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SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - I

Smart Grid – SEEA3006

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, Concept of Resilient & Self-Healing Grid, Present development & International policies in Smart Grid, Diverse Prospective from experts and global Smart Grid initiatives

1.1 Evolution of Electric Grid

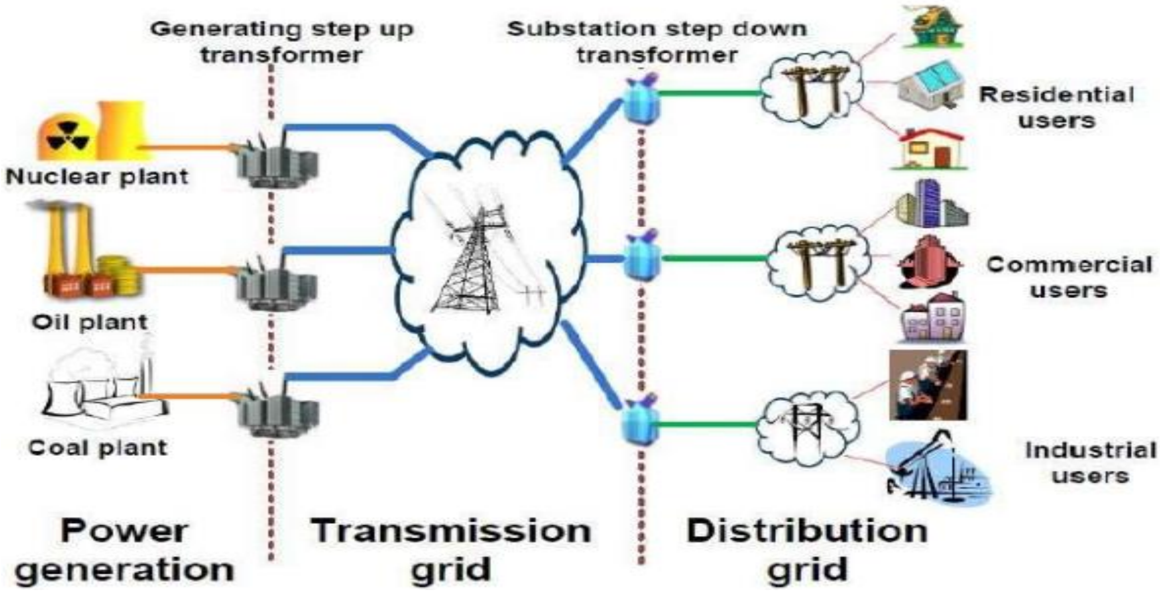

Figure 1.1 Existing Electric Grid.

1.2 Disadvantages of Existing Electric Grid

1. Over strained and interregional bulk power transfer is limited
2. Cannot fully support the integration of renewable energy
3. Low reliability of power and outages
4. Fluctuating Power quality

5. Lack of Consumer Discipline
6. Increasing levels of Green house gases
7. Almost Zero Customer Participation
8. Low billing and collection
9. Less Efficiency

1.3 Concept, Definitions and Need for Smart Grid

A Smart Grid is an electricity Network based on Digital Technology that is used to supply electricity to consumers via Two-Way Digital Communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce the energy consumption and cost and maximise the transparency and reliability of the energy supply chain.

The term "Smart Grid" was coined by Andres E. Carvallo on April 24, 2007 at an IDC energy conference in Chicago.

Definition: Smart grid is integration of an electric power system, communication network, advanced Sensing, metering, measurement infrastructure, complete decision support and human interfaces software and hardware to monitor, control and manage the creation, distribution, storage and consumption of energy.

The areas of application of smart grids include: smart meters integration, demand management, smart integration of generated energy, administration of storage and renewable resources, using systems that continuously provide and use data from an energy network.

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.

- System (Generation, Transmission, Distribution) with an advanced two- way communications system
- Enables real-time monitoring and control
- Provide greater visibility and transparency
- Consequently, enables cost reduction and efficiency improvement

Smart Grid is based on Digital Technology that is used to supply electricity to consumers via Two-Way Digital Communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce the energy consumption and cost and maximise the transparency and reliability of the energy supply chain.

The flow of electricity from utility to consumer becomes a two-way conversation, saving consumers money, energy, delivering more transparency in terms of end-user use, and reducing carbon emissions.

A smart grid distribution system, whose objective is to develop a power grid more efficient and reliable, improving safety and quality of supply in accordance with the requirements of the digital age.

- ✓ Higher Penetration of renewable resources or distributed generation
- ✓ Extensive and effective communication overlay from generation to consumers
- ✓ Use of advanced sensors and high speed control
- ✓ Higher operating efficiency.
- ✓ Greater resiliency against attacks and natural disasters
- ✓ Automated metering and rapid power restoration
- ✓ Provided greater customer participation

Presently the Indian Electricity System faces a number of challenges such as:

- ✓ Shortage of power
- ✓ Power Theft
- ✓ Poor access to electricity in Rural areas
- ✓ Huge losses in the Grid
- ✓ Inefficient Power Consumption
- ✓ Poor reliability

To overcome these problems; smart grid is needed.

1.4 Smart grid drivers & functions

- ❖ **Increasing demand**: Information and communications technology, Measurement and control Demand response, Advanced metering infrastructure (AMI)
- ❖ **High Aggregate Technical &Non-Technical, Losses**:18%-62%
- ❖ **Ageing Assets**: Transformers, Feeders etc.,
- ❖ **Grid to carry more power**: Need for, Reliability and greater Security
- ❖ **Billing and collections**: Profitability of distribution companies
- ❖ **Energy mix**: Need for Renewable Energy [Hydro Power, Solar Thermal Energy, Wind, Biomass, Biogas] to reduce carbon footprint

- ❖ **Deliver sustainable energy**: Voltage & VAR control, Resource planning, analysis, and forecasting tools, Fault Detection, Identification, and Restoration (FDIR)
- ❖ **Increased efficiency**: Direct load control, Distributed energy resources, Distributed energy resources integration, Energy storage, Advanced metering infrastructure (AMI)
- ❖ **Empower consumers**: Consumer education and awareness, Residential consumer energy management, Information and communications technology
- ❖ **Improve reliability**: System wide monitoring, Measurement and control, Distributed energy resources, Distributed energy resources integration, Energy storage, Advanced metering infrastructure (AMI)

1.5 Challenges of Smart Grid

- ✓ Policy and regulation
- ✓ Ageing and outdated Infrastructure
- ✓ Lack of integrated communication platform
- ✓ High Capital and operating costs
- ✓ Big Data Handling
- ✓ Compatibility of older equipment
- ✓ Lack of standards for interoperability
- ✓ Smart Grid Cybersecurity
- ✓ Lack of Smart consumers

Technology	Challenges	Obligations
Self-Healing Action	Security	Exposed to internet attacks (Spasm, Worms,virus etc.), question of National security
	Reliability	Failure during natural calamities, system outagesand total blackout
Renewable Energy Integration	Wind/Solar Generation	Long-term and un-predictable intermittent sources of energy, unscheduled power flow and dispatch
	Power Flow Optimization	Transmission line congestions and huge investments
	Power System Stability	Decoupling causes system stability issues causes reduced inertia due to high level of windpenetration

Energy Storage Systems	Cost	Expensive energy storage systems like Ultra-capacitors, SMES, CAES etc.
	Complexity	Complex customary design module and networks
	Non-Flexibility	Unique designs for all individual networks notease adaptation.
Consumers Motivation	Security	Malware, data intercepting, data corruption,Illegal power handling and Smuggling
	Privacy	Sharing of data cause privacy invasion, etc.,
	Consumer awareness	Corruption and system threats like security andprivacy issues
Reliability	Grid Automation	Need of strong data routing system, with secure and private network for reliable protection, control and communication
	Grid Reconfiguration	Generation demand equilibrium and power systemstability with grid complexity
Power Quality	Disturbance Identification	Grid disturbances due to local faults in grids, loadcentres or sources
	Harmonics Suppression	System instability during sags, dips or voltage variation such as over-voltages, under-voltages,voltage flickers, etc.

1.6 Benefits of Smart Grid

- Self-Healing :A smart grid automatically detects and responds to routineproblems and quickly recovers if they occur, minimizing downtime and financial loss.
- Resists Attack: A smart grid has security built in from the ground up.
- Motivates and Includes the Consumer: A smart grid gives all consumers industrial, commercial, and residential-visibility in to real-time pricing, and affords them the opportunity to choose the volume of consumption and price that best suits their needs.
- Reduction in AT & C losses
- Reduction in CO_2 Emission
- Enabling Energy Audit

- Reduction in Cost Billing
- Remote Load Control
- Shifting of Peak requirement to non-peak time [Peak Shaving]
- Integration of Renewable Energy
- Clean Energy Development.
- Provides Power Quality
- Optimizes Assets and Operates Efficiently
- Safety, Reliable and Efficient
- Improved National Security
- Improved Environmental Conditions
- Improved Economic Growth

1.7 Difference between conventional & Smart Grid,

Sl.No.	Smart Grid	Conventional Grid
1.	Self-Healing	Manual Restoration
2.	Digital	Electromechanical
3.	Pervasive Control	Limited Control
4.	Two-Way Communication	One-Way Communication
5.	Distributed Generation	Centralized Generation
6.	Network	Hierarchical
7.	Adaptive and Islanding	Failures and Blackouts
8.	Sensors Throughout	Few Sensors
9.	Remote Check/Test	Manual Check/Test
10.	Self-Monitoring	Blind
11.	Many Customer Choices	Few Customer Choices
12.	Extensive real time monitoring	Lack of real time monitoring
13.	Extremely quick reaction time	Slow Reaction time
14.	Energy Storage	No energy Storage
15.	Increased customer participation	Total control by Utility

1.8 Concept of Resilient

The capability of a strained body to recover its size and shape after deformation caused especially by compressive stress

An ability to recover from or adjust easily to misfortune or change

Resilience is the property of a material to absorb energy when it is deformed elastically and then, upon unloading to have this energy recovered. In other words, it is the maximum energy per volume that can be elastically stored. It is represented by the area under the curve in the elastic region in the Stress-Strain diagram.

A resilient electric grid begins with

- a system that is designed and built to withstand high winds, powerful storms,
- cybersecurity threats and
- other disruptions that could result in outages

1.9 Concept of Self-Healing Grid

- A self-healing grid is expected to respond to threats, material failures, and other destabilizing influences by preventing or containing the spread of disturbances. This requires the following capabilities:
- Timely recognition of impending problems
- Redeployment of resources to minimize adverse impacts
- A fast and coordinated response to evolving disturbances
- Minimization of loss of service under any circumstances
- Minimization of time to reconfigure and restore service

A smart grid automatically detects and responds to routine problems and quickly recover if they occur, minimizing downtime and financial loss.

Self-healing concept important to the Energy Infrastructure

A secure ―architected sensing, communications, automation (control), and energy overlaid infrastructure as an integrated, reconfigurable, and electronically controlled system that will offer unprecedented flexibility and functionality, and improve system availability, security, quality, resilience and robustness.

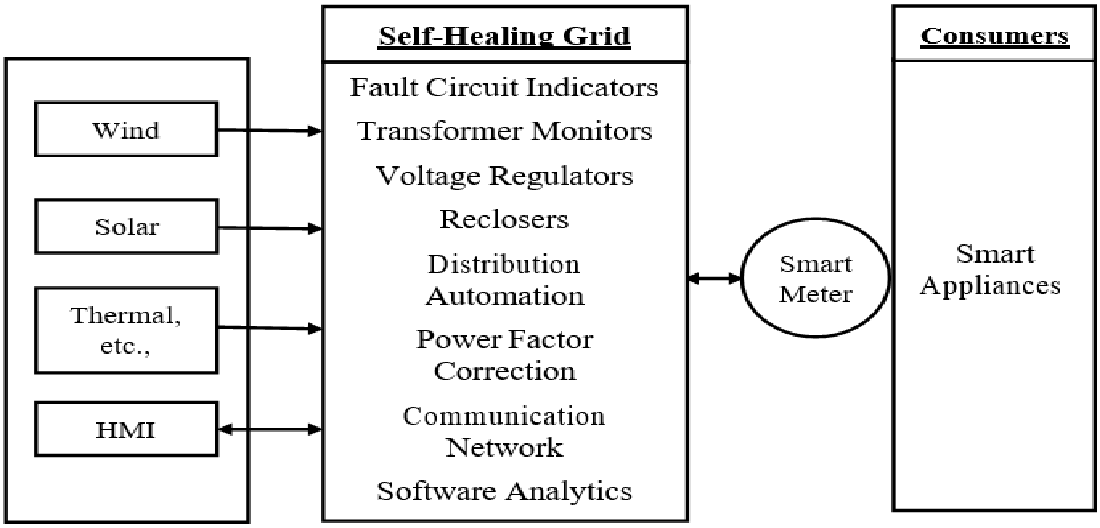

Figure 1.2 Block Diagram for Self-Healing Grid

The Self-Healing Grid is a system comprised of sensors, automated controls, and advanced software that utilizes real-time distribution data to detect and isolate faults and to reconfigure the distribution network to minimize the customers impacted.

One of the main goals of a Self-Healing Grid is to improve system reliability.

This can be accomplished by reconfiguring the switches and reclosers installed on the distribution feeder to quickly isolate the faulted section of the feeder and re-establish service to as many customers as possible from alternate sources/feeders.

1.10 International policies in Smart Grid

1.10.1 Smart grids policies For USA

The Energy Policy Act of 2005 is the first federal law that specifically promotes the development of smart meters. It directs utility regulators to consider time-based pricing and other forms of demand response for their states. Utilities are required to provide each customer a time-based rate schedule and a time-based meter upon customer request.

The 2007 Energy Independence and Security Act (EISA) lays out a national policy for the Smart Grid in the U.S.

- The Act assigned NIST the primary responsibility to coordinate development of standards for the Smart Grid

    - NIST is also supporting future FERC and State PUC rulemaking to adopt Smart Grid standards

- Key Federal policy recommendations:
    - Enable cost-effective smart grid investments
    - Unlock innovation
    - Empower and inform consumers
    - Secure the grid

The National Institute of Standards and Technology (NIST), a major standards

developing federal agency, is directed to develop a smart-grid interoperability framework that provides protocols and standards for smart-grid technologies.

EISA established a federal smart-grid investment matching grant program to reimburse 20% of qualifying smart-grid investments.

The next important legislative effort is the

American Recovery and Reinvestment Act of 2009. It accelerates the development of smart-grid technologies by appropriating $4.5 billion for electricity delivery and energy reliability modernization efforts. Utilities and other investors can apply stimulus grants

to pay up to 50% of the qualifying smart-grid investments. To date, the Smart Grid Investment Grant authorized under this Act has 99 recipients, with a total public investment of $3.5 billion

1.10.2 Smart grids policies For UK

To modernize and reduce the carbon footprint of electric grids, one major initiative of the United Kingdom is to encourage energy efficiency through smart-meter deployment.

The British government expects full penetration of smart meters by 2020, with a total financial investment of £8.6 billion ($13.5 billion) and total benefits of £14.6 billion ($22.9 billion) over the next 20 years

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[3] Vehbi C. Güngör,DilanSahin, TaskinKocak, SalihErgüt, Concettina Buccella, Carlo Cecati, and GerhardP. Hancke, “Smart Grid Technologies: Communication Technologies and Standards”, IEEE Transactions On Industrial Informatics, Vol. 7, No. 4, November 2011.

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S. No.	Question	Course Outcomes (Level)
	UNIT – I **Part – A**	
1.	Interpret the term smart grid.	**CO1(2)**
2.	List out the Benefits of Smart Grid.	**CO1(4)**
3.	Examine the Need of Smart Grid in Power system.	**CO1(4)**
4.	List out the Challenges of Smart Grid.	**CO1(4)**
5.	List out the applications of Smart Grid.	**CO1(4)**
6.	Classify the different types Smart Grid Drivers.	**CO1(4)**
7.	Explain the concept of self- Healing Grid.	**CO1(5)**
8.	Interpret the term Resilient.	**CO1(2)**
9.	List out the opportunities of Smart Grid.	**CO1(4)**
10.	Compare the difference between Conventional Grid and Smart Grid	**CO1(5)**

	Part – B	
1.	Explain the concept of smart Grid in the power system network.	**CO1(5)**
2.	Compare the difference between Conventional Grid and Smart Grid	**CO1(5)**
3.	Discuss the opportunities of smart grid in power system network	**CO1(6)**
4.	Analyze the Challenges of Smart Grid in a power system network	**CO1(4)**
5.	Briefly explain the concept of Resilient & Self-Healing Grid	**CO1(4)**
6.	Explain the International policies in Smart Grid.	**CO1(5)**

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UNIT - II

Smart Grid – SEEA3006

II. Introduction to Smart Grid

Components and Architecture of Smart Grid Design –Review of the proposed architectures for Smart Grid. The fundamental components of Smart Grid designs – Transmission Automation – Distribution Automation –Renewable Integration

2.1 Components and Architecture of Smart Grid Design

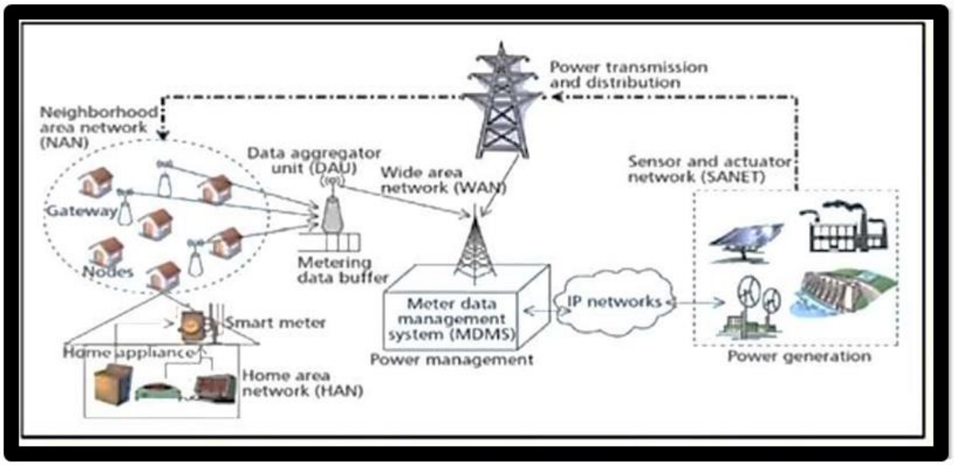


Figure 2.1 Block Diagram for Smart Grid Architecture.

Figure 2.2 Components of Smart Grid Architecture

2.1.1 Smart Home

Smart home uses emerging smart grid technologies to save energy, seek out the lowest rates, and contribute to the smooth and efficient functioning of our electric grid

The interactive relations hip between the grid operators, utilities, and consumers helps in proper functioning of smart grid technologies

Computerized controls in smart homes helps to minimize energy use at times when the power grid is under stress from high demand ,or even to shift some of their power use to times when power is available at a lower cost, Le.,from on- peak hours to off-peak hours

Smart home depends on -

- Smart meters a1nd home energy management systems
- Smart a ppl ian Ce$
- Home power generation

Smart Meters

- Provide the Smart Grid interface between consumer and the energy service provider
- Operate digitally
- Allow for automated and complex transfers of information between consumer -end and the energy service provider
- Help to reduce the energy costs of the consumers
- Provides information about usage of electricity in different service areas to the energy service providers

Home energy management systems

- Allows consumers to track energy usage In detail to better save energy
- Allows consumers to monitor real-time Information and price signals from the energy service provider
- Allows to create settings to automatically use power when prices are lowest
- Avoids peak demand rates
- Helps to balance the energy load In different area
- Prevents blackouts
- In return, the service provider also may choose to provide financial incentives

2.1.2 Renewable Energy

According to the International Energy Agency -

"Renewable energy Is derived from natural processes that are replenished constantly.

In Its various forms, It derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources."

Reduced environmental pollution

Consumers capable of generating energy from renewable energy resources are less dependent on the micro-grid or main grid

In addition to that,they can supply surplus amount of energy from the renewable resources and can make profit out of it

2.1.3 Consumer Engagement

Consumers can -

Save energy w it h proper scheduling of sma rt home appliances

Pay less for consuming energy in off-peak hours

Energy service provider gives incentives based on t he energy consumption of the consumer and they can save money

Consumers' involveme nt in following ways:

Time-of-Use pricing

Net metering

In Time-of-Use pricing

The consumers are encouraged to consume energy in off-peak hours when the energy load is less

Throughout the day,the energy load on the grids are dynamic

In on-peak hours, if the requested amount of energy is higher,it leads to -

Less-efficient energy distribution

Home energy management system tries to schedule the smart appliances in off- peak hours

2.1.4 Operation Centres

Drawbacks of traditional operation centers

- ✓ Tries to make sure the amount of generated energy Is getting used

- ✓ The grid is unstable,if the grid voltage drops due to excess energy generation
- ✓ Limited control capabilities
- ✓ No means to detect oscillation which leads to blackout
- ✓ Limited information about the energy flow through the grid

Smart grid

- ✓ Provides information and control on the transmission system
- ✓ Makes the energy grid more reliable
- ✓ Minimize the possibility of widespread blackouts
    - ✓ For monitoring and controlling the transmission System in smart grid, phasor measurement unit (PMU) is used
    - ✓ PMU samples voltage and current with a fixed sample rate at the installed location
    - ✓ It provides a snapshot of the active power system at that location
    - ✓ By increasing the sampling rate, PMU provides the dynamic scenario of the energy distribution system
    - ✓ PMU helps to identify the possibility of blackout in advance
    - ✓ Multiple PMUs form a phasor network
    - ✓ Collected information by the phasor network is analyzed at centralized system, i.e.,Superviso ry Control And Data Acquisition (SCADA) system

Self-healing of grid

- ✓ Dampen unwanted power oscillations
- ✓ Avoid unwanted flows of current through the grid
- ✓ Reroute power flows in order to avoid overloading in a transmission line
- ✓ This is part of distribution intelligence

2.1.5 Distribution Intelligence

Distribution intelligence means the energy distribution sys tems equipped with smart loT devices

- ✓ Along with smart meters,distribution intelligence can -
- ✓ Identify the source of a power outage
- ✓ Ensure power flow automatically by combining automated switching
- ✓ Optimize the balance between realand reactive power

Reactive power:

- ✓ Devices that store and release energy
- ✓ Cause increased electrical currents without consuming real power

Intelligent distribution System

- ✓ Maintains the proper level of reactive power in the System
- ✓ Protect and control the feeder lines

2.1.6 Plug in Hybrid Electric Vehicles (PHEV)

Plug-In Hybrid Electric vehicles (PHEVs) are being introduced in the marketas an option for transportation. The introduction of HEVs into the transportation sector can be viewed as a good start, but the range (the distance that can be travelled with one charging cycle) is not adequate. So PHEVs have started penetrating the market, in which the batteries can be charged at any point where a charging outlet is available. For HEVs, the impact on the grid is not a matter of concern, since HEVs are charged from their internal combustion engine by regenerative braking, whenever the driver applies a brake.

As a resultbatteries in HEVs maintain a certain amount charge (70–80%). In the case of PHEVs the car batteries are used steadily while driving in order to maximize fuel efficiency and the battery charge decreases over time. The vehicle thus needs to be connected to the power grid to charge its batteries when the vehicle is not in use. During its charging time, the plug-in vehicle more than doubles the average household load [1]. Hence, for PHEVs, a major concern is the impact on the grid, since they can be plugged in for charging at any point in thedistribution network regardless of time. PHEVs will be posed as a new load on the primary and secondary distribution network, where many of these circuits are already being operated at their maximum capacity.

With the increase in the number of PHEVs, the additional load has the potential to disrupt the grid stability and significantly affect the power system dynamics as a whole. The following sections will discuss the various approaches that have been proposed in order to face the problem of overloading the grid. There has been movement in the recent years to modernize the aging US power grid and the concept of smart grid has been introduced as the power grid of the future which will be reliable, providing dependable power at competitive prices and offer means for swift correction.

2.2 Smart Grid Communication

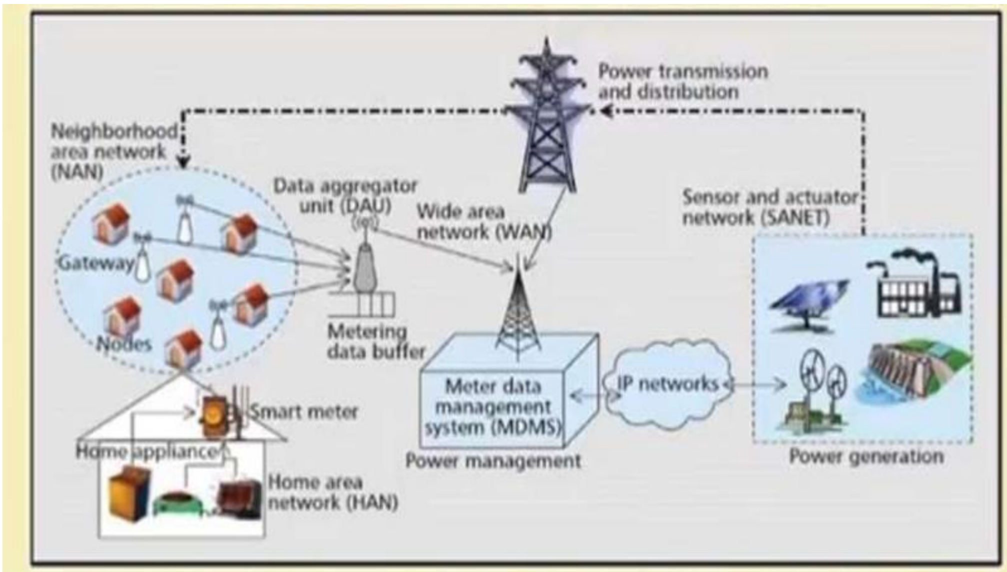


Figure 2.3 Block Diagram for Smart Grid Communication

PAN (Personal Area Network): The network that connects devices in an an individual workspace. Think of your PC talking to your smart phone and your blueray player.This is rarely used when we're talking about smart grid.

HAN (Home Area Network):The network that allov-.rs devices located within a home to communicate with each other. In the smart grid context,these devices could include smart meters, smart appliances,and home energy management devices.

NAN (Neighborhood Area Network) and **LAN** (Local Area Network).The network that allm.vs devices in a small area,such as a neighborhood, to communicate with each other_ For example, all the smart meters in a neighborhood may communicate with each other and with with a router to form an interconnected mesh of smart devices.

2.3 Smart Grid Technologies

Transmission Automation

1. Dynamic Line rating
2. High Temperature Low sag conductors
3. HVDC and FACTS
4. Wide Area Monitoring Systems (WAMS)
5. Renewable Energy Management System

Distribution Automation

1. Smart metering and Advanced Metering Infrastructure (AMI)
2. Demand Response Programs/ Demand side management
3. Peak load management
4. Power Quality Management

2.4 Advanced Automation Capabilities

Beside SCADA data, advanced Logical applications can be grouped and classified based on voltage level example:

- Generation, Transmission and Feeder Bay automation.
- Distribution Automation Applications.
- Alternating Current Monitoring
- Communication Monitoring
- Data logging, I Storage or Historian applications
- Data Reduction and Summarizing
- Data Conversion

Other non-common logic can be achieved using programmable logic applications or PLC's in the substation.

2.5 Transmission Automation

FACTS – Flexible AC Transmission System
HVDC – High Voltage DC Machine

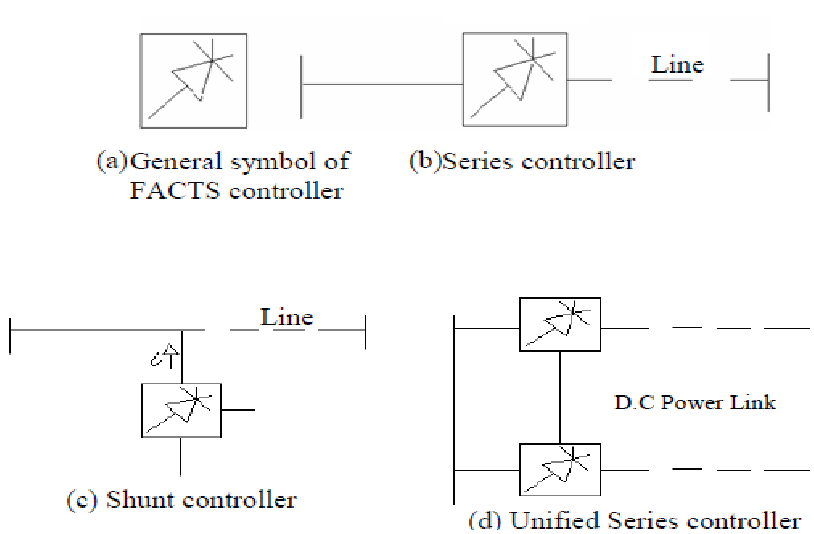
2.5.1 **Flexible** AC Transmission System

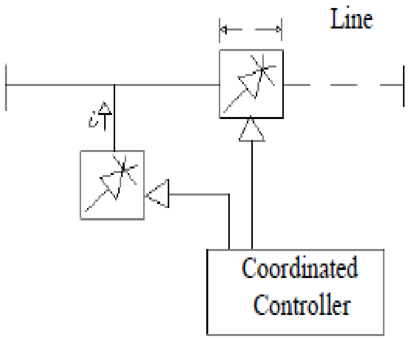
FACTS is a new integrated concept based on power electronic-Switching converters and dynamic controllers to enhance the system utilization controllability and increase power transfer capability as well as the stability, security, reliability and power quality of AC system interconnections.

2.5.2 Classification of FACTS controller

In general FACTS controllers can be classified into four categories.

- Series controllers - TCSC , SSSC
- Shunt controllers – SVC ,STATCOM
- Combined series-series controllers - IPFC
- Combined series-shunt controllers - UPFC





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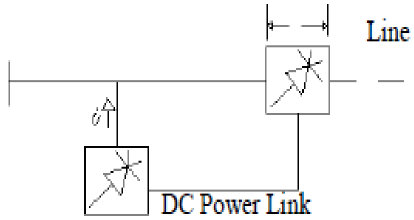

(f) Unified Series shunt controller

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S. No.	Question	Course Outcomes (Level)
	UNIT – I **Part – A**	
1.	Write the smart grid components.	**CO2 (2)**
2.	Examine the Distribution Intelligence of Smart Grid in Power system.	**CO2 (4)**
3.	Classify the different types FACTS on a power system.	**CO2 (4)**
4.	Explain the concept of plug in hybrid electric vehicles in smart grid.	**CO2 (5)**
5.	Interpret the term FACTS in a power system Network.	**CO2 (2)**
6.	List out the components of HVDC in the Transmission Automation.	**CO2 (4)**
	Part – B	
1.	Explain the Components and Architecture of Smart Grid Design.	**CO1(5)**
2.	Explain functions of smart grid components	**CO2 (5)**
3.	Discuss the Transmission Automation of smart grid in power system network	**CO2 (6)**
4.	Analyze the Plug in Hybrid Electric Vehicles (PHEV) of Smart Grid in a power system network	**CO2 (4)**
5.	Briefly explain the concept of Smart Grid Communication	**CO2 (4)**
6.	Explain the components of HVDC	**CO2 (4)**

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UNIT - III

Smart Grid – SEEA3006

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.

3.1 Introduction to Smart Meters

A smart meter is an electronic measurement device installed by the utility to maintain a two-way communication between the consumer and the utility. Also manage the electrical system of the consumer.

A smart meter is capable of communicating the real time energy-consumption of an electrical system in very short intervals of time to the connected utility.

In the electronic meters/electromechanical meters, the cumulative number of electricity units was recorded at the end of a month (or more). whereas a smart reader is connected to the utility which is capable of transmitting the electricity usage on a real-time basis.

Smart meters do not save energy themselves but consumers do.

The purpose of smart meters is to change the behaviour of the consumers. It is hoped that the consumers would save energy through awareness and the estimated bills.

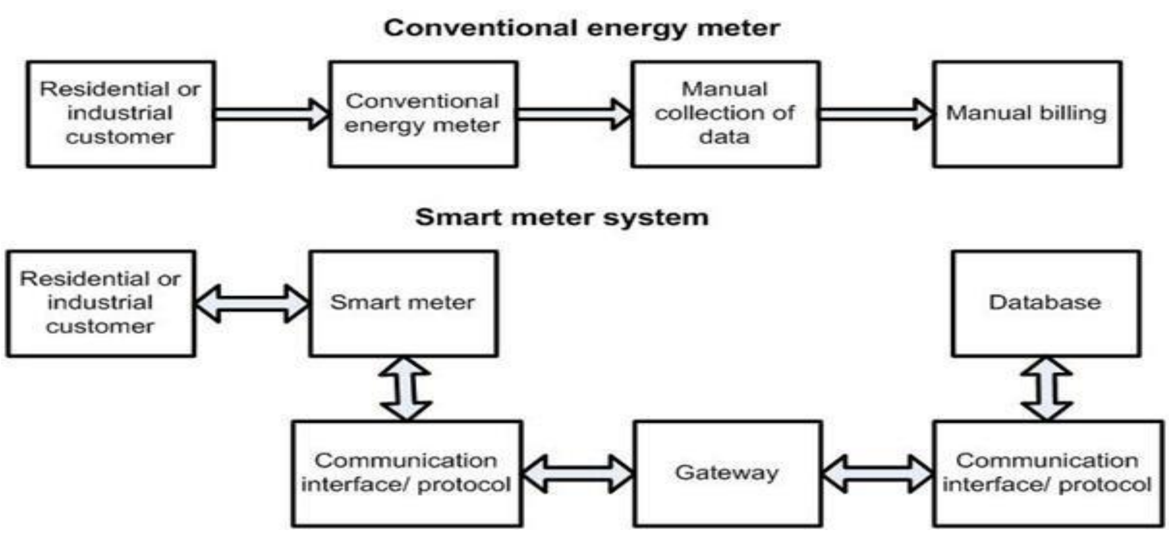

Fig 3.1 Block Diagram for Smart Meters

3.2 Advantages to Smart Meters

Accuracy in meter reading:

- In case of electromechanical/electronic meters, the meter readings have to be read by a representative of the utility.
- Smart meters automatically transmit the readings to the connected utility.

Data Recording:

- Conventional meters only record the electricity consumption of a system, and not how and when the electricity is used.
- Smart meters record real-time data corresponding to the electricity consumption. It means that they also record the time and patterns of electricity consumption

Real time tracking:

- What 's really nice about these meters is that consumers can go online and check out their electricity usage patterns and make changes to their consumption accordingly.
- In this way, smart meters offer a strong control to the consumers over their usage.

Automatic outage detection:

- A person having a conventional meter has to call the utility whenever there is a power outage whereas in case of smart meters, there is automatic outage detection as they are constantly synchronised with the electric grid.

Better service:

- As smart meters are directly connected to the utility, it becomes much simpler to connect/disconnect power for a particular house/property, saving the need of a technician going to the house in person and connect/disconnect the supply.

3.3 Purpose & Benefits of Smart Meters

For utility companies: -

- Easy to match energy consumption and generation in both peak time and low time .
- Smart meter can easily connect or disconnect the service .
- Customers can pay through internet by reading the meter themselves so the labour cost is highly reduced .
- Misprint during billing should completely reduced .
- No more energy theft .

For customers: -

- They should aware about there energy uses so that they can reduce there consumption.
- Real time pricing encourage people to adjust their consumption habit .
- Payment options like prepaid etc .
- A survey says this system reduce the energy consumption by 7 – 9 % .
- This is a win-win situation for both utility and customer.

3.4 Comparison Conventional Metering Vs. Smart Metering

Sl. No	Smart Metering	Conventional Metering
1.	Digital with Alpha Numeric Display	Analog with Spinning Dials
2.	Will Measure how much and when electricity is used (Hourly with date and Time Stamping)	Measurement only for how much Electricity is used over a Billing Period (One or Two Months)
3.	Automated Meter Reading: Meters send data Electronically to Distribution Companies through a Wireless Network	Manual Meter Reading: Distribution comp[any Staff Physically visit ratepayer premises to Record Data
4.	Two Way communication between Meters and Distribution Companies	No Communication capability

3.5 Advanced Metering infrastructure (AMI)

The present system of energy metering as well as billing in India uses electromechanical and somewhere digital energy meter. It consumes more time and labour.

One of the prime reasons is the traditional billing system which is very inaccurate, slow, costly, and lack in flexibility as well as reliability.

Today accuracy in electricity billing is highly recommended. The ‘Smart energy meter’ gives real power consumption as well as accurate billing. It provides real time monitoring of utility of electricity.

AMI (Advanced Metering Infrastructure) is the collective term to describe the whole infrastructure from smart meter to two-way communication network to control centre equipment and all the applications that enable the gathering and transfer of energy usage information in near real-time. AMI makes a two-way communication with customers possible and is the backbone of smart grid.

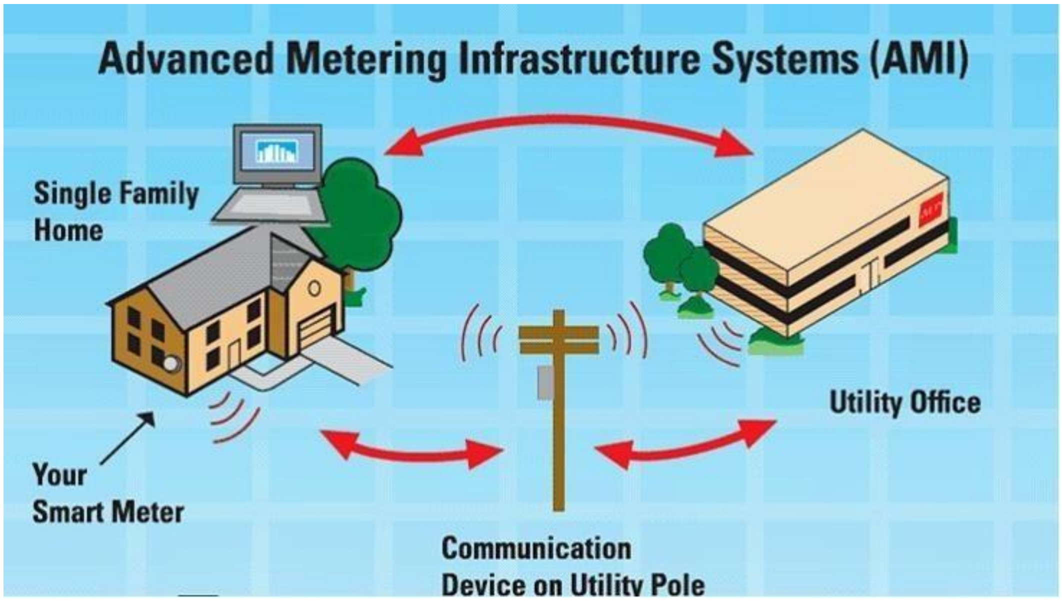

Fig 3.2 Block Diagram for Advanced Metering infrastructure (AMI)

3.6 Building blocks of AMI

AMI is comprised of various hardware and software components, all of which play a role in measuring energy consumption and transmitting information about energy, water and gas usage to utility companies and customers.

The technological components include:

1. Smart meters
2. Wide-area communications infrastructure
3. Home(local) area networks (HAN's)
4. Meter Data Management Systems (MDMS)
5. Operational gateways

3.6.1 Smart meters

Smart meters have the capacity to collect information about energy, water, and gas usage at various intervals and transmitting the data through fixed communication networks to utility, as well as receiving information like pricing signals from utility and conveying it to consumer.

3.6.2 Home Area Networks(HANs)

A Home Area Network (HAN) interfaces with a consumer portal to link smart meters to controllable electrical devices

3.6.3 Meter Data Management System (MDMS)

A MDMS is a database with analytical tools that enable interaction with other information systems. One of the functions of MDMS is to perform validation, editing and estimation on the AMI data to ensure that despite disruptions in the communications network or at customer premises, the data flowing to the systems described above is complete and accurate.

3.7 Challenges in AMI

Despite its widespread benefits, deploying AMI presents three major challenges that include

1. **High capital costs:**
   A full scale deployment of AMI requires expenditures on Hardware and software components including meters, network infrastructure and network management software, along with cost associated with the installation and maintenance of meters and information technology systems.
2. **Integration:** AMI is a complex system of technologies that must be integrated with utilities, information technology systems including Customer Information Systems (CIS), Geographical Information Systems (GIS), etc.
3. **Standardization:** Interoperability standards need to be defined, which set uniform requirements for AMI technology, deployment and general operations and are the keys to successfully connecting and maintaining an AMI based grid system.

3.8 AMI needs in the smart grid

AMI is an integrated system of smart meters, data management systems and communication networks that enable two-way communication between the utilities and the customers.

AMI makes two-way communications with customers possible and is the backbone of smart grid. The objectives of AMI can be remote meter reading for error free data, network problem identification, load profiling, energy audit and partial load curtailment in place of load shedding.

3.9 Phasor Measurement Unit (PMU)

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

Time synchronization is usually provided by GPS and allows synchronized real-time measurements of multiple remote points on the grid.

PMUs are capable of capturing samples from a waveform in quick succession and reconstructing the phasor quantity, made up of an angle measurement and a magnitude measurement.

The resulting measurement is known as a synchrophasor. These time synchronized measurements are important because if the grid's supply and demand are not perfectly matched, frequency imbalances can cause stress on the grid, which is a potential cause for power outages.

PMUs can also be used to measure the frequency in the power grid.

A typical commercial PMU can report measurements with very high temporal resolution in the order of 30-60 measurements per second. This helps engineers in analyzing dynamic events in the grid which is not possible with traditional SCADA measurements that generate one measurement every 2 or 4 seconds.

Therefore, PMUs equip utilities with enhanced monitoring and control capabilities and are considered to be one of the most important measuring devices in the future of power systems.

A PMU can be a dedicated device, or the PMU function can be incorporated into a protective relay or other device.

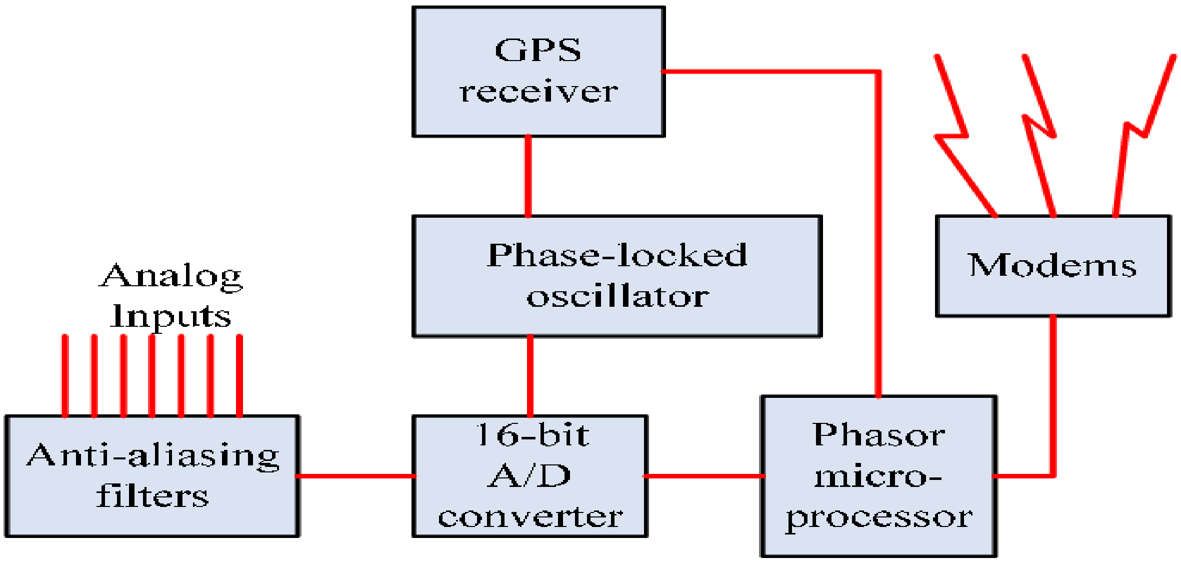

Fig 3.3 Block Diagram for Phasor Measurement Unit (PMU)

3.10 Main Components Of PMU

1. Analog Inputs
2. GPS receiver
3. Phase locked oscillator
4. A/D converter
5. Anti-aliasing filters
6. Phasor micro-processor
7. Modem

3.10.1 Analog Inputs

Current and potential transformers are employed at substation for measurement of voltage and current.

The analog inputs to the PMU are the voltages and currents obtained from the secondary winding of potential and current transformers.

3.10.2. Anti-aliasing filters

Anti-aliasing filter is an analog low pass filter which is used to filter out those components from the actual signal whose frequencies are greater than or equal to half of nyquist rate to get the sampled waveform.

Nyquist rate is equal to twice the highest frequency component of input analog signal.

If anti aliasing filters are not used, error will be introduced in the estimated phasor

3.10.3 A/D Converter

Quantization of the input involves in ADC that introduces a small amount of error.

The output of ADC is a sequence of digital values that convert a continuous time and amplitude analog signal to a discrete time and discrete amplitude signal.

It is therefore required to define the rate at which new digital values are sampled from the analog signal.

The rate of new values at which digital values are sampled is called the sampling rate of the converter.

3.10.4 Global Positioning System

The synchronized time is given by GPS uses the high accuracy clock from satellite technology.

Without GPS providing the synchronized time, it is hard to monitor whole grid at the same time.

The GPS satellites provide a very accurate time synchronization signal, available, via an antenna input, throughout the power system. This means that that voltage and current recordings from different substations can be directly displayed on the same time axis and in the same phasor diagram.

3.10.5 Processor

The microprocessor calculates positive- sequence estimates of all the current and voltage signals using the DFT techniques.

Certain other estimates of interest are frequency and rate of change of frequency measured locally, and these also are included in the output of the PMU.

The timestamp is created from two of the signals derived from the GPS receiver. The time-stamp identifies the identity of the “universal time coordinated (UTC) second and the instant defining the boundary of one of the power frequency periods**.**

3.11 Intelligent Electronic Devices (IED)

The name Intelligent Electronic Device (IED) describes a range of devices that perform one or more of functions of protection, measurement, fault recording and control.

An IED consists of a signal processing unit, a microprocessor with input and output devices, and a communication interface.

An intelligent electronic device (IED) is a device that is added to industrial control systems (ICS) to enable advanced power automation

IED configuration consist of

- Analog/Digital Input from Power Equipment and Sensors
- Analog to Digital Convertor (ADC)/Digital to Analog Converter (DAC)
- Digital Signal Processing Unit (DSP)
- Flex-logic unit
- Virtual Input/ Output
- Internal RAM/ROM
- Display

In the electric power industry, an intelligent electronic device (IED) is an integrated microprocessor-based controller of power system equipment, such as circuit breakers, transformers and capacitor banks
IEDs receive data from sensors and power equipment and can issue control commands, such as tripping circuit breakers if they sense voltage, current, or frequency anomalies, or raise/lower tap positions in order to maintain the desired voltage level.

IEDs are used as a more modern alternative to, or a complement of, setup with traditional remote terminal units (RTUs). Unlike the RTUs, IEDs are integrated with the devices they control and offer a standardized set of measuring and control points that is easier to configure and require less wiring.

Most IEDs have a communication port and built-in support for standard communication protocols (DNP3, IEC104 or IEC61850), so they can communicate directly with the SCADA system or a substation programmable logic controller. Alternatively, they can be connected to a substation RTU that acts as a gateway towards the SCADA server.

Intelligent electronic devices (IEDs) are Microprocessor-Based devices with the capability to exchange data and control signals with another device (IED, Electronic Meter, Controller, SCADA, etc.) over a communications link. IEDs perform Protection, Monitoring, Control, and Data Acquisition functions in Generating Stations, Substations, and Along Feeders and are critical to the operations of the electric network.

IEDs are widely used in substations for different purposes. In some cases, they are separately used to achieve individual functions, such as Differential Protection, Distance Protection, Over- current Protection, Metering, and Monitoring. There are also Multifunctional IEDs that can perform several Protection, Monitoring, Control, and User Interfacing functions on one hardware platform.

IEDs receive measurements and status information from substation equipment and pass it into the Process Bus of the Local SCADA. The substation systems are connected to the Control Centre where the SCADA master is located and the information is passed to the EMS Applications.

IEDs are a key component of substation integration and automation technology. Substation integration involves integrating protection, control, and data acquisition functions into a minimal number of platforms to reduce capital and operating costs, reduce panel and control room space, and eliminate redundant equipment and databases.

IED technology can help utilities improve reliability, gain operational efficiencies, and enable asset management programs including predictive maintenance, life extensions, and improved planning.

3.12 Protection, Monitoring, and Control Devices (IED)

Intelligent electronic devices (IEDs) are microprocessor-based devices with the capability to exchange data and control signals with another device (IED, electronic meter, controller, SCADA, etc.) over a communications link. IEDs perform protection, monitoring, control, and data acquisition functions in generating stations, substations, and along feeders and are critical to the operations of the electric network.

IEDs are widely used in substations for different purposes. In some cases, they are separately used to achieve individual functions, such as differential protection, distance protection, over current protection, metering, and monitoring. There are also multifunctional IEDs that can perform several protection, monitoring, control, and user interfacing functions on one hardware platform.

The main advantages of multifunctional IEDs are that they are fully IEC 61850 compatible and compact in size and that they combine various functions in one design, allowing for a reduction in size of the overall systems and an increase in efficiency and improvement in robustness and providing extensible solutions based on mainstream communications technology.

IED technology can help utilities improve reliability, gain operational efficiencies, and enable asset management programs including predictive maintenance, life extensions, and improved planning

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S. No.	Question	Course Outcomes (Level)
	UNIT – I **Part – A**	
1.	Interpret the term Smart Meters in the smart grid.	**CO3(2)**
2.	List out the Advantages of Smart Meters in Smart Grid.	**CO3(4)**
3.	Examine the Need of Smart Meters in the Smart Grid	**CO3(4)**
4.	Compare between Conventional Meter and Smart Meter	**CO3(5)**
5.	List out the Benefits of Smart Meters in Smart Grid.	**CO3(4)**
6.	List out the issues of Smart Meters in Smart Grid.	**CO3(4)**
7.	Interpret the term Advanced Metering infrastructure in the smart grid.	**CO3(2)**
8.	Classify the Building blocks of AMI in the smart Grid	**CO3(4)**
9.	Examine the Need of AMI in Smart Grid	**CO3(4)**
10.	List out the Benefits of AMI in Smart Grid.	**CO3(4)**
11.	Interpret the term Phasor Measurement Unit (PMU)	**CO3(2)**
12.	List out the applications of Phasor Measurement Unit (PMU) in Smart Grid.	**CO3(4)**
13.	Compare between SCADA and PMU	**CO3(5)**
14.	Examine the Need of Intelligent Electronic Devices (IED) in Smart Grid	**CO3(4)**
	Part – B	
1.	Explain the concept of smart metering in Smart Grid and advantages of it.	**CO3(5)**
2.	Briefly explain the advantages of Smart Meters in the Smart Grid	**CO3(5)**

3.	Explain the role of smart meters to make the system smart.	**CO3(5)**
4.	Explain the Building Blocks of AMI in the smart Grid	**CO3(5)**
5.	Explain the concept of phase measuring unit (PMU) with neat block diagram.	**CO3(5)**
6.	Elaborate the applications of phase measuring unit (PMU) in the Smart Grid	**CO3(6)**
7.	Explain how the reliability of smart grid can be enhanced by integrating intelligent electronic devices (IED) into it	**CO3(5)**
8.	Explain IED application for monitoring and protection	**CO3(5)**

SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - IV

Smart Grid – SEEA3006

IV. Power Quality Management In Smart Grid

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

4.1 Power Quality Management in Smart Grid

Power Quality Management address events like Voltage flickering (Sags/Swells), unbalanced phases voltages and harmonic distorted/contaminated supply etc.

This will facilitate efficient and reliable operation of the power system, reduce losses, improve customer satisfaction and reduced equipment (utility/consumer) failures.

Power Quality management shall include voltage / VAR Control, Load balancing, Harmonics Controller etc.

High level power quality measurement information is provided as power quality alarms: Voltage swells, voltage and current levels, power outages etc. These events may then be analysed using statistical metering or SCADA equipment.

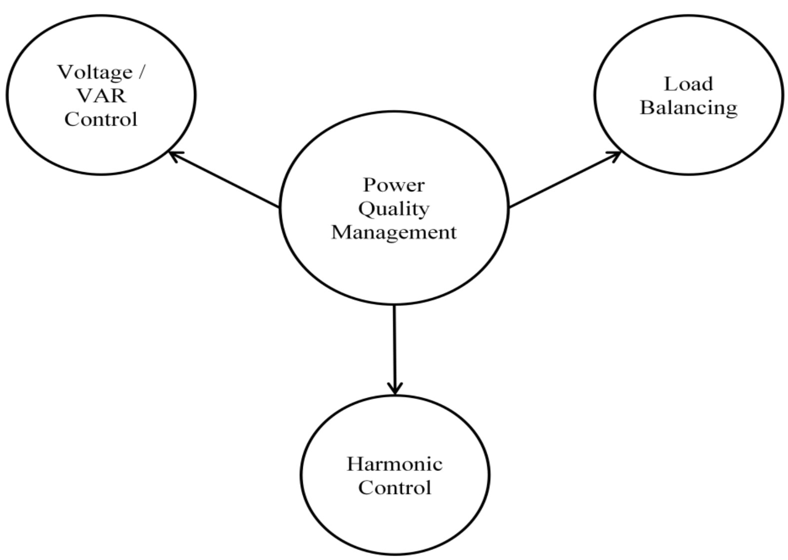

Fig 4.1 Block Diagram for Power Quality Management in Smart Grid

4.2 Smart Grid help improve power quality

The Smart Grid includes several components that help utilities better deliver quality power to your home: smart meters and technology on the distribution grid that helps manage voltage and power factor.

Smart meters are advanced electric meters that provide both you and your utility with more information about the power delivered to your home. Like other digital devices, they include a transformer to step down voltage for the digital electronics. Also like other digital devices, they are engineered to meet strict FCC requirements to keep from interfering with other electronic or communications equipment.

Smart meters allow your utility to see what the actual voltage delivered to your home is. Before smart meters, utilities would base their equipment settings on voltage readings at an electric substation and engineering estimates of what that would mean for actual voltage at each customer‘s home. They would often set voltages unnecessarily higher to ensure that the last home on a line didn‘t receive voltage below 114.

With actual information on voltage, utilities can use Smart Grid technology to optimize the voltage for every customer they serve—settings are based on actual customer voltages rather than engineering estimates, which enables a more efficient and accurate supply of power.

4.3 EMC and it is role in Smart Grid

The physical characteristic of Smart Grids technologies with an increased incorporation of potentially sensitive electronics has naturally implications with respect to Electromagnetic Compatibility – EMC.

The satisfactory function of electrical and electronic equipment with respect to electromagnetic disturbances is the aim of EMC.

The IEC – International Electrotechnical Commission defines Electromagnetic Compatibility as ―the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment‖.

In the European Union EMC Directive [15] ―equipment and system‖ of IEC corresponds to the EU term equipment, where equipment is subdivided into apparatus and fixed installation.

Electromagnetic disturbances may be radiated or conducted and electrical/electronic equipment potentially sensitive to any or to both of these types of disturbances.

Disturbances are in turn subdivided into a number of low and high frequency phenomena, where IEC defines low frequency up to and including 9 kilohertz.

Both IEC and EU define EMC to cover electromagnetic phenomena from zero hertz. Furthermore the IEC defines the following principal electromagnetic conducted phenomena:

Conducted low-frequency phenomena:

- Harmonics, Inter-Harmonics
- Signals superimposed on power lines
- Voltage fluctuations
- Voltage dips and interruptions
- Voltage unbalance
- Power frequency variations
- Induced low frequency voltages
- DC component in AC networks

Conducted high-frequency phenomena:

- Induced voltages or currents
- Unidirectional transients
- Oscillatory transients

EMC including Power Quality for Smart Grid:

- Standardise electromagnetic compatibility levels for disturbances in terms of Voltage Quality for all standard voltage levels
- Standardise limits of electromagnetic disturbances in terms of Voltage Quality at sites in electrical networks, based on compatibility levels.
- Standardise allocation of available immunity of electrical networks in order to meet planning levels.

Role of EMC in Smart Grid

- EMC is essential for a robust Smart Grid; both with respect to radiated and to conducted disturbances.
- Power Quality is a means to achieve EMC between the Smart Grid and connected

equipment.

- Protection requirements on networks and connected equipment should be economically fairly balanced.
- With a view of EMC as a technical issue where cost optimisation to a large extent is made.

4.4 Future PQ Challenges

Transients

A transient can be defined as the response of an electrical network to a sudden change in network conditions, either intended or accidental, (e.g. a switching operation or a fault) or network stimuli (e.g. lightning strike).Impulsive and oscillatory are the types.

Voltage Unbalance

Voltage Unbalance is defined as the largest difference between the average RMS voltage and the RMS value of single phase voltage divided by the average RMS voltage.ie Maximum Deviation of voltage. Cause : Single-phase loads in three-phase circuits.

It is pointed out in that if electric vehicle chargers are single-phase units, they will constitute a load with little diversity but which might impose significant unbalance on the system. This could limit the maximum power taken through the distribution transformer below the firm capacity.

For 50% of the charging scenarios the maximum power taken from the network is no more than 50% of the maximum available under balanced conditions.

DC Offset

The presence of direct voltage or Direct Current in an AC power system is termed as DC Offset.

Harmonics

Harmonics are sinusoidal voltages or currents having frequencies as integer multiples of fundamental or supply frequency.

The Harmonics due to increasing use of electronics with front-end capacitor filtered rectifiers, etc.,

If power factor correction is widely used without detuning inductors, there will be harmonic resonances at the important harmonic in the orders 5-9

Voltage fluctuation:

Voltage fluctuations are defined as repetitive or random variations in the magnitude of the supply voltage.

Voltage Variations:

Systematic random variations in supply voltages. A very rapid change in the supply voltage is called Voltage Flicker.

Cause : Rapid variations in current magnitude of loads. Eg. Arc furnaces.

Voltage Control

Voltage control is expected to be the major issue.

The voltage standard requires extensive retuning of the whole distribution system. Voltage retuning has to be done simultaneously at the zone-substation and downstream distribution transformers since there are interactions both upstream and downstream.

At LV, the dominant PV solar cell units will encourage high voltages in the day time, particularly at times of light load. Conversely, electric vehicle charging will reduce the voltage at night. The length and cross-section of LV conductors will need to be re-evaluated for future LV system construction.

The use of distributed voltage regulators simplifies the technical challenges but may impose an unacceptable additional cost in most situations.

Voltage Sags

The increasingly sophisticated equipment within residential customer installations in particular, being made up of many components, is expected to show a greater susceptibility to voltage sags. Grid developments of both the smart and strong type will improve sag rates as well.

Voltage sags and interruptions are generally caused by faults (short circuits) on the utility system.

- Fault on the same feeder,
- A fault on one of the other feeders from the substation,(a fault on a parallel feeder)
- A fault somewhere on the transmission system

Voltage sag durations will be greatly reduced if the smart grid is developed to give unit protection with fast breaker operation for MV feeders.

4.5 Impacts of Renewable Energy into the Grid

Integration of large-scale DER in particular wind and solar energy with adequate PQ into the grid is a challenging task due to the intermittent and weather-dependent nature of these resources.

The integration of variable generation sources presents unique challenges on system performance, and the key factors include

- RE generator design parameters and power movers' type.
- RE power generation's expected types of run.
- Position of the RE plant's connection to the grid.
- Variability in production of RE sources with changing weather conditions.
- Characteristics of the grid including the loads connected to it

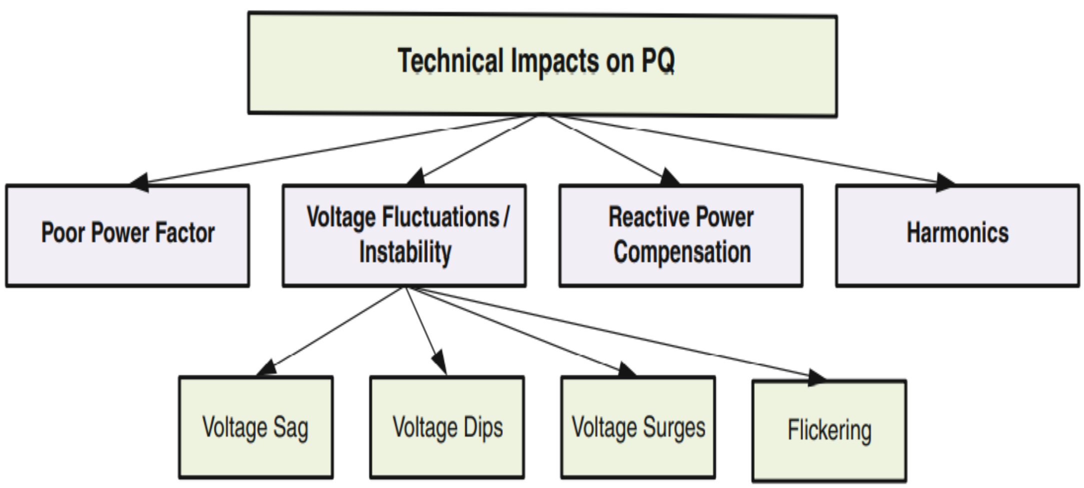

Fig 4.2 Block Diagram for Major potential technical impacts of integrating RE into the grid

With the increased penetration of RE to the grid, the key potential technical challenges that effect quality of power observed include voltage fluctuation, power system transients and harmonics, reactive power and low power factor that detracts overall PQ of the power systems. These problems mostly occurred for wind and solar energy.

Biomass, hydro- and geothermal energy sources are more predictable, and they have no significant problem on integration with the smart grid.

Voltage fluctuation

Voltage fluctuation or instability as well as voltage sags/ dips, noise, surges/spikes and power outages is the common problem encountered during integration of large-scale solar or wind energy into the grid.

Variability in wind speed or solar irradiation with time is grid connection issues, and faults during operations and starting of large motors, etc., are also responsible.

Large penetration of solar or wind power can lead to voltage control or the stability problem of power systems.

Periodic disturbances to the network voltage are denoted as flicker.

Reactive power compensation

The **consumption of reactive power by induction generators** is a common problem which affects the grid PQ.

An induction generator requires an increasing amount of reactive power as the amount of power generated increases, and it is essential to provide reactive power locally as close as possible to the demand levels.

The most widely used reactive power compensation is **capacitor compensation**, which is static, low cost and readily available in different sizes.

Reactive power compensation is typically implemented by using **a fixed capacitor, a switched capacitor or a static compensator**

The **power factor** of the wind turbine can be improved significantly by appropriate compensation that enhances overall **efficiency and voltage regulation of the system.**

Precise **reactive power compensation** considering proper size and proper control can **remove voltage collapse and instability of the power system** and enhances the overall operation of wind turbines

Harmonic distortion

Power electronic devices, together with operation of nonlinear appliances, inject harmonics into the grid, which may potentially create voltage distortion problems.

These results increase power system heat losses and reductions in the life of nearby connected equipment.

Harmonic currents create problems both on the supply system and within the installation.

Harmonics is one of the most dominant attributes that need to be kept to a minimum level to ensure good PQ of networks.

Harmonic distortion can be minimised by good control algorithm design in the current control loop. Different types of filters are also used to mitigate harmonic distortion.

Appropriate design of electrical circuits with control systems mitigates voltage fluctuations, harmonic distortion, reactive power compensation and power factor improvements and ensures PQ improvements in the power system.

Custom power devices such as **static var compensators (SVCs), shunt active power filters (static synchronous compensators (STATCOMs)), series active power filters (dynamic voltage regulators (DVRs**)) and a **combination of series and shunt active power filters (unified power quality conditioners (UPQCs**)) are the latest developments in interfacing devices between grids and consumer appliance.

These devices **reduce voltage/current disturbances** and **improve the PQ** by compensating the reactive and harmonic power generated or absorbed by the load.

4.6 Issues of Power Quality Monitoring

- Realization of Smart Meter with Advanced Power Quality Analysis Functions
- Wide-area Power Quality Measurement
- Realization of Mechanisms for Tracking Source of Power Quality Disturbance and Identification Algorithms via Robust Communication Network
- Integration of Real- time Power Quality Signal Analysis Methods
- Management of Measured Power Quality Data
- Power Quality Standards

4.7 Smart Grid PQ Measurement Issues

- Smart meter with Advance PQ Analysis Functions
- Wide Area Monitoring Scheme with PQ Disturbance Identification and Remedy
- Integration of Measured PQ Data and Database Design
- Tracking PQ Disturbances and Real-Time PQ Analysis
- Deployment of Advanced PQ Meters in Power Network

- Embedding Advanced PQ Monitoring Functions in Substation/Feeder Automations
- Communication Protocols for PQ Monitoring
- PQ-related Standards Development
- PQ Analytics

4.8 Power Quality Audit

- The Power Quality Audit (PQA), checks the reliability, efficiency and safety of an organisation's electrical system. It verifies the following aspects:
- The continuity of the power supply: i.e., that the power in the network is available on a regular basis and is able to ensure the efficient operation of the equipment
- The quality of the voltage: i.e., that there are no low or high frequency disturbances in the network capable of damaging the system components.
- The PQA uses network analysers, instruments specially designed to detect faults and deteriorations and record parameters and information that may be of use in locating the causes of disturbances. The data is collected and analysed by engineers, who can then diagnose the problems and suggest the most appropriate solutions

4.9 Applications

- **Energy monetization** – calculate the fiscal cost of energy waste due to poor power quality
- **Energy assessment** – quantify the before and after installation improvements in energy consumption to justify energy saving devices
- **Frontline troubleshooting** – quickly diagnose prob-lems on-screen to get your operation back online
- **Predictive maintenance** – detect and prevent pow-er quality issues before they cause downtime
- **Long-term analysis** – uncover hard-to-find or inter-mittent issues
- **Load studies** – verify electrical system capacity be-fore adding loads

4.10 Power Quality Conditioners for Smart Grid

The quality of electrical power supply is a set of parameters which describe the process of electric power delivery to the user under normal operating conditions, determine the continuity of supply (short and long supply interruptions) and characterize the supply voltage (magnitude, asymmetry, frequency, and waveform shape).

Power quality phenomena can be divided into two types :-

- ❖ A characteristic of voltage or current (e.g., frequency or power factor) is never exactly equal to its nominal and desired value. The small deviations are called voltage variations or current variations.
- ❖ When the voltage or current deviates significantly from its normal or ideal wave shape. These sudden deviations are called events. Power quality events are the phenomena which can lead to tripping of equipment, to interruption of the production or of plant operation, or endanger power system operation. This includes interruptions, under voltages, overvoltage, phase angle jumps and three phase unbalance.

A power conditioner (also known as a line conditioner or power line conditioner) is a device intended to improve the quality of power that is delivered to electrical load equipment.

In a smart grid the role of a power quality conditioner is to:-

- ➢ Deliver voltage & current of the proper level and characteristics to enable load equipment to function properly.
- ➢ Ensure efficient power transfer between utility grid & micro grid.
- ➢ Isolate each micro grid and the utility grid from there respective noises and disturbances.
- ➢ Energy creation i.e. to convert DC power generated by Solar panels to AC.
- ➢ Integration with energy storage system.

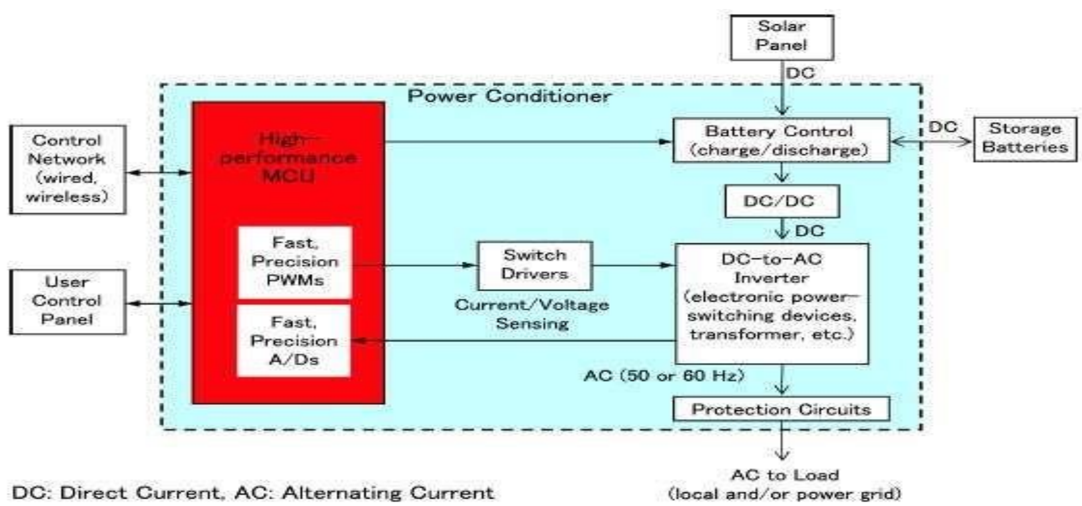

Fig 4.3 Block Diagram for Power Quality Conditioners for Smart Grid

4.11 Types of Power Quality Conditioners

- Distribution Static Compensator (DSTATCOM)
- Active power filters
  - -Shunt active power filters
  - -Series active power filters
  - -Hybrid Active Power Filters
- Unified Power Quality conditioner (UPQC)

4.11.1 Distribution Static Compensator (DSTATCOM)

The DSTATCOM is a custom power device based on a voltage Source Converter (VSC) shunt connected to the distribution networks.

A DSTATCOM is normally used to precisely regulate system voltage, improve voltage profile, reduce voltage harmonics and for load compensation.

D-STATCOM can also mitigate voltage dips and can compensate both magnitude and phase angle by injecting reactive or reactive power to the point of connection with the grid.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes: voltage regulation and compensation of reactive power, correction of power factor, and elimination of current harmonics.

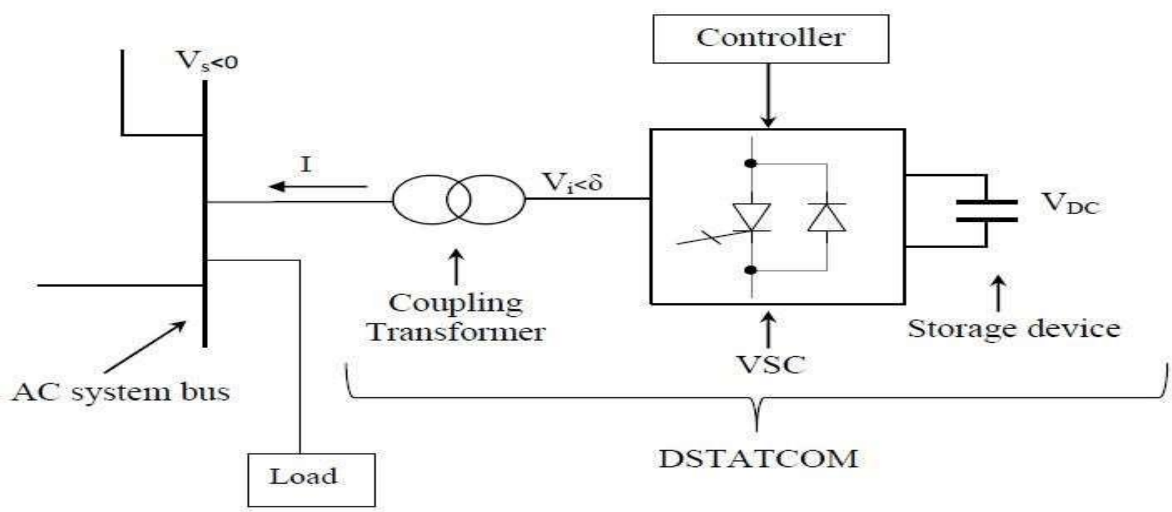

Fig 4.4 Block Diagram for DSTATCOM

The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the coupling transformer.

Such configuration allows the device to absorb or generate controllable active and reactive power.

4.11.2 Active Power Filters

Active power filter technology has evolved in the past quarter century with varying configurations and control topologies as a full fledged technique for providing compensation for reactive power, harmonics and neutral current in ac networks.

Active filters are also used to terminate the voltage harmonics, to regulate terminal voltage, to inhibit voltage flicker and to advance voltage balance in 3- phase systems.

Generally there are three configurations in which they are connected in power system :-

- Shunt active power filters
- Series active power filters
- Hybrid Active Power Filters

Shunt active power filter

It compensate current harmonics by injecting equal-but-opposite harmonic compensating current.

It operates as a current source injecting the harmonic components generated by the load but phase shifted by 180deg.

They are usually connected across the load to compensate for all current related problem such as reactive power compensation, power factor correction, current harmonics and load unbalance compensation.

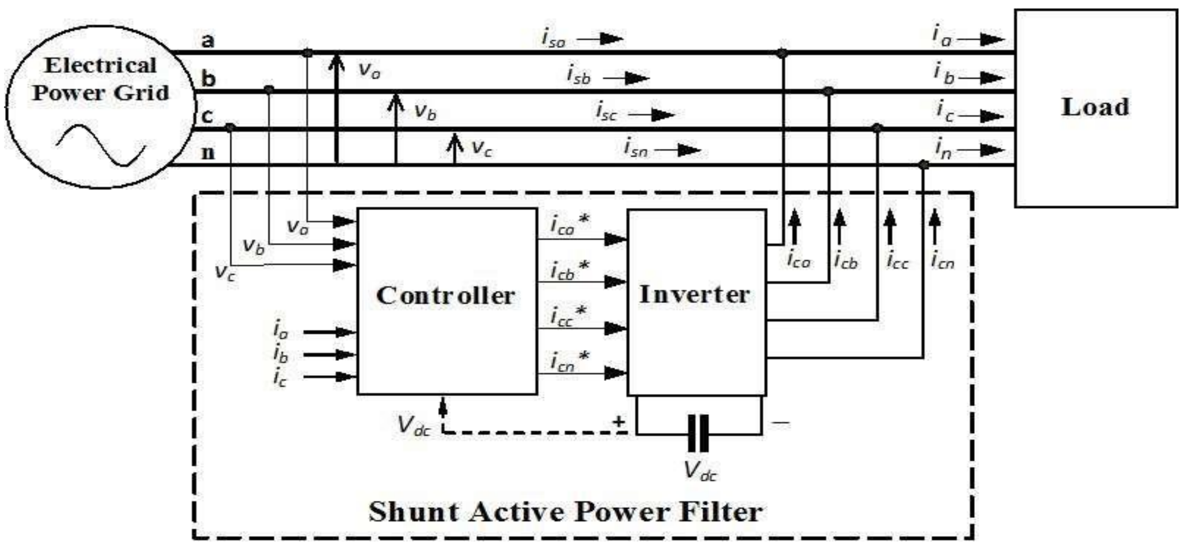

Fig 4.4 Block Diagram for Shunt active power filter

Series active power filters

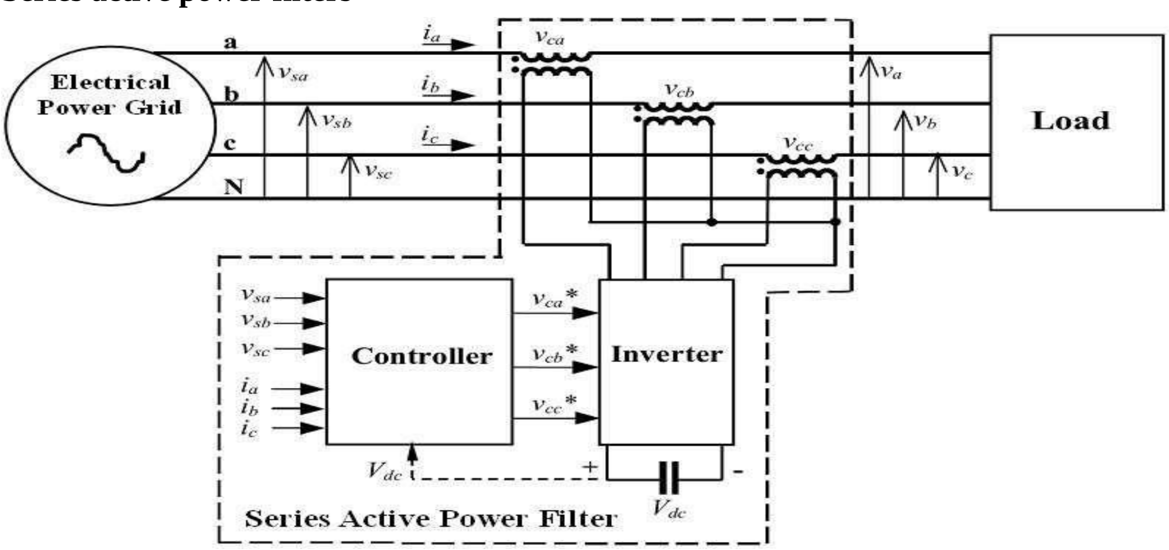

Fig 4.5 Block Diagram for Series active power filter

It compensates current system distortion caused by non-linear loads.

The high impedance imposed by the series APF is created by generating a voltage of the same frequency as that of harmonic component that needs to be eliminated.

It act as a controlled voltage source and can compensate all voltage related problems such as voltage harmonics, voltage sags & swells, voltage flicker etc.

Hybrid Active Power Filters

By controlling the amplitude of the voltage fundamental component across the coupling transformer, the PF of the power distribution system can be adjusted.

The control of the load power factor imposed a higher voltage across the filter capacitor.

This type of configuration is very convenient for compensation of high power medium voltage non linear loads

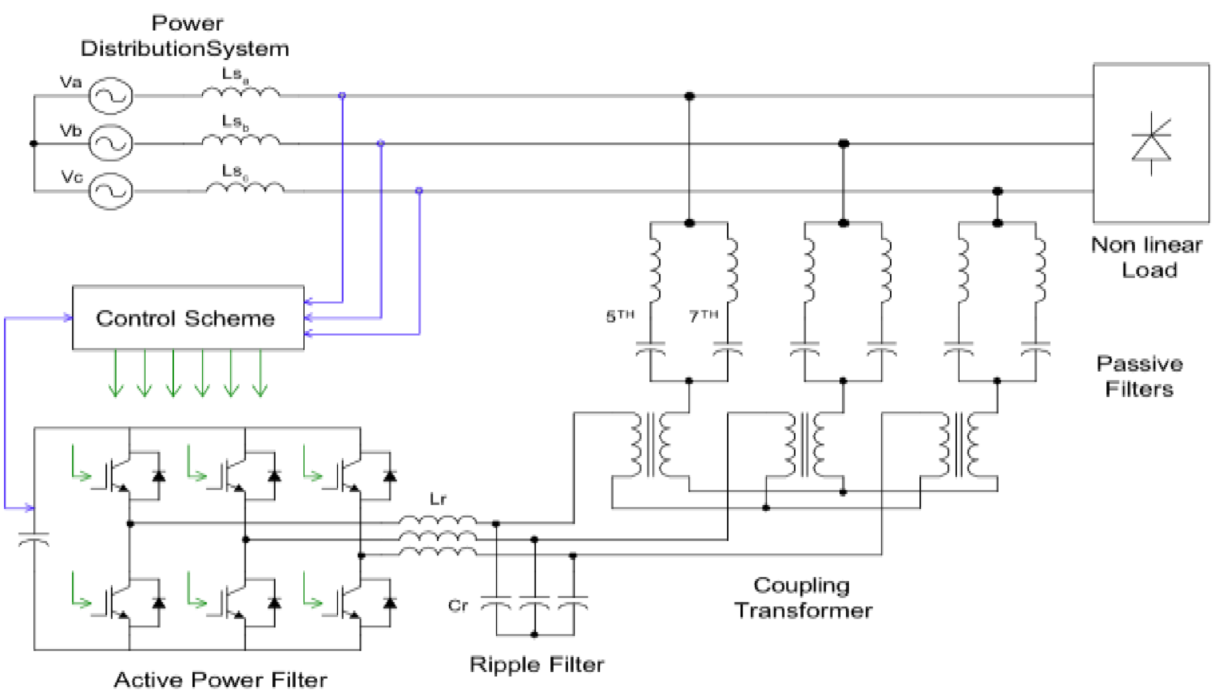

Fig 4.6 Block Diagram for Hybrid active power filter

4.11.3 Unified Power Quality conditioner (UPQC)

The Unified Power Quality Conditioner (UPQC) combines the Shunt Active Power Filter with the Series Active Power Filter, sharing the same DC Link, in order to compensate both voltages and currents, so that the load voltages become sinusoidal and at nominal value, and the source currents become sinusoidal and in phase with the source voltages.

UPQC can compensate both voltage related problems such as voltage harmonics, voltage sags/swells, voltage flicker as well as current related problems like reactive power compensation, power factor correction, current harmonics and load unbalance compensation.

There is a significant increase in interest for using UPQC in distributed generation associated with smart grids because of availability of high frequency switching devices and advanced fast computing devices (microcontrollers, DSP, FPGA) at lower cost.

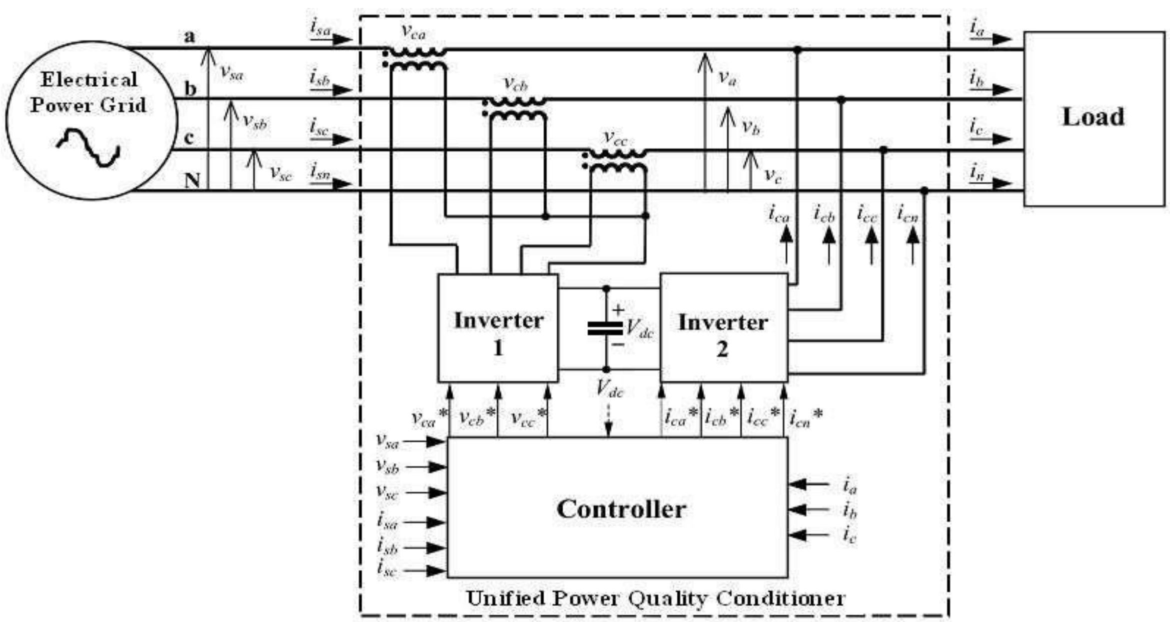

Fig 4.7 Block Diagram for Unified Power Quality conditioner (UPQC)

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S. No.	Question	Course Outcomes (Level)
	UNIT – I **Part – A**	
1.	Interpret the term Power Quality in the smart grid.	**CO4(2)**
2.	Examine the role of EMC in smart grid.	**CO4(4)**
3.	Examine the Power Quality Problems in the Smart Grid	**CO4(4)**
4.	List out the Issues of Power Quality Monitoring	**CO4(4)**
5.	Interpret the term Power Quality Audit in the smart grid.	**CO4(2)**
6.	List out the Applications of Power Quality Audit in the smart grid.	**CO4(4)**
7.	Interpret the term Power Quality Conditioners for Smart Grid.	**CO4(2)**
8.	Classify the Power Quality Conditioners for Smart Grid	**CO4(4)**
9.	Analyze how DSTACOM is improve the power quality in the smart Grid	**CO4(4)**

10.	Construct the block diagram of UPQC in the Smart Grid	**CO4(3)**
11.	Examine the Web based Power Quality monitoring in Smart Grid	**CO4(4)**
	Part – B	
1.	Explain the importance of power quality in smart grid.	**CO4(5)**
2.	Analyze the role of EMC in smart grid.	**CO4(4)**
3.	Explain the issues about power quality monitoring and power quality measurement in smart grid	**CO4(5)**
4.	Discuss the Power Quality Problems of Grid connected Renewable Energy Sources	**CO4(6)**
5.	Explain about power quality Audit and its applications	**CO4(5)**
6.	Elaborate the Power Quality Conditioners for Smart Grid with Neat Block Diagram.	**CO4(5)**
7.	Explain the different types of Power Quality Conditioners for Smart Grid	**CO4(5)**
8.	Dsicuss the web based power quality monitoring system.	**CO4(6)**

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SCHOOL OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

UNIT - V

Smart Grid – SEEA3006

V. High Performance Computing for Smart Grid Applications

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.

5.1 Introduction

- Smart Grid Communication **Needs:**
  - High - speed
  - Full integration
  - two - way communication technologies
  - to allow the smart grid to be a dynamic, interactive mega - infrastructure for real - time information and power exchange.
- **Possible** wired and wireless communication **technologies** can include:
  - Multiprotocol Label Switching (MPLS): High - performance telecommunications networks for data transmission between network nodes
  - Worldwide Interoperability for Microwave Access (WiMax): Wireless telecommunication technology for point to multipoint data transmission utilizing Internet technology
  - Broadband over Power Lines (BPL): Power line communication with Internet access
  - Wi - Fi: Commonly used wireless local area network
  - Additional technologies: Fiber, mesh, and multipoint spread spectrum

5.2 Characteristics of smart grid communications technology

- High bandwidth
- IP - enabled digital communication (IPv6 support is preferable)

- Encryption
- Cyber security
- Support and quality of service and Voice over Internet Protocol (VoIP)

5.3 Local Area Network (LAN)

A local area network is a data communication network, typically a packet communication network, limited within the specific network. A local area network generally provides high-bandwidth communication over inexpensive transmission media. The information flow is between smart meters and sensors. For this data exchange LAN technology is used. PLC which used existing power cable and Zigbee can be ideal communication technologies for LAN in the smart grid. Wi-Fi provide high data rate but it consumes more electric power than other. Bluetooth is limited for implementing HAN because of its limited capability

The Technologies of LAN for the Smart Grid can be detailed as

Technology	Data Rate	Coverage Range	Band Licensed	Cost
Ethernet	10 – 100 Mbps	100 M	Free	High
PLC	10 – 100 Mbps	10 – 10 M	Free	Medium
Wi-Fi	5 – 100 Mbps	30 – 100 M	Free	Low
ZigBee	0.02 – 0.2 Mbps	10 – 75 M	Free	Low
Bluetooth	0.7 – 2.1 Mbps	10 – 20 M	Free	Low

5.4 LAN topologies

Bus topology: Linear LAN architecture in which transmission from network station propagates the length of the medium and is received by all other stations connected to it.

- Ring bus topology: A series of devices connected to one another by unidirectional transmission links to form a single closed loop.
- Star topology: The end points on a network are connected to a common central hub or switch by dedicated links.
- Tree topology: Identical to the bus topology except that branches with multiple nodes are also possible.

5.5 LAN -Categories of data transmission

Unicast transmission: A single data packet is sent from a source node to a destination (address) on the network

▶ Multicast transmission: A single data packet is copied and sent to a specific subset of nodes on the network; the source node addresses the packet by using the multicast addresses

▶ Broadcast transmission:A single data packet is copied and sent to all nodes on the network; the source node addresses the packet by using the broadcast address.

5.6 House Area Network (HAN)

A home area network is a dedicated network connecting device in the home such as displays, load control devices and ultimately "smart appliances" seamlessly into the overall smart metering system. It also contains software applications to monitor and control these networks.

Building Blocks of HAN

The HAN is a subsystem within the Smart Grid dedicated to demand-side management (DSM), and includes energy efficiency and demand response which are the key components in realizing value in a Smart Grid deployment.

A few examples of demand-side management applications are:

a) Behavioural energy efficiency

b) Technology-enabled dynamic pricing

c) Deterministic direct load control

The latest application of Home Area Networks is installation of smart meters with an in-home display to monitor and manage the power consumption within the networked area. It also allows remote monitoring and control of electric appliances like thermostats etc. "Smart" meters have the capacity to connect wirelessly with the home appliances that contain RF antennas on the same frequency (usually 2.4-2.5 GHz). The meters can, thus, control appliances and generate detailed data on power consumption of each appliance.

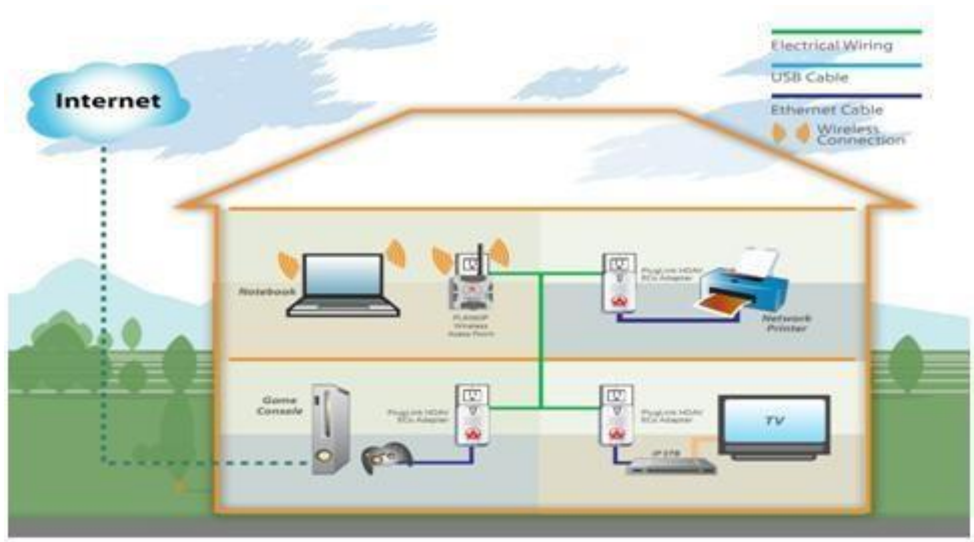

Figure 5.1: Home area network

The network that allows devices located within a home to communicate with each other. In the smart grid context, these devices could include smart meters, smart appliances, and home energy management devices.

Benefits of Home Area Network:

Home Area Network empowers the consumers and allows the smart grid infrastructure to benefit the home owners directly.

HAN allows the Smart Grid applications to communicate intelligently by providing centralized access to multiple appliances and devices.

Utilities can effectively manage grid load by automatically controlling high energy consuming systems with HAN and Smart Grid infrastructure.

Home Area Networks provide energy monitoring, controlling and energy consumption information about the appliances and devices and hence support energy usage optimization by allowing the consumers to receive price alerts from the utility.

5.7 Wide Area Network (WAN)

The WAN connects several subsystem and smart meters with control center which is far from subsystem and customer side network. For example several meter data collectors, mobile meter readers, and substation automation devices might send information to the utility offices over a WAN. However low data rate and significant signal attenuation limit its usage for WAN. The dedicated copper or fiber optic cable support reliable and secure communication however it is very costly to deploy new cable for long distance. Cellular communication like as WiMAX, 3G and LTE is also considered for WAN in the smart grid since the same can support wide area communication between control center and subsystems.

To be fully effective, the utility‘s WAN will need to span its entire distribution footprint, including all substations, and interface with both distributed power generation and storage facilities such as capacitor banks, transformers, and re- closers. The utility‘s WAN will also provide the two-way network needed for substation communication, distribution automation (DA), and power quality monitoring.

It also supports aggregation and backhaul for the advanced metering infrastructure (AMI) and any demand response / demand-side management applications. Each application running on the utility‘s WAN has its own set of requirements. Some applications like Supervisory Control And Data Acquisition (SCADA), automatic restoration and protection, and VoIP will require prioritization for real-time or near-real-time response and satisfactory Quality of Service (QoS). Some applications like AMI backhaul and video surveillance will consume considerable bandwidth, requiring broadband data rates end-to-end. And others like substation load management and crew communications will require both high bandwidth and fast response times.

―Integrated communications will enable the grid to become a dynamic, interactive medium for real-time information and power exchange. When integrated communications are fully deployed, they will optimize system reliability and asset utilization, enable energy markets, increase the resistance of the grid to attack, and generally improve the value proposition for electricity.‖

5.8 Broadband over Power line (BPL)

Broadband over power line (BPL) is a technology that allows data to be transmitted over utility power lines. BPL is also sometimes called Internet over power line (IPL), power line communication (PLC) or power line telecommunication (PLT). The technology uses medium wave, short wave and low-band VHF frequencies and operates at speeds similar to those of digital subscriber line (DSL).

Initially it was hoped that BPL would allow electric companies to provide high- speed access to the Internet across what providers call "the last mile." In this scenario, the service provider would deliver phone, television and Internet services over fiber or copper-based long haul networks all the way to the neighborhood or curb and then power lines would bring the signals into the subscriber's home. The BPL subscriber would install a modem that plugs into an ordinary wall outlet and pay a subscription fee similar to those paid for other types of Internet service. No phone, cable service or satellite connection would be required.

Proponents of the technology speculate that even if BPL is not accepted as a viable way to deliver high-speed Internet access, it may find a place in helping consumers to manage their energy consumption. High-speed data transmission between electrical plugs in a building would allow devices such as thermostats, appliances and smart meters to communicate with each other.

5.9 IP based Protocols

The Internet Protocol (IP) is the method or protocol by which data is sent from one computer to another on the Internet. Each computer known as a host on the Internet has at least one IP address that uniquely identifies it from all other computers on the Internet.

When you send or receive data (for example, an e-mail note or a Web page), the message gets divided into little chunks called packets. Each of these packets contains both the sender's Internet address and the receiver's address. Any packet is sent first to a gateway computer that understands a small part of the Internet. The gateway computer reads the destination address and forwards the packet to an adjacent gateway that in turn reads the destination address and so forth across the Internet until one gateway recognizes the packet as belonging to a computer within its immediate neighborhood or domain. That gateway then forwards the packet directly to the computer whose address is specified.

Because a message is divided into a number of packets, each packet can, if necessary, be sent by a different route across the Internet. Packets can arrive in a different order than the order they were sent in. The Internet Protocol just

delivers them. It's up to another protocol, the Transmission Control Protocol (TCP) to put them back in the right order The reason the packets do get put in the right order is because of TCP, the connection-oriented protocol that keeps track of the packet sequence in a message

The most widely used version of IP today is Internet Protocol Version 4 (IPv4). However, IP Version 6 (IPv6) is also beginning to be supported. IPv6 provides for much longer addresses and therefore for the possibility of many more Internet users. IPv6 includes the capabilities of IPv4 and any server that can support IPv6 packets can also support IPv4 packets.

5.10 Basics of Web Service

A web service is any piece of software that makes itself available over the internet and uses a standardized XML messaging system. XML is used to encode all communications to a web service. Web services are XML-based information exchange systems that use the Internet for direct application-to- application interaction. These systems can include programs, objects, messages, or documents. Web services are self-contained, modular, distributed, dynamic applications that can be described, published, located, or invoked over the network to create products, processes, and supply chains. These applications can be local, distributed, or web-based. Web services are built on top of open standards such as TCP/IP, HTTP, Java, HTML, and XML.

A web service is a collection of open protocols and standards used for exchanging data between applications or systems. Software applications written in various programming languages and running on various platforms can use web services to exchange data over computer networks like the Internet in a manner similar to inter-process communication on a single computer.

To summarize, a complete web service is, therefore, any service that: Is available over the Internet or private (intranet) networks

Uses a standardized XML messaging system

Is not tied to any one operating system or programming language Is self-describing via a common XML grammar

Is discoverable via a simple find mechanism

5.11 Need of Cloud Computing

Cloud Computing is the term referring to the delivery of hosted services over the internet.

Cloud computing is a model for delivering information technology services in which resources are retrieved from the internet through Web based tools and applications rather than a direct connection to the server

Any smart grid infrastructure should support real-time, two-way communication between utilities and consumers, and should allow software systems at both the producer and consumer ends to control and manage the power usage.

Cloud computing is an emerging technology advocated for enabling reliable and on-demand access to different computing sources that can be quickly provisioned and released in a cost-effective way to the service providers.

Using cloud infrastructure, a customer can gain access to their applications anytime, and from anywhere, through a connected device to the network.

In order to balance the real-time demand and supply curves, rapid integration and analyzation of information that streams from multiple smart meters simultaneously is required that necessitates the scalable software platform. Cloud platforms are well suited to support huge data and computationally- intensive, always-on applications. Cloud platforms serve as essential components due to the various benefits they offer.

- Cloud acts elastically to avoid costly capital investment by the utility during the peak hours.
- Customers can be benefited from the real-time information by sharing the real-time energy usage and pricing information.
- Some data can be shared with a third party by using cloud services, after meeting the data privacy policies for developing intelligent applications to customize consumer needs.
- To manage large amounts of data, cloud computing is the best way for smart grids due to its scalable, economical, and flexible characteristics.

There are various applications and different types of role are played by cloud computing. Here is an example of cloud based economic load dispatch.

In order to take decisions at different instances, implementation of specialized data abstraction for data streams generated from the different components is required for real-time monitoring. On the other hand, third-party vendors are allowed to participate in such real-time monitoring system that necessitates defining an effective privacy policy as a security mechanism

5.12 Importance of Cloud Computing

A smart grid is conceptualized as a combination of electrical network and communication infrastructure. With the implementation of bidirectional communication and power flows, a smart grid is capable of delivering electricity more efficiently and reliably than the traditional power grid.

A smart grid consists of a power network with ‗intelligent' entities that can operate, communicate, and interact autonomously, in order to efficiently deliver electricity to the customers. Any smart grid infrastructure should support real-time, two-way communication between utilities and consumers, and should allow software systems at both the producer and consumer ends to control and manage the power usage.

Cloud computing is an emerging technology advocated for enabling reliable and on-demand access to different computing sources that can be quickly provisioned and released in a cost-effective way to the service providers. Using cloud infrastructure, a customer can gain access to their applications anytime, and from anywhere, through a connected device to the network.

Flexible resources and services shared in network, parallel processing and omnipresent access are some features of Cloud Computing that are desirable for Smart Grid applications.

5.13 Cyber Security for Smart Grid.

Smart Grid has transformed the electric system into a two-ways a) flow of electricity b) information. The information technology (IT) and telecommunications infrastructures have become critical to the energy sector. Therefore, the management and protection of systems and components of these infrastructures must also be addressed by an increasingly diverse energy sector. To achieve this a security system should be so designed which comprises of the following.

Requirements of the system

Plans that could be formulated and implemented.

Risks involved in maintaining the security systems and smart methods to eradicate the risks.

Strategy to be evolved.

Study and analyse for future improvement.

Requirments:

The requirements are being developed using a high-level risk assessment process. These requirements are implicitly recognized as critical in all of the particular priority application plans.

Plans:

The critical role of cyber security in ensuring the effective operation of the Smart Grid by

a) Increasing the use of digital information and controls technology to improve reliability, security, and efficiency of the electric grid.

b) Dynamic optimization of grid operations and resources, with full cyber- security. A robust, resilient energy infrastructure in which continuity of business and services is maintained. This can be achieved through secure and reliable information sharing, effective risk management programs.

Risks involved:

Deliberate attacks, such as from disgruntled employees, industrial espionage, and terrorists. Inadvertent compromises of the information due to user errors, equipment failures. Natural disasters. Vulnerabilities might allow an attacker to penetrate a network, gain access to control software, and alter load conditions to destabilize the grid in unpredictable ways.

Additional risks to the grid which could bring vulnerabilities

i) Increasing the complexity of the grid

ii) Increase exposure to potential attackers and unintentional errors;

- Interconnected networks can introduce common vulnerabilities;
- Increasing vulnerabilities to communication disruptions and introduction of malicious software that could result in denial of service or compromise the integrity of

software and systems;

- Increased number of entry points and paths for potential adversaries to exploit; and
- Smart Grid has additional vulnerabilities due to its complexity, large number of stakeholders, and highly time-sensitive operational requirements.

Strategy to be evolved:

Implementation of a cyber-security strategy requires the development of an overall cyber security risk management framework. This framework is based on existing risk management approaches developed by both the private and public sectors. This risk management framework establishes the processes for combining impact, vulnerability, and threat information to assess the risk. Because the Smart Grid includes systems and components from the IT, telecommunications, and energy sectors. The goal is to ensure that a comprehensive assessment of the systems and components of the Smart Grid. llowing the risk assessment

In a typical risk management process, assets, systems and networks are identified; risks are assessed, and specified. Security controls are selected, implemented, assessed for effectiveness. Then the same are monitored. The risk assessment process for the Smart Grid will be completed when the security requirements are specified. These requirements will not be allocated to specific systems, components, or functions of the Smart Grid. The output from the Smart Grid risk management process should be used in these steps.

Study and analyse for future improvement:

The approach taken herein is to more quickly identify fruitful areas for solution development, A list of evident and specific security problems in the Smart Grid that are amenable and should have open and interoperable solutions are created. General problems such as poor software engineering practices, key management, etc.are not included. From the above a catalogue of design patterns that serve as a means of identifying and formulating requirements is developed and documented. This document is to be treated as an interim work product with some apparent redundancies, but in the next iteration of the groups‘ analysis process these will be worked out for improvement.

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[2] Janaka Ekanayake, Nick Jenkins, Kithsiri Liyanage, JianzhongWu, Akihiko Yokoyama, “Smart Grid: Technology and Applications”,Wiley, 2012.

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S. No.	Question	Course Outcomes (Level)
	UNIT – I **Part – A**	
1.	Interpret the term Tree topology in the smart grid.	**CO5(2)**
2.	Examine the role of HAN in smart grid..	**CO5(4)**
3.	Examine the role of LAN in smart grid.	**CO5(4)**
4.	Examine the LAN topology in the Smart Grid	**CO5(4)**
5.	List out the Characteristics of smart grid communications technology	**CO5(4)**
6.	Examine the Broadband over Power line (BPL)in Smart Grid	**CO5(4)**
7.	Analyze the Importance of Cloud Computing in the smart Grid	**CO6(4)**
8.	Interpret the term Cyber Security in the Smart Grid.	**CO6(2)**
	Part – B	
1.	Explain the importance of Wide area network. in smart grid.	**CO6(5)**
2.	Analyze the role of LAN & HAN in the smart grid.	**CO5(4)**

3.	Explain the concept IP based protocols. in smart grid	**CO5(5)**
4.	Discuss about Broadband over Power line in the smart grid	**CO5(6)**
5.	Explain about cloud computing and its need in the smart Grid	**CO6(5)**
6.	Discuss the necessity Cyber Security for Smart Grid.	**CO6(6)**