the barrage during high tide and then it is released during low tide while moving a set of turbines. Tidal stream generators rotate underwater and produce electricity using the kinetic energy of tidal streams.

Q.17 State the general functions of a substation.

▣ **Ans. :** The general functions of a substation are :

- Transformation of voltage level.
- Transmission and distribution power lines connecting point.
- Switchyard for electrical transmission and distribution system configuration.
- Monitoring point for the control center.
- Protection of power lines and other apparatus.
- Reliable communication with other substations and regional control centers.

Q.18 What the challenges faced by substation designer when advanced technologies are used ?

▣ **Ans. :**

- Very high numbers of operating contingencies different from expected system design.
- High penetration of intermittent renewable and distributed energy resources, with their present characteristic of limited controllability and dispatch ability.

- Power quality issues (voltage and frequency variation) that cannot be readily addressed by traditional solutions.
- Effective and highly distributed, advanced control and operations logic.
- Slow response during quickly developing disturbances.
- Adaptability of advanced protection schemes to rapidly changing operational behavior due to the intermittent nature of renewable and DER (Distributed Energy Resources).

Q.19 Classify substation based on their types.

▣ **Ans. :** Substations are classified as :

- Transmission substation
- Sub-transmission substation
- Distribution substation

Q.20 Outline the objectives of smart substation.

▣ **Ans. :** The following are the objectives of smart substation :

- The real time testing of intelligent distribution with highest reliability and control this will drive the underlying grid.
- Ensuring automatic energy saving concepts and systems for the satisfaction and convenience of consumers.
- Providing a reasonable, reliable and affordable electricity supply to consumers.

Q.21 Name the features of smart substation.

▣ **Ans. :**

- Gathering information about power flows and stabilizing it in the medium a low voltage networks.
- Incorporating intelligent devices for all kind of operations.
- Ensuing whether all control and protection devices have been networked properly.
- Maintaining the voltage levels of all networks efficiently.
- Minimizing power shortages and identifying power theft.
- Reducing power quality problems such as harmonics, sudden voltage drops and flicker.
- Ensuring the formation of microgrids and increasing their autonomous operation.

Q.22 What is IED ?

▣ **Ans. :** An intelligent electronic device (IED) is an integrated microprocessor-based controller of power system equipment, such as circuit breakers, transformers and capacitor banks.

Q.23 Illustrate Energy Management System (EMS).

▣ **Ans. :** An energy management system (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation or transmission system. Also, it can be used in small scale systems like microgrids.

Q.24 What is RTU ?

▣ **Ans. :** A remote terminal unit (RTU) is a microprocessor-controlled electronic device that interfaces objects in the physical world to a distributed control system or SCADA (supervisory control and data acquisition) system by transmitting telemetry data to a master system, and by using messages from the master supervisory system to control connected objects.

Q.25 What is SCADA ?

▣ **Ans. :** Supervisory control and data acquisition (SCADA) is a control system architecture comprising computers, networked data communications and graphical user interfaces (GUI) for high-level process supervisory management. It may also have other peripheral devices like programmable logic controllers (PLC) and discrete proportional integral derivative (PID) controllers to interface with process plant or machinery. The use of SCADA has been considered also for management and operations of project-driven-process in construction. The key characteristic of a SCADA system is its ability to perform a supervisory operation over a variety of other proprietary devices.

Q.26 What are three levels of equipment function in substation automation ?

▣ **Ans. :** The configuration of modern substation automation consists of three levels of equipment function :

- The station level function
- The bay level function
- The Process level function

Q.27 What is smart substation ?

▣ **Ans. :** The concept of smart substation is to construct a thoroughly intelligent substation environment where all the devices can work and collaborate on the same network. With the help of intelligent electronic devices it becomes easy to control the substation and empower remote users to manage system devices.

Q.28 What is feeder automation ?

▣ **Ans. :** Feeder automation is a constituent of distribution automation system, which principally focuses on remote monitoring and control of the distribution systems and their equipment.

Q.29 What is substation automation ?

▣ **Ans. :** Substation automation system is a collection of hardware and software components that are used to monitor and control an electrical system, both locally and remotely. It also refers to using data from intelligent electronic devices (IEDs) which are having control & automation capabilities within the substation. They receive control commands from remote users to control power system devices.

Q.30 List out few feeder automation functions.

▣ **Ans. :** The following are the few feeder automation functions :

- Fault identification, Faulty part isolation, and service restoration
- Network reconfiguration
- Load management/demand response
- Active and reactive power control
- Power factor control
- Short-term load forecasting
- Three-phase unbalanced power flow

Q.31 What is Energy Management System (EMS) ?

▣ **Ans. :** An energy management system is a very important function necessary to increase efficiency and to provide best possible coordination between different energy sources. It is a computer-aided tool used by power system operators to monitor, control, and carry out optimal energy management.

Q.32 List out some of the FACTS devices.

▣ **Ans. :** The following are the some of the FACTS devices :

SVC - Static VAR compensator

STATCOM - Static synchronous compensator, with VSC

FSC - Fixed series compensation

TCSC - Thyristor controlled series compensation

TPSC	-	Thyristor protected series compensation
UPFC	-	Unified power flow controller
CSC	-	Convertible synchronous compensator
GPFC	-	Grid power flow controller (FACTS-B2B)

Q.33 What are the types of reactive power compensation in power system ?

▣ **Ans. :** The following are the types of reactive power compensation used in power system :

- Series compensation
- Shunt compensation
- A combination of series/shunt compensation

Q.34 What is HVDC system ?

▣ **Ans. :** A HVDC system is high voltage direct current transmission system. It takes electrical power from an alternating current (AC) system and converts it into high voltage direct current (DC) using converter station. After that it transmits the DC to a distant system. At receiving end station, the DC is converted back into AC by another converter station.

Q.35 Illustrate the advantages of HVDC transmission.

▣ **Ans. :** The following are the advantages of HVDC transmission :

- Power system stability margins improve significantly due to the ability of rapidly changing power transfer.
- The short circuit level of the power system remains stable.
- No transfer of faults across the interconnected systems.

Q.36 List out the types of HVDC links.

▣ **Ans. :** The following are the types of HVDC links :

- Monopolar link
- Bipolar link
- Homopolar link

Q.37 State some advantages of HVDC system.

▣ **Ans. :**

- Reactive power stations are not required.
- System stability increases significantly.

- Provides independent control of AC system.
- Energy flow changes in a fast manner.
- Corona loss is minimized
- Radio interference is minimized.
- Provides greater reliability.
- Transmission of power is not limited by distance.
- Power flow direction can be changed instantly.
- Cost is lower.

Q.38 What is WAMPAC ?

▣ **Ans. :** Wide Area Monitoring, Protection and Control (WAMPAC) is defined as a system that is based on Synchronized Measurement Technology represented by Phasor Measurement Units (PMUs) which is an important part of the solution. It is also known as a synchrophasor.

Q.39 What is phasor measurement unit (PMU) ?

▣ **Ans. :** The phasor measurement unit (PMU) is a device used to estimate the magnitude and phase angle of an electrical phasor quantity such as voltage and current in the electric grid using a common time source for synchronization.

Q.40 List out the advantages of WAMPAC.

▣ **Ans. :** The following are the advantages of WAMPAC :

1. Reliability, stability and security is maintained against large disturbances.
2. Large numbers of intermittent generating sources like solar, wind, etc., are managed properly.
3. Power quality is maintained to better level.
4. Transmission efficiency is increased.

Q.41 What are the distribution systems topologies ?

▣ **Ans. :** The following are the distribution systems topologies :

- Secondary-selective 'Main-Tie-Main' topology
- Main-Tie-Main topology
- Ring bus topology
- Primary loop topology
- Composite primary loop/secondary selective topology

Q.42 What is Distribution Management System (DMS) ?

▣ **Ans. :** A DMS is a collection of applications incorporated to monitor and control the whole distribution network efficiently and reliably. It works as a decision support system to help the control room and field operating engineers with the monitoring and control of the electric distribution system.

Q.43 Explain Volt/VAR Control (VVC).

▣ **Ans. :** Volt/VAR Control or VVC implies the process of balancing voltage levels and reactive power (VAR) throughout the power distribution systems. VVC maintains acceptable voltage at all points along the distribution feeder under all loading conditions.

Q.44 Explain Fault Management and System Restoration (FMSR).

▣ **Ans. :** Fault management and system restoration is the component of network management concerned with detecting, isolating and resolving network faults. FMSR is well known for automated switching applications under fault condition which plays an important role in power system stability and reliability.

Q.45 State the advantages of Fault Detection Identification and Restoration (FDIR).

▣ **Ans. :** The following are the advantages of FDIR :

- The chief benefit of the incorporated FDIR is power system reliability increases. The peak load or annual energy consumption is not affected.
- When the FDIR is coordinated with reclosers, sectionalizers, DMS and OMS, it becomes one of the most fruitful ways to increase the reliability of a distribution feeder.
- Only when the power system is having low reliability, coordination of FDIR is mandatory.

Q.46 What is Outage Management Systems (OMS) ?

▣ **Ans. :** Outage management systems or OMS are a variety of computer-aided systems which are used by electrical distribution systems. They are primarily used by the grid and distributed system supervisors to return power to the grid. OMS helps to solve either customer problems or utility problems.

Q.47 What is Phase Shifting Transformer (PST) ?

▣ **Ans. :** A phase shifting transformer is power system device which creates a phase shift in voltage between primary (source) and secondary (load) side. This phase shift can be varied even under load conditions.

Q.48 What is Plug-In Hybrid Electric Vehicles (PHEV) ?

▣ **Ans. :** Plug-In Hybrid Electric Vehicles are hybrid vehicles with high capacity batteries that can be charged by plugging them into power socket or in a charging station. They can store more than enough power in their batteries and reduce fuel consumption under driving conditions.

Q.49 Illustrate the merits of PHEV.

▣ **Ans. :** The following are the merits of PHEV :

- The fuel consumption is reduced from 30% to 60%, reduces fuel consumption.
- Due to the application of battery and charging abilities of PHEV, greenhouse gases produced by the vehicle are minimized.
- Since battery is largely used for the movement of the vehicle, fuel consumption cost is reduced. Even though initial cost of buying is relatively higher, in the long run compared to regular cars PHEV is economical.
- PHEV has several energy generators and motors which are smaller in size and lesser in weight. Therefore this reduces fuel consumption without interfering with the performance of the vehicle.

➥ 2.18.2 Long Answered Questions

Q.1 Discuss the various kinds of smart grid technology drivers. **[Refer section 2.1]**

Q.2 Explain Demand-Side Management (DSM). **[Refer sections 2.1.6, 2.1.7 and 2.1.8]**

Q.3 Discuss in details about smart energy sources for smart grid function. **[Refer section 2.2]**

Q.4 With neat diagram explain the operation of smart substation. **[Refer sections 2.3,2.3.1 and 2.3.7]**

Q.5 Illustrate substation automation. **[Refer sections 2.4 and 2.4.1]**

Q.6 Enumerate feeder automation. **[Refer section 2.5]**

Q.7 Illustrate energy management systems with neat diagram. **[Refer section 2.7]**

Q.8 Explain various FACTS devices used in smart grid with neat diagrams. **[Refer section 2.8]**

Q.9 Discuss about various methods of reactive power compensation. **[Refer sections 2.8.3, 2.8.4, 2.8.5 and 2.8.6]**

Q.10 Discuss with neat diagram about HVDC systems ? **[Refer sections 2.8.7, 2.8.2, 2.8.9, 2.8.10 and 2.8.11]**

Q.11 Explain about WAMPAC in detail. **[Refer sections 2.9, 2.9.1, 2.9.2 and 2.9.3]**

Q.12 With neat diagram discuss about distribution system topologies. **[Refer sections 2.10, 2.10.1, 2.10.2, 2.10.3, 2.10.4, 2.10.5 and 2.10.6]**

Q.13 Explain distribution management system in detail. **[Refer section 2.11]**

Q.14 Discuss in detail about Volt/VAR Control (VVC). **[Refer section 2.12]**

Q.15 Illustrate Fault Detection Identification and Restoration in detail. **[Refer section 2.13]**

Q.16 Explain OMS in detail. **[Refer section 2.14]**

Q.17 Discuss about high-efficiency distribution transformers in detail. **[Refer section 2.15]**

Q.18 Explain about phase shifting transformers in detail. **[Refer section 2.16]**

Q.19 Discuss about plug in hybrid electric vehicles in detail. **[Refer section 2.17]**

➡ 2.18.3 Multiple Choice Questions

Q.1 Smart grid technologies are aimed at improvement of _________.

a only power transmission system

b only power distribution system

c both power transmission & distribution system

d neither power transmission nor power distribution system

Q.2 Power grid has demonstrated the smart grid technology capabilities in collaboration with various solution providers at ___________.

a Bengaluru b Mysore c Puducherry d New Delhi

Q.3 Which of the following sensors are widely used in power transformers to detect moisture and gas contents in transformer oil ?

a Temperature sensor b Humidity sensor

c Gas sensor d Smoke sensor

Q.4 Traditional electric grids are associated with ___________.

a energy generation is done in centralized power plants

b energy distribution is one directional - from the power plant to the homes or industries

c unidirectional communication

d all of these

Q.5 Benefits of powering the vehicle with electricity from the grid are ___________.

[a] reduces fuel cost [b] cuts petroleum consumption

[c] reduces pollution [d] all of the above

Q.6 The two basic types of electric vehicles are ___________

[a] PHEVs and BEVs [b] AEVs and PHEVs

[c] FCEVs and BEVs [d] AEVs and FCEVs

Q.7 _____________ are used to provide flexibility to control distribution network. It involves conversion from AC to DC and DC to AC.

[a] Three phase transformer [b] Smart transformer

[c] Two winding transformer [d] Outdoor transformer

Q.8 In which of the following mode the electric vehicles are required to be charged periodically by connecting to smart grid through charging stations and smart transformers.

[a] G2V mode [b] V2G mode

[c] V2G2V mode [d] G2V2V mode

Q.9 In addition to charging from the electrical grid, EVs are charged in part by ___________.

[a] hydraulic braking [b] electromagnetic braking

[c] regenerative braking [d] mechanical braking

Q.10 The goal of distribution automation are ___________.

[a] reduced cost [b] improve service reliability

[c] better consumer service [d] all of the above

Q.11 Smart grid enables ___________.

[a] distributed energy management

[b] centralized energy management

[c] both distributed and centralized energy management

[d] none of the above

Q.12 ___________ are electronic devices which are used to store extremely large amounts of electrical charge.

a Electrolytic capacitors
b Variable capacitors
c Super capacitors
d Film capacitors

Q.13 The relationship between stress and strain is given by the following relation ________.

a Young's modulus=Stress*Strain
b Stress= Strain* Young's modulus
c Strain= Young's modulus* Stress
d Stress= Strain/Young's modulus

Q.14 The transmission systems are three phase three wire whereas distribution systems are ___________.

a three phase three wire
b three phase four wire
c single phase three wire
d single phase four wire

Q.15 OMS means ___________.

a Overall Maintenance System
b Overall Management System
c Outage Management System
d Outage Maintenance System

Q.16 _____________ is a collection of functions, tools and procedures that an operator/dispatcher uses to manage the detection, location, isolation, correction and restoration of faults that occur in the power supply system.

a SPM
b OMS
c GIS
d TCM

Q.17 ________ is designed to reduce energy consumption, improved operational security, improve the utilization of the system, increase services reliability and predict electrical system performance.

a EMS
b DMS
c OMS
d SPM

Q.18 The function of WACS ___________.

a power flow control
b reactive power control
c wide area damping control
d all of the above

Q.19 From insulation point of view, many lines are designed very conservatively. It is often possible to increase normal operating voltage by 10% or even higher.

[a] Thermal limit [b] Dielectric limit

[c] Stability limit [d] Insulator limit

Q.20 Smart substation enables a significant reduction in harmonic voltages and resonances, as well as a reduction of peak load by _______.

[a] 30% [b] 25% [c] 20% [d] 35%

❒ Answer Keys for Multiple Choice Questions

Q.1	c	**Q.2**	c	**Q.3**	b	**Q.4**	d
Q.5	d	**Q.6**	b	**Q.7**	b	**Q.8**	a
Q.9	c	**Q.10**	d	**Q.11**	a	**Q.12**	c
Q.13	b	**Q.14**	b	**Q.15**	c	**Q.16**	b
Q.17	a	**Q.18**	d	**Q.19**	b	**Q.20**	a

❑❑❑

Notes

UNIT - III

3 Smart Meters and Advanced Metering Infrastructure

Syllabus

Introduction to Smart Meters, Advanced Metering infrastructure (AMI) drivers and benefits, AMI protocols, standards and initiatives, AMI needs in the smart grid, Phasor Measurement Unit (PMU), Intelligent Electronic Devices (IED) & their application for monitoring and protection.

Contents

3.1 Introduction to Smart Meters

The conventional power grid structure has been degraded and energy demand has increased to a maximum extent. These changes have introduced serious issues like overloading, blackout and curtailments. The changes in conventional power grid paved ways for inducing power quality related issues. Apart from this, underperforming generators, electric machines, pumping systems, industrial and critical loads contributing to capital losses have been observed. To address these issues, Governments and grid authorities have been forced to curtail losses through grid modernization.

3.1.1 Role of Utility Metering Operations

For providing customer billing measurement, traditionally metering services operation have been used. The robust operation of meters and support devices decides the accuracy, precision, and metering function. In global electric industry, the national standard metering service operations have been considered as best system. As the advancement in technology enhanced, the metering system along with communication services have paved a new path for smart metering system. The success of smart metering system depends upon the traditional metering system because it is integral part of the system. The integration of advanced measurement techniques and communication systems into basic meters will definitely be a challenge in grid. Such system deployment will demand for more sophisticated billing and measurement systems design and development.

3.2 Smart Metering Concept and Systems

The conventional electricity meters were electromechanical type of meters. Since recording the electricity consumption alone is done by conventional meters, they are also referred as accumulation meters. The mechanical rotation triggers counter mechanism which is used for computing the electricity consumption. Based on this, the monthly periodic billing and consumers energy consumptions are used for billing. Such billings are performed as on-site detection process. Such metering systems shown in the Fig. 3.2.1 were considered as a primitive and unreliable management system against malicious interventions.

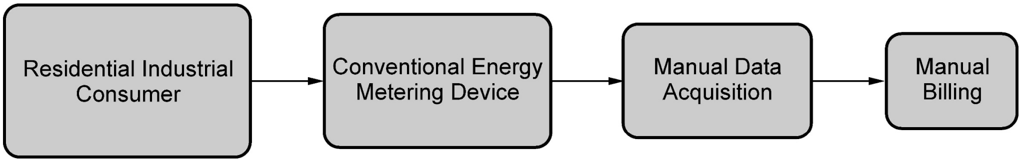

Fig. 3.2.1 : Conventional Metering System

3.3 Evolution of Metering Systems

- The first improvements on metering systems executed with the support of AMR (Automatic Meter Reading), where one way communication between meters to reader has been implemented. The most widely used electricity meter is known as electromechanical accumulation meter, which measures the consumption. The measurement is created as a record of consumption based on time intervals. Since accumulation meters cannot be operated or controlled remotely. Due to this billing was performed manually. Hence, the billing periods were too long as months. But in recent years, with advancement in technology, there are possibilities of generating data for billing and meter readings in short intervals.
- To support this, advanced electricity meters called interval meters have been deployed for hourly recording of consumption data. In early 2000, the next development in metering system has been achieved with smart metering systems. Such system with the supports information and communication technology, energy consumption data can be measured, collected, analyzed and managed.
- The improvements in AMI systems have initialized the two way communication for various applicants namely residential and industrial sector. This AMI (Advanced Metering Infrastructure) system only acts as a fundamental component of smart metering. In the Fig. 3.3.1, the growth and evolution of smart metering systems have been illustrated.

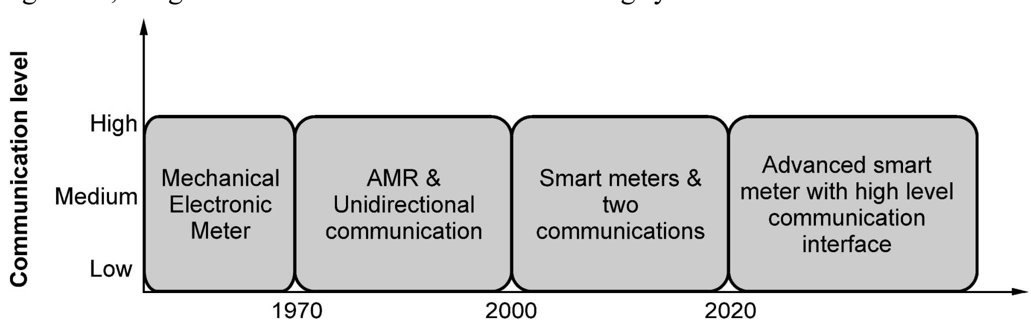

Fig. 3.3.1 : Evolution of smart metering systems

3.4 Smart Metering System

- Smart metering is a single interfacing technology, where the customer and system operator are integrated with an intelligent control and management system. The Fig. 3.4.1, illustrates the smart metering technology. Apart from intelligent integration, smart meter supports estimation, decision-making and data management technologies also. Thus, the smart metering is a technology which connects grid, consumer loads, generation and transmission network, and asset management through intelligent integration via Home Area Network (HAN) and Wide Area Networks (WANs).

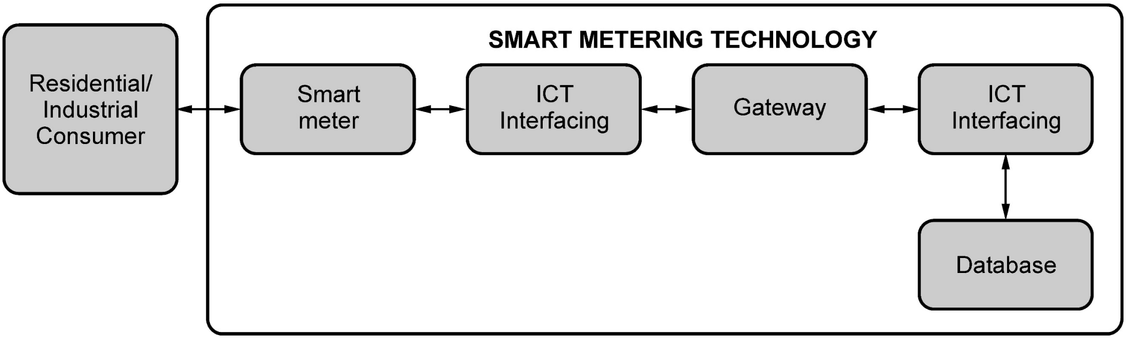

Fig. 3.4.1 : Smart metering technology

- Comparison of conventional metering and smart metering systems architectures are shown in Fig. 3.4.1, states that in conventional metering information flows in a single direction and all processes are performed manually, while on the other end, bidirectional communication dependency of smart metering operations is observed. In this communication is established between customer and operating / monitoring center for data transmission. A communicational channel established has paved a path for interaction between gateways and database.

3.4.1 Functionalities of Smart Meters

- To ensure security and reliability of transmission system, the smart meter employs various sensors in addition to the ICT interfaces. Moreover, in conventional meters there are no programming functionalities to execute predefined functions. When compared with conventional meters, the smart meters support various functionalities as listed below :
  - Provides instant and accurate consumption data
  - Communicates with remote monitoring center
  - Provides data base for analyzing and assessment of power quality
  - Processes control commands received from monitoring and control station
  - Performs scheduled operations
  - Interacts with interfacing devices and home energy management system (HEMS)
  - Detect and prevent power losses
  - Tamper detection and energy theft interventions

3.4.2 Types of Smart Meter Systems

- Based on the type of LAN (Local Area Network), categorization of smart meter system technologies has been defined. Radio Frequency (RF) and Power Line Carrier (PLC) are the two types of smart meter systems. Depending on the demographic and business needs, the utility selects any of these two types of system. There are few factors that influence the meter selection. The following are smart meter selection factors.

- Infrastructure
- Legacy equipment
- Functionality
- Technical requirements

- The selection of the technology requires a thorough evaluation and analysis of the above mentioned factors.
- The data transmission in RF smart meter measurements is performed by wireless radio. This creates a connection between meters to a collection point. For processing the data at central location, various methods are deployed for data transmission to the utility data systems. The transmitted data is used for utility billing and outage management in a smart grid. Further RF smart meters are classified into two more types based on the technologies used. Mesh technology based RF smart meter communicates with each node to form a LAN cloud. Through this data can be collected by data collector. Point to Point technology based smart meter is another type of RF smart meter. In this system, a direct communication to a data collector can be enabled. The data collector transmits data using various methods to the utility central location for processing. When compared to mesh type point to point RF technologies yields better throughput.
- In a PLC type smart meter, the measurements and data communication is enabled across the utility power lines from the meter to a collection point. The data is then delivered to the utility data systems for processing at a central location. The utility billing, outage management, and other systems use the data for operational purposes.

3.5 Smart Metering Infrastructure

- Smart metering architecture is purely dependent on ICT interface. A group of smart meters for measurement and transmission of data is referred as intelligent collector devices, which is an important part in ICT interface. Such data collectors are also known as data concentrators. The measurement data from smart meters and support of data exchange over wireless gateway channels are performed by data concentrator.
- In a smart metering architecture, the core system for data management is Metering Data Management System (MDMS). The Fig. 3.5.1, shows the servers perform various operation namely Customer Information System (CIS), Outage Management System (OMS), Geographical Information System (GIS), and DMS. The role of data concentrators is to couple the customer premises and smart meters with MDMS, thus data exchange between terminal ends are initiated.

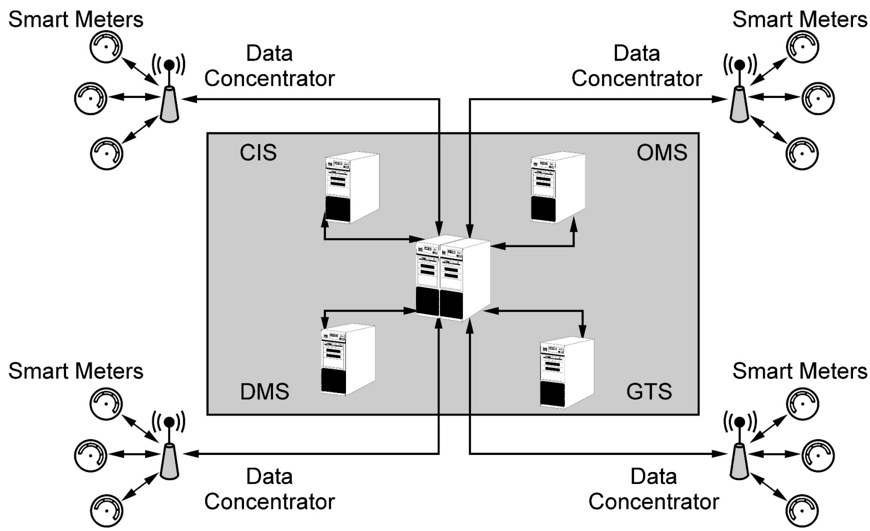

Fig. 3.5.1 : Smart Metering Architecture

➡ 3.5.1 Metering Data Management System (MDMS)

In a distribution network level, MDMS acts as a data acquisition system from smart metering. At this level, the data collected are processed, evaluated, and stored for performing actual status analysis of distribution network. Apart from this, the power quality parameters of grid are monitored by OMS. The detection of any fault or disturbance situations in a grid is reported to MDMS immediately. The OMS neglects data transmitted at high frequencies while considers low frequency detection signals.

➡ 3.5.2 Geographical Information System (GIS)

A better decision making process is supported by GIS, where the geographical data of smart meters and customer premises are collected. A common platform to store, to analyze and to display geographical information on asset management and under or over loaded substations is executed by GIS service.

➡ 3.5.3 Customer Information System (CIS)

The CIS is essential to make sure customer services for generating reliable billing services. The data from GIS is provided to CIS. This data assists the billing operation. During consumption rate detection and billing operation, the GIS data provides information including geographical location. The user interaction with database namely user account, consumption rates with time stamps are managed by this system. Thus, DMS supervises the whole architecture for tracking the power quality and load demand. Such tracking supports in decision making and estimation of load utilized.

3.6 Communication Architecture in Smart Metering Infrastructure

- The communication interface and ICT technologies are the significant component of smart metering architecture. The communication established in the entire smart meter architecture through HAN (Home Area Network) and WAN (Wide Area Network) networks. These networks connect the customer premises with MDMS. In addition to this, it also provides security and reliability of consumer data and entire metering system. Hence, a secure energy management system is achieved for the household appliances.
- Various services such as remote control, monitoring, multimedia systems, surveillance cameras and energy management applications are operated by HAN infrastructure. By using NAN (Neighborhood Area Network) and WAN infrastructures, the internal residential networks are associated with utility grid. The consumption data of customers from smart meters to WAN devices is supported by NAN is shown in Fig. 3.6.1.

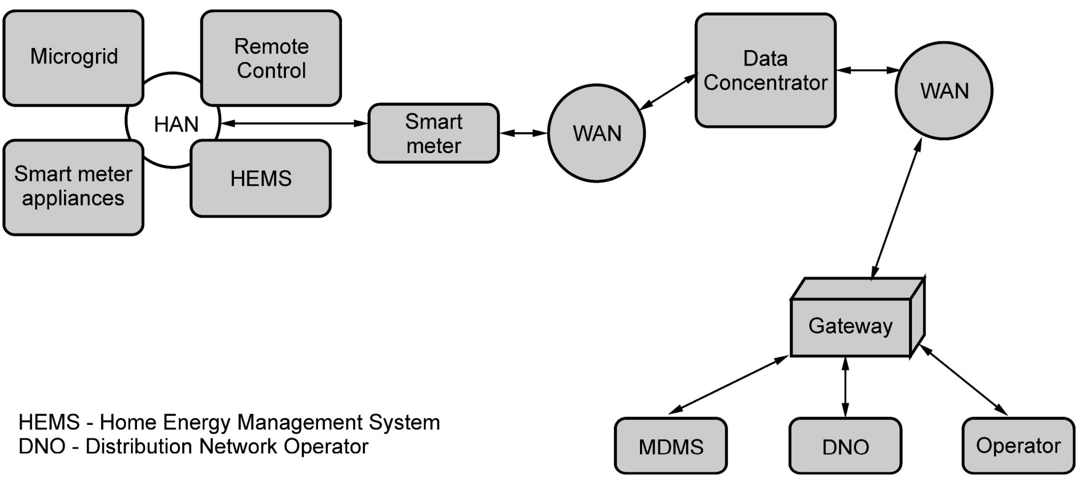

Fig. 3.6.1 : Communication Infrastructure of smart grid

- As the data size of residential smart meter is lower than 100 KB / day, data concentrators are required to support the massive data transmission between NAN and WAN connection nodes. Thus, the data management is managed through concentrator devices. A WAN is a network which comprises several NANs for exchanging information between smart meters and monitoring center. A licensed frequency bands and technologies such as General Packet Radio Service (GPRS) are employed as the communication medium of a WAN.

3.7 Smart Meter

In a smart grid, two essential components are required to monitor the grid situation, namely sensor networks and smart meters. These components are operated either as a wired or wireless communication infrastructures. Among these components, the smart meter is found to be a robust device supporting various kinds of functions in a grid such as consumption measurement, data storage and its processing etc. In the existing system, the conventional meters are employed for measurement of consumed energy only. But deployment of smart meters will provide additional information such as Total Harmonic Distortion (THD) rates, frequency rates, power quality, peak load times and specific interval data. Above all these, smart meters deployment supports rapid detection of outages, assisting to troubleshooting and self-healing processes, and also reports the causes of outages. The measurement data acquired from sensors are transmitted to smart meters and then the processed measurements are delivered to Data Management Unit (DMU) by using communication interface of smart meter. A smart meter uses DMU for secure transmission of the acquired and processed data. A smart meter creates a smart environment where control for disconnection or reconnection of customer premises can be done remotely. This is possible because of the two-way communication capability of smart meter.

➥ 3.7.1 Hardware of Smart Meter

- The conventional electricity meter is an electromechanical structure, where the consumption data is measured by the revolutions of rotating magnetically conductive disc. While in electronics meters, the rotating element is replaced by resistors or sensors. Still, electronic meters require many advanced control and calibration functions, and digital microprocessor technologies to be incorporated for attaining the maximum benefit.
- Ensuring regular and accurate metering are the fundamental requirements of smart grid. The deployment of smart meter supports in waste consumption reduction while decreasing the demand at peak hours. The important features of smart grid are frequency measurement, data recording and warning. Smart grid provides information about consumption rates and usage limits of utility operators and customers. In prepaid metering systems, the consumers are able to consume electricity until the credit discharged. A smart meter provides as an alarm-based warning to the consumers. Such alarm based warning function uses a programmed system in which an exact usage limit is indicated. Thus, the smart meter warns consumer when the limit is reached.
- The Fig. 3.7.1 shows the internal structure of a three-phase four-wire smart meter. The smart meter comprises analog front end (AFE) components namely current transformers (CTs) and voltage transformers (VTs). The internal structure of smart meter and converter devices are powered by the rectifier. In addition to these, few more auxiliary circuits such as power conditioning and filtering are provided to ensure supply reliability. The continuous monitoring of utility or power grid is performed by using direct or indirect measurement of current and voltage values.
- Most of the smart meters can calculate phase difference and frequency of current and voltage values, in addition to the basic measurement capabilities. Such processes are performed by embedded signal processor. The protection and connection / disconnection controls of smart meter are acquired by tamper detector relay driver and temperature sensors along with the embedded System on Chip (SoC) software. Apart from these, the

SoC is responsible for operating several communication protocols and services including wired and wireless technologies such as Ethernet, CAN bus, RS232, RS485, PLC, infrared data association (IrDA), and 2.4 GHz wireless communication for integrating to HAN or BAN networks. In advanced version smart meters have near field communication (NFC) functions for prepaid utilization. The advanced functions like dynamic real time pricing (RTP), demand response (DR), remote connection and disconnection control, network security are executed by MCU of a smart meter.

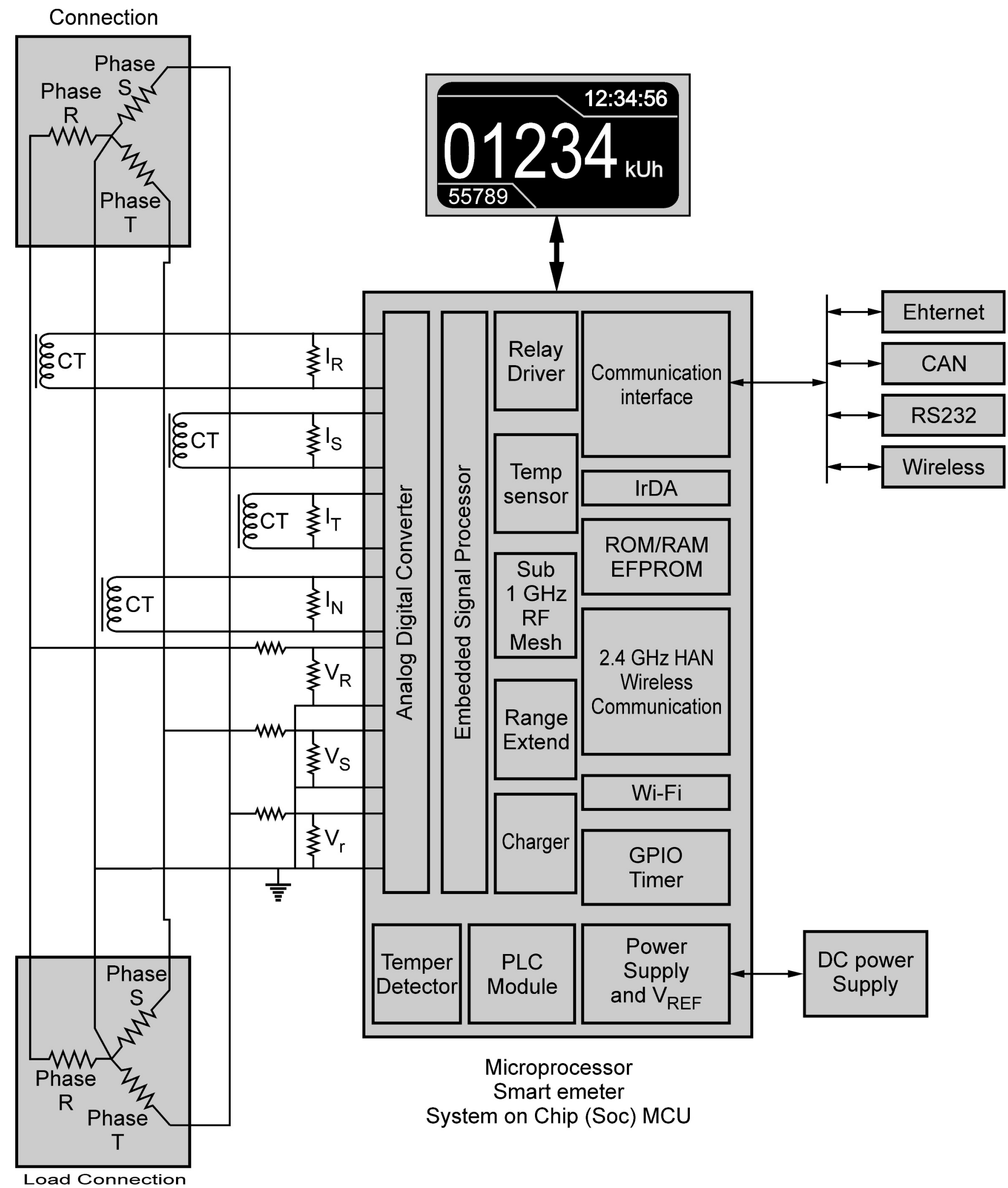

Fig. 3.7.1 : Internal structure of a three-phase four-wire smart meter

- Communication interface is a communication network of a smart meter which enables two-way data transmission. The connection procedures between consumer and network operator are defined using smart metering and monitoring concepts. The communication module of smart meters is independent from AFE and recording sections of smart meter. Thus, disturbance in smart meter function is not found under erroneous in connection module.
- Apart from the transmission of measured consumption data, several special control requirements of smart appliances are enable due to two-way communication capability. Turn on or turn off any specific residential device through communication link is enabled by smart meter. Wireline or wireless transmission technologies are the two different communication interface of a smart meter. Therefore, the installed communication medium should ensure bidirectional data transmission between customers and network operators in addition to customer-network operator channel. Moreover, the communication technologies should cooperate with network architectures such as HAN, NAN, and WAN for ensuring secured and reliable communication.
- The communication networks that are used in smart metering are classified into three groups namely WAN, NAN and HAN. Home area network HAN is deployed for monitoring and controlling integrated devices and to perform smart metering processes at consumer's premises. Hence, HAN is known as fundamental network architecture in a smart grid. HAN facilitates interaction of energy management systems and smart appliances.
- To improve control of users and network operators, an interaction between EMS and smart appliances are needed. HAN is one such network that facilitates an effective interaction in a smart grid. Neighborhood area network (NAN) is located between HAN and NAN to serve as a central bridge of smart metering infrastructure devices. Better reliability, security, and flexibility of system are attained through NAN. An internet-based communication technology to be used in architecture is enabled by NAN. The backbone between DA and power network operators is Wide Area Network (WAN). It supports two-way communication in the system. The communication with various elements of utility namely bulk generation, transmission and distribution systems are done using WAN architecture.
- The detection of unauthorized consumption, theft and fraud use of electricity is enabled by smart meter. The advanced communication infrastructures facilitates such theft detection and addressing of fraud with the support of smart meters. The exact consumption can be reported by the time-stamp feature of smart meters. Such features enable increased control on detection of losses and leakages through utility grid. Any abnormal consumption or unauthorized use of electricity can be immediately detected by the network operator. Based on unauthorized detection smart meters can remotely disconnect the consumers from grid.

3.8 Advanced Metering Infrastructure

- Smart metering unit, communication network and data acquisition and management unit are the important components of AMI architecture. The Fig. 3.8.1 shows the general architecture of AMI. The components of AMI system are associated with fault detection and localization, protection, isolation, energy efficiency, asset management and remote control. Such functionalities are executed by DA which entirely depends on smart metering capabilities of entire grid. The shortfalls caused by one-way data transmission can be overcome by AMI. Since, AMI holds the ability to communicate bi-directionally, several benefits can be acquired from the system is shown in Fig. 3.8.1. Instant decision-making, generation of signal for controlling the system automation are the few functions to be performed by AMI. The data acquisition is highly accurate because of the reliable communication infrastructure. Thus, smart sensors, smart meters and AMI systems are highly needed to yield a sophisticated DMS system.

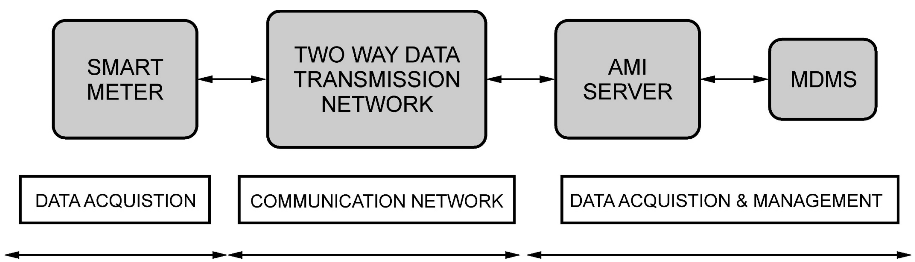

Fig. 3.8.1 : General structure of AMI

- A nationwide grid infrastructure modernization covers transmission and distribution systems with smart metering and monitoring capabilities. In modernization of grid, the electricity grid stakeholders are included directly. For supporting such modernization, deployment of AMI has become mandatory. Hence, it would be possible to monitor and react to instantaneous demand changes.

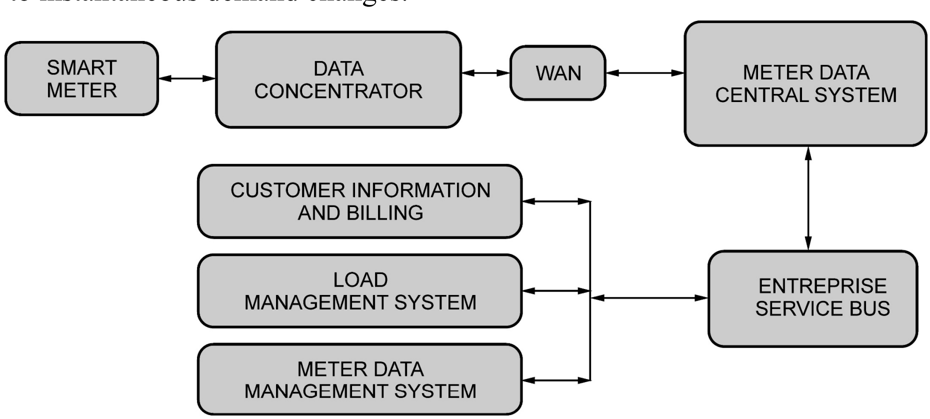

Fig. 3.8.2 : Block diagram of AMI

- AMI is a process of selection and deployment of a specific metering technology to the modern grid. It can also be referred as a new arrangement of utilities processes and applications for collecting meter readings, integrating customers in the daily grid operations. The infrastructure includes the following components in AMI are smart meters, wide-area communication network (WAN), meter data central (MDC) system, meter data management (MDM) system and home area network (HAN) is shown in Fig. 3.8.2.
- Smart meters are solid-state electronic electricity meters employed in AMI. Such meters supports the measurement of electricity consumption and provides smart functionalities as hourly electricity consumption, time-based load control, remote connection and disconnection of delivery site, tamper detection, etc. The above specified functionalities can be remotely configured and customized in the metering devices. Smart meters can be managed remotely either on demand or on a scheduled basis. This would be possible by using data concentrators. The data concentrators are devices that manage a set of smart meters into one single device. This facilitates information gathering from the smart meters, grouping the communications to them. Different technologies such as power line carrier (PLC), wireless, etc are used by data concentrators to communicate with their set of smart meters. Thus, the overall operating cost can be reduced.
- The communication between various components of AMI platform has been established through WANs. The technologies used can vary from 3G wireless communication channels to broadband PLC, optical fiber, wireless radio, etc. for providing continuous communication between the data concentrators and the AMI Meter Data Central (MDC) system. Wide area networks provide transparent links between the metering infrastructure installed on sites and the MDC system. A bidirectional communication channel is deployed for machine to machine (M2M) services connection.
- MDC is a system where data gathered from every single smart meter and concentrator are transferred to a unique central database. MDC system also interfaces with other utility systems, to furnish the required meter data to the infrastructure. The validation, estimation, and editing (VEE) of meter data are done by MDM system which includes a set of software tools and databases. MDM is built on top of MDC system for processing billing systems.
- HANs manage consumers' installed in-home devices such as displays to present instantaneous electricity consumption, time-based electricity prices, planned outages, load control devices as load switches, thermostats, etc. These networks are implemented at residential consumer's location, where the smart meters are linked to in-home installed controllable electrical devices.

- The transformation of conventional power grid towards smart grid aims to increase efficiency, reliability and flexibility. Apart from these targets, smart grid is deployed for Distributed Generation (DG), decentralized control and integration of Renewable Energy Sources (RESs) and Distributed Energy Resources (DERs) in order to satisfy both the customers and utilities. The modern grid would monitor and react to instant demand changes due to improved Demand Side Management (DSM) and Demand Response (DR) programs installed in it. To ensure the balance between generation and consumer sides, DSM approach applies DR programs for altering habits of consumers. DSM can also be used for rehabilitating load capacity of transmission and distribution networks. The DSM applications highly depend on smart metering and smart monitoring infrastructures in transmission and distribution networks in the modernized grid. The feature of smart metering systems can be used to ensure instant monitoring of generation, consumption rates and demand profile parameters of an active grid. The modern grid uses bidirectional communication is used for demand side integration. The communication between Advanced Metering Infrastructure (AMI), Automatic Meter Management (AMM) and comprehensive monitoring technologies have to be optimized efficiently. For accomplishing such efficient optimization, the best choice is replacement of conventional meters by smart meters.
- The measurement and recording of electricity consumption in the infrastructure that has been located is done by smart meter system. The measured consumption data will be locally saved and transmitted to monitoring center in specified intervals of a few minutes to daily periods. Thus, for performing the above mentioned functions, an equipped smart meter is required. The important features of a smart meter are internal data storage, two-way communication, report generating, remote control for connection and disconnection, and tamper detection to prevent malicious interventions.
- The recent technological advancement in metering technologies has enabled evolution of smart automated meter reading devices to AMIs. Such meter allows Transmission System Operators (TSOs) and Distribution System Operators (DSOs) for managing various processes and services. Using these features, a smart metering system can acquire instant demand data, to manage outage and curtailment faults, to operate service restoration and self-healing procedures, and to perform distribution network analysis, demand planning and billing operations through TSOs and DSOs. Besides measurement interfaces, the key components of an AMI system are based on communication, database management and server technologies.

3.8.1 Benefits of AMI Platforms

- The deployment of AMI platforms have been driven by regulatory factors. Various parties namely utilities, consumers, and society have been benefited through AMI platform deployment. The benefits of AMI can be generally categorized as operational, financial, consumer and security.
- **Operational benefits -** AMI benefits the entire grid by improving the accuracy of meter reads, energy theft detection and response to power outages, while eliminating the need for on-site meter reading.
- **Financial benefits -** AMI brings financial gains to utility by reducing equipment and maintenance costs, enabling faster restoration of electric service during outages and streamlining the billing process.
- **Customer benefits -** AMI benefits electric customers by detecting meter failures early, accommodating faster service restoration, and improving the accuracy and flexibility of billing. Further, AMI allows for time-based rate options that can help customers save money and manage their energy consumption.
- **Security benefits -** AMI technology enables enhanced monitoring of system resources, which mitigates system intrusion and cyber attacks.

3.8.2 AMI Protocols and Standards

- For any system, the establishment of regulation is highly important to enable interoperability. This is done by defining the protocols and standards for a system. The ability of two or more components or systems to exchange information and use the information exchanged is defined as interoperability of a system. The exchange of data and its usage is defined by Institute of Electrical and Electronics Engineers (IEEE). IEEE, International Electrotechnical Commission (IEC), American National Standards Institute (ANSI), National Institute of Standards and Technology (NIST) are few standard development organizations. There have been numerous standards to be defined for AMI technology because it is ICT based architecture. Different vendors produce different devices that are integrated to AMI. There should not be any compatibility problem during data transmission, reception and its processing. Apart from these standard development organizations, there are many types of interoperability standards available. The following are standards developed for application specific, namely
  - Multimedia related standards for wire line communication and cellular communications.
  - Data transmission standards such as internet standards, Internet Protocol (IP), Transmission Control protocol (TCP), Usage based Dynamic Pricing (UDP) and Hypertext Transfer Protocol (HTTP) standards.
  - Application related standards as IEC 61850, IEC 61968 and ANSI C.12.

- The standards of communication and interoperability for smart grid was developed by the leading standard development organization called IEC. The featured communication standards that are developed by IEC TC57 for electric power networks include standards for interoperability layers, domains and zones. Components layer, communication layer, information layer, function layer and business layer are list of interoperability layers. Generation, transmission, distribution, DER and customer premises are domains. The process, field, station, operation, enterprise, and market are zones. The standards developed by IED TC57 are classified according to zones and communication layers have been listed below.
  - For improved mapping, service models, and object models in the field zone IEC 61850 is used. IEC 61850 is associated with substation automation, integration of RES and supervisory control and data acquisition (SCADA) communications.
  - At control centers for transmission and distribution, abstract modeling, application and data based integration are implemented using IEC 61970.
  - In Common Information Model (CIM) and AMI back office interface, IEC 61968 are involved.
  - IEC protocols focuses on management operations of network and authorized access control. IEC 62351 provide the support and security services for managing the operation of network.

➥ 3.8.3 AMI Needs in the Smart Grid

The technology, installation, operation and maintenance are the driving factors for AMI deployment. AMI is required to ensure accurate, precise and reliable data acquisition in smart grid. The capability of communicating among different devices is yet another important need in a smart grid. Above all these needs, the concerns on data protection and privacy have become the most important need of AMI in a smart grid. The advancement in metering and communication technologies has become vulnerable to cyber attacks. The metering infrastructures are exposed potential threats and attacks due to the deployment of wireless communication technologies. Modification of metering and billing data the communication networks are intruded by attackers. Hence, there arises a need for curtailing such unauthorized controlling through cyber attacks. Authentication, authorization, and privacy controls are the preventive measures for intrusion by attackers. To ensure the privacy control of smart grid, there are several robust solutions available. Advanced Encryption Standard (AES), Public Key Infrastructure (PKI), Triple Data Encryption Algorithm (3DES) are few technologies deployed for ensuring privacy control. The wireless communication technologies are protected by standards such as IEEE 802.11i and IEEE 802.16e while, firewalls, virtual private networks

(VPN), and IP Security (IPSec) methods are used in wire line communication systems. Still to improve and offer a high level security, an improved protection mechanism like Secure Shell or Secure Socket Shell (SSH), Security Socket Layer (SSL) and Transport Layer Security (TLS) are required in a smart grid. For increasing entire system security by ensuring availability, reliability, and conformity to requirements are done by AMI. Confidentiality, integrity, availability, accountability, and authorization are the parameters related security related issues.

➡ 3.8.3.1 Confidentiality

Confidentiality is a term which deals with consumer privacy. It is defined as privacy on personal information such as consumption behavior and patterns. An indicator about daily life of consumer is metered data and consumption rates, periods, and durations. AMI system is exposed to cyber-attacks and intrusions due to lack of confidentiality.

➡ 3.8.3.2 Accountability

It is term that refers to reliability of remote control and metering compatibility. This parameter is related to financial applications. To ensure accountability, the metering results are converted into data with time stamps. Thus accurate billing can be generated by the system.

➡ 3.8.3.3 Integrity

The security of metered and transmitted AMI data to utility center is defined as integrity. To protect the grid from unauthorized access, the data and commands of AMI system are protected by integrity. Usually cyber attacks are planned on data transmission between consumer and monitoring center. This is because the consumer premises have a protected AMI structure.

➡ 3.8.3.4 Availability

The connectivity of data transmission through the communication infrastructure between smart meter and utility control center is ensured. A guaranteed availability of data communication leads to a better reliable system.

➡ 3.8.3.5 Authorization

- Authorization is a term that enables right to access specific resources and applications of a device by consumers. The authorization assigns privilege to users and thus intentional attacks targeting system security is avoided. The cyber-attacks are usually performed at generation, transmission, distribution and consumption sides of smart grid infrastructure. Thus the need of AMI in a smart grid is to provide proper protection and authentication procedures for users and operators.

- Apart from the above mentioned need, following are the few benefits of AMI which are essential for a smart grid.
  - In case of utilities, the deployment of the AMI platform has paved a way for immediate transition from traditional manual reading process.
  - Automated reading process provides the utilities with reliable and accurate consumption data on a daily basis.
  - The estimation of accurate energy consumption by consumers will increase the overall grid operation efficiency.
  - AMI platforms improve the relationship between utilities and customers.
  - Offers new remote services to customers.
  - Establishing reconnection of customer sites and alarms about planned outages.
  - Increased customer satisfaction and fidelity is observed.

3.9 Phasor Measurement Unit (PMU)

- The establishment of a national grid will be a major boost to the power network of the country. However still there are major issues like gap in demand and supply, high level of losses, untapped enormous renewable energy potential and lack of automation. For a growing economy in a better way, such issues need to be addressed for providing surplus energy. To improve the power scenario in the country, smart grid deployment is highly essential. It is expected that the deployment of PMUs in the Indian grid will continue at an accelerated pace to realize a smarter national grid.
- The real time monitoring of generation and transmission lines using WAMS holds an essential device called Phasor Measurement Unit (PMU). A phasor measurement unit (PMU) is a dedicated device used to estimate the magnitude and phase angle of an electrical phasor quantity in the electricity grid using time synchronization. A phasor is a mathematical representation of a sinusoidal waveform. The phase angle at a given frequency is determined with respect to a time reference. Synchrophasors are phasor values that represent power system sinusoidal waveforms referenced to the nominal power system frequency and coordinated universal (UTC) time.
- The phase angle of a synchrophasor is governed by the waveform, the system frequency, and the instant of measurement. Thus, with a universal precise time reference, power system phase angles can be accurately measured throughout a power system.
- Usually GPS provides time synchronization, which allows synchronized real-time measurements of multiple remote points on the grid. An important advantage of the GPS technology is that its receiver can automatically detect accurate synchronization.

3.9.1 Structure of PMU

- The device which provides synchronized phasor measurements is called a Phasor Measurement Unit (PMU). A quick reconstruction of the phasor quantity of sample waveforms captured is obtained by PMUs. The resulting measurement is known as a synchrophasor. These times synchronized measurements are important in a smart grid because frequency imbalances can cause stress on the grid. Under such imbalances there are more possibilities for power outage occurrence. Therefore, with PMUs installation, an advanced monitoring and controlling can be exercised over the grid.
- The PMUs used in a power system can be utilized for performing the following functions :
  - Real time monitoring and control
  - State estimation Protection and control for distributed generation
  - Network congestion management
  - Angular and voltage stability monitoring
  - Analysis of disturbances and faults
- Phasor Measurement Units (PMUs) are electronic devices that use digital signal-processing components to measure AC waveforms and convert them into phasors, according to the system frequency, and synchronize these measurements under the control of GPS reference sources. The analog signals are sampled and processed by a recursive phasor algorithm to generate voltage and current phasors. Different components of a PMU are Phase Locked Loop (PLL), microprocessor, filters, ADC and GPS are shown in Fig. 3.9.1.

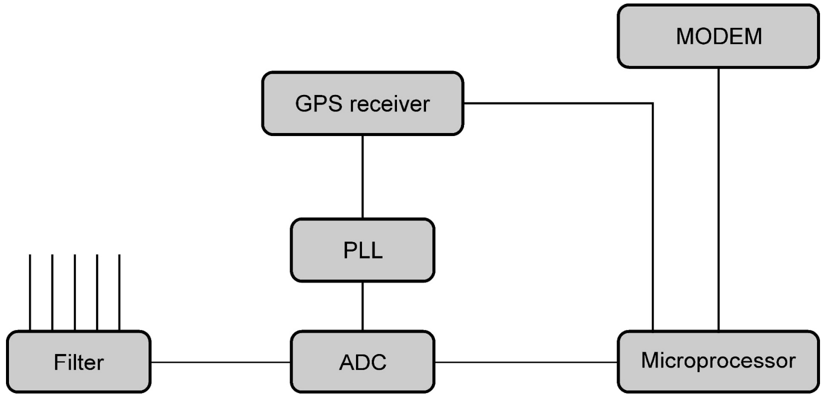

Fig. 3.9.1 : Structure of PMU

- PMUs are mostly installed at high voltage transformers and power generation plants. In a three-phase generation or transmission network, each phase is equipped with a voltage and a current transformer as shown in Fig. 3.9.2. The voltage and current transformers are required to attenuate high power input of transmission network. These signals are transmitted to ADC of PMU. The processed measurement data are transmitted using satellite and GPS transceiver that operates as receiver and transmitter.

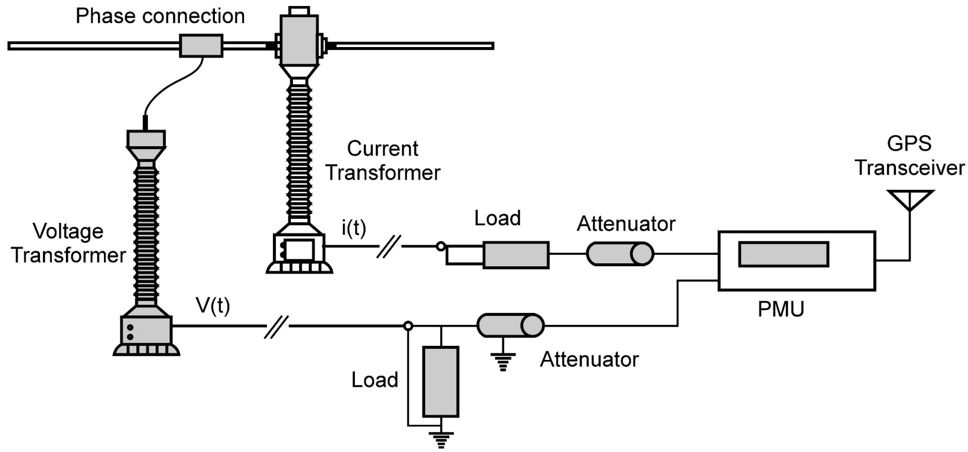

Fig. 3.9.2 : PMU in a transmission network

➥ 3.9.2 Hardware of PMU

- The hardware architecture and components of a basic PMU system has been illustrated in Fig. 3.9.3.

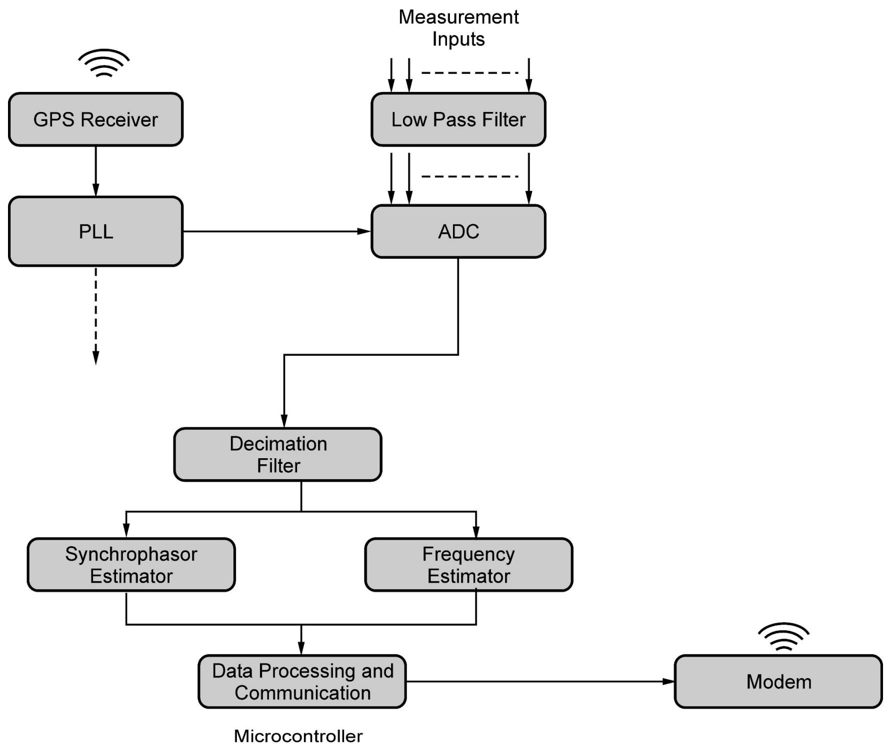

Fig. 3.9.3 : Hardware structure of PMU

- The initial section is comprised by analog inputs where a Low-Pass Filter (LPF) is used for anti-aliasing of measured signals. There are two LPFs used for anti-aliasing operation, where one of two LPFs can be used for attaining the anti aliasing operation. To enhance the filtering performance, a combination of analog and digital filters can be employed. Such combination will provide better performance when compared with analog LPFs. The calculation, detection and processing blocks for measured voltage and current phasor signals are done by microprocessor / controller unit. The measured and processed data are arranged with time stamp generated by GPS signals and transmitted to receivers by modem section.

3.9.3 Applications of PMU

- PMU data enable excellent visualization, analytics and alarming which can improve operator's ability to understand the dynamics of power system. It can also help to anticipate or identify potential problems, and evaluate, implement and assess remedial measures. The following are the applications of PMUs in transmission systems.
  - Wide area situational awareness and monitoring
  - Voltage stability and monitoring
  - Oscillation monitoring and detection
  - State estimation
  - Fault location identification and protective relaying

3.10 Intelligent Electronic Devices (IED)

- A continuous monitoring and control of power system operation is highly demanded for ensuring reliable and uninterrupted power supply. The measured data from different locations of power system are communicated to Central Control Room (CCR) for further processing through Remote Terminal Unit (RTU).
- In the electric power industry, circuit breakers, transformers and capacitor banks are operated by microprocessor based controllers. Such controllers are called as Intelligent Electronic Devices. It receives data from sensors and power equipment for executing the control commands on the power system. In order to maintain a desired voltage level, sensors are involved. The sensed signals are used for tripping of circuit breakers based on the voltage, current, or frequency deviation. Protective relaying devices, On Load Tap Changer controllers, circuit breaker controllers, capacitor bank switches, recloser controllers, voltage regulators are the commonly available IEDs.

- Several protective and control functions are performed by microprocessor based system. Such systems are also known as digital protective relay. Nearly 5-12 protection functions and 5-8 control functions are executed by a typical IED. Intelligent Electronic Devices are named because of their functions executed. The advancement in technologies has still widen the functions performed by IED. Substation automation and advanced communications capabilities are also available in few recent IEDs.
- An IED consists of three major blocks namely, signal processing unit, microprocessor and communication interface. Since IEDs are microprocessor based devices that has the ability to exchange data and control signals with other devices like IED or SCADA. The exchange of data takes place through a communications link. Apart from protection, IEDs has the ability to perform monitoring, control and data acquisition in a powers system. Thus, IEDs are a key component of substation integration and automation technology. IED technology can help utilities improve reliability, operational efficiencies of a power system. This is because the implementation of IEDs provides both operational and non operational information that are required by various users in a grid.

3.11 Smart Monitoring Systems

- The demand for exhaustive monitoring and remote controlling methodologies are found in recent smart grid applications. The creation of such infrastructures is done with AMR, AMI and ICT technologies. Accurate monitoring is highly required for detecting critical conditions and continuous changes happening in a smart grid. Based on these only the diagnostic and troubleshooting technology frameworks are implemented. At the stage of planning itself, monitoring infrastructure consideration is needed for attaining predictive smart grid architecture.
- The sensor networks and IEDs trap the data at field location. The measurements made by devices located at field and ICT interface are transferred to MDMS. This is a mass storage point of measured data in a smart grid. Such database provides data for performing various decision making process in a smart grid. These are referred as detailed monitoring and diagnostics system. An advanced grid monitoring, diagnostic software, and predictions rely on efficient and proactive grid management.
- The key component for grid monitoring that is based on time-synchronized measurements is WAM. The improved features of WAMs are defined as Wide Area Monitoring, Protection And Control (WAMPAC) system is shown in Fig. 3.11.1. It is a synchronized measurement acquired over utility network and transmission of the signals. The utility network is monitored based on the fundamental bus voltage and current measurements in phasor type data. Such data is used to compute the phase differences, frequency and power factor parameters. To acquire high level of accuracy in a system, GPS and time stamping

based data is used for time synchronization. Such synchronizations are used for maintaining high accuracy of measurand.

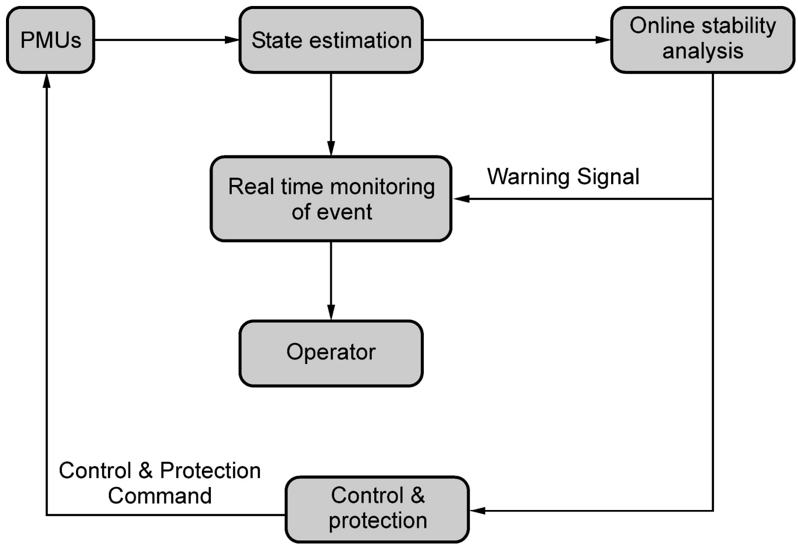

Fig. 3.11.1 : Structure of WAMPAC

- The PMU measurements collected from the different part of the network and state estimation are used for online stability analysis. When an event occurs, its location, time, magnitude and type are first identified. Real-time visualization of the event allows it to be replayed several seconds after it occurs. The future system condition is then analyzed using the information that has been gathered. An on-line stability assessment algorithm continuously assesses the system to check whether the system is still stable and how quickly the system would collapse if it became unstable. If instability is predicted, then the necessary corrective actions to correct the problem or to avert system collapse are taken. Finally, the control and protection commands are provided back to PMUs using a WAMPAC system.
- Apart from conventional sources and power plants, smart grid comprises RES based systems in its infrastructure. The success of Plug-in Electric Vehicle (PEV) integration to utilities is due to the advancements in power electronics. The reliable operation and distribution of generated power makes the smart grid to be self healing system against power system faults. The integration of RES to utility network makes the system to be intermittent at times. Due to this, the power generation is affected; though a well planned structure to resist the faults have been implemented. Thus for ensuring a healthy operation of grid, RES integrations have to be disconnected under fault occurrence. Based on the demand, the grid condition is monitored and operating procedures are executed by WAMPAC system.

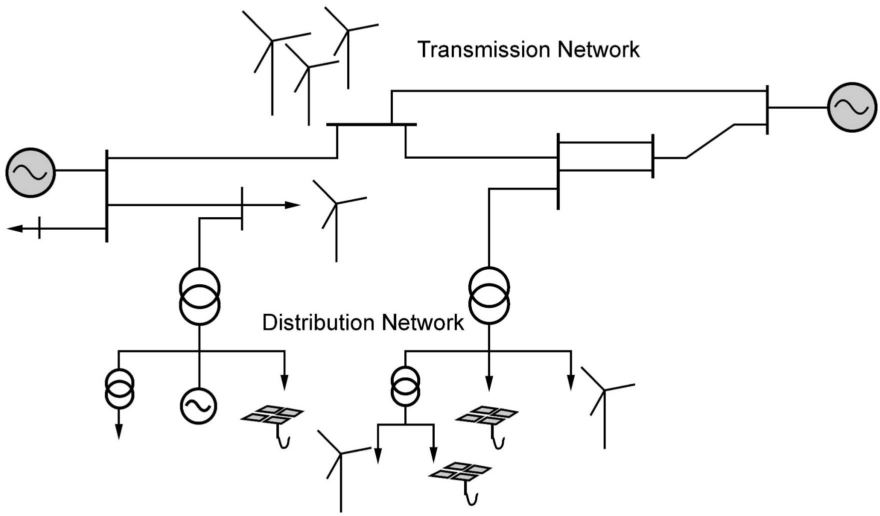

Fig. 3.11.2 : Integration of RES in smart grid

- A large integration of RES and storage systems are required by smart grid is shown in Fig. 3.11.2. The fluctuations in generations are to be managed by EMS and DMS systems. At substation level, an advanced monitoring system provides control signal to curtail the power fluctuations caused by RES structure. Thus to create a self healing system, the data collected are analyzed and predicted for ensuring the monitoring and troubleshooting processes of a smart grid. SCADA and Remote Terminal Units (RTUs) are data acquisition systems that are used for deploying a monitoring architecture.
- In RTUs, lack of time synchronization pulls down the system accuracy. This can be overcome by using the information provided by PMUs of smart grid. PMUs are devices that assure both time synchronized and reliable data of a smart grid. With the deployment of smart sensors in a smart grid, still the monitoring process can be made better. The role of monitoring system is not only to provide data acquisition, but also to generate warning signal under fault occurrence. The smart sensors in the field locations produce such warning signals during system failure. For trapping real time data from system, various sensors like temperature, pressure and vibration sensors are used. To monitor the various functions of a smart grid, the smart sensors are deployed at various locations of a system.
- According to sensing and analysis operations, the monitoring architectures are categorized as local, centralized and substation monitoring. In a local monitoring system, the smart sensors are used for satisfying the system requirements is shown in Fig. 3.11.3. Transformer monitoring, feeder and asset current measurements, and Fault Passage

Indicators (FPIs) are monitored locally by SCADA systems. Thus, fault detection data is acquired and used for warning the system during faulty condition. In the substation monitoring structure, the smart sensors are arranged hierarchically to interact with gateways are used for controlling the system. Thus in a smart monitoring system of a smart grid, a central database holds the acquired data for real time monitoring as well as for analyzing monitoring requirements.

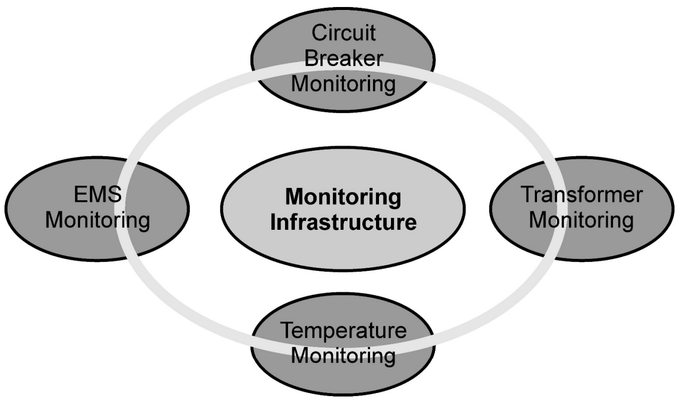

Fig. 3.11.3 : Monitoring infrastructure of smart grid

3.12 Questions with Answers

3.12.1 Short Answered Questions

Q.1 What is accumulation meter ?

Ans. : The conventional electricity meters were electromechanical type of meters. Since recording the electricity consumption alone is done by conventional meters, they are also referred as accumulation meters.

Q.2 Why billing timing is high in an accumulation meter ?

Ans. : The most widely used electricity meter is known as electromechanical accumulation meter, which records consumption based on time intervals. Since accumulation meters cannot be controlled remotely, billing was performed manually. Hence, the billing periods were too long as months.

Q.3 Compare conventional and smart meter.

Ans. : In conventional metering information flows in a single direction and all processes are done manually. On the other hand, the smart metering operations are based on two-way data transmission between customer and operating / monitoring center. A communication channel is established has paved a path for interaction between gateways and database.

Q.4 List the functions of smart meter.

▣ **Ans. :**

- Provides instant and accurate consumption data
- Communicates with remote monitoring center
- Provides data base for analyzing and assessment of power quality
- Processes control commands received from monitoring and control station
- Performs scheduled operations
- Interacts with interfacing devices and home energy management system (HEMS)
- Detect and prevent power losses
- Tamper detection and energy theft interventions

Q.5 What is smart metering system ?

▣ **Ans. :** Smart metering is a single interfacing technology, where the customer and system operator are integrated with an intelligent control and management system. Apart from intelligent integration, smart meter supports estimation, decision-making and data management technologies also. Thus, the smart metering is a technology which connects grid, consumer loads, generation and transmission network, and asset management through intelligent integration via home area network (HAN) and wide area networks (WANs).

Q.6 Highlight the impact of ICT in smart metering infrastructure.

▣ **Ans. :** Smart metering architecture is purely dependent on ICT interface. A group of smart meters for measurement and transmission of data is referred as intelligent collector devices, which is an important part in ICT interface. Such data collectors are also known as data concentrators. The measurement data from smart meters and support of data exchange over wireless gateway channels are performed by data concentrator.

Q.7 State the various functions performed by smart metering infrastructure.

▣ **Ans. :** In a smart metering architecture, the core system for data management is metering data management system (MDMS). In this system, the servers perform various operation namely customer information system (CIS), outage management system (OMS), geographical information system (GIS), and DMS.

Q.8 What is role of data concentrator ?

▣ **Ans. :** The role of data concentrators are to couple the customer premises and smart meters with MDMS , thus data exchange between terminal ends are initiated.

Q.9 Why GIS is important in a smart grid ?

▣ **Ans. :** A better decision making process is supported by GIS, where the geographical data of smart meters and customer premises are collected. A common platform to store, to analyze and to display geographical information on asset management and under or over loaded substations is executed by GIS service.

Q.10 How secure energy management system is achieved for the household appliances ?

▣ **Ans. :** The communication interface and ICT technologies are the significant component of smart metering architecture. The communication established in the entire smart meter architecture through HAN and WAN networks. These networks connect the customer premises with MDMS. In addition to this, it also provides security and reliability of consumer data and entire metering system. Hence, a secure energy management system is achieved for the household appliances.

Q.11 Name the various services operated by HAN infrastructure.

▣ **Ans. :** Various services such as remote control, monitoring, multimedia systems, surveillance cameras and energy management applications are operated by HAN infrastructure.

Q.12 What is role of CIS in a smart grid ?

▣ **Ans. :** CIS is known as Customer Information System. The CIS is crucial to ensure customer services and providing reliable billing services. GIS provides data to CIS to facilitate its operation during consumption rate detection and billing operation by including geographical location. The user interaction with database namely user account, consumption rates with time stamps are managed by this system.

Q.13 How decision making process is initiated in a smart grid environment ?

▣ **Ans. :** DMS supervises the whole architecture for tracking the power quality and load demand. Such tracking supports in decision making and estimation of load utilized.

Q.14 Specify the essential components in a smart grid.

▣ **Ans. :** In a smart Grid, two essential components are required to monitor the grid situation, namely sensor networks and smart meters.

Q.15 What are the drawbacks of conventional meters in a grid ?

▣ **Ans. :** The conventional electricity meter is an electromechanical structure, where the consumption data is measured by the revolutions of rotating magnetically conductive disc. While in electronics meters, the rotating element is replaced by resistors or sensors. Still, electronic meters require many advanced control and calibration functions, and digital microprocessor technologies to be incorporated for attaining the maximum benefit.

Q.16 State the benefits of communication module in a smart grid.

▣ **Ans. :** Communication interface is a communication network of a smart meter which enables two-way data transmission. The connection procedures between consumer and network operator are defined using smart metering and monitoring concepts. The communication module of smart meters is independent from AFE and recording sections of smart meter. Thus, disturbance in smart meter function is not found under erroneous in connection module.

Q.17 Classify the communication network in a smart grid.

▣ **Ans. :** The communication networks that are used in smart metering are classified into three groups namely WAN, NAN and HAN.

Q.18 Why HAN is called fundamental network architecture in a smart grid ?

▣ **Ans. :** Home area network HAN is deployed for monitoring and controlling integrated devices and to perform smart metering processes at consumer's premises. Hence, HAN is known as fundamental network architecture in a smart grid. HAN facilitates interaction of energy management systems and smart appliances.

Q.19 What is the need for HAN in a smart grid ?

▣ **Ans. :** To improve control of users and network operators, an interaction between EMS and smart appliances are needed. HAN is one such network that facilitates an effective interaction in a smart grid.

Q.20 What is NAN in a smart grid ?

▣ **Ans. :** Neighborhood area network (NAN) is located between HAN and NAN to serve as a central bridge of smart metering infrastructure devices. Better reliability, security, and flexibility of system are attained through NAN. An internet-based communication technology to be used in architecture is enabled by NAN.

Q.21 What is the role of WAN in a smart grid ?

▣ **Ans. :** The backbone between DA and power network operators is Wide area network (WAN). It supports two-way communication in the system. The communication with various elements of utility namely bulk generation, transmission and distribution systems are done using WAN architecture.

Q.22 State the importance of advanced communication infrastructure in a smart grid.

▣ **Ans. :** The advanced communication infrastructures facilitates such theft detection and addressing of fraud with the support of smart meters. The exact consumption can be reported by the time-stamp feature of smart meters. Such features enable increased control on detection of losses and leakages through utility grid. Any abnormal consumption or unauthorized use of electricity can be immediately detected by the network operator. Based on unauthorized detection smart meters can remotely disconnect the consumers from grid.

Q.23 List the components of AMI.

▣ **Ans. :** Smart metering unit, communication network and data acquisition and management unit are the important components of AMI architecture.

Q.24 What is AMI ?

▣ **Ans. :** AMI is a process of selection and deployment of a specific metering technology to the modern grid. It can also be referred as a new arrangement of utilities processes and applications for collecting meter reading, integrating customers in the daily grid operations. The infrastructure includes the following components in AMI are smart meters, wide-area communication network (WAN), meter data central (MDC) system, meter data management (MDM) system and home area network (HAN).

Q.25 What are smart meters ?

▣ **Ans. :** Smart meters are solid-state electronic electricity meters employed in AMI. Such meters supports the measurement of electricity consumption and provides smart functionalities as hourly electricity consumption, time-based load control, remote connection and disconnection of delivery site, tamper detection. The above specified functionalities can be remotely configured and customized in the metering devices.

Q.26 How smart meters can be managed remotely ?

▣ **Ans. :** The data concentrators are devices that manage a set of smart meters into one single device. This facilitates information gathering from the smart meters, grouping the communications to them. Thus smart meters can be managed remotely.

Q.27 Mention the benefits of AMI platform.

▣ **Ans. :** The benefits of AMI can be generally categorized as operational, financial, consumer and security.

- **Operational benefits -** AMI benefits the entire grid by improving the accuracy of meter reads, energy theft detection and response to power outages, while eliminating the need for on-site meter reading.
- **Financial benefits -** AMI brings financial gains to utility by reducing equipment and maintenance costs, enabling faster restoration of electric service during outages and streamlining the billing process.
- **Customer benefits -** AMI benefits electric customers by detecting meter failures early, accommodating faster service restoration, and improving the accuracy and flexibility of billing. Further, AMI allows for time-based rate options that can help customers save money and manage their energy consumption.

- **Security benefits -** AMI technology enables enhanced monitoring of system resources, which mitigates system intrusion and cyber attacks.

Q.28 Define interoperability.

▣ **Ans. :** The ability of two or more components or systems to exchange information and use the information exchanged is defined as interoperability of a system.

Q.29 Name the standards developed in AMI platform.

▣ **Ans. :** The following are standards developed for application specific, namely :

- Multimedia related standards for wire line communication and cellular communications.
- Data transmission standards such as internet standards, Internet Protocol (IP), Transmission Control protocol (TCP), Usage based Dynamic Pricing (UDP) and Hypertext Transfer Protocol (HTTP) standards.
- Application related standards as IEC 61850, IEC 61968 and ANSI C.12.

Q.30 Why the advancement in metering and communication technologies has become vulnerable to cyber attacks ?

▣ **Ans. :** The use of wireless communication networks and data acquisition nodes are exposed to potential intrusion and attacks on metering infrastructure. Attackers intrude the communication channel for modifying metering and billing data. Hence, there arises a need for curtailing such unauthorized controlling through cyber attacks.

Q.31 List the security related issues in a smart grid.

▣ **Ans. :** Confidentiality, integrity, availability, accountability, and authorization are the security related issues.

Q.32 Define authorization.

▣ **Ans. :** Authorization is a term that enables right to access specific resources and applications of a device by consumers. The authorization assigns privilege to users and thus intentional attacks targeting system security is avoided.

Q.33 Specify the benefits of AMI for a smart grid.

▣ **Ans. :** The following are the few benefits of AMI which are essential for a smart grid.

- In case of utilities, the deployment of the AMI platform has paved a way for immediate transition from traditional manual reading process.
- Automated reading process provides the utilities with reliable and accurate consumption data on a daily basis.

- The estimation of accurate energy consumption by consumers will increase the overall grid operation efficiency.
- AMI platforms improve the relationship between utilities and customers.
- Offers new remote services to customers.
- Establishing reconnection of customer sites and alarms about planned outages.
- Increased customer satisfaction and fidelity is observed.

Q.34 What is PMUs ?

▣ **Ans. :** Phasor Measurement Units (PMUs) are electronic devices that use digital signal-processing components to measure AC waveforms and convert them into phasors, according to the system frequency, and synchronize these measurements under the control of GPS reference sources. The analog signals are sampled and processed by a recursive phasor algorithm to generate voltage and current phasors.

Q.35 What are the functions of PMUs ?

▣ **Ans. :** The PMUs used in a power system can be utilized for performing the following functions :

- Real time monitoring and control
- State estimation Protection and control for distributed generation
- Network congestion management
- Angular and voltage stability monitoring
- Analysis of disturbances and faults

Q.36 Give few applications of PMUs.

▣ **Ans. :** The following are the applications of PMUs in transmission systems.

- Wide area situational awareness and monitoring
- Voltage stability and monitoring
- Oscillation monitoring and detection
- State estimation
- Fault location identification and protective relaying

Q.37 What are IEDs ?

▣ **Ans. :** In the electric power industry, circuit breakers, transformers and capacitor banks are operated by microprocessor based controllers. Such controllers are called as Intelligent Electronic Devices. It receives data from sensors and power equipment for executing the control commands on the power system.

Q.38 What is WAMPAC ?

▣ **Ans. :** The improved features of WAMs are defined as wide area monitoring, protection and control (WAMPAC) system. It is a synchronized measurement acquired over utility network and transmission of the signals.

Q.39 State the need for acquiring high level of accuracy.

▣ **Ans. :** The utility network is monitored based on the fundamental bus voltage and current measurements in phasor type data. Such data is used to compute the phase differences, frequency and power factor parameters. To acquire high level of accuracy in a system, GPS and time stamping based data is used for time synchronization. Such synchronizations are used for maintaining high accuracy of measurand.

Q.40 List the role of smart sensor in a smart grid.

▣ **Ans. :** The role of monitoring system is not only to provide data acquisition, but also to generate warning signal under fault occurrence. The smart sensors in the field locations produce such warning signals during system failure. For trapping real time data from system, various sensors like temperature, pressure and vibration sensors are used. To monitor the various functions of a smart grid, the smart sensors are deployed at various locations of a system.

➡ 3.12.2 Long Answered Questions

Q.1 Discuss the role of utility metering operation in a grid. **[Refer section 3.1.1]**

Q.2 Compare conventional metering system with smart metering system. **[Refer sections 3.2 and 3.4]**

Q.3 Explain the operation of smart meter and also list out its functionalities. **[Refer section 3.4]**

Q.4 Classify the smart meter systems. **[Refer section 3.4.2]**

Q.5 With a neat sketch explain the smart meter infrastructure. **[Refer section 3.5]**

Q.6 Summarize the role of communication architecture in smart metering infrastructure. **[Refer section 3.6]**

Q.7 Explain the smart meter hardware architecture. **[Refer section 3.7]**

Q.8 Discuss the various standards used in smart meter communication infrastructure. **[Refer section 3.7]**

Q.9 Outline the structure of AMI with relevant diagram. **[Refer section 3.8]**

Q.10 Summarize the benefits of AMI platforms. **[Refer section 3.8.1]**

Q.11 List out the AMI standards and explain it. **[Refer section 3.8.2]**

Q.12 Explain the AMI driving factors in a smart grid. **[Refer section 3.8.3]**

Q.13 What is phasor measurement unit ? Explain the structure of PMU. **[Refer section 3.9.1]**

Q.14 Discuss the role of IEDs in a smart grid. **[Refer section 3.10]**

Q.15 Explain the importance of smart monitoring systems in a grid. **[Refer section 3.11]**

Q.16 Explain the working of WAMPAC with neat diagram. **[Refer section 3.11]**

3.12.3 Multiple Choice Questions

Q.1 Smart Grid Technology comprises the following :

a AMI, PLM, OMS, Renewable Integration, Micro grid

b DR/DSM, Distribution Automation, Energy Efficient Systems

c All of the above

d None of the above

Q.2 Opportunities of smart grid ________.

a cyber security in future

b optimal power flow

c defence model

d all the above

Q.3 Smart grid goals include all but the following :

a Potentially reducing our carbon footprint

b Introducing advancements and efficiencies yet to be envisioned

c Assimilate all cultures, all categories of consumers

d Maintaining grid affordability

Q.4 AMI means ________.

a Automated Metering Instrument

b Alternate Metering Instrument

c Advanced Metering Infrastructure

d Advanced Metering Instrument

Q.5 What is the example for smart grid edge device for utility ?

[a] Smart meters [b] Smart home

[c] Smart car [d] Smart collage

Q.6 Smart meter is an important element in building the smart gri(d) These advanced meters ________.

[a] measure electricity usage in real time

[b] can send data to and from electric companies and their customers

[c] allows companies to give consumers more information about their electricity usage, and communicate current electricity prices

[d] all of the above

Q.7 Web-enabled residential smart meter use web principles to interconnect ________.

[a] home electrical appliances to smart micro grid

[b] smart micro grid to utilities

[(c)] utilities to home electrical appliances

[d] smart micro grid to distribution system

Q.8 In smart grids, PMU stands for ________.

[a] Phase Measurement Unit [b] Phasor Measurement Unit

[c] Phase Monitoring Unit [d] All of these

Q.9 Which of the following systems consist of IEDs and the communication networks for performing control, protection and monitoring tasks.

[a] Substation automation system

[b] Statistical analysis system

[c] Substation analytical system

[d] Statistical automation system

Q.10 "A device that produces synchronized measurements of phasor, frequency, ROCOF from voltage and/or current signals based on a common time source that typically is the one provided by the GPS" ________.

[a] RTU [b] IED [c] RMU [d] PMU

Q.11 The ________ work on time of the day tariff or on availability based traiff or any other tariff.

[a] analog meters [b] smart meters

[c] digital meters [d] aron meter

Q.12 The main functions performed by smart meters are ________.

[a] net metering [b] remote operations

[c] energy bill prepayment [d] all of the above

Q.13 If the meter is stopped or tampered, the event is recorded. Such event is called as ________.

[a] interrupted event [b] cut-off event

[c] tamper event [d] stopped event

Q.14 Second quadrant of Four quadrant meteris named as ________.

[a] export lag [b] export lead

[c] import lag [d] import lead

Q.15 ___________ for a short time during peak demand can reduce the need for establishment of new power generation plants.

[a] Load acquiring [b] Load balancing

[c] Load shedding [d] Load distributing

Q.16 The data retrieval from smart meters and decision making should be as quick as possible by using which software ?

[a] ETAP [b] EMS [c] SCADA [d] PWA

Q.17 In order to complete repair and maintenance work in minimum amount of time by providing alternate supply arrangement, it is required to provide ________.

[a] load management system

[b] power quality management system

[c] outage management system

[d] peak load management system

Q.18 The main goal of real time pricing and demand management from consumer point of view is ________.

- [a] to encourage the customers to use less energy using peak hours
- [b] to encourage the customers to use more energy during peak hours
- [c] to encourage the customers to use more energy during storage of energy
- [d] to encourage the customers to use less energy during crest hours

Q.19 Which of the following conditions have to be satisfied for the power equation to be true ?

- [a] V_{rms} (line-line) on all the three phases is identical
- [b] I_{rms} on all the three phases is identical
- [c] The phase angles between voltages and currents are always 120°
- [d] All of the above

Q.20 In real time pricing, the price of electricity varies on _____ basis.

[a] Hourly [b] Weekly [c] Daily [d] Monthly

❐ Answer Keys for Multiple Choice Questions

Q.1	c	**Q.2**	d	**Q.3**	c	**Q.4**	c
Q.5	a	**Q.6**	d	**Q.7**	a	**Q.8**	b
Q.9	a	**Q.10**	d	**Q.11**	b	**Q.12**	d
Q.13	c	**Q.14**	b	**Q.15**	c	**Q.16**	b
Q.17	c	**Q.18**	a	**Q.19**	d	**Q.20**	a

❑❑❑

Notes

UNIT - IV

4 Power Quality Management in Smart Grid

Syllabus

Power Quality and EMC in Smart Grid, Power Quality issues of Grid connected Renewable Energy Sources, Power Quality Conditioners for Smart Grid, Web based Power Quality monitoring, Power Quality Audit.

Contents

4.1 Introduction

- A term that is used for assessing the quality of electric power is known as power quality (PQ). It is involved maintaining better quality of power at different levels of power system namely generation, transmission and distribution and utilization of AC power. Thus, power quality can be defined as the grid's capability to provide or supply clean and stable power in a system. In a power system, it is vital to maintain a pure sinusoidal wave form within specified voltage and frequency tolerances.
- But in today's electrical networks, the ideal conditions are frequently deviated due to increase intervention of non-linear loads. Such intrusion creates disturbances in the grid. Since new technologies are emerging in the power generation sector, the challenges to be faced by grid also increase. Thus a huge loss on economy is observed due to impact of insufficient power quality.
- At utilization level, deviation of electric power supply systems is much severe. This is due to the intrusion of flashover, equipment failure and faults. In recent days, high level of supply deviations is observed due to the intrusion of more number of customer's equipment. This is because they draw non-sinusoidal current and behave as nonlinear loads. Therefore, voltage, current, or frequency deviations of the supply system are used for quantifying the term power quality. These terms may lead to failure or mal-function of customer's equipment. The reasons for seeking good power quality are to save money and energy. There are two types of saving can be derived namely direct and indirect savings. In a direct savings, the consumers attain lower energy cost and reactive power tariffs. While in an indirect savings, accomplishment of savings are done by avoiding circumstances where premature aging of equipment is employed for production. Apart from this, damage and loss of production or loss of data can be avoided for attaining indirect savings.

4.2 Effects of Power Quality Problems

- A huge detrimental effect on industrial and commercial sectors has been observed. In industries, clean-up costs, product quality and equipment failure are few major accountable parameters for power quality consideration. The implementation of systems to overcome power quality problems have to reflect in terms of cost. While, domestic customers tend not to be so adversely affected by power quality problems in that equipment as observed in industries. However, introduction of IT equipment and sophisticated communications equipment for home entertainment purposes will definitely create a shift in power quality requirements. This will lead to problems by customers in the near future. Ideally, every consumer location receives a perfectly sinusoidal voltage signal by electricity grid.

However, there are number of reasons for utilities to preserve such desirable conditions. Such deviation of the voltage and current waveforms from sinusoidal is defined as harmonic distortion. The harmonic distortion was mainly due to saturation of transformers, industrial arc furnaces, and other arc devices like large electric welders.

- In the past, the problems related to harmonics were very less due to the conservative design of power equipment. There is increase in harmonics distortion observed due to the increasing usage of nonlinear loads in industry. In the steel, paper, and textile industries, nonlinear devices are used as static power converter. Such situation may trigger large oscillatory currents and voltages, which creates stress on the insulation. Hence, there emerges a need for addressing this serious challenge by industry and utility engineers. To maintain the equipment under acceptable operating conditions, it has become mandatory to perform harmonic studies on the electrical networks and equipment. This will help to anticipate potential problems with the installation or addition of nonlinear loads.
- The introduction of harmonics, imbalance, sags, and spikes has created disturbances in the distribution system. This affects the power quality of a grid. Therefore, a huge damage power quality can occur due to the intrusion of electronic devices in a grid. A severe damage of equipment is observed due to low power quality. It can pull down the equipment life expectancy and grid reliability also. This leads to the causes for utility's financial distress and paves a way for huge loss. Such losses can be compensated by increasing the generation. There are more number of devices or equipments available in the grid for maintaining the power quality. To , name a few such as voltage regulators, capacitor banks and transformers are power quality ensuring devices. A high level of consumer satisfaction can be obtained through power quality enhancement. This will also support reduction in operating cost.

4.3 Basics of Harmonic Theory

The term harmonics is the vibration that is found in a string or an air column. This vibration is at a frequency which is a multiple of base frequency. A sinusoidal component of a periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of the system is defined as the harmonic component in an AC power system. Thus, the harmonics in voltage or current waveforms can be considered as a perfect sinusoidal components of frequency multiples of the fundamental frequency.

$$f_h = (h) \times (\text{Fundamental frequency})$$

where h is an integer

4.4 Linear and Nonlinear Loads

The source of several power quality problems such as harmonics, reactive power, flicker and resonance are based on load used in the system. The loads can be categorized as linear and non load.

4.4.1 Linear Loads

- It is a load, whose voltage and current signals follow one another very closely, such as the voltage drop that develops across a constant resistance, which varies as a direct function of the current that passes through it. Few examples of linear loads are listed below
  - **Resistive elements :** Incandescent lighting and electric heaters.
  - **Inductive elements :** Induction motors, Current limiting reactors ,Induction generators and Tuning reactors in harmonic filters.
  - **Capacitive elements :** Power factor correction capacitor banks, Underground cables, Insulated cables and Capacitors used in harmonic filters.

4.4.2 Nonlinear Loads

- Non linear loads are loads in which the current waveform does not resemble the applied voltage waveform. There are several reasons for such variations, for example, the use of electronic switches that conduct load current only during a fraction of the power frequency period. Few examples of non linear loads are listed below.
  - **Power electronics :** Power converters, variable frequency drives, DC motor controllers, cycloconverters , cranes, elevators, steel mills, UPS, battery chargers and inverters
  - **ARC devices :** Fluorescent lighting • ARC furnaces • Welding machines
- Therefore, it is clear that degradation of electrical power grid voltage and current waveforms, mainly due to the contamination created by the loads added. The Fig. 4.4.1 shows the level of contamination of power in an electrical utility.

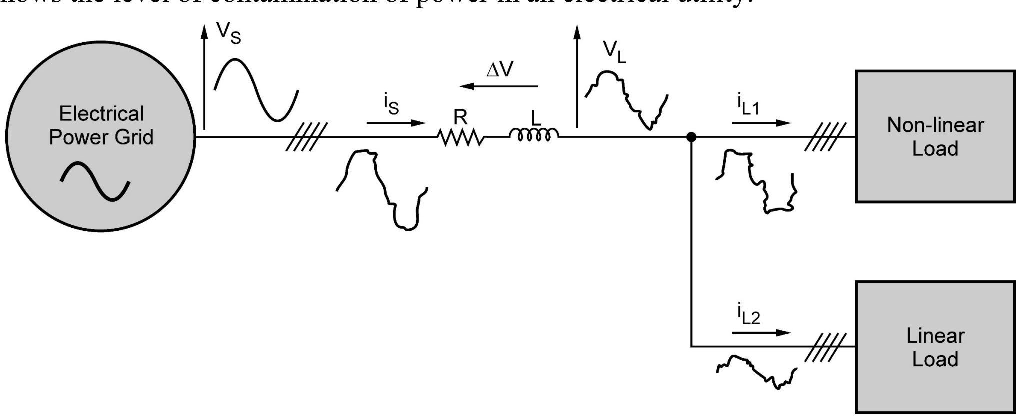

Fig. 4.4.1 : Contamination of power in an electrical utility

4.5 Power Quality Indices Under Harmonic Distortion

There are various terminologies used for describing power quality indices under harmonic distortion. The following are few terms discussed below.

4.5.1 Total Harmonic Distortion (THD)

A widely used index to reveal issues related to power quality in transmission and distribution systems. THD considers the impact of each and every harmonic component in a system. The ratio of the sum of powers of all harmonic components to fundamental frequency of power is known as total harmonic distortion. This measure the harmonics present in all signals. At the output of a device under specified condition, the measurement of THD is been made and is usually expressed in percent or in dB relative to the fundamental as distortion attenuation.

$$\text{THD} = \frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + \ldots..}}{V_1}$$

4.5.2 Total Demand Distortion

Usually a weak source with a large demand current relative to their rated current will have a tendency to show greater waveform distortion. While on the other side, a decreased waveform distortion is observed for sources with low demand currents. The total demand distortion is based on the demand current, I_L, over the monitoring period.

$$\text{TDD} = \frac{\sqrt{I_1^2 + I_2^2 + I_3^2 + \ldots..}}{I_L}$$

4.5.3 Telephone Influence Factor TIF

It is measure of audio circuit interference produced by harmonics in electric power systems. Such indices can influence the level of sensitivity of human ear to noise under different frequencies.

$$\text{TiF} = \frac{\sqrt{w_1^2 I_1^2 + w_2^2 I_2^2 + w_3^2 I_3^2 + \ldots..}}{I_{rms}}$$

4.5.4 Harmonic Waveform Distortion

- In an electrical system, the harmonic waveform distortion is one of the many disturbances observed during power system operation. This disturbance gets aggravated when there is an increase usage of power electronics devices for switching operations. The harmonic spectrum gets varied with different nonlinear loads. Such discriminations supports in identifying the various sources of harmonic distortion. In recent days, both utilities and consumers of electric power are familiar with different waveform distortions produced by specific harmonic sources. This has paved a way for developing various techniques for removal of harmonics at the site of their generation itself. Thus the reduction of impact of harmonics intruding in the electrical system over adjacent installations is observed. It has also become highly important to properly accounted parallel resonant peaks while waveform distortion is being assessed. In a distribution system, harmonic propagation is assessed appropriately.

- At times large number of consumers on same feeder is affected by harmonic distortion due to the impact of weak sources. This will turn out to be troublesome when harmonics are created at more than one location. This causes the major reason for power quality degradation and thus emerging as a heavy harmonics producer in the system.
- The term power quality means receiving a clean sinusoidal voltage waveform with RMS variations and total harmonic distortion within thresholds dictated by a number of industrial standards. But quite often it is found to be difficult by the utilities to maintain the standards. It is observed that more frequently the consumer's loads act as the source of harmonics generation. This is due to power conversion from one form into another through rectification and inversion processes. The power becomes polluted because of waveform chopping process. Such chopping process leads to noise-like structures which are considered as dirty and unclean power. The prolonged usage of such unclean power will lead to a serious effect called lifetime reduction of equipment like transformers and cables.
- Earlier the industrial equipments and processes were considered to be the source for harmonic distortion. Now, this is no longer valid because of deployment of various residential loads Uninterruptible Power Supplies (UPSs), Personal Computers (PCs), and electronic and entertaining devices such as TV sets, music amplifiers, video recorders, battery chargers for smart phones and tablets, digital clocks, data centers, and other sensitive electronic equipment. Above all these, the integration of renewable wind and solar power, High-Voltage Direct Current (HVDC), and smart devices will contribute to an overall rise in harmonic distortion in electric distribution networks. Thus mitigation of harmonics will lead to have harmonic distortion within allowable limits.

4.6 Effects of Harmonics on Distribution Systems

- As electricity demand increases, there will be a steady expansion of harmonic distortion with respect to increase in load. The energy growth prediction reveals within a short span of time the electricity demand will increase by 20 to 41 %. The forecasting has disclosed that the energy consumption by industrial sector has increased to 28 %. While in commercial sectors, growth of energy demand will increase by 0.6 % per year. The projection highlighted that in residential sector, an increase of 0.2 % per year from 2010 to 2040 will be observed. Around the year 2040, the integration of renewable energy sources will be the potential harmonic source and in particular solar, wind energy sources will constitute 62.3 % of commercial capacity. All these are due to the falling prices for photovoltaic inverters and panels.

- Overall, by considering the energy consumption trends it is anticipated that the harmonic will increase in industrial, commercial and residential sector in next 25 years. For the same it is highly important to assess the effects of unfiltered harmonics present in the power system by different equipments with different operation. The following sections will discuss about the various effects observed over different equipments installed into a grid.

4.6.1 Thermal Effects on Transformers

As mentioned earlier , that the modern industrial and commercial networks have been highly influenced by variety of non linear loads. Such loads are the cause for huge amounts of harmonic currents production by variable speed drives, electric and induction furnaces, and fluorescent lighting etc. Along with these, the usages of uninterruptible power supplies and massive numbers of home entertaining devices have still aggravated the harmonics distortion in an electrical power system. The transformer is major electrical equipment that will experience the above mentioned current due to harmonics. Such transformer turns out as a source of harmonics under saturation. Neutral conductors get over heated when transformers trap zero-sequence currents. In particular, transformers with delta connection would increase RMS value of current, which further kindles the heat produced. Thus, the lifetime of transformers will be reduced due to loss in transformer insulation property. The excessive heat pulls down the insulation level of transformer leading operational damage. In industry based applications, the transformers are loaded with nonlinear loads and their continuous operation at or above rated power will create a high operating temperature. This increase in temperature will affect the lifetime of transformer.

4.6.2 Neutral Conductor Overloading

- The increase in RMS current is found in a single-phase circuit. This is due to the presence of significant amount of harmonics carried through transformer neutral connections. Therefore, a need of neutral current evaluation for transformer operation in harmonics environment is highly demanded. Such transformer evaluation will support to avoid the possibility of missing the grounding connection as a consequence of overloading. There is no current on the neutral in a balanced three phase, four-wire systems. In such case, the presence of neutral currents under these conditions should be attributed to the circulation of zero-sequence harmonics. Mostly single phase power supplies cause these issues.
- In case of an unbalanced system, an unbalanced current get circulated on the neutral conductor. Since the conductors are equally sized, unbalanced currents are handled comfortably to reduce over heating of conductors. In office or commercial building, the computers act as alarming source of harmonic currents. The electronic switched power supplies used in computers are the reason for the harmonic currents. Thus, temperature monitoring of the neutral conductor of transformers can detect the overstressing level of neutral connections.

4.6.3 Miscellaneous Effects on Capacitor Banks

- Overstressing of capacitor bank can lead to malfunctioning of dielectric. The overstress and lifetime degradation of capacitor bank are due to the increased voltage of the system. There are several factors acting as driver for capacitor stress such as voltage, temperature, and current. These stresses are cause for dielectric breakdown. The following equation reveals the relation between output reactive power from a capacitor bank and the voltage.

$$VAR = \frac{V^2}{X_c}$$

- Usually the major portion of system is left to face a overvoltage condition under two different conditions, namely increase operating voltage in distribution system or fuse operated link for isolating failed capacitor unit. Nearly 110 % increase of rated reactive power is found for a 5 % increase in the nominal voltage of a capacitor unit. Another serious problem faced by industrial sector with unfiltered large power converter is due voltage stresses on capacitor banks.
- Under undesired operation of fuses in capacitor banks that operate large nonlinear loads may increase the harmonic distortion. Abnormal operation of electronic relays can occur due to trip response of over current. Thus, harmonic distortion is assessed, when protective relays trigger during the operation of a nonlinear load.

4.6.4 Lighting Devices

Fluorescent lamps using magnetic and electronic ballasts are the example for harmonic current generation. The impact of interharmonics is observed as light flickering. This is due to the modulated steady-state interharmonic voltage on the power frequency voltage. The noninteger multiple of the fundamental frequency is known as interharmonics and this is more prone to excited voltage oscillations. The cycloconverters that are widely employed used in the steel, cement, mining industries, arc welding and furnaces are the main source of interharmonics.

4.6.5 Telephone Interference

The electrical power system is prone to interference due to the construction of telephone lines underneath power conductors on electric utility distribution poles. Various interferences namely inductive, capacitive, and conductive interference occurs between a power and a telephone line.

4.7 Power Quality

- Since the inception of electric power system, the power quality problems have been presented. For mitigation of power quality several conventional techniques are available. Apart from this various equipments have been designed and developed for identifying power quality problems. In recent days the awareness of consumer on power quality issues have tremendously increased due to the following reasons :

- The sophistication of consumer's equipment has become highly sensitive and such equipments are sensitive to disturbances. This is because of inclusion of power electronics converters in all consumer equipments.
- Inorder to increase beneficial in equipments, several solid-state controllers are included in consumer equipments. To attain the benefits namely decreasing the losses and increasing overall efficiency. Beside these benefits several other such as production cost reduction has triggered up harmonic levels, distortion and power quality problems.

4.8 Power Quality Problems and Mitigation Techniques

- For addressing the power quality issues, it is highly needed to mitigate it. There are several techniques used for mitigating power quality related problems. From the consumer end the awareness of power quality problems has scaled up due to interruptions, loss of production and equipment failure. The consumers have been forced to either reduce or eliminate power quality problems because of interference on various appliances. The appliance such as telecommunication network, TVs, computers, metering, and protection systems demand the reduced power quality issues. Thus, the device creating power pollution can be removed from the system. The power quality acts as a performance indicators and thus demand for maintaining good power quality has become highly essential. This is due to the deregulation of power system it has become mandatory to maintain quality of power supplied through grid. The integration of renewable energy sources to distributed generation has added more power quality problems because of solid-state conversion. By addressing the above highlighted power quality issues, there are several possibilities of improving the power quality. Such initiatives have increased need for monitoring the harmonic distortion levels. Thus the evolution of power quality mitigation techniques were used for addressing polluted power in a system.
- A significant growth is observed in deploying customer's equipment with improved power quality and improving the utilities' premises. It is observed that a drastic growth in research and development work on mitigation techniques for power quality problems. In particular, the research on power filters of various types such as passive, active, and hybrid in shunt, series, or a combination of both configurations for single-phase two-wire, three-phase three-wire, and three-phase four-wire systems has used for mitigating power quality issues. Apart from this, problems related to reactive power, excessive neutral current, and balancing of the linear and nonlinear loads can also be addressed by power filters.
- On the other hand, custom power devices such as DSTATCOMs for power factor correction, voltage regulation, compensation of excessive neutral current, and load balancing have been evolved. For transient and steady-state conditions, DVRs and series static synchronous compensators (SSSCs) are used for mitigating voltage quality problems. A combination of DSTATCOM and DVR for mitigating current and voltage quality problems called UPQC are also deployed in a number of applications. With all these, an exponential growth in power quality improvement has been achieved through devising a number of circuit configurations of input front-end converters.

4.9 Classification of Power Quality Problems

- In the fast changing electrical systems, numerous power quality problems arise in the system. These problems may be categorized based on transient and steady state. Sag, swell, short-duration voltage variations, power frequency variations, and voltage fluctuations are classified as transient type of power quality problems. The steady-state type of power quality problems covers long-duration voltage variations and waveform distortions. In addition to these, there are several other issues related to steady state power quality issues namely, unbalanced voltages, flicker, poor power factor, unbalanced load currents, load harmonic currents, and excessive neutral current.
- Based on quantity such as voltage, current, and frequency, the power quality problems can also be classified. The voltage distortions, flicker, notches, noise, sag, swell, unbalance, under voltage, and overvoltage falls under the category voltage related issues while for the current related issues covers reactive power component of current, harmonic currents, unbalanced currents, and excessive neutral current.
- Based on load or supply system, the classification of power quality issues can be classified. Normally, power quality problems due to nature of the load depending on either fixed or fluctuating loads. While voltage- and frequency related issues such as notches, voltage distortion, unbalance, sag, swell, flicker, and noise are referred as supply system related power quality problems.

4.10 Classification of Mitigation Techniques for Power Quality Problems

It has become highly essential to address the power quality related problems in term of financial loss, loss of production and wastage of raw material. Based on this, a wide variety of mitigation techniques towards power quality improvements have been developed. The mitigation techniques covers passive components based system such as capacitors, reactors, custom power devices, a series of power filters, improved power quality AC–DC converters, and matrix converters. Apart from harmonic distortion, the problems related to voltage regulation, low power factor, load unbalancing, excessive neutral current also need to be addressed. For mitigation of such issues custom power devices namely DSTATCOMs, DVRs, and UPQCs are extensively deployed. Power quality improvement techniques used in newly designed and developed equipment are based on the modification of the input stage of these systems with Power Factor Corrected (PFC) converters. Such converters are also known as Improved Power Quality Controller (IPQCs), multipulse AC–DC converters, matrix converters for AC–DC or AC–AC conversion. These converters are used for mitigation of power quality problems and support in drawing clean power from the utility.

4.11 Electromagnetic Compatibility (EMC)

- The smart grid technology has deployed several sensitive electronic circuits in it for accomplishing maximum benefit in the utility. The increased incorporation of such electronic circuits has implications with respect to Electromagnetic Compatibility. The objective EMC is defined as the satisfactory function of electrical and electronic equipment with respect to electromagnetic disturbances.
- Electromagnetic compatibility is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. This definition was stated by International Electrotechnical Commission to highlight the need for removal of EMI in equipment. Electromagnetic disturbances may be either radiated or conducted type. Any electrical / electronic equipment may be potentially sensitive to any or to both of types of electromagnetic disturbances. These disturbances are further categorized as low and high frequency phenomena, where IEC defines low frequency up to and including 9 kHz.

4.11.1 Relation between Voltage Quality and EMC

- It has been defined by IEC that EMC can cover electromagnetic phenomena from zero hertz. Beyond this, IEC classified the principal electromagnetic conducted phenomena as conducted low-frequency and conducted high frequency type.
- In conducted low frequency phenomena the following types have been derived.
  - Harmonics, interharmonics
  - Signals superimposed on power lines
  - Voltage fluctuations
  - Voltage dips and interruptions
  - Voltage unbalance
  - Power frequency variations
  - Induced low frequency voltages
- While in conducted high-frequency phenomena, the following types are categorized.
  - Induced voltages or currents
  - Unidirectional transients
  - Oscillatory transients

- The voltage quality can be considered as variation from ideal voltage conditions at a site in a system. It can be due to electromagnetic disturbances of the voltage in a system. When there is no such disturbance presented in a system, then the quality of voltage is perfect and it can lead to a satisfactory performance of equipment. On the other hand, in presence of disturbances the performance of equipment gets degraded. It is highly needed to gain a satisfactory functioning of electrical and electronic equipment in terms of Electromagnetic Compatibility.
- In an electrical network, the transfer of electromagnetic energy with an adequate voltage quality between various connection nodes is observed. It is also noticed that there is immunity for an electrical network. This can create an ability to absorb disturbing emissions such as distorted current with adequate voltage quality while transferring energy. Such transfer of energy will yield a satisfactory function in a system. The networks will strengthen its immunity for low order harmonics and voltage fluctuations, network strength.
- The importance of power quality to achieve EMC is clearly stated in a report energy regulators. The nature of electricity creates the power quality related issues, where all consumers connected to the grid are affected. The power quality becomes significant when the disturbance is injected by consumer's installed equipment or weak spots of power system. The main objective of the system is to have an electromagnetic environment where all electrical equipment and systems function satisfactorily without getting influenced by electromagnetic disturbances. Such situation is referred to as electromagnetic compatibility (EMC).

➥ 4.11.2 Practical Experience of Interference with Smart Grid Technology

It is observed that the data transferred from Kilowatthour meter of consumer on power lines introduces interference with dimmer controlled lamps and other electrical appliances. At times in certain cases errors get popped out from Kilowatthour meter during energy registration. This is also due to the interferences or disturbances caused in the power system by electromagnetic signals. Several reports states that the power electronics in wind power plants have emitted disturbances interfering with transfer of Kilowatthour meter readings as signals on power lines. Similarly, voltage fluctuations and unbalance are noticed with power electronic based photovoltaic solar and wind energy equipment. Such system or equipment may cause or emit disturbances to the system. All the above mentioned issues can be addressed by a proper design of equipment contributing to better power quality.

4.12 EMC Directive and Electrical Networks

- In recent days manufacturers are urged to produce equipments with the ability to withstand electromagnetic disturbances. It is expected to provide a satisfactory performance even in presence of unacceptable disturbances. Network operators should construct their networks in such a way that manufacturers of equipment liable to be connected to networks do not suffer a disproportionate burden in order to prevent networks from suffering an unacceptable degradation of service.
- A power system made up of fixed installations has no difference between electrical networks or connected equipment in terms of electromagnetic disturbances. In this context, both networks and connected equipment can emit electromagnetic disturbances and immunity. Such network may be connected to other may either emit disturbances or get affected by disturbances in terms of poor power quality. There are possibilities for performance degradation due to lack of immunity during energy transmission. Geomagnetically induced currents creating interference during energy transfer is an example for the performance degradation. In a system, the disturbance can either move from a network to connected equipment or from equipment to network is shown in Fig. 4.12.1 and Fig. 4.12.2. There are few cases in which disturbances may also propagate between networks and in such cases the emission from a network is considered as a cumulative effect of emissions from a large number of connected equipment in terms of improper power quality at a specific site.

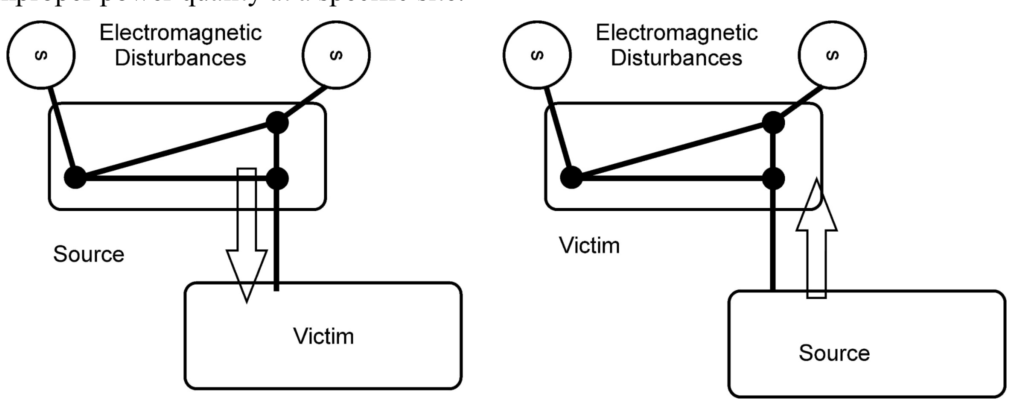

Fig. 4.12.1 : Propagation of electromagnetic disturbance between network and equipment connected to network

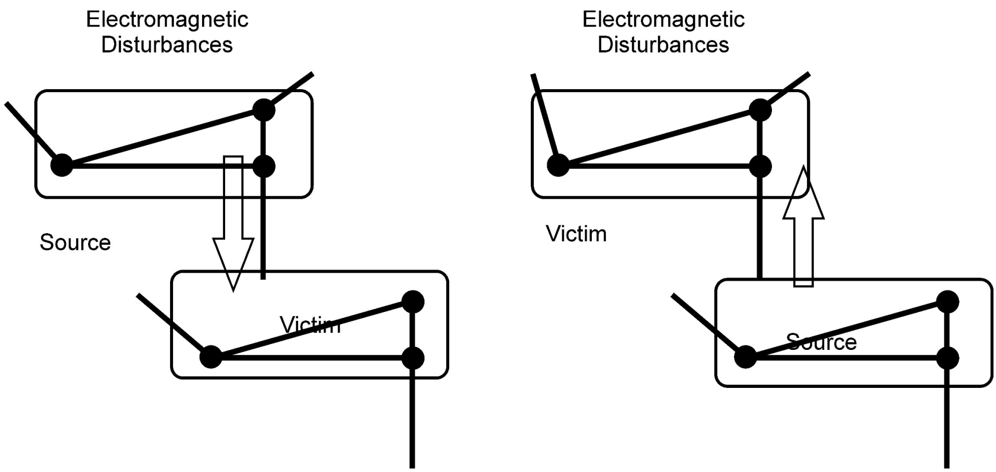

Fig. 4.12.2 : Propagation of electromagnetic disturbance between networks

4.13 Power Quality Standards and Monitoring

- In the past quarter century, there has been exponential growth in power quality related research. The few reasons behind this are enhanced sensitivity of equipment, awareness of consumers and increased use of solid-state controllers. With the aim of energy conservation in energy intensive equipment and power loss reduction it has become mandatory to create standards for power quality. Such initiatives will provide better utilization of utility assets and minimize the environmental pollution such as interference to telecommunication systems.
- Economic penalty in terms of power loss, equipment failure, mal-operation, interruption in the process, and loss of production are various consequences faced by consumer due to power quality problems. In view of these facts, a number of standards have been developed by various organizations and institutes that are enforced on the customers, manufacturers, and utilities to maintain an acceptable level of power quality. In addition to these, various techniques and instruments are developed to study and monitor the level of power quality pollution and their causes. A continuous development instruments, recorders and analyzers to measure, record and analyze power quality data have been initiated by various manufacturers. By considering the impact of increasing issues of power quality, an awareness of power quality is highly demanded by various sectors.

4.13.1 Power Quality Terminologies

- To quantify the power quality problems based on power quality issues, awareness, and mitigation techniques several terminologies have been defined in IEEE Standards. In this section, various terminologies used in power quality standards and monitoring process are discussed below.

- **Flicker :** Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.
- **Imbalance (voltage or current) :** The ratio of the negative-sequence component to the positive sequence component, usually expressed as a percentage.
- **Impulsive transient :** A sudden non-power frequency change in the steady-state condition of voltage or current that is unidirectional in polarity (primarily either positive or negative).
- **Interharmonic (component) :** A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is operating (e.g., 50 Hz, 60 Hz).
- **Root-Mean-Square Variation :** A term often used to express a variation in the RMS value of a voltage or current measurement from the nominal value. See sag, swell, momentary interruption, temporary interruption, sustained interruption, undervoltage, and overvoltage.

➥ 4.13.2 Objectives of Power Quality Monitoring

- Power quality monitoring is required to quantify power quality phenomena at a particular location on electric power equipment. Depending on the situation, the objective of monitoring gets varied. In certain cases, to diagnose incompatibilities between the supply and the consumer loads is performed while in other cases, the evaluation of electrical environment at a particular site demanded by an equipment is done. Apart from these in few cases, prediction of equipment performance and for mitigating power quality issues is executed. The selection criteria for power quality monitoring are listed below
  - Proper selection of monitoring equipment
  - Method of data collection
  - Financial damages caused by PQ events either in critical or sensitive equipment
  - PQ problems and events may cause malfunctions or damages in the equipment.
- The methodology for quantifying monitoring objectives may differ in nature. There are cases where power quality monitoring is required to find out shutdown problems in critical equipment. While in the other side, recorded voltages and currents are used for quantifying the existing level of power quality. Such monitoring is categorized as preventive and predictive monitoring. Power quality monitoring may be provided by the utility, the customers, or any other personnel such as energy auditors.

4.13.3 Benefits of PQ Monitoring

- Basic PQ monitoring system can be considered as a tool for ensuring the availability of power to the customers. The following are benefits of PQ monitoring
  - Mitigation of PQ problems
  - Scheduling preventive and predictive maintenance
  - Ensuring the performance of equipment
  - Assessing the sensitivity of equipment to PQ disturbances
  - Identifying the power quality events and problems
  - Reducing the power losses in the process and distribution system
  - Upgrading and modernizing of data to be analyzed.

4.14 Passive Shunt and Series Compensation

- Since the inception of the AC supply system, passive shunt and series compensators are deployed to improve the power quality in power system. This will inturn enhance the efficiency and utilization of equipment in transmission and distribution networks. Usually, the passive compensators consist of lossless reactive elements such as capacitors and inductors either with or without switching devices. Inorder to improve transient, steady state and dynamic, voltage , passive compensators are used in power system. Apart from these, losses reduction and transmission capacity improvement can also be attained.
- For improving the voltage profile at the point of common coupling (PCC), the passive shunt and series compensators are also extensively used in distribution systems. The mitigation of power quality issues can be done using passive compensators, which can supply or absorb variable or fixed reactive power locally.

4.14.1 Uses of Passive Compensators

As pointed out earlier, in AC networks, a passive compensation has turned out as a mature technology for providing reactive power compensation for power factor correction and/or voltage regulation, load balancing, and reduction of neutral current. A passive compensator are used for regulating the terminal voltage, suppressing voltage flicker, improving voltage balance, power factor correction, load balancing, and neutral current mitigation in three-phase distribution systems. These objectives are achieved either individually or in combination depending upon the requirements and configurations that need to be selected appropriately.

4.14.2 Classification of Passive Shunt and Series Compensators

Based on topology and number of phases, the passive compensators can be classified based on the topology and the number of phases. Based on system and it connections, compensators are categorized as shunt, series and hybrid connection. While the phase based classification is based on the number of phases, namely single-phase two wire and three phases three- or four-wire (three-phase) systems.

4.14.3 Topology-Based Classification

- The passive compensators can be classified based on the topology, for example, series, shunt, or hybrid compensators. Inorder to improve the power transfer ability of a transmission system, passive series compensators are employed. Apart from this the enhancement of voltage profile and stability can be attained through passive series compensator. Inspite of these benefits, still passive series compensator suffers from resonance and performance problems. Thus, another topology can be deployed for yielding satisfactory performance.
- As loads are connected parallel to load, in majority of the cases shunt compensators are used in practice. The cancellation of reactive power is done by injecting equal compensating currents in opposite to the phase. Such reactive power components removal of the load current supports in power factor correction. For voltage regulation and load balancing at the load end, passive shunt topology is employed. In addition to these, such topology is suited for voltage stabilization in static VAR generators. A hybrid compensator is a combination of series and shunt topology compensators. It is used for improving the voltage profile and enhancing the stability in self excited induction generators.

4.14.4 Supply System-Based Classification

- As mentioned earlier, mainly passive shunt compensators are used in the distribution system for reactive power compensation and load balancing. This classification of passive compensators is based on the supply and/or the load systems having single-phase (two-wire) and three-phase (three-wire and four-wire) systems. There are many varying loads such as domestic appliances connected to single-phase supply systems.
- Some three-phase unbalanced loads are without neutral terminal, such as AC motors, traction, metros, and furnaces fed from three-phase three-wire supply systems. There are many other single-phase loads distributed on three-phase four-wire supply systems, such as heating and lighting systems, among others. Hence, passive compensators may also be classified as single-phase two-wire, three-phase three-wire, and three-phase four-wire passive shunt compensators.

4.15 Active Shunt Compensation

In a distributed system, the power quality problems are classified as voltage and current quality problems. This is due to the employment of sensitive equipment in various sectors namely industries, residential and commercial. The power quality issues can be addressed by Custom Power Devices (CPDs). DSTATCOMs (Distribution Static Compensators), DVRs (Dynamic Voltage Restorers), and UPQCs (Unified Power Quality Conditioners) are the CPDs used to mitigate power quality issues depending upon the requirements. Among these, DSTATCOMs are widely deployed for mitigating current based power quality issues such as poor power factor, unbalanced currents and increased neutral current. The harmonics gets increased due to the above mentioned issues.

4.15.1 DSTATCOM

- The best technology to mitigate current-based power quality problems is DSTATCOM. It is basically categorized into three types, namely, single-phase two-wire, three-phase three-wire, and three-phase four-wire configurations. Using these , requirements of three types of consumer loads on supply systems can be satisfied effectively. Single-phase two-wire DSTATCOMs have been investigated in varying configurations and control strategies to meet the needs of single-phase system loads such as domestic lights and ovens, TVs, computer power supplies, air conditioners, laser printers, and Xerox machines.
- Instantaneous reactive power theory, synchronous frame d–q theory, and synchronous detection method are used in the development of three-phase DSTATCOMs. In three-phase four-wire systems, unbalanced loads such as computer power supplies and fluorescent lighting causes poor power factor in additional to neutral current issues.
- At the earlier stage of DSTATCOM development, BJTs (bipolar junction transistors) and power MOSFETs (Metal Oxide Semiconductor Field-Effect Transistors) have been used. Later SITs (Static Induction Thyristors), GTOs (Gate Turn-off Thyristors) and IGBTs (Insulated Gate Bipolar Transistors) were used in DSTATCOM technology. With the advent of microelectronics revolution, DSTATCOM development attained the next breakthrough. Apart from these, microprocessors, microcontrollers, and DSPs (Digital Signal Processors) progression implemented complex algorithms for online control of DSTATCOMs. With these improvements, the DSTATCOMs are capable of providing fast corrective action even with dynamically changing loads such as furnaces and traction.

4.16 Web based Power Quality Measurement

In a deregulated market, monitoring power quality has become highly essential. Industrial and commercial customers are increasingly getting affected by poor power quality problems. Corrective measures can be taken through a real time power quality monitoring. One such system is a web based power quality monitoring system. It is a near real time power quality monitoring system, which provides local as well as global information to the consumers. The power quality data from various utilities are collected and formed as a database. Using this database, the power quality web based system provides auto email notification of a consumer's power quality. Apart from this, other facilities like auto plotting of various RMS voltage variation, total harmonic voltage and current distortion are also provided to the consumers. Such web based power quality will provide useful information to industrial customers and utilities.

4.16.1 Need for Web based Power Quality Monitoring System

- In the current situation, there is a high demand for permanent power quality monitoring system because of following reasons :
  - The current harmonics must be monitored on a continuous basis to ensure that, over a time, the incremental addition of loads does not cause excessive heating that can lead to power loss, premature failure of transformer, capacitor etc.
  - For future extension of distribution system, a continuous tracing of power consumption data is need for planning.
  - For taking remedial action against power quality issues, there is a need to detect on continuous basis various symptoms of power quality such as harmonic distortion, voltage dips, interruption, transient etc.
  - For forecasting specific breakdown conditions such as overheating of switch boards, current surges, over voltage, voltage sags and fluctuations or to detect deterioration and PQ degradation.
  - During procurement of new equipments, a proper decision making has to be done for avoiding incompatibility issues.
  - Inorder to make changes in design of equipment, there is need for identifying the information related to sensitive equipment. Such information can be collected through power quality data base on web.

➥ 4.16.2 Evolution of Web based Power Quality Monitoring

Analyzing large volume of power quality data is the major problem faced during power quality monitoring. A laborious manual processing is carried out to identify the required power quality event that has occurred. Other than this, problem associated with storage and distribution of data from various power quality equipments is limited. When the memory gets exhausted, then monitoring process will be halted. Thus, there arises the need for automatic downloading of data. Many researchers have proposed various solutions for addressing power quality monitoring related issues. One such methodology is a web based power quality monitoring system. The following section will provide various types of web based PQ monitoring system for collecting information both locally and globally.

➥ 4.16.3 Master - Slave Architecture based PQ Monitoring

To monitor a number of power quality indices on every load connected to the point of common coupling, a methodology called distributed power quality measuring system was proposed. In this system, the measured value is transmitted to master device, where processing to identify the source of unbalance, harmonic distortion and impact of disturbance on power quality are done. The system has a distributed master slave structure for performing measurement process. In each metering section, a slave system is incorporated which acquires the line voltages and currents in the metering section and determines the RMS value and frequency domain components. All measured quantities are averaged on a pre-settable time interval and transmitted to master system via internet. The most critical point of master slave architecture is simultaneous processing data obtained from various slave devices. Thus, a synchronization clock is introduced to establish synchronization proposed between master and slave devices.

➥ 4.16.4 Centralized PQ Monitoring System

The system contains a single PQ analyzer and multiple PQ meters for monitoring purpose. The data acquisition is performed by PQ meters while PQ analyzer performs all calculations. This system is economical for large scale system, because the price of power quality meter is low. The major drawback of this system is that the communication channel gets burden due to transfer of raw data for each PQ meter.

➥ 4.16.5 Web based Multi Channel Power Quality Monitoring System

This system is well suited for a large network. PQ monitoring instrument, Modems for communications, Central server, UPS, Back up tape and GPS are the various components provided in the mutli channel PQ monitoring system. MODEM is used for communicating the captured PQ data. The PQ meter measures and store the data. Then the data is transmitted to the central system server through leased dial up line, customer intranet, Ethernet network or DSL modem. The network is specially designed to be able to use various communication means, so that different customer needs would be met. For very remote sites where communication network is not available, wireless communication using GMS format or radio would be adopted.

4.17 Power Quality Audit

- IEEE – 519, 1992 and IEC-61000, and EN-50160 standards for power grid system protection are benchmarking methods used by power quality auditors. In current situation, maintaining reliability in an electrical grid is highly essential. This is used for ensuring safety aspects and for identifying risk in a grid. Such functions can be executed with the support of Instant power quality auditing. The auditing provides a summary of data, which facilitates power quality problem mitigation. Power quality has become a major concern to all types of industries. Power quality audit measures the various features of power namely Active Power, Apparent Power, Kilo watt hour, Phase angle, Telephonic interference factor, Power Factor, Under voltage, Over voltage, Short-Term Voltage Fluctuations, Voltage Sags, Voltage Swells, Imbalance, Flickers, Imbalanced Voltage, Unbalanced load, RMS Value, Harmonics, Frequency, interruptions etc.
- A power quality audit is a new technique that is deployed to accomplish various objectives such as better performance, control and minimum power consumption of the loads. Many of sensitive devices included in the grid introduce power quality issues. Such issues become more critical in process industries and information technology services. A huge financial loss may happen, with the consequent loss of productivity due to disturbances in power network.
- An intensive analysis and reporting of power quality problems are stated through power quality audit. The audit reveals deficiencies and risk present in the power system and ways to overcome the major power quality issues. Power quality audit reports recommended reliable product specification for several applications to get benefits of Harmonics Mitigations. The product recommended depends upon the type of risk identification in Power System for achieving the maximum energy savings due to the production of wasteful harmonics and energy losses in plant system equipment's reliability.
- Thus, the power quality audit can be defined as a systematic study of the incoming raw power, the measurement of the extent of distortion in the incoming raw power, the identification of the causes of distortion and the various recommendations for seeking to solve these power quality problems, a facility will realize the cost-saving benefits.

4.17.1 Need for Power Quality Audit

- The severity fault identifications throughout the power system are demanded by clients. The power quality audit provides various recommendations for attaining energy savings. Power quality audit can also be monitored in the plant system for the benefit of client's work place engineers by observing power quality data's recording instrument's availability at the time of data logging. The following are few needs for power quality audit.
  - Improves the power quality and brings in efficiency
  - Helps to identify and eradicate Harmonics which minimizes line losses and minimize reduction in the equipment lifetime due to harmonics.
  - Helps to identify and eradicate transients to avoid short-duration change in voltage
  - Helps to identify and eradicate hours-long voltage sags caused by system overload
  - Improve and maintain continuous supply of quality electricity supply

4.17.2 Power Quality Audit Process

- The systematic process is carried out under three different phases namely, planning, site audit and analysis and reporting. The Fig. 4.17.1 shows various stages of a power quality audit. Planning is considered to be the pre audit phase, where the focus is on objectives of audit. It supports to identify the risk found in the system. The following are the various steps carried out in pre audit phase.
  - Pre-audit information based on walkthrough of facility and discussion with plant personnel
  - Study of past trend and direct site readings is also undertaken

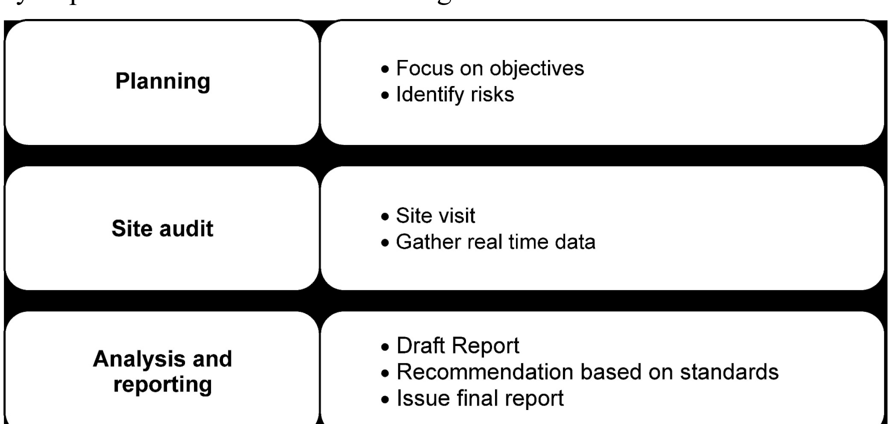

Fig. 4.17.1 : Various stages in power quality audit

- While in second phase of audit, the direct inspection of site is done. Site audit includes site visit, and real time data collection. The gathering of data reveals the exact condition of the system. Based on these data, various analyses are done and audit documentation is prepared. The following are the step performed in site audit.
    - Site visit
    - Gathering of data
    - Analysis of collected data
    - Recommendations provided based on standards.
    - Comprehensive audit report will contain the information of source of power quality problems and appropriate solution to the same
    - Identification of vendors and corresponding quotations is also provided to the client
- In report preparation phase, the documentation provides recommendations depending upon the client requirement as per mentioned below standards.
    - Institute of Electrical and Electronic Engineers (IEEE)
    - International Electro Technical Commission (IEC)
    - Bureau of Indian Standards (BIS)
    - American National Standards Institute (ANSI)
    - Canadian Standards Association (CSA)
    - Japanese Industrial Standards (JIS)

4.18 Power Quality Conditioner

- A power quality conditioner is a device deployed for improving the quality of power that is being delivered to electrical load or equipment. It is also known as a line conditioner or power line conditioner. The role of a power quality conditioner are listed below
    - Deliver voltage and current of the proper level
    - To enable load equipment to function properly
    - Ensure efficient power transfer between utility grid and micro grid
    - Isolate utility grid from disturbances
    - Integration with energy storage system

- A drastic increase in usage of nonlinear loads in modern power distribution system has been noticed in recent days. Voltage sag, swell, harmonics, very short interruptions, long interruptions, voltage spike, noise, voltage unbalance are the consequences of power quality issues. With the advancement in technologies, various Custom Power devices were used for power quality mitigation. DSTATCOM and UPQC are the two custom power devices reported for the effective mitigation of voltage sag / swell.
- An integration of series and shunt active filters connected in cascade via a common DC link capacitor is known as UPQC. The role of a UPQC is to provide compensation for supply voltage.
- In UPQC, the series component mitigates supply side disturbances such as voltage sags / swells, flicker, voltage unbalance and harmonics. While, the shunt component mitigates the current quality problems caused by the consumer such as poor power factor, load harmonic currents, load unbalance etc. For maintaining the load voltages at desired level and free from distortion by series component , a voltage is inserted. Shunt component injects currents in the AC system such that the source currents become balanced sinusoids and in phase with the source voltages. The series and shunt Active Power Filter (APF) controller are responsible for the overall function of UPQC.

4.18.1 Structure of UPQC

- UPQC consists of two IGBT based VSC, one shunt and one series cascaded by a common DC bus. The main components of a UPQC are series and shunt power inverter, DC capacitors and LC filters are shown in Fig. 4.18.1.

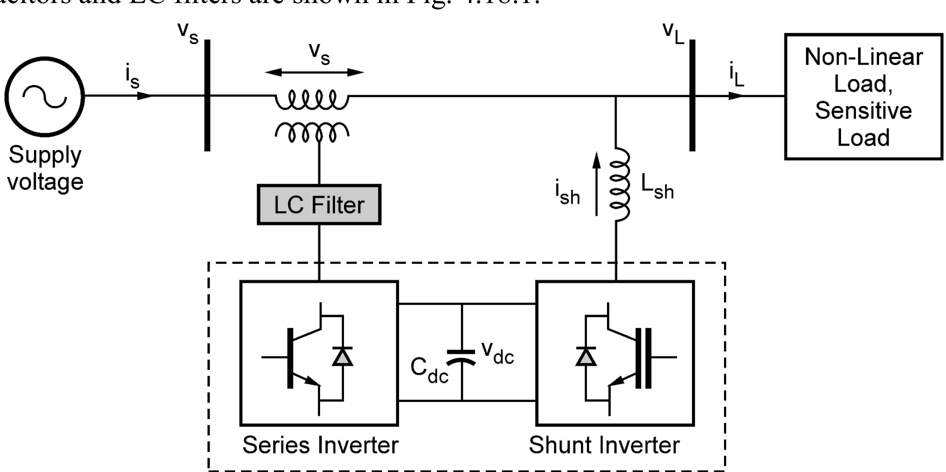

Fig. 4.18.1 : Structure of UPQC

- There are two inverters in UPQC, where one is connected across the load. This acts as a shunt APF. While the other connected in series with the line. An interface between shunt inverter and network is done by a shunt coupling inductor L. This inductor provides smoothening of current waveform. DC link is formed by using a capacitor or an inductor. A passive low-pass LC filter helps to eliminate high-frequency switching ripples on generated inverter output voltage. The series inverter is connected to the network using series injection transformer. To reduce the voltage and current rating of series inverter, a desired turns ratio is selected. The integrated controller of the series and shunt APF of the UPQC to provide the compensating voltage reference V_c and compensating current reference I_c.
- To have an effective performance of UPQC, certain control strategies are required. The shunt component needs to balance the source currents by injecting negative and zero sequence components required by the load. By injecting required harmonic current, the load current compensation can be done. While the series component balances the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source. Apart from this, the isolation of load bus from harmonics is done by injecting harmonic voltages. It also regulates the magnitude of load bus voltage by injecting the required active and reactive components.

4.18.2 Classification of UPQC

- The UPQC is classified in two types namely, VSI (Voltage Source Inverter) and CSI (Current Source Inverter). The Fig. 4.18.2 and 4.18.3 shows the topology of VSI and CSI topology.

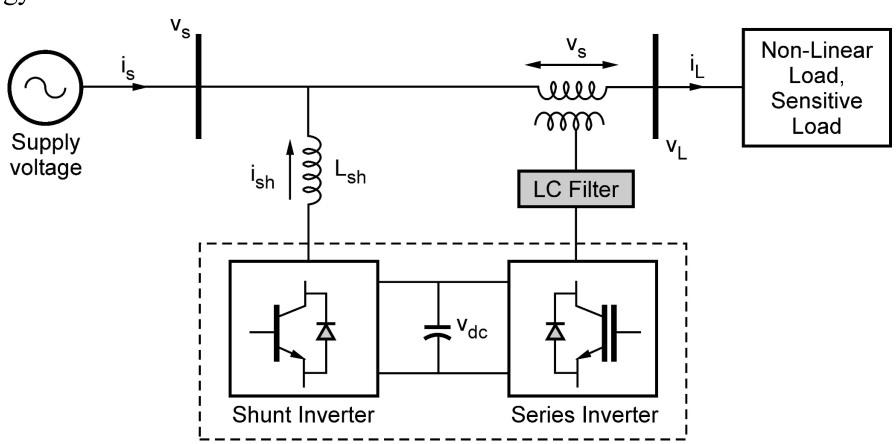

Fig. 4.18.2 : VSI topology

- A VSI based UPQC topology is more popular when compared with CSI based UPQC topology. VSI shares a common energy storage capacitor (C_{dc}) to form the dc-link while a CSI shares a common Energy storage inductor (L_{dc}) to form the dc-link. VSI type is light weight, small in size and low cost but suffers from low efficiency and limited lifetime due to capacitor. CSI type has high efficiency when the load power is low, but the bulky and heavy DC inductor creates high losses.

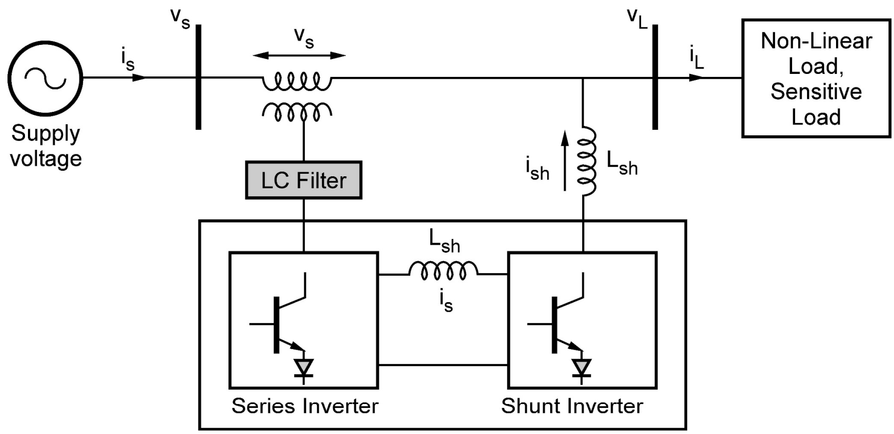

Fig. 4.18.3 : CSI topology

- Control strategy of UPQC may be implemented in three different stages for improving the performance of UPQC. The following are the strategies for improving performance of the system.
  - o Voltage and current signals are sensed.
  - o Compensating commands in terms of voltage and current levels are derived.
  - o The gating signals for semiconductor switches of UPQC are generated using PWM, hysteresis or fuzzy logic based control techniques.

4.19 Questions with Answers

4.19.1 Short Answered Questions

Q.1 Define the term power quality.

Ans. : The electric power quality (PQ) is a term that is used for assessing and maintaining the good quality of power at the level of generation, transmission, distribution, and utilization of AC electrical power.

Q.2 Why there is a deviation of ideal condition in an electrical network ?

Ans. : In today's electrical networks, the ideal conditions are frequently deviated due to increase intervention of non-linear. Such intrusion creates disturbances in the grid. Since new technologies are emerging in the power generation sector, the challenges to be faced by grid also increase. Thus a huge loss on economy is observed due to impact of insufficient power quality.

Q.3 State the reason for severity condition observed at the utilization level.

▣ **Ans. :** At utilization level, deviation of electric power supply systems is much severe. This is due to the intrusion of flashover, equipment failure and faults. In recent days, more number of customer's equipment also creates deviation of the supply system. This is because; they draw non-sinusoidal current and behave as nonlinear loads.

Q.4 Mention the need for seeking power quality.

▣ **Ans. :** The voltage, current, or frequency deviations of the supply system are used for quantifying the term power quality. These terms may lead to failure or malfunction of customer's equipment. The reasons for seeking good power quality are to save money and energy. There are two types of saving can be derived namely direct and indirect savings. In a direct savings, the consumers attain lower energy cost and reactive power tariffs. While in an indirect savings, accomplishment of savings are executed by avoiding circumstances such as damage and premature aging of equipment, loss of production or loss of data and work.

Q.5 What are the reasons for deviation in power quality at consumer's end ?

▣ **Ans. :** The domestic customers tend not to be so adversely affected by power quality problems in that equipment as observed in industries. However, introduction of IT equipment and sophisticated communications equipment for home entertainment purposes will definitely create a shift in power quality requirements. This will lead problems by customers in the near future.

Q.6 Is it mandatory to perform harmonic study in an electrical network ? Justify your answer.

▣ **Ans. :** Yes, it is mandatory to perform harmonic analysis in an electrical network. To maintain the equipment under acceptable operating conditions, it has become mandatory to perform harmonic studies on the electrical networks and equipment. This will help to anticipate potential problems with the installation or addition of nonlinear loads.

Q.7 What is harmonics ?

▣ **Ans. :** The term harmonics is the vibration of a string or an air column at a frequency that is a multiple of the base frequency. A sinusoidal component of a periodic waveform that has a frequency equal to an integer multiple of the fundamental frequency of the system is defined as the harmonic component in an AC power system.

Q.8 Give few examples of linear loads.

▣ **Ans. :**

- **Resistive elements :** Incandescent lighting and Electric heaters
- **Inductive elements :** Induction motors, Current limiting reactors ,Induction generators and Tuning reactors in harmonic filters
- **Capacitive elements :** Power factor correction capacitor banks, Underground cables, Insulated cables and Capacitors used in harmonic filters

Q.9 What is linear load ?

▣ **Ans. :** It is a load, whose voltage and current signals follow one another very closely, such as the voltage drop that develops across a constant resistance, which varies as a direct function of the current that passes through it.

Q.10 What is meant by non linear load ?

▣ **Ans. :** Non linear loads are loads in which the current waveform does not resemble the applied voltage waveform. There are several reasons for such variations, for example, the use of electronic switches that conduct load current only during a fraction of the power frequency period.

Q.11 State few examples for non linear loads.

▣ **Ans. :** Few examples of non linear loads are listed below :

- **Power electronics :** Power converters, Variable frequency drives, DC motor controllers, Cycloconverters, Cranes , Elevators, Steel mills, UPS, Battery chargers and Inverters.
- **ARC devices :** Fluorescent lighting, ARC furnaces, Welding machines.

Q.12 Define THD.

▣ **Ans. :**

- THD stands for Total Harmonic Distortion.
- This total harmonic distortion is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. The measures the harmonics present in all signals. At the output of a device under specified condition, the measurement of THD is been made and is usually expressed in percent or in dB relative to the fundamental as distortion attenuation.

$$THD = \frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + \ldots}}{V_1}$$

Q.13 What is telephone influence factor ?

▣ **Ans. :** Telephone Influence Factor (TIF) is measure of audio circuit interference produced by harmonics in electric power systems. Such indices can influence the level of sensitivity of human ear to noise under different frequencies.

$$TIF = \frac{\sqrt{w_1^2 I_1^2 + w_2^2 I_2^2 + w_3^2 I_3^2 + \ldots}}{I_{rms}}$$

Q.14 Define total demand distortion.

▣ **Ans. :** The total demand distortion is based on the demand current, I_L, over the monitoring period.

$$TDD = \frac{\sqrt{I_1^2 + I_2^2 + I_3^2 + \ldots}}{I_L}$$

Usually a weak source with a large demand current relative to their rated current will have a tendency to show greater waveform distortion. While on the other side, a decreased waveform distortion is observed for sources with low demand currents.

Q.15 List out the effects of harmonics in an electrical system.

▣ **Ans. :** The modern industrial and commercial networks have been highly influenced by variety of non linear loads. Such loads are the cause for huge amounts of harmonic currents production by variable speed drives, electric and induction furnaces, and fluorescent lighting etc. The following are effects of harmonics in an electrical system.

- Thermal effects on transformers
- Neutral conductor overloading
- Lighting devices
- Telephone interference

Q.16 What is meant by neutral conductor overloading ?

▣ **Ans. :** The increase in RMS current is found in a single-phase circuit. This is due to the presence of significant amount of harmonics carried through transformer neutral connections. Therefore, the operation of transformers in harmonic environments demands that neutral currents be evaluated. Such transformer evaluation will support to avoid the possibility of missing the grounding connection as a consequence of overloading.

Q.17 State the impact of overstressing of capacitor bank in an electrical system.

▣ **Ans. :** Overstressing of capacitor bank can lead to malfunctioning of dielectric. The overstress and lifetime degradation of capacitor bank is due to the increased voltage in the system. There are several factors acting as driver for capacitor stress such as voltage, temperature, and current. These stresses are cause for dielectric breakdown.

Q.18 How harmonics are generated due to lighting devices ?

▣ **Ans. :** Fluorescent lamps using magnetic and electronic ballasts are the example for harmonic current generation. Light flicker is one of the main impacts of interharmonics due to the modulated steady-state interharmonic voltage on the power frequency voltage. The noninteger multiple of the fundamental frequency is known as interharmonics and this is more prone to excited voltage oscillations. The cycloconverters that are widely employed used in the steel, cement, mining industries, arc welding and furnaces are the main source of interharmonics.

Q.19 List the various telephone interferences in an electrical network.

▣ **Ans. :** The electrical power system is prone to interference due to the construction of telephone lines underneath power conductors on electric utility distribution poles. Various interferences namely inductive, capacitive, and conductive interference occurs between a power and a telephone line.

Q.20 Highlight the reasons for power quality mitigation.

▣ **Ans. :**

- The sophistication of consumer's equipment has become highly sensitive and such equipments are sensitive to disturbances. This is because of inclusion of power electronics converters in all consumer equipments.
- Inorder to increase beneficial in equipments, several solid-state controllers are included in consumer equipments. To attain the benefits namely decreasing the losses, increasing overall efficiency, and reducing the cost of production has triggered up harmonic levels, distortion and power quality problems.

Q.21 Classify the power quality problems.

▣ **Ans. :**

- In the fast changing electrical systems, numerous power quality problems arise in the system. These problems may be categorized based on transient and steady state.
- Sag, swell, short-duration voltage variations, power frequency variations, and voltage fluctuations are classified as transient type of power quality problems. The steady-state types of power quality problems covers long-duration voltage variations, waveform distortions, unbalanced voltages, flicker, poor power factor, unbalanced load currents, load harmonic currents, and excessive neutral current.

Q.22 Summarize the mitigation techniques in an electrical system.

▣ **Ans. :**

- A wide variety of mitigation techniques towards power quality improvements have been developed.

- The mitigation techniques covers passive components based system such as capacitors, reactors, custom power devices, a series of power filters, improved power quality AC–DC converters, and matrix converters.
- Apart from harmonic distortion, the problems related to voltage regulation, low power factor, load unbalancing, excessive neutral current also need to be addresses. For mitigation of such issues custom power devices namely DSTATCOMs, DVRs, and UPQCs are extensively deployed.
- Power quality improvement techniques used in newly designed and developed equipment are based on the modification of the input stage of these systems with PFC converters, also known as IPQCs, multipulse AC–DC converters, matrix converters for AC–DC or AC–AC conversion, and so on, are used for mitigation of power quality problems and support in drawing clean power from the utility.

Q.23 What is EMC ?

▣ **Ans. :** Electromagnetic Compatibility (EMC) is the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Q.24 State the objective of EMC.

▣ **Ans. :** The objective EMC is to assure a satisfactory function of electrical and electronic equipment with respect to electromagnetic disturbances.

Q.25 List the power quality problems faced by consumers.

▣ **Ans. :** The various consequences faced by consumer due to power quality problems.

- Economic penalty in terms of power loss
- Equipment failure
- Mal-operation
- Interruption in the process
- Loss of production

Q.26 What is the relation between voltage quality and EMC ?

▣ **Ans. :** The voltage quality can be considered as variation from ideal voltage conditions at a site in a system. It can be due to electromagnetic disturbances of the voltage in a system. When there is no such disturbance presented in a system, then the quality of voltage is perfect and it can lead to a satisfactory performance of equipment. On the other hand, in presence of disturbances the performance of equipment gets degraded.

Q.27 Define flicker.

▣ **Ans. : Flicker :** Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time.

Q.28 Give the selection criteria for power quality monitoring.

▣ **Ans. :** The selection criteria for power quality monitoring needed are listed below :

- Proper selection of monitoring equipment
- Method of data collection
- Financial damages caused by PQ events either in critical or sensitive equipment
- PQ problems and events may cause malfunctions or damages in the equipment.

Q.29 Enumerate the benefits of PQ mitigation.

▣ **Ans. :** Basic PQ monitoring system can be considered as a tool for ensuring the availability of power to the customers. The following are benefits of PQ monitoring have been listed below.

- Mitigation of PQ problems
- Scheduling preventive and predictive maintenance
- Ensuring the performance of equipment
- Assessing the sensitivity of equipment to PQ disturbances
- Identifying the power quality events and problems
- Reducing the power losses in the process and distribution system
- Upgrading and modernizing of data to be analyzed

Q.30 Highlight the uses of passive compensators during PQ monitoring.

▣ **Ans. :** A passive compensation has turned out as a mature technology for providing reactive power compensation for power factor correction and/or voltage regulation, load balancing, and reduction of neutral current. The following uses a passive compensator during PQ monitoring.

- Regulating the terminal voltage
- Suppressing voltage flicker
- Improving voltage balance
- Power factor correction
- Load balancing
- Neutral current mitigation

Q.31 Classify passive shunt and series compensators.

▣ **Ans. :** Based on topology and number of phases, the passive compensators can be classified based on the topology and the number of phases. Shunt, series and hybrid connection are the categories under based system. While the phase based classification is based on the number of phases, namely single-phase two wire and three phases three- or four-wire (three-phase) systems.

Q.32 What are CPDs ?

▣ **Ans. :** The power quality issues can be addressed by custom power devices (CPDs). DSTATCOMs (distribution static compensators), DVRs (dynamic voltage restorers), and UPQCs (unified power quality conditioners) are the CPDs used to mitigate power quality issues depending upon the requirements.

Q.33 Which is the best technology to mitigate power quality problem ? Justify your answer.

▣ **Ans. :**

- The best technology to mitigate current-based power quality problems is DSTATCOM.
- It is basically categorized into three types, namely, single-phase two-wire, three-phase three-wire, and three-phase four-wire configurations. Using these requirements of three types of consumer loads on supply systems can be satisfied effectively. Single-phase two-wire DSTATCOMs have been investigated in varying configurations and control strategies to meet the needs of single-phase system loads such as domestic lights and ovens, TVs, computer power supplies, air conditioners, laser printers, and Xerox machines.

Q.34 What is meant by web based power quality measurement ?

▣ **Ans. :** Corrective measures can be taken through a real time power quality monitoring. One such system is a web based power quality monitoring system. It is a near real time power quality monitoring system, which provides local as well as global information to the consumers. The power quality data from various utilities are collected and formed as a database. Using this database, the power quality web based system provides auto email notification of a consumer's power quality.

Q.35 Mention the need for web based power quality monitoring system.

▣ **Ans. :**

- In the current situation, there is a high demand for permanent power quality monitoring system because of following reasons :

- The current harmonics must be monitored on a continuous basis to ensure that, over a time, the incremental addition of loads does not cause excessive heating that can lead to power loss, premature failure of transformer, capacitor etc.
- For future extension distribution system, a continuous tracing of power consumption data is needed for planning.
- For taking remedial action against power quality issues, there is a need to detect on continuous basis various symptoms of power quality such as harmonic distortion, voltage dips, interruption, transient etc.
- For forecasting specific breakdown conditions such as overheating of switch boards, current surges, over voltage, voltage sags and fluctuations or to detect deterioration and PQ degradation.
- During procurement of new equipments, a proper decision making has to be done for avoiding incompatibility issues.
- In order to make changes in design of equipment, there is need for identifying the information related to sensitive equipment. Such information can be collected through power quality data base on web.

Q.36 List out the standards in report preparation during power quality audit.

▣ **Ans. :** In report preparation phase, the documentation provides recommendations depending upon the client requirement as per mentioned below standards.

- Institute of Electrical and Electronic Engineers (IEEE)
- International Electro Technical Commission (IEC)
- Bureau of Indian Standards (BIS)
- American National Standards Institute (ANSI)
- Canadian Standards Association (CSA)
- Japanese Industrial Standards (JIS)

Q.37 State the need for power quality audit.

▣ **Ans. :** The following are few needs for power quality audit.

- Improves the power quality and brings in efficiency
- Helps to identify and eradicate Harmonics which minimizes line losses and minimize reduction in the equipment lifetime due to harmonics.
- Helps to identify and eradicate transients to avoid short-duration change in voltage

- Helps to identify and eradicate hours-long voltage sags caused by system overload.
- Improve and maintain continuous supply of quality electricity supply.

Q.38 What is power quality audit ?

▣ **Ans. :** The systematic process is carried out under three different phases namely, planning, site audit and analysis and reporting. Planning is considered to be the pre audit phase, where the focus is on objectives of audit. It supports to identify the risk found in the system.

Q.39 What is power quality conditioner ?

▣ **Ans. :** A power quality conditioner is a device deployed for improving the quality of power that is being delivered to electrical load or equipment. It is also known as a line conditioner or power line conditioner.

Q.40 What are role of a power quality conditioner ?

▣ **Ans. :** The role of a power quality conditioner are listed below :

- Deliver voltage and current of the proper level
- To enable load equipment to function properly
- Ensure efficient power transfer between utility grid and micro grid
- Isolate utility grid from disturbances
- Integration with energy storage system

➥ 4.19.2 Long Answered Questions

Q.1 Highlight the effects of power quality issues. **[Refer section 4.2]**

Q.2 Outline the dependency of loads on harmonics. **[Refer section 4.4]**

Q.3 Discuss the various power quality indices. **[Refer section 4.5]**

Q.4 Elaborate the influence of harmonics in distribution system. **[Refer section 4.6]**

Q.5 Define power quality and classify the power quality problems. **[Refer sections 4.8 and 4.9]**

Q.6 What is meant by power quality mitigation ? Also outline the mitigation techniques for power quality problem. **[Refer section 4.10]**

Q.7 Explain the objective of EMC in smart grid. **[Refer section 4.11]**

Q.8 Interpret the power quality standards in smart grid. **[Refer section 4.13]**

Q.9 List the selection criteria for power quality monitoring. **[Refer section 4.13.2]**

Q.10 Infer the PQ monitoring benefits in smart grid. **[Refer section 4.13.3]**

Q.11 Classify passive shunt and series compensators deployed for power quality mitigation. **[Refer section 4.14]**

Q.12 Explain the role of web based power quality monitoring in smart grid. **[Refer section 4.16]**

Q.13 Summarize the various types of power quality monitoring. **[Refer sections 4.16.3 to 4.16.5]**

Q.14 Infer the importance of power quality audit in industries. **[Refer section 4.17]**

Q.15 Explain the various stages of power quality audit process. **[Refer section 4.17.2]**

Q.16 Summarize the various types of UPQC. **[Refer section 4.18.2]**

➡ 4.19.3 Multiple Choice Questions

Q.1 Renewable energy is generated from ________.

a natural resources
b artificial resources
c nuclear resources
d all of the above

Q.2 Which of the following is not a property associated with power quality of smart grids ?

a Self-healing
b Frequency monitoring and control
c Load forecasting
d Asset management

Q.3 ____________ is a meter with a waveform display screen, voltage leads, and current probes.

a Voltmeter
b Ammeter
c Harmonic analyzer
d DMM

Q.4 _______________ are advanced data acquisition devices for capturing, storing, and presenting short-duration, subcycle power system disturbances.

a Harmonic analyzer
b Transient-disturbance analyzers
c Oscilloscope
d Data loggers and chart recorders

Q.5 Most of the power quality problems are related to _______.

a transmission Issue
b grounding Issue
c distribution Issue
d all of the above

Q.6 Interruption is ________.

a) complete loss of power
b) complete loss of voltage
c) complete loss of current
d) all the above

Q.7 The main mitigation equipments is ________.

a) UPS
b) storage device
c) voltage source converter
d) all the above

Q.8 Various types of quality audits are ________.

a) product
b) process
c) management (system) and registration (certification)
d) all of the above

Q.9 The most comprehensive type of audit is the ___________ system audit, which examines the suitability and effectiveness of the system as a whole.

a) quantity
b) quality
c) preliminary
d) sequential

Q.10 Transients are difficult to detect because of their ________.

a) amplitude variation
b) frequncy variation
c) short duration
d) long duration

Q.11 Which of the following can not be considered as transient ?

a) Spikes
b) Power pulses
c) Surges
d) Interruption

Q.12 An electrical signal present in a circuit other than the desired signal is known as _____.

a) noise
b) distortion
c) interference
d) all of these

Q.13 The selection criteria for power quality monitoring ________.

a) proper selection of monitoring equipment
b) method of data collection
c) financial damages caused by PQ events either in critical or sensitive equipment
d) all of these

Q.14 The UPQC classified into________ types.

[a] 2 [b] 3 [c] 4 [d] 5

Q.15 Example for non linear loads ________.

[a] power converters [b] elevators

[c] battery chargers [d] all of the above

Q.16 Full form of STATCOM is ____________.

[a] Static Synchronous Counter [b] Static Synchronous Compensator

[c] State Synchronized Compensator [d] State System Counter

Q.17 ____________ is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.

[a] Power factor [b] Power system

[c] Power quality [d] Power field

Q.18 In power system, the full form of PCC is ________.

[a] Primarily Common Coupling [b] Point of Common Coupling

[c] Primarily of Coupling Common [d] Primarily Coupling Common

Q.19 ______________ indicates the deviation of a periodic wave from its ideal waveform characteristics.

[a] Flicker [b] Power factor [c] Distortion [d] Noise

Q.20 Sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency is the ______________.

[a] flickering [b] harmonics [c] distortion [d] deviation

❒ Answer Keys for Multiple Choice Questions

Q.1	a	**Q.2**	d	**Q.3**	c	**Q.4**	b
Q.5	b	**Q.6**	b	**Q.7**	d	**Q.8**	d
Q.9	b	**Q.10**	c	**Q.11**	d	**Q.12**	c
Q.13	d	**Q.14**	a	**Q.15**	d	**Q.16**	b
Q.17	c	**Q.18**	b	**Q.19**	c	**Q.20**	b

❑❑❑

UNIT - V

5 High Performance Computing for Smart Grid Applications

Syllabus

Local Area Network (LAN), House Area Network (HAN), Wide Area Network (WAN), Broadband over Power line (BPL), IP based Protocols, Basics of Web Service and CLOUD Computing to make Smart Grids smarter, Cyber Security for Smart Grid.

Contents

5.1 Communications in the Smart Grid

- In a smart grid the communication infrastructure plays a vital role. The analogue of smart grid can be compared with human nervous system for better understanding. In a human body, the overall control is executed by brain. Similarly, all the entities of smart grid system are controlled by communication infrastructure. The transmission and distribution lines carry energy that can be correlated to the blood vessels which carry blood.
- In recent years, the modernization of electrical grid has been done with the support of an integrated communication infrastructure. Several communication technologies covered by various levels of standard have been developed by Standards Developing Organizations (SDOs). Inorder to ensure cost efficiency and reliability, numerous technical specifications were created by manufacturers, vendors, and service providers.
- The complex system, smart grid can meet the specific requirements of various applications through the integrated communication architecture. The following are the key features of communication technologies :

5.1.1 Reliability

To ensure smooth operation for 24 / 7, the term reliability is highly demanded. Inorder to prevent blackouts and overload condition, it has become essential to meet out the reliability requirements of communication architecture.

5.1.2 Security

In a smart grid, the information flows bidirectionally, where customer privacy must be ensured. The information related to billing and energy consumption by consumers can be attacked by hacking. Hence, deploying a secured environment has become mandatory in a smart grid.

5.1.3 Scalability

Due to technological advancements, millions of devices and appliances are expected to add in the smart grid. This makes the grid to expand vertically and horizontally. In such expansion, the communication infrastructure is expected to last for decades.

5.1.4 Quality of Service

It is decided by the minimum bit rate, low error rate and latency limits. The service quality is vital for various applications in a smart grid.

5.1.5 Interoperability

For global interoperability between different communication technologies, a standardized solution is highly important.

5.1.6 Low Cost

- In any system, cost effectiveness is considered a crucial parameter, because infrastructure creation and maintenance should not incur high capital.
- In the following sections, discussion on communication technologies for transportation of data, its standard and security are dealt.

5.2 Communication Requirements for the Smart Grid

- The support of many different applications with specific requirements for communication links and network topologies are required by smart grid. Defining communication requirements in a smart grid is important because it is a wide area integrating various technologies in a single platform. Several applications such as Distributed Energy Resources (DERs) , Electric Vehicles (EVs), Demand Response (DR), Advanced Metering Infrastructure (AMI), substation automation, fault management and blackout requires proper communication flow. Such communication flow has become crucial inorder to prevent serious issues in a smart grid.
- The information communicated related to metering and measurements, payment information, and outage notification are done by AMI. It is located on the line between a distribution network and consumers' premises. Such communication infrastructure in consumer's premises monitors the energy consumption levels by consumer's appliances. In these cases, the information amount per device is likely be 10-100 kbps. Hence, a significant constraint on the capacity of the links is not made. While in larger premises such as office buildings and industries scaling up of communication devices are highly demanded.
- At times very large number of communication devices may be involved for ensuring proper operation of all domains in the grid. Thus, it is clear that the metering dependency on communication reliability gets varied with applications. There are certain cases where high reliable links are demanded in a smart grid. To prevent from overload condition in on-site micro generation and distribution network, the requirement of communication link is entirely different from other cases. Bandwidth requirements of DER, AMI and DR are very similar.
- Monitoring of the power system across large geographic areas is done by Wide Area Situational Awareness (WASA). This supports in enhancing the entire system reliability and also avoids power supply disruption. Hence, WASA is considered to be a typical mission critical application. WASA requires only low communication latency, but highly reliable communication technology. The automation in substation and distribution network demands a relatively fast responsiveness with latencies less than 100 ms. This is because of life-critical situations involving high-voltage lines and isolating potential faults. Thus, emerges a limitation on the selection of the proper communication technologies for both applications. The communication between EVs and grid are bidirectional, which does not require very low latency. Hence, EV is not considered as a critical application.

5.3 Features of Smart Grid Communication Networks

The communication network of smart grid is very similar to Internet interms of structure and complexity. However, there exist few fundamental differences between these two complex systems.

5.3.1 Performance Metric

Offering data service is the preliminary function of internet for users. While designing an internet, it is highly important to attain high throughput and fairness among users. But in case of smart grid communication network, accomplishment of reliable, secure, and real-time message delivery and non-real time monitoring and management are highly demanded. In case of power substation communications, to avoid redundant processing application layer directly passes time-critical messages to MAC layer. Such messages are used for protection purposes in a substation.

5.3.2 Traffic Model

Raw data sampling in power substations are done for constant monitoring of grid information. Thus, large amount of periodic traffic flows in home-area networks.

5.3.3 Timing Requirement

Smart grid has much more stringent timing requirements for message delivery than the Internet. This is due to milliseconds delay requirement in grid. In case of trip protection messaging, only 3 ms delay constraint is provided. While in internet, nearly 100 to 150 ms delay can be provided.

5.3.4 Communication Model

Smart grid enables a two-way communication model such as center to device and device to center. In bidirectional communication, both power and information flow are observed.

5.4 Architecture of the Communication System in the Smart Grid

- In a smart grid, a hierarchical structure is observed in deployment of communication systems. The architecture of communication system in a smart grid is slightly different from the typical Information and Communication Technology (ICT) network architecture. Different types of area networks are deployed for establishment of communication infrastructure in a smart grid. The Fig. 5.4.1 shows the simplified structure version of communication system.
- The smallest network type which is the area behind customer's premises is HAN. It connects various devices namely Personal Computers (PCs), entertainment equipment, security devices, smart home appliances, and smart meter. Similarly, Heating Ventilation and Air Conditioning (HVAC) systems, local power generators and storages is deployed in Building Management Systems (BMS). While in an Industrial Area Network (IAN) includes machinery and industrial automation.

- Several AMI can be connected together to create the Neighborhood Area Network (NAN). In this network smart meter acts as essential part of AMI. Similarly, putting together several NANs constitute Field Area Network (FAN). It connects DER, Distribution Automation and substation network. The various networks found in this communication infrastructure is connected by Wide Area Network (WAN). Thus, a centralized control is established between various entities in a smart grid. In WAN, SCADA monitors the entire operation of the grid. Apart from this, there are AMI head end, operation centers, and application servers.

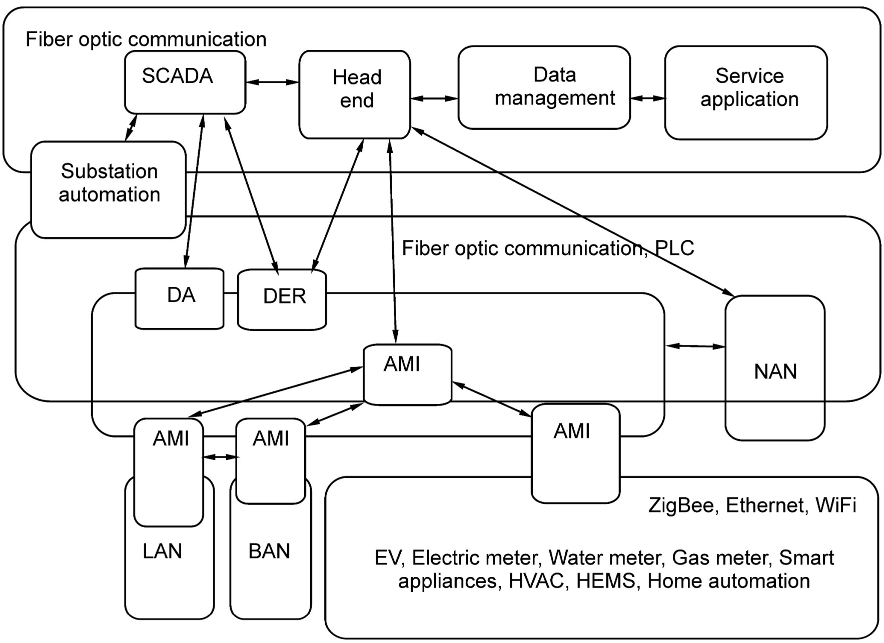

Fig. 5.4.1 : Various networks in smart grid infrastructure

5.5 IP in the Smart Grid

- The Internet Protocol (IP) plays a vital role in enabling the end-to-end connectivity and interoperability of the smart grid networks. The reason for using IP in smart grid is controllability and network visibility of various sensors in the distribution system and substation automation. The smart grid applications are independent of physical media and data link communication technologies by IP. It is used for satisfying requirements for the given application. The complexity of developing upper-layer applications gets reduced through IP. It also enables interoperability. Integration of millions of devices in a smart grid demands good scalability. Such scalability can be easily accomplished through IP. The problem of IP is the currently insufficient in addressing range of IPv4 (Internet Protocol version 6). This seeks the need for support of IPv6 (Internet Protocol version 6) routing protocol. Both wired and wireless communication technologies are deployed for supporting IPv6.

- Internet Engineering Task Force (IETF) has designed various adaption layers with IPv6 header compression, neighbor discovery optimization, and various other functionalities. The figure shows the implementation of a layered architecture with unified network layer for end-to-end connectivity and interoperability.

Application	IEC 61850, IEC 60870, CIM, SNMP, and so on							
Network	TCP / UDP							
	RPL							
	IPv4 / IPv6							
	EAP-TLS							
Adaptation	6LoWPAN RFC 2464						RFC 5072	RFC 5121
MAC	IEEE 802.15.4	IEEE 802.15.4e		Wave2M	IEEE 802.11 b/g/n (2.4 Ghz), a/n/ac (5 Ghz) ah (subgigahertz)	IEEE 802.3 Ethernet	2G/3G/LTE	IEEE 802.16/WiMAX
		IEEE 802.15.4	IEEE P1901.2					
PHY		IEEE 802.15.4g						
Media	Radio	Radio	Powerline	Radio	Radio	Coax/twist Pair/fiber	Radio	Radio

Where

TCS - Transmission Control Protocol ,

UDP - User Datagram Protocol,

RPL - Routing Protocol for Low-Power and Lossy Networks,

EAP - Extensible Authentication Protocol ,

TLP - Traffic Light Protocol

Fig. 5.5.1 : Layered architecture of smart grid communication

- Low-Power Wireless Personal Area Networks (6LoWPANs) is an open standard that is defined by IETF. The role of 6LoWPANs is to ensure interoperability among different applications. Inorder to transport communication over IPv6, 6LoWPAN was designed to provide adaption layer for physical layer (PHY) and MAC (Medium Access Control) layer. To provide end-to-end connectivity, extension of global connectivity via various devices and IP based wireless sensor networks requires certain standards. Such standards are provided by 6LoWPAN. The default routing protocol for a low-power link is RPL (Routing Protocol for Low-Power and Lossy Networks). In mesh networks, the proper path selection over several hops is done by RPL. It has an impact on end-to-end throughput and latency.

5.6 Wired Communication

Power Line Communication (PLC) offers a cost effective solution by data transmission in the exiting electrical network. When compared to Digital Subscriber Line (DSL) and fiber optic communication technologies, PLC eliminates installation of additional wires such as twisted pair or coaxial cables to interconnect devices. Since every home appliance is connected to power line, it is easy for PLC to monitor electricity, demand response and load control.

5.6.1 Types of PLC

PLC can be categorized into two groups namely Narrowband Power line Communication (NB-PLC) and Broadband Power line Communication (BB-PLC). The operation frequency band of NB-PLC is 3 - 500 kHz and it is suited for wide-area access applications of smart grid. NB-PLC offer low cost and high reliability. While, BB-PLC is operated in a high-frequency band such as 2 - 100 MHz. This is preferred in-home broadband applications such as VoIP (Voice over Internet Protocol), Video Game, and Internet is shown in Fig. 5.6.1.

5.6.1.1 BB-PLC Technologies

HomePlug AV2 is the latest BB-PLC technology that offers a peak rate of more than 1 Gbps. This is attained by using advanced signal processing technologies such as Multiple Input Multiple Output (MIMO) and pre-coding. But these technologies introduce increase in system complexity, power consumption, and capital cost.

5.6.1.2 NB-PLC Technologies

To meet the requirements of long-range and outside-the-home applications NB-PLC technologies are deployed. It provides low complexity, low power consumption, and high reliability.

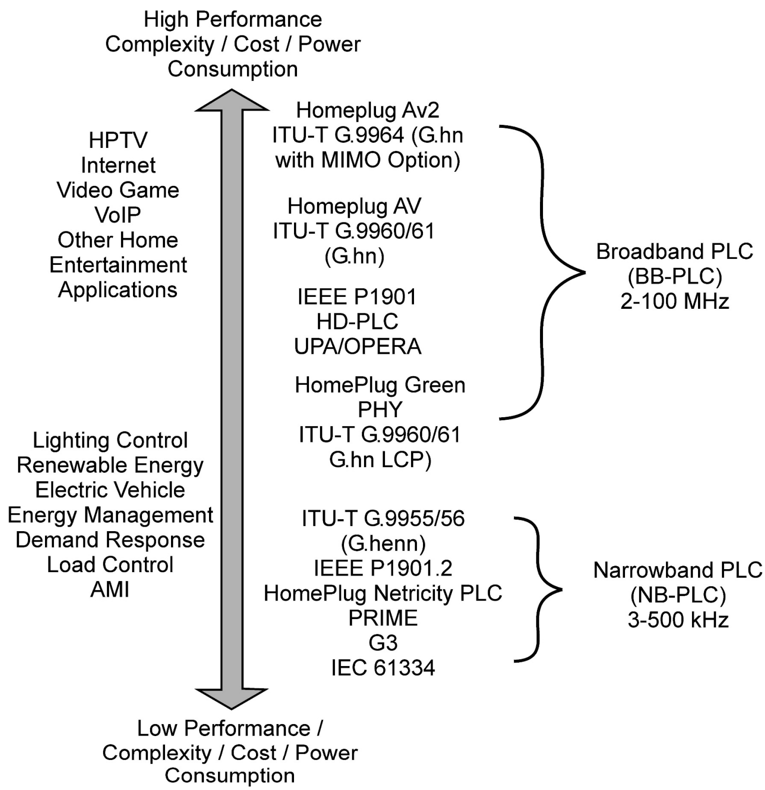

Fig. 5.6.1 : Classification of PLC technologies

5.6.2 Challenges of PLC Technologies

- There are several challenges faced by PLC during data transmission. When PLC signals reach a receiver over more than one path multipath fading occurs. This is due to the existence of multiple branches between transmitters and receiver. In such multiple path, the data transmission experiences delay and it is due to different length of each path between transmitter and receiver. The data passing through various paths reach the single receiver. This is the point where signals are recombined at receiver node. In this node partial cancellation of multiple signals are observed. This cancellation is known as frequency-selective fading.
- The following are the issues observed :
  - Physical characteristics of the transmission medium
  - Power line cables were not designed to carry communication signals
  - Multipath fading
  - Frequency selective fading
  - Interference.

5.6.3 PLC Specifications and Standards

- For smart home, building automation, and smart metering applications, NB-PLC technologies are deployed. For such applications various regional/international standards, such as ISO / IEC 14543 (KNX) standard series and BACnet protocol are included in NB-PLC. A broad set of technologies and standards such as PoweR line Intelligent Metering Evolution (PRIME) and HomePlug Netricity PLC have been developed by different SDOs (Standards Developing Organizations) for smart metering applications.
- In BB-PLC technologies, Internet, VoIP, and HPTV are widely used as broadband networking applications. The HomePlug AV specification was developed by the HomePlug Alliance to be completely interoperable with the IEEE P1901 standard for BB-PLC technologies. High Definition Power Line Communication (HD-PLC) using the wavelet OFDM and M-PAM modulation schemes are the other BB-PLC technologies used. IEEE (Institute of Electrical and Electronics Engineers) have developed internationally adopted BB-PLC standards for enabling interoperability between multiple PLC vendors.

5.7 Optical Communication

Since 1990s, for attaining high-demand, high-reliability, and long-distance applications, fiber-optic communication has been employed. But at the time of establishment, cost of optical fiber based communication was costlier. However, in early 2000, the decrease in prices of optical fiber with other components made optical communication to be a cost effective technology. In current scenario, optical-fiber networks are considered as a core network.

5.7.1 Fiber Optic Communication in Smart Grid

The data bandwidth for two-way communication for smart grid-related data in large cities and dense populations is high. The aggregated data bandwidth rises to several gigabytes per second in a highly populated region. The smart city deployment is another reason for preferring fiber optic communication in smart grid. The need for replacement or upgradation of the infrastructure can be avoided in optical communication because it can accommodate a very high bandwidth depending upon the application requirements.

5.7.2 Structure of Fiber-Optic Network

The network comprises an optical transmitter, optical amplifiers and an optical receiver. Usually, LED or Laser diode acts as an optical transmitter, where emission of light for transmission is observed. For handling attenuation and distortion of transmitted signal, an optical amplifier is placed in between transmitter and receiver. Since long distance transmission is required in the system, optical amplifier amplifies directly the signal in the form of light. At the receiver end, a photodiode detects the light and convert it back into the electrical signal by the photoelectric effect.

5.7.3 Types of Optical Fibers

- Optical fibers are classified as multimode optical fibers and single-mode optical fibers. Based on the core size, the classification of optical fibers has been done. In multimode optical fibers, larger core diameters, allowing several modes of various wavelengths are transmitted. The core size is typically 50 - 100 µm. The core diameter of a single mode fiber varies between 8 and 10.5 µm. For multimode transmitters, LED can be used for light emission in multimode transmitter, while a single mode one requires a precise laser-based transmitter. Multimode optical fibers are used for relatively short distance transmissions such as application for buildings, while single-mode optical fibers are used for very long distance high bandwidth transmissions over tens or hundreds of kilometers.
- A commonly used technology that detects light dedicated to each channel is Wavelength Division Multiplexing (WDM). It uses multiplexing of parallel channels. At the transmitter end multiplexing of signals are done, while demultiplexing of signal executed at receiver end.

5.8 Wireless Communication

- Over many decades wireless communication technologies and wireless standards have been used However, wide utilization of wireless technologies for the consumer market started only a few decades ago. Still these technologies move ahead with several advancements. The tremendous development of wireless technologies have reduced the hardware size, cost, and increased energy efficiency. Wireless technologies hold numerous merits when compared with wired technologies. Speed of deployment, flexibility, mobility, and accessibility to remote sites is few advantages of this technology.
- An application of wireless technologies to the electrical grid and power system has been already used for home and building automation, monitoring, data collection, and metering. However, the Machine-to-Machine (M2M) concept and its utilization find a potential application in smart grid. When a communication is established between devices without human interference is known as M2M communication. Autonomous operation, power efficiency, reliability, self-organization, and scalability are the important characteristics of M2M communication. The requirement of Wireless Sensor and Actuator Networks (WSANs) satisfy the key characteristics of M2M communication and thus it is considered as driving force WSAN.

5.9 Wireless Personal and Local Area Networks

- The wireless communication technologies operated in unlicensed spectrum are Wireless Local Area Networks (WLANs) and Wireless Personal Area Networks (WPANs). Usually within a home, office, warehouse, or building, WLANs establish connection between two or more devices. The range of coverage in such networks is from tens of meters to about a hundred meters. On the other hand, WPANs provide connection between devices within personal area, covering distances ranges from a few centimeters to tens of meters. In recent days, the technological advancements have made WLANs and WPANs to offer high data rates, reliability, security and increasing range of coverage.
- WLAN and WPAN technologies are currently offering long-range communication which is known as Wireless Metropolitan Area Networks (WMANs) or Wireless Regional Area Networks (WRANs). For smart home and building automation and home energy management systems (EMSs) can be deployed with the support of WLAN and WPAN. Similarly, the neighborhood communication can be established with WMAN and WRAN technologies. These technologies offer AMI-to-AMI communication, remote metering and monitoring, communication between various logical blocks within NANs and FANs.

5.10 Home Area Networks (HAN)

- To manage the energy consumption, storage, and generation devices, Home energy management systems (HEMS) have been deployed. It includes a wide spectrum of devices, including lights, appliances, heaters, air conditioners and local generation facilities (such as solar panels) are shown in Fig. 5.10.1. These devices are communicated with the support of home area network. HANs are wireless networking technologies that are defined by ZigBee standards. A ZigBee standard is a suite of high-level communication protocols supported over the PHY and MAC layers of IEEE 802.15 wireless networks. The IEEE 802.15.4 standard can be enhanced by adding mesh networking and security functions required in HAN environments. For the purpose of remote monitoring and control, external devices are connected to HAN.
- The energy consumption / supply into and out of the systems are monitored by HEMS. To turn ON/OFF of devices can be controlled based on the need of energy efficiency. Further, HEMS may control their operation, turning them on and off as needed and managing their energy efficiency. The smart meter can also be connected into the HAN and thus HEMS can access the meter measurements.

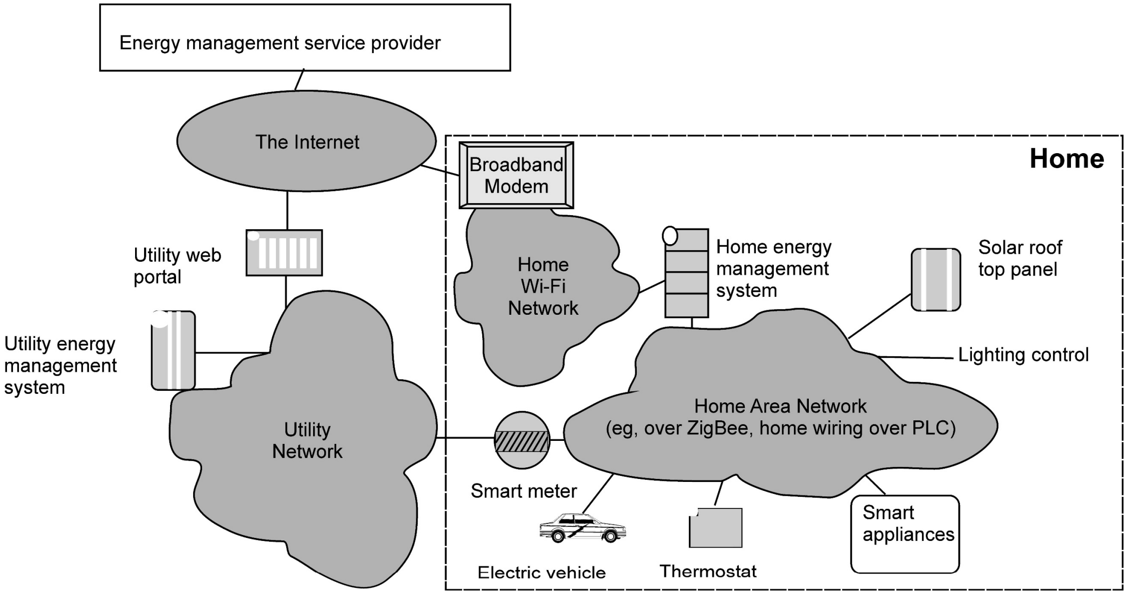

Fig. 5.10.1 : Home area network

- Such access can be executed by smart phones which are outside from home. Internet access can be accomplished by connecting HEMS to home Wi-Fi network. Apart from these, the Utility Energy Management System (UEMS) can report information related past consumption, consumption predictions and variation to HEMS. The information of UEMS and HEMS can be supplied to utility web portal through Internet or other IP network.

5.11 Wide Area Network

- A Wide Area Network (WAN) is a network containing huge information. But the network is not tied to a single location. WANs can assist communication, information sharing between devices from around the globe through a WAN provider. For smart grid applications, the WAN provides a two-way communication link, which acts as backbone for reliable operation of system. The huge data from the NAN and FAN are sent to the service providers, data and control centers through high-bandwidth media. The WAN covers the transmission and distribution domains between 10 and 100 km range. Alternative technologies for this tier include WiMAX, Synchronous Digital Hierarchy (SDH) and Passive Optical Network (PON). Fibre optics remains the first choice for this segment because it is not susceptible to electromagnetic interferences and with very high transmission capacity, albeit costly to deploy.

- In smart grid, transmission substation LAN, utility LAN and public internet are connected via WAN. The transmission substation LAN comprises of all connected transmission substations which use protection and control devices in order to achieve substation automation functionality. The utility LAN is used to manage, monitor and control data flows by the utilities. It would be used to provide services such as field device automation, metering, demand response and load control. The Wide Area Network connected to the public internet, allows third parties to partake in Smart Grid activities using a secured communications channel.

5.12 Cloud Computing for Smart Grid Applications

A robust, affordable and secure supply of power through smart grid is accomplished through reliable and efficient communication system. Cloud Computing (CC) model is an emerging area through which the computational requirements of smart grid applications can be easily met out. Some unique features of cloud computing namely flexible resources, flexible services, parallel processing and omnipresent access are highly desirable for smart grid applications.

5.12.1 Benefits of Cloud Computing in Smart Grid

- In an electric power system, there are several applications which require the need of cloud computing shown in Fig. 5.12.1. The following are the needs of cloud computing in power system.
  - Supports in recovery of blackout condition in a power system
  - Monitoring and scheduling functions can be performed in power system
  - Reliable evaluation of the power system

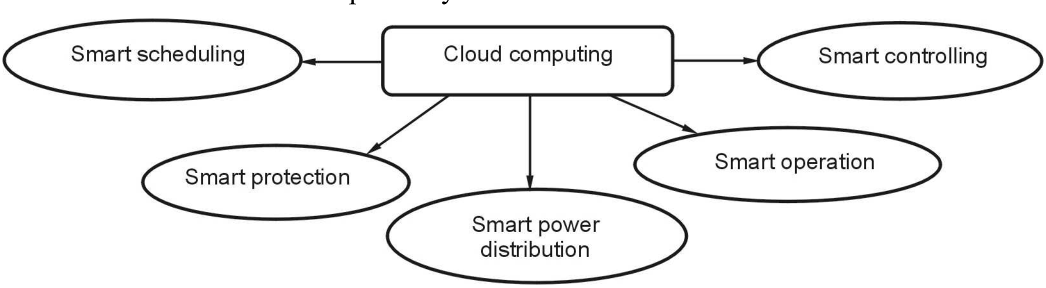

Fig. 5.12.1 : Function of cloud computing

  - Instant information sharing aids in quick power restoration process
  - Reduced system complexity
  - Reduced implementation and maintenance costs.

5.12.2 Cloud Computing Architecture

- Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Data as a Service (DaaS) are the three types of cloud computing architecture. Based on demand, the device retrieves the software and information shared through network. The core principle behind cloud computing is distribution of services to a large number scattered computers. The information sharing is enabled by Enterprise Data Center in Cloud Computing. This information sharing is executed based on the need. It also provides access to all storage systems when needed. Using the power of Cloud Computing, the requirements of smart grid can be attained easily. Real time response is important for smart grid applications for addressing immediate demand response.
- When a request is sent from client through cloud platform, then a response is sent to client in real time. Self healing system is highly essential in a smart gird. Such self healing process can be done by cloud computing which provides instant response to customers. The entire communication in smart grid is attained via the Internet. Thus, there should be no internet outages to provide consistent transmission. Such continuous transmission is handled by Cloud Computing through two or more IP address assignment to a client. This multi IP address assignment to client is known as multi homing.
- Cloud computing has many characteristics that can yield improved smart grid applications. These characteristics of cloud computing is listed below :
  - Communication between the machine and cloud software is done via CC Application Programming Interface (API).
  - Any device by a consumer that needs to access the systems can use public cloud delivery model via internet. By this an independent feature of cloud computing between device and location is observed.
  - Maintenance and virtualization are properties of cloud computing.
  - For running an application and performing computation, there is no need for software installation.
  - Cloud computing offers an easy access to services from anywhere and at anytime.
  - Using the virtualization property of cloud computing, the servers and storage devices can be shared and carried easily from one server to another.
  - Large numbers of users located in a pool have the access to shared resources. Such access is possible by multitenacy characteristic of cloud computing.
  - To increase the system performance cloud computing platform uses web services.
  - Losses can be prevented by using private cloud platforms. This will improve the reliability of smart grid.

5.13 Challenges in Using Cloud Computing for Smart Grids

To grab the majority benefits of cloud computing in smart grid, certain challenges have to be overcome. The main issue considered is authenticity of cloud computing in smart grid. Such issues can create inefficiency in smart grid performance. The following are major challenges to be faced by cloud computing in smart grid applications.

5.13.1 Location of Data

Business enterprises are unaware of location of server that stores and processes smart grid information. This is because of placement of cloud servers in any location. Thus, identifying the data location has become highly important. This is defined by Cloud Service Providers (CSPs), which can be used for meeting out the requirements of data management in smart grid.

5.13.2 Mixing of Data

Many multi-user applications in CSPs create security and scalability issues for enterprises. Therefore, security methods like data encryption algorithms must be applied on CSPs for ensuring reliability and confidentiality in smart grid SG applications.

5.13.3 Inefficient Cloud Security Policy

Weaker security policies applied to CSPs may create disagreements between smart grid utilities. This can be addressed by deploying service level agreements into effect between each others. Thus security in smart grid can be ensured at proper level.

5.13.4 Redundant Data Management and Disaster Recovery

- Under emergency situation, recovery of smart grid utilities is crucial because cloud computing distributes data to multiple servers in different geographical location. Thus assuring reliability for smart grid application becomes a problem. In such situation, CSP can go for outsourcing of services to address recovery related problems.
- All networks are incorporated in cloud computing of electric power system using computer application software. This is the inner network of power system to work coordinately with support of cluster application, distributed computer system. Using software interface, all levels of network of electric power system can be reached. Structure of the hierarchical model of the intelligent cloud of power system is shown in Fig. 5.13.1. [See Fig. 5.13.1 on next page].
- In this structural model, basic storage layer becomes the fundamental element of the smart grid. Here storage devices are interconnected through network in a smart grid. While the basic management layer incorporates integration of all devices in cloud atmosphere.

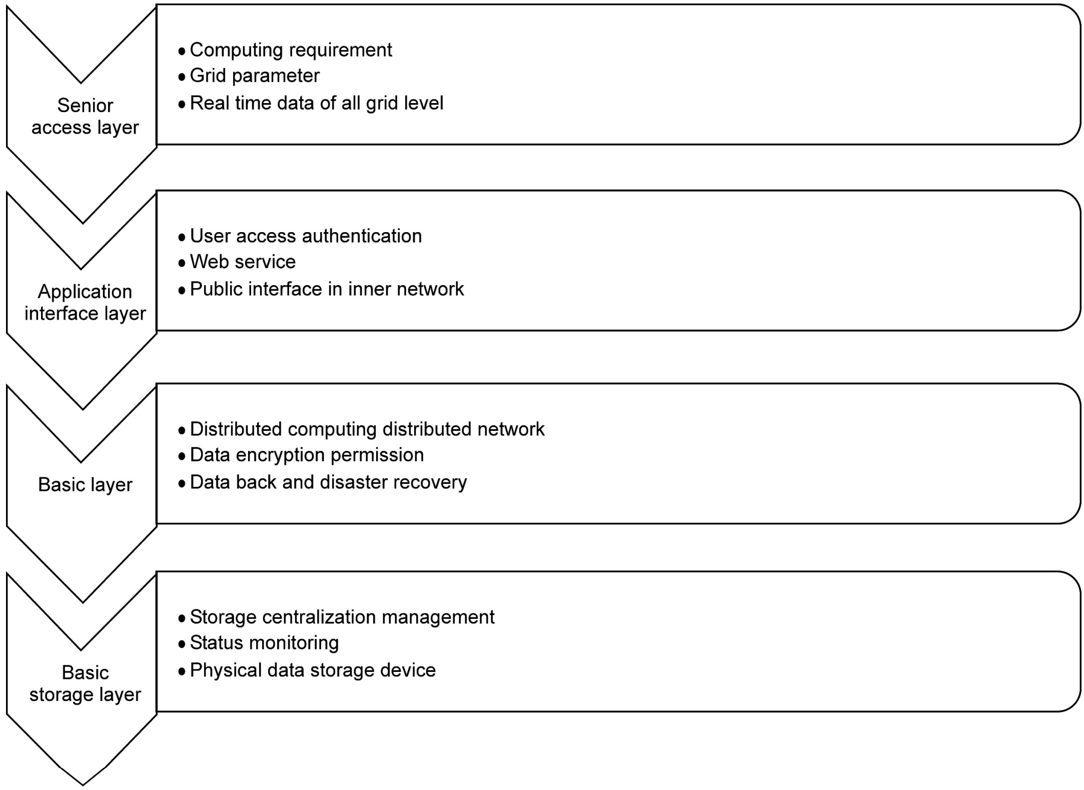

Fig. 5.13.1 : Cloud computing in smart grid application

5.14 Cyber Security in the Smart Grid

- In smart grid, the cyber security is a new area of research that has grabbed rapid attention in all sectors. To enhance efficiency and reliability of future power systems, integration of advanced computing and communication technologies are used. The integration of million electronic devices via communication networks has demanded the need for cyber security. A smart grid has potential vulnerabilities associated with communications and networking systems. This enhances the risk of compromising reliable and secure power system operation. But the objective of smart grid is to accomplish a reliable and efficient system operation.
- The intrusion of network by enemies may lead to a numerous severe consequences in smart grid. Leakage of customer information, massive blackout and destruction of infrastructures are the few consequences due to network intrusion. In communication network of smart grid, malicious threats create cyber and it is defined as cyber security threat. A smart grid is a communication network, where information exchange in power infrastructures is attained. For proper energy delivery and management, it is essential to understand objectives and requirements of cyber security.

5.15 Smart Grid Security Objectives

The NIST (National Institute of Standards and Technology) Smart Grid interoperability panel has given a comprehensive guideline for smart grid cyber security. Availability, integrity and confidentiality are the three levels of objectives in a smart grid.

5.15.1 Availability

In a smart grid, reliable access of information and its timely availability have to be ensured for smooth operation of grid. Disruption of information access can occur due loss of information availability. This can create impact on power delivery of the system.

5.15.2 Integrity

Integrity deals with safe guarding against improper information modification or destruction. Inorder to ensure information authenticity, integrity is required. A loss of integrity may lead to unauthorized modification or destruction of information. Such unauthorized directions can further induce incorrect decision regarding power management.

5.15.3 Confidentiality

To protect personal privacy and proprietary information, confidentiality is needed. It is a process of preserving authorized restriction on information access. Inorder to prevent unauthorized disclosure of information to public or individuals, the confidentiality is required.

5.16 Cyber Security Requirements

The three high-level cyber security objectives namely availability, integrity and confidentiality are used for defining the requirements cyber security in smart grid. The following are cyber security requirements in a smart grid.

5.16.1 Attack Detection and Resilience Operations

In smart grid, an open communication network over large geographical areas is observed. Monitoring each and every node in such a wide area is little tedious. Thus, it is almost impossible to ensure grid safety from network attacks. By consistent testing and comparison of communication network, the network traffic status can be monitored. This supports the detection and identification abnormal incidents due to attacks. The presence of attacks can be overcome by self-healing ability of the network.

5.16.2 Identification, Authentication and Access Control

- The smart grid infrastructure incorporates millions of electronic devices and users in it. In such structure, verifying the identity of a device or user is done by identification and authentication. This can be considered as a prerequisite for granting access to resources in the smart grid information system. The objective of access control is to ensure that access of resources is done by the appropriate personnel only. Enforcement of strict access control can prevent unauthorized users from accessing sensitive information and controlling critical infrastructures.
- For ensuring the authentication of data access, it is mandatory satisfy certain requirements. In smart grid, deployment of cryptographic functions, such as symmetric and asymmetric cryptographic primitives can assure the data access with authenticated user alone. For implementation of such initiative, smart grid must allow data encryption and authentication.

5.16.3 Secure and Efficient Communication Protocols

In distribution and transmission systems, message delivery requires both time-criticality and security. In the design of communications protocols and architectures for smart grid, optimal tradeoffs are required to balance communication efficiency and information security. Inorder to fully achieve efficient and secure information delivery for critical power infrastructures, smart grid imposes strict security requirements than the Internet.

5.17 Network Security Threats in the Smart Grid

- A malicious cyber attacks via communication networks creates disruption of the smart grid. The network security threats can be defined by type of attacks made on the communication network. Attack classification in communication networks are categorized as selfish attacks on security, selfish misbehaving users and cruel users. The communication protocols are violated and make an attempt to access the network resources. Such selfish misbehaving user attack can create performance degradation in the system. While, illegally acquire, modify or disrupt information in the network are done by cruel user called malicious users
- It is very clearly stated that both selfish and cruel users pose challenging security problems to communication networks. In such situation, high level of attention is paid towards cruel users when compared to self behavior attack. This is because cruel users may attack r create disrupt in the millions of electronic computing devices are used for monitoring and control purposes. Cruel attack may at times hack data services such as file downloading and sharing. Thus, malicious attacks may induce severe damage to power supplies and widespread power outage. As smart grid infrastructure large and complex, enumerating all type of attacks is highly impossible. So based on smart grid security objective such as availability, integrity and confidentiality the attacks can be categorized.

- Attacks targeting availability is known as Denial-of-Service (DoS) attacks. This attack, introduces delay, block or corrupt the communication in smart grid.
- Attacks targeting integrity intentionally modify or disrupt data exchange in smart grid.
- Attacks targeting confidentiality aim to acquire unauthorized information from network resources in smart grid.

5.18 Denial-of-Service Attacks

Availability of data on time is the primary security goal of smart grid operations. When there is a lag in data availability, then the system performance gets degraded. In worst case, operations of electronics devices are impaired. In a smart grid, DoS executes attacks at different levels of communication layers. Thus , performance degradation is mainly due to communication issues.

5.18.1 Physical Layer

In wireless communication, channel jamming is one of the most efficient ways to launch physical-layer DoS attacks. When intruders only need to connect to communication channels rather than authenticated networks, it is very easy for them to launch DoS attacks at the physical layer. LANs are widely used in smart grid, where wireless jamming becomes the primary physical-layer attack. At times jamming attacks can lead to a wide range of damages to the network performance of power substation systems, from delayed delivery of time-critical messages to complete Denial-of-Service.

5.18.2 MAC Layer

Intentionally attacker can modify its MAC parameters. A reliable point to-point communication is done by MAC layer. Such intrusion creates better opportunities in accessing the network at the cost of performance degradation. Thus, attacks at MAC layer is considered to be a weak version of DoS attack. Spoofing is considered to the most harmful threat in smart grid. This is due to possibility of attack at MAC layers. This attack targets both availability and integrity of information in smart grid. In this layer fake information can be send using the openness of address field in MAC layer. Such a process of sending fake information to devices is referred as spoofing

5.18.3 Network and Transport Layers

In a network and transport layer, to degrade the end-to-end communication performance attacks takes place. Distributed traffic flooding and worm propagation attacks on the Internet are few examples for attacks leading to performance degradation in smart grid.

5.18.4 Application Layer

The main focus of lower layer attacks is on transmission bandwidth in communication channels, computers or routers. DoS attacks on application-layer intend to exhaust resources of a computer, such as CPU or I/O bandwidth. Thus, CPU suffers from limited computing resources.

5.19 Attack Detection for Power Networks

It has become highly essential to provide countermeasures for cyber attacks in a smart grid. Such detection can be triggered based on network countermeasures, such as network traffic monitoring and filtering. An effective network approaches are required to identify the DoS attacks. The following are the existing DoS attack detection techniques shown in Fig. 5.19.1.

5.19.1 Signal-Based Detection

To detect the presence of attack, this signal based detection can be employed. In this methodology, at the physical or MAC layer the level of attack can be measured. This is done by a DoS attack detector, which computes the Received Signal Strength Information (RSSI). Using RSSI, the attack presence can be identified. Example wireless jamming can be detected by signal based detection.

5.19.2 Packet-Based Detection

Inorder to avoid network performance degradation, it has become mandatory to detect the attack at every level. In each layer, transmission results of all packets are measured. This leads to a significant identification of transmission failure. Thus, packet-based detection is considered as an effective detection scheme. The performance decline is measured interms of packet loss or delay during transmission.

5.19.3 Proactive Method

An algorithm is to design that attempt to identify DoS attacks at the early stage. By proactively sending probing packets to test or measure the status of potential attackers are identified.

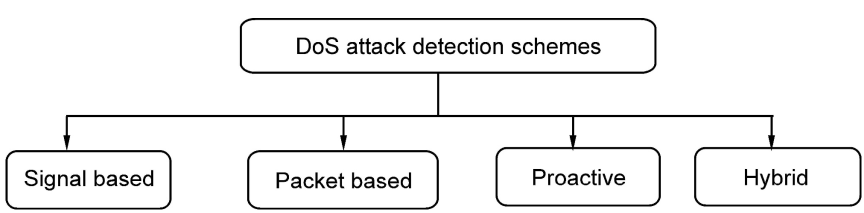

Fig. 5.19.1 : Classification of DoS attack detection schemes

5.19.4 Hybrid Method

It combines both signal based detection and pocket based detection for DoS attack identification. The DoS attack detection accuracy is high when compared with other detection schemes.

5.20 Questions with Answers

5.20.1 Short Answered Questions

Q.1 State the need for communication in smart grid.

▣ **Ans. :** In recent years, the modernization of electrical grid has been done with the support of an integrated communication infrastructure. Several communication technologies covered by various levels of standard have been developed by Standards Developing Organizations (SDOs). Inorder to ensure cost efficiency and reliability, numerous technical specifications were created by manufacturers, vendors, and service providers.

Q.2 What is meant by quality of service ?

▣ **Ans. :** It is decided by the minimum bit rate, low error rate and latency limits. The service quality is vital for various applications in a smart grid.

Q.3 List the key features of communication technologies.

▣ **Ans. :** The following are the key features of communication technologies :

- Reliability
- Security
- Scalability
- Quality of service
- Interoperability
- Low cost.

Q.4 Give the timing requirements for smart grid communication technologies.

▣ **Ans. :** Smart grid has much more stringent timing requirements for message delivery than the Internet. This is due to milliseconds delay requirement in grid. In case of trip protection messaging, only 3 ms delay constraint is provided. While in internet, nearly 100 to 150 ms delay can be provided.

Q.5 Why IP is used in smart grid communication ?

▣ **Ans. :** The Internet Protocol (IP) plays a vital role in enabling the end-to-end connectivity and interoperability of the smart grid networks. The reason for using IP in smart grid is controllability and network visibility of various sensors in the distribution system and substation automation.

Q.6 Highlight the merits of PLC in smart grid.

▣ **Ans. :** Power Line Communication (PLC) offers a cost effective solution by data transmission in the exiting electrical network. When compared to Digital Subscriber Line (DSL) and fiber optic communication technologies, PLC eliminates installation of additional wires such as twisted pair or coaxial cables to interconnect devices. Since every home appliance is connected to power line, it is easy for PLC to monitor electricity, demand response and load control.

Q.7 Mention the types of PLC.

▣ **Ans. :** PLC can be categorized into two groups namely Narrowband Power line Communication (NB-PLC) and Broadband Power line Communication (BB-PLC). The operation frequency band of NB-PLC is 3-500 kHz and it is suited for wide-area access applications of smart grid. NB-PLC offer low cost and high reliability. While, BB-PLC is operated in a high-frequency band such as 2-100 MHz.

Q.8 Write short notes on BB-PLC technologies.

▣ **Ans. :** HomePlug AV2 is the latest BB-PLC technology that offers a peak rate of more than 1 Gbps. This is attained by using advanced signal processing technologies such as Multiple Input Multiple Output (MIMO) and pre-coding. But these technologies introduce increase in system complexity, power consumption, and capital cost.

Q.9 List the merits of NB-PLC technologies.

▣ **Ans. :** To meet the requirements of long-range and outside-the-home applications NB-PLC technologies are deployed. It provides low complexity, low power consumption, and high reliability.

Q.10 What are challenges of PLC ?

▣ **Ans. :**

- Physical characteristics of the transmission medium
- Power line cables were not designed to carry communication signals
- Multipath fading

- Frequency selective fading
- Interference

Q.11 State the role of fiber optic communication in smart grid.

▣ **Ans. :** The data bandwidth for two-way communication for smart grid-related data in large cities and dense populations is high. The aggregated data bandwidth rises to several gigabytes per second in a highly populated region. The smart city deployment is another reason for preferring fiber optic communication in smart grid. The need for replacement or upgradation of the infrastructure can be avoid in optical communication because it can accommodate a very high bandwidth depending upon the application requirements.

Q.12 What are the components connected in fiber optic communication system ?

▣ **Ans. :**

- The network comprises an optical transmitter, optical amplifiers and an optical receiver
- LED or Laser diode acts as an optical transmitter, where emission of light for transmission is observed.
- For handling attenuation and distortion of transmitted signal, an optical amplifier is placed in between transmitter and receiver.
- At the receiver end, a photodiode detects the light and convert it back into the electrical signal by the photoelectric effect.

Q.13 Classify optical fibers.

▣ **Ans. :** It is classified as multimode optical fibers and single-mode optical fibers. Based on the core size, the classification of optical fibers has been done. such as application for buildings, while single-mode optical fibers are used for very long distance high bandwidth transmissions over tens or hundreds of kilometers.

Q.14 Compare multimode and single mode optical fibers.

▣ **Ans. :** In multimode optical fibers, larger core diameters, allowing several modes of various wavelengths are transmitted. The core size is typically 50-100 μm. The core diameter of a single mode fiber varies between 8 and 10.5 μm. For multimode transmitters, LED can be used for light emission in multimode transmitter, while a single mode one requires a precise laser-based transmitter. Multimode optical fibers are used for relatively short distance transmissions.

Q.15 What is WDWM ?

▣ **Ans. :** A commonly used technology that detects light dedicated to each channel is Wavelength Division Multiplexing (WDM). It uses multiplexing of parallel channels. At the transmitter end multiplexing of signals are done, while demultiplexing of signal executed at receiver end.

Q.16 What is WRAN ?

▣ **Ans. :** WLAN and WPAN technologies are currently offering long-range communication which is known as Wireless Metropolitan Area Networks (WMANs) or Wireless Regional Area Networks (WRANs).

Q.17 What is the need for HEMS ?

▣ **Ans. :** To manage the energy consumption, storage, and generation devices, Home energy management systems (HEMS) have been deployed. It includes a wide spectrum of devices, including lights, appliances, heaters, air conditioners and local generation facilities.

Q.18 What is WAN ?

▣ **Ans. :** A Wide Area Network (WAN) is a large network of information. But the network is not tied to a single location. WANs can facilitate communication, the sharing of information and much more between devices from around the world through a WAN provider. The WAN provides a two-way backbone communication link for all the smart grid applications.

Q.19 Why cloud computing is used in smart grid ?

▣ **Ans. :** Cloud Computing (CC) model is an emerging area through which the computational requirements of smart grid applications can be easily met out. Some unique features of cloud computing namely flexible resources, flexible services, parallel processing and omnipresent access are highly desirable for smart grid applications.

Q.20 Mention the benefits of cloud computing.

▣ **Ans. :**

- Supports in recovery of blackout condition in a power system
- Monitoring and scheduling functions can be performed in power system
- Reliable evaluation of the power system
- Instant information sharing aids in quick power restoration process
- Reduced system complexity
- Reduced implementation and maintenance costs.

Q.21 What are the types of cloud computing architecture ?

▣ **Ans. :** Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Data as a Service (DaaS) are the three types of cloud computing architecture.

Q.22 State the principle of cloud computing.

▣ **Ans. :** The core principle behind cloud computing is distribution of services to a large number scattered computers. The information sharing is enabled by Enterprise Data Center in CC. This information sharing is executed based on the need. It also provides access to all storage systems when needed. Using the power of CC , the requirements of smart grid can be attained easily. Real time response is important for smart grid applications for addressing immediate demand response.

Q.23 Define multi homing.

▣ **Ans. :** When a request is sent from client through cloud platform, then a response is sent to client in real time. Self healing system is highly essential in a smart gird. Such self healing process can be done by CC by providing instant response to customers. The entire communication in smart grid is attained via the Internet. Thus, there should be no internet outages to provide consistent transmission. Such continuous transmission is handled by CC through two or more IP address assignment to a client. This multi IP address assignment to client is known as multi homing.

Q.24 List the characteristics of cloud computing.

▣ **Ans. :** The characteristics of cloud computing are :

- Communication between the machine and cloud software is done via CC Application Programming Interface (API).
- Any device by a consumer that needs to access the systems can use public cloud delivery model via internet. By this an independent feature of cloud computing between device and location is observed.
- Maintenance and virtualization are properties of cloud computing.
- For running and application and performing computation, there is no need for software installation.
- Cloud computing offers and easy access to services from anywhere and at anytime.

Q.25 Specify the challenges in using cloud computing for smart grids.

▣ **Ans. :** The following are major challenges to be faced by cloud computing in smart grid applications.

- Location of data
- Mixing of data
- Inefficient cloud security policy
- Redundant data management and disaster recovery.

Q.26 Why cyber security is needed in smart grid ?

▣ **Ans. :** The intrusion of network by enemies may lead to a numerous severe consequences in smart grid. Leakage of customer information, massive blackout and destruction of infrastructures are the few consequences due to network intrusion. In communication network of smart grid, malicious threats create cyber and it is defined as cyber security threat. A smart grid is a communication network, where information exchange in power infrastructures is attained. For proper energy delivery and management, it is essential to understand objectives and requirements of cyber security.

Q.27 What is integrity ?

▣ **Ans. :** Integrity deals with safe guarding against improper information modification or destruction. Inorder to ensure information authenticity, integrity is required. A loss of integrity may lead to unauthorized modification or destruction of information. Such unauthorized directions can further induce incorrect decision regarding power management.

Q.28 How attacks are classified based on cyber security objectives ?

▣ **Ans. :**

- Attacks are classified based on smart grid security objective such as availability, integrity and confidentiality and the attacks can be categorized.
- Attacks targeting availability is known as Denial-of-Service (DoS) attacks. This attack introduces delay, block or corrupt the communication in smart grid.
- Attacks targeting integrity intentionally modify or disrupt data exchange in smart grid.
- Attacks targeting confidentiality aim to acquire unauthorized information from network resources in smart grid.

Q.29 Mention the smart grid security objectives.

▣ **Ans. :** Smart grid security objective are,

- Availability
- Integrity
- Confidentiality.

Q.30 What is Denial-of-service attacks ?

▣ **Ans. :** As a primary security goal of Smart Grid operations is availability. The investigations of attack under DoS severely degrade the communication performance. In worst case, operations of electronics devices are impaired. DoS attacks can happen at a variety of communication layers in smart grid.

Q.31 Classify attacks based on DoS.

▣ **Ans. :**

- Signal-based detection
- Packet-based detection
- Proactive method
- Hybrid method.

➥ 5.20.2 Long Answered Questions

Q.1 Discuss the communication requirements for smart grid. **[Refer section 5.2]**

Q.2 Explain the features of smart grid communication technologies. **[Refer section 5.3]**

Q.3 With a neat sketch, outline the architectural details of smart grid communication. **[Refer section 5.4]**

Q.4 Infer the need for IP in smart grid communication system. **[Refer section 5.5]**

Q.5 Outline the power line communication role in smart grid. **[Refer section 5.6]**

Q.6 Classify PLC technologies. **[Refer section 5.6]**

Q.7 Discuss the role of fiber optic communication in smart grid. **[Refer section 5.7]**

Q.8 Explain HAN and WAN. **[Refer sections 5.10 and 5.11]**

Q.9 Explain the cloud computing role in smart grid. **[Refer sections 5.12 and 5.13]**

Q.10 Outline the security issues in smart grid. **[Refer section 5.14]**

Q.11 Infer the smart grid security objectives. **[Refer section 5.15]**

Q.12 Discuss the cyber security requirements in smart grid. **[Refer section 5.16]**

Q.13 Explain the network security threat found in smart grid. **[Refer section 5.17]**

Q.14 Classify attack detection in power networks. **[Refer section 5.19]**

Q.15 Explain the various layers in Denial-of-service attacks. **[Refer section 5.18]**

5.20.3 Multiple Choice Questions

Q.1 Self-healing in smart grid can be done using __________.

[a] dampening unwanted power oscillations

[b] avoiding unwanted flows of current through the grid

[c] rerouting power flows in order to avoid overloading in a transmission line

[d] all of these

Q.2 ICT stands for _________.

[a] Information and Communication Technology

[b] Internet and Communication Technology

[c] Internet and Communication of Things

[d] Information and Communication of Things

Q.3 WAN stands for ____________.

[a] World Area Network [b] Wide Area Network

[c] Web Area Network [d] Web Access Network

Q.4 A sensor uses which network __________.

[a] LAN and HAN [b] HAN and PAN

[c] LAN and PAN [d] LAN, PAN and HAN

Q.5 Which of the following is best known service model ?

[a] SaaS [b] IaaS [c] PaaS [d] All of the mentioned

Q.6 The __________ cloud infrastructure is operated for the exclusive use of an organization.

[a] public [b] private

[c] community [d] all of the mentioned

Q.7 ___________ refers to the location and management of the cloud's infrastructure.

[a] Service [b] Deployment

[c] Application [d] None of the mentioned

Q.8 __________ computing refers to applications and services that run on a distributed network using virtualized resources.

[a] Distributed [b] Cloud [c] Soft [d] Parallel

Q.9 ______________ as a utility is a dream that dates from the beginning of the computing industry itself.

[a] Model [b] Computing [c] Software [d] All of the mentioned

Q.10 Which of the following is essential concept related to cloud ?

[a] Reliability [b] Productivity

[c] Abstraction [d] All of the mentioned

Q.11 DoS is abbreviated as ________________.

[a] Denial of Service [b] Distribution of Server

[c] Distribution of Service [d] Denial of Server

Q.12 During DoS attack, the regular traffic on the target ____________ will be either dawdling down or entirely interrupted.

[a] network [b] system [c] website [d] router

Q.13 The intent of a ______________ is to overkill the targeted server's bandwidth and other resources of the target website.

[a] Phising attack [b] DoS attack

[c] Website attack [d] MITM attack

Q.14 Which among the following features is present in IPv6 but not in IPv4 ?

[a] Fragmentation [b] Header checksum

[c] Options [d] Anycast address

Q.15 In IPv6 header, the traffic class field is similar to which field in the IPv4 header ?

[a] Fragmentation field [b] Fast switching

[c] ToS field [d] Option field

Q.16 IPv6 does not use _____________ type of address.

[a] Broadcast [b] Multicast [c] Anycast [d] Unicast

Q.17 What is the full form of WLAN ?

[a] Wide Local Area Network
[b] Wireless Local Area Network
[c] Wide Land Access Network
[d] Wireless Local Area Node

Q.18 Connection authentication is offered for ensuring that the remote host has the likely InternetProtocol ______________ and ____________.

[a] address, name
[b] address, location
[c] network, name
[d] network, location

Q.19 There are __________ different versions of IP popularly used.

[a] 2
[b] 3
[c] 4
[d] 5

Q.20 What will security provide ?

[a] Saves time and cost
[b] Product life span increases
[c] Secure long term
[d] Secure remote management

❒ Answer Keys for Multiple Choice Questions

Q.1	d	**Q.2**	a	**Q.3**	b	**Q.4**	d
Q.5	d	**Q.6**	b	**Q.7**	b	**Q.8**	b
Q.9	b	**Q.10**	c	**Q.11**	a	**Q.12**	c
Q.13	b	**Q.14**	d	**Q.15**	c	**Q.16**	a
Q.17	b	**Q.18**	a	**Q.19**	a	**Q.20**	c

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SOLVED MODEL QUESTION PAPER

(As Per New Syllabus)

Smart Grid

Semester - VIII (EEE) Professional Elective-VI

Time : Three Hours] **[Maximum Marks : 100**

Answer All Questions

PART - A **(10 × 2 = 20 Marks)**

Q.1 *Compare traditional grid with smart grid.*

Ans. :

Traditional grid	Smart grid
One-way communication	Two-way communication
Centralized generation	Distributed generation
Hierarchical structure	Network type structure
Low level of automation	High level of automation
High losses	Losses are minimized
Low efficiency and reliability	High efficiency and reliability
Low customer satisfaction	High customer satisfaction

Q.2 *State the need of improving smart grid awareness.*

Ans. : In many developing countries, a major obstruction in deployment of new technologies is lack of awareness among users. End users have only a minimal knowledge on the way power to them. With a deployment of new technology, it has become mandatory to educate end users regarding benefits of smart grid. Consumers should be made aware about their energy consumption pattern at home, office etc. utilities need to focus on the overall capabilities of smart grids rather than mere implementation of smart meters. Policy makers and regulators must be very clear about the future prospects of smart grids.

Q.3 *Outline the objectives of smart substation.*

Ans. : The following are the objectives of smart substation,

- The real time testing of intelligent distribution with highest reliability and control this will drive the underlying grid.

- Ensuring automatic energy saving concepts and systems for the satisfaction and convenience of consumers.
- Providing a reasonable, reliable and affordable electricity supply to consumers.

Q.4 *List out the advantages of WAMPAC.*

Ans. : The following are the advantages of WAMPAC :

1. Reliability, stability and security is maintained against large disturbances.
2. Large numbers of intermittent generating sources like solar, wind, etc., are managed properly.
3. Power quality is maintained to better level.
4. Transmission efficiency is increased.

Q.5 *Give few applications of PMUs.*

Ans. : The following are the applications of PMUs in transmission systems.

- Wide area situational awareness and monitoring.
- Voltage stability and monitoring.
- Oscillation monitoring and detection.
- State estimation.
- Fault location identification and protective relaying.

Q.6 *Define authorization.*

Ans. : Authorization is a term that enables right to access specific resources and applications of a device by consumers. The authorization assigns privilege to users and thus intentional attacks targeting system security is avoided.

Q.7 *Is it mandatory to perform harmonic study in an electrical network ? Justify your answer.*

Ans. : Yes, it is mandatory to perform harmonic analysis in an electrical network. To maintain the equipment under acceptable operating conditions, it has become mandatory to perform harmonic studies on the electrical networks and equipment. This will help to anticipate potential problems with the installation or addition of nonlinear loads.

Q.8 *Define THD.*

Ans. : THD stands for Total Harmonic Distortion.

This total harmonic distortion is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. The measures the harmonics present in all signals. At the output of a device under specified condition, the measurement of THD is been made and is usually expressed in percent or in dB relative to the fundamental as distortion attenuation.

Q.9 *What is the need for HEMS ?*

Ans. : To manage the energy consumption, storage and generation devices, Home Energy Management Systems (HEMS) have been deployed. It includes a wide spectrum of devices, including lights, appliances, heaters, air conditioners and local generation facilities.

Q.10 *Why cloud computing is used in smart grid ?*

Ans. : Cloud Computing (CC) model is an emerging area through which the computational requirements of smart grid applications can be easily met out. Some unique features of cloud computing namely flexible resources, flexible services, parallel processing and omnipresent access are highly desirable for smart grid applications.

PART - B **(5 × 13 = 65 Marks)**

Q.11 a) *i) Summarize the smart driver role in India.* **(Refer sections 1.5 and 1.5.1)** **[6]**

ii) Explain renewable energy integration into smart grid.

(Refer sections 1.2.5, 1.2.6 and 1.3.4) **[7]**

OR

b) *Discuss the role of automation in smart grid implementation.*

(Refer sections 1.4.4, 1.4.5, 1.4.7 to 1.4.10) **[13]**

Q.12 a) *i) Explain about phase shifting transformers in detail.* **(Refer section 2.16)** **[7]**

ii) Illustrate energy management systems with neat diagram. **(Refer section 2.7)** **[6]**

OR

b) *With neat diagram discuss about distribution system topologies.*

(Refer sections 2.10, 2.10.1, 2.10.2, 2.10.3, 2.10.4, 2.10.5 and 2.10.6) **[13]**

Q.13 a) *i) Summarize the role of communication architecture in smart metering infrastructure.* **(Refer section 3.6)** **[7]**

ii) List out the AMI standards and explain it. **(Refer section 3.8.2)** **[6]**

OR

b) *Explain the importance of smart monitoring systems in a grid.* **(Refer section 3.11)** **[13]**

Q.14 a) *i) Interpret the power quality standards in smart grid.* **(Refer section 4.13)** **[6]**

ii) List the selection criteria for power quality monitoring. **(Refer section 4.13.2)** **[7]**

OR

b) *Summarize the various types of power quality monitoring.*
(Refer sections 4.16.3 and 4.16.5) **[13]**

Q.15 a) *i) Discuss the cyber security requirements in smart grid.* **(Refer section 5.16)** **[6]**
ii) Explain the network security threat found in smart grid. **(Refer section 5.17)** **[7]**

OR

b) *i) Classify attack detection in power networks.* **(Refer section 5.19)** **[7]**
ii) Explain the various layers in Denial-of-service attacks. **(Refer section 5.18)** **[6]**

PART - C **(1 × 15 = 15 Marks)**

Q.16 a) *i) Discuss in detail about volt/VAR Control (VVC).* **(Refer section 2.12)** **[7]**
ii) Illustrate fault detection identification and restoration in detail.
(Refer section 2.13) **[8]**

OR

b) *i) Discuss the role of IEDs in a smart grid.* **(Refer section 3.10)** **[7]**
ii) Explain the smart meter hardware architecture. **(Refer section 3.7)** **[8]**

MULTIPLE CHOICE BASED SOLVED MODEL QUESTION PAPER

(As Per New Syllabus)

Smart Grid

Semester - VIII (EEE) Professional Elective - VI

Time : 1 Hour] **[Maximum Marks : 60**

Answer All Questions

PART - A **(30 × 1 = 30 Marks)**

Q.1 *In a traditional grid which of the below mentioned is/are true ?*

a One-way communication
b Centralized Generation
c Hierarchical Structure
d All the above

[Ans. : d]

Q.2 ____________________ *is the benefit of smart grid.*

a Information hacking
b Delivers low efficiency
c Increasing carbon emissions
d Improving power quality

[Ans. : d]

Q.3 *Real time monitoring can be done in ______________.*

a Traditional grid
b Smart grid
c Both a & b
d None of the above

[Ans. : b]

Q.4 *Mark the functions of smart grid.*

a Improved fault protection
b Diagnosis and notification of equipment condition
c Wide Area Monitoring, Visualization, & Control
d All of the mentioned

[Ans. : d]

Q.5 *Self-Healing of grid is defined as ____________ .*

a response to routine problems
b automatic detection of faults
c Both a & b
d smoothening of power quality

[Ans. : c]

Q.6 *India's aggregate technical and commercial losses are __________ .*

a 25-30%
b 35-40%
c 15-20%
d 10-25%

[Ans. : a]

Q.7 *Power grid has demonstrated the smart grid technology capabilities in collaboration with various solution providers at __________ .*

a Bengaluru
b Mysore
c Puducherry
d New Delhi

[Ans. : c]

Q.8 *The two basic types of electric vehicles are __________ .*

a PHEVs & BEVs
b AEVs & PHEVs
c FCEVs &BEVs
d AEVs & FCEVs

[Ans. : b]

Q.9 *In addition to charging from the electrical grid, EVs are charged in part by ______ .*

a Hydraulic braking
b Electromagnetic braking
c Regenerative braking
d Mechanical braking

[Ans. : c]

Q.10 __________ *are electronic devices which are used to store extremely large amounts of electrical charge.*

a Electrolytic capacitors
b Variable capacitors
c Super capacitors
d Film capacitors

[Ans. : c]

Q.11 *OMS means ___________ .*

[a] Overall Maintenance System
[b] Overall Management System
[c] Outage Management System
[d] Outage Maintenance System

[Ans. : c]

Q.12 *The function of WACS :*

[a] Power flow control
[b] Reactive power control
[c] Wide area damping control
[d] All of the above

[Ans. : d]

Q.13 *Opportunities of smart grid ___________ .*

[a] cyber Security in future
[b] optimal Power Flow
[c] defence Model
[d] all the above

[Ans. : d]

Q.14 *AMI means ___________ .*

[a] Automated Metering Instrument
[b] Alternate Metering Instrument
[c] Advanced Metering Infrastructure
[d] Advanced Metering Instrument

[Ans. : c]

Q.15 *Web-enabled residential smart meter use web principles to interconnect ________ .*

[a] home electrical appliances to smart micro grid
[b] smart micro grid to utilities
[c] utilities to home electrical appliances
[d] smart micro grid to distribution system

[Ans. : a]

Q.16 *"A device that produces synchronized measurements of phasor, frequency, ROCOF from voltage and/or current signals based on a common time source that typically is the one provided by the GPS" ___________ .*

[a] RTU
[b] IED
[c] RMU
[d] PMU

[Ans. : d]

Q.17 *If the meter is stopped or tampered, the event is recorded. Such event is called as ___________ .*

[a] Interrupted event
[b] Cut-off event
[c] Tamper event
[d] Stopped event

[Ans. : c]

Q.18 *The data retrieval from smart meters and decision making should be as quick as possible by using which software ?*

a ETAP b EMS
c SCADA d PWA

[Ans. : b]

Q.19 *___________ is a meter with a waveform display screen, voltage leads, and current probes.*

a Voltmeter b Ammeter
c Harmonic analyzer d DMM

[Ans. : c]

Q.20 *The main mitigation equipments is________ .*

a UPS b Storage device
c voltage source converter d All the above

[Ans. : d]

Q.21 *Transients are difficult to detect because of their ___________ .*

a amplitude variation b frequncy variation
c short duration d long duration

[Ans. : c]

Q.22 *Which of the following can not be considered as transient ?*

a spikes b power pulses
c surges d interruption

[Ans. : d]

Q.23 *The selection criteria for power quality monitoring ___________ .*

a proper selection of monitoring equipment
b method of data collection
c financial damages caused by PQ events either in critical or sensitive equipment
d All of these

[Ans. : d]

Q.24 *The UPQC classified into________ types.*

a 2 b 3 c 4 d 5

[Ans. : a]

Q.25 *ICT stands for ________.*

a Information and Communication Technology
b Internet and Communication Technology
c Internet and Communication of Things
d Information and Communication of Things

[Ans. : a]

Q.26 *A sensor uses which network ________.*

a LAN and HAN
b HAN and PAN
c LAN and PAN
d LAN, PAN and HAN

[Ans. : d]

Q.27 *Which of the following is best known service model?*

a SaaS
b IaaS
c PaaS
d All of the mentioned

[Ans. : d]

Q.28 ____________ *as a utility is a dream that dates from the beginning of the computing industry itself.*

a Model
b Computing
c Software
d All of the mentioned

[Ans. : b]

Q.29 *DoS is abbreviated as ______________.*

a Denial of Service
b Distribution of Server
c Distribution of Service
d Denial of Server

[Ans. : a]

Q.30 *Which among the following features is present in IPv6 but not in IPv4?*

a Fragmentation
b Header checksum
c Options
d Anycast address

[Ans. : d]

PART B **(15 × 2 = 30 Marks)**

Q.31 *Mark the functions of smart grid.*

a Improved fault protection
b Diagnosis and notification of equipment condition
c Wide Area Monitoring, Visualization, & Control
d All of the mentioned

[Ans. : d]

Q.32 *Power theft happens due to_________________ .*

a Hooking lines
b Insulated overhead lines
c Replacement of LT overhead wires with insulated cables
d Smart meter

[Ans. : a]

Q.33 *The smart grid co-ordinates needs of ________________ for ensuring an effective operation.*

a generators
b grid operators and end-users
c electricity market stakeholders
d all the mentioned

[Ans. : d]

Q.34 *From insulation point of view, many lines are designed very conservatively. It is often possible to increase normal operating voltage by 10 % or even higher __________ .*

a thermal limit
b dielectric limit
c stability limit
d insulator limit

[Ans. : b]

Q.35 *Smart substation enables a significant reduction in harmonic voltages and resonances, as well as a reduction of peak load by ______.*

a 30%
b 25%
c 20%
d 35%

[Ans. : a]

Q.36 __________ *are electronic devices which are used to store extremely large amounts of electrical charge.*

a Electrolytic capacitors
b Variable capacitors
c Super capacitors
d Film capacitors

[Ans. : c]

Q.37 *In smart grids, PMU stands for :*

a Phase measurement unit
b Phasor measurement unit
c Phase monitoring unit
d All of these

[Ans. : b]

Q.38 *Which of the following systems consist of IEDs and the communication networks for performing control, protection and monitoring tasks ?*

a Substation Automation System
b Statistical Analysis System
c Substation Analytical System
d Statistical Automation System

[Ans. : a]

Q.39 *Second quadrant of Four quadrant meteris named as ___________ .*

a Export Lag
b Export Lead
c Import Lag
d Import Lead

[Ans. : b]

Q.40 *___________ for a short time during peak demand can reduce the need for establishment of new power generation plants.*

a Load Acquiring
b Load Balancing
c Load Shedding
d Load Distributing

[Ans. : c]

Q.41 *______________ are advanced data acquisition devices for capturing, storing, and presenting short-duration, subcycle power system disturbances.*

a Harmonic analyzer
b Transient-disturbance analyzers
c Oscilloscope
d Data loggers and chart recorders

[Ans. : b]

Q.42 *Most of the power quality problems are related to ______.*

a Transmission Issue
b Grounding Issue
c Distribution Issue
d all of the above

[Ans. : b]

Q.43 *_________ computing refers to applications and services that run on a distributed network using virtualized resources.*

a Distributed
b Cloud
c Soft
d Parallel

[Ans. : b]

Q.44 *_____________ as a utility is a dream that dates from the beginning of the computing industry itself.*

a Model
b Computing
c Software
d All of the mentioned

[Ans. : b]

Q.45 *In IPv6 header, the traffic class field is similar to which field in the IPv4 header?*

a Fragmentation field
b Fast switching
c ToS field
d Option field

[Ans. : c]

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Notes

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