ST. ANNE'S COLLEGE OF ENGINEERING AND TECHNOLOGY
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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

NOTES

VI SEMESTER

EE3007 – SMART GRID

Academic Year 2023-24 (EVEN)

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I. Introduction to Smart Grid

Evolution of Energy Systems, Concept, Definitions and Need, Difference between Conventional & Smart Grid, Drivers, structures, functions, opportunities, challenges and benefits of Smart Grid, Basics of Micro grid, National and International Initiatives in Smart Grid.

1.1 Evolution of Energy system

The evolution of energy systems is a complex topic that spans millennia, from the earliest human use of fire to modern-day global energy networks. Here's a brief overview of the key stages in the evolution of energy systems:

Agricultural Revolution (10,000 BCE - 5,000 BCE):

With the advent of agriculture, humans began using animals (e.g., oxen, horses) for labor.

Mechanical energy from animals supplemented human labor, leading to increased agricultural productivity.

Industrial Revolution (late 18th to early 19th centuries):

The invention of the steam engine by James Watt in 1769 marked a significant turning point.

Coal became a dominant energy source, powering steam engines in factories, trains, and ships.

The Industrial Revolution led to rapid urbanization, economic growth, and the mechanization of many tasks.

Electrification (late 19th to early 20th centuries):

Thomas Edison and Nikola Tesla's contributions led to the widespread adoption of electricity.

Electricity replaced steam as the primary power source in many industries and homes.

The development of electric grids enabled the distribution of power over long distances.

Fossil Fuel Dominance (20th century):

The 20th century saw a rapid increase in the use of fossil fuels (coal, oil, natural gas) for energy production.

The discovery of oil reserves and advancements in drilling technology further fueled industrial growth and transportation.

Nuclear power also emerged as a significant source of energy, particularly for electricity generation.

Renewable Energy Revolution (late 20th century to present):

Concerns about environmental degradation, climate change, and resource depletion spurred interest in renewable energy sources.

Technologies such as solar photovoltaics, wind turbines, hydropower, and geothermal energy gained traction.

Government policies, technological advancements, and declining costs have led to rapid growth in renewable energy deployment.

Smart Grids and Energy Storage (21st century):

Advancements in information technology have facilitated the development of smart grids, enabling more efficient and reliable energy distribution.

Energy storage technologies (e.g., batteries, pumped hydro, hydrogen storage) have become increasingly important for balancing supply and demand in renewable-dominated systems.

Decentralization and Electrification of Transportation (ongoing):

The rise of electric vehicles (EVs) and renewable energy integration are driving efforts towards decentralization of energy systems.

Vehicle-to-grid (V2G) technology allows EV batteries to store and supply electricity, further blurring the lines between transportation and energy sectors.

1.2 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.

1.3 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)

1.4 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.

1.5 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

1.6 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

1.7 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

1.8 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.

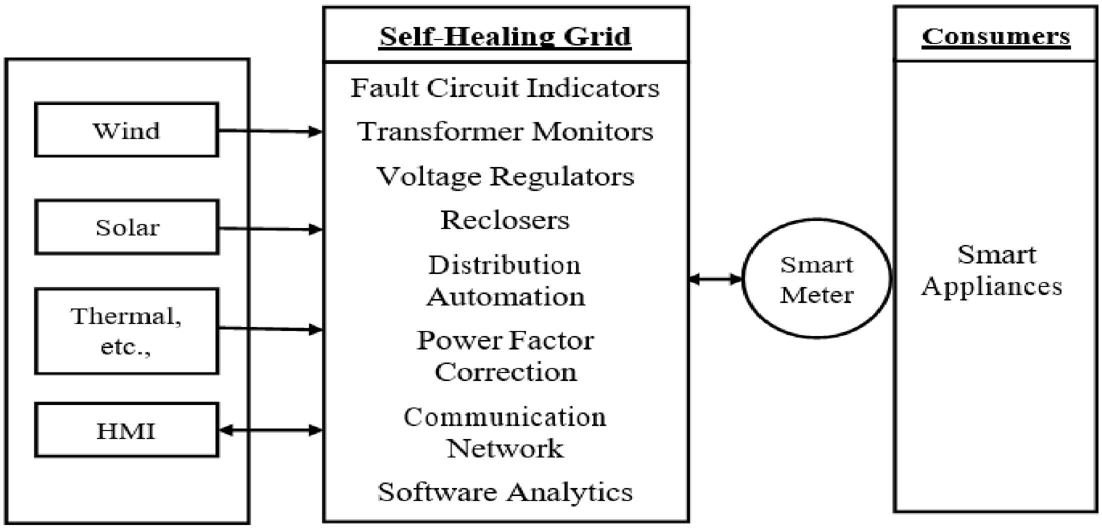

Figure 1.2 Block Diagram for Self-Healing Grid

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.

1.9 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 pricingand 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.

II. 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.

2.1 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.

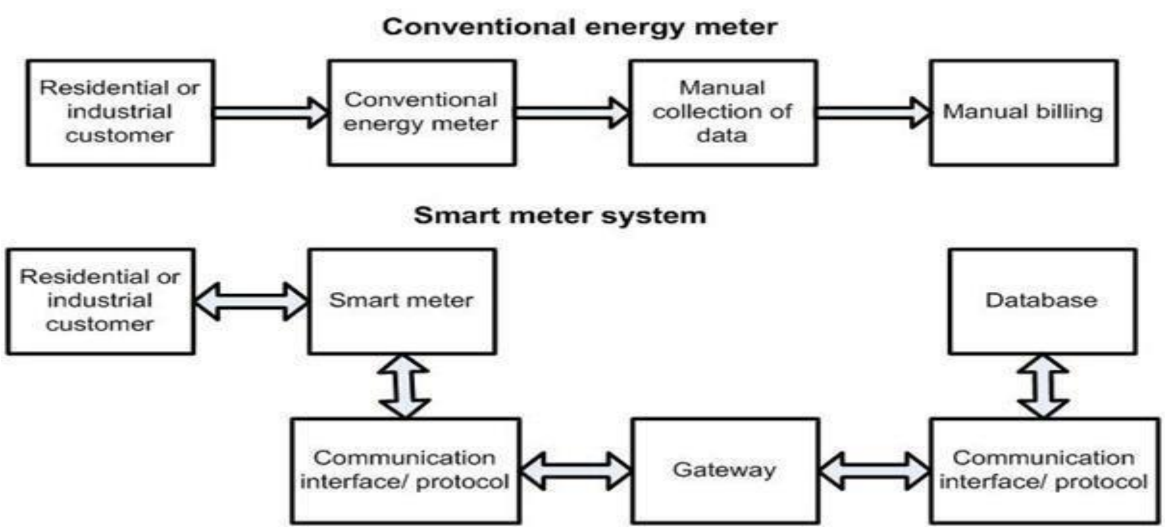

Fig 2.1 Block Diagram for Smart Meters

2.1 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.

2.2 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.

2.4 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

2.5 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 ofutility 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.

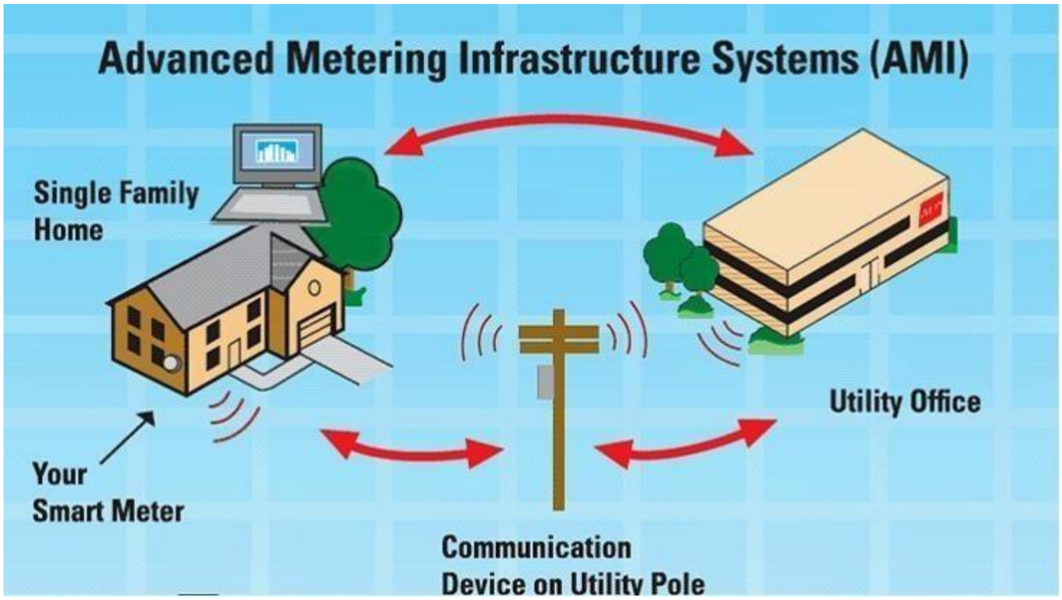

Fig 2.2 Block Diagram for Advanced Metering infrastructure (AMI)

2.6 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

2.6.1 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.

2.6.2 Home Area Networks(HANs)

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

2.6.3 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.

2.7 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.

2.8 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.

2.9 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.

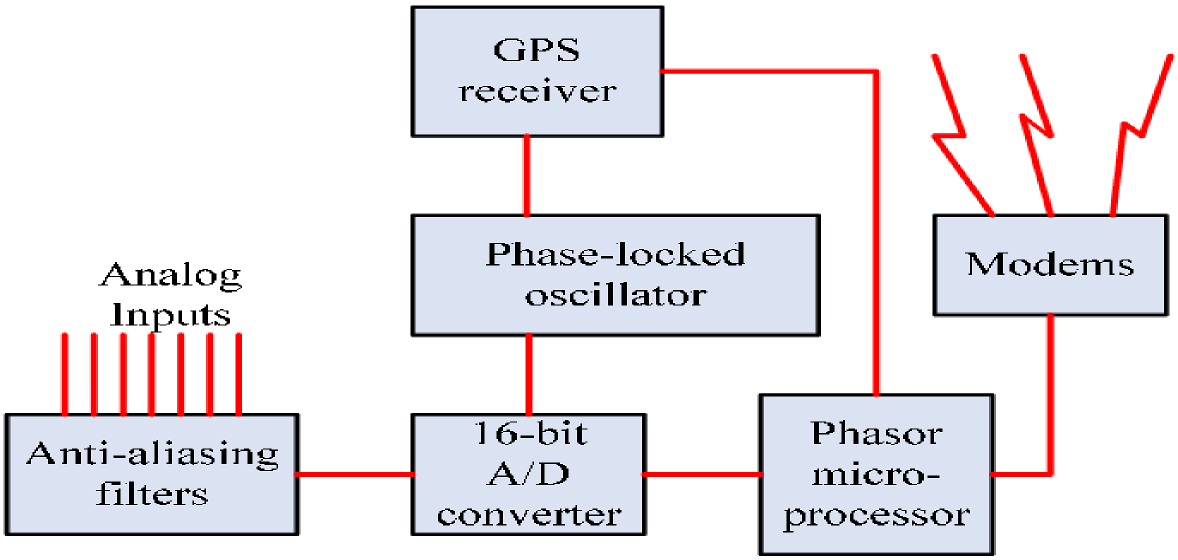

Fig 3.3 Block Diagram for Phasor Measurement Unit (PMU)

2.10 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

2.10.1 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.

2.10.2. 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

2.10.3 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.

2.10.4 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 andin the same phasor diagram.

2.10.5 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**.**

2.10 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 easierto 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.

2.11 Protection, Monitoring, and Control Devices (IED)

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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.

III. SMART GRID TECHNOLOGIES (Transmission)

Technology Drivers, Smart energy resources, Smart substations, Substation Automation, Feeder Automation, Transmission systems: EMS, Wide area Monitoring, Protection and control.

DRIVES:

Smart grid technologies in transmission systems are driven by several key factors that aim to address the challenges of an evolving energy landscape. Firstly, the increasing integration of renewable energy sources, such as wind and solar, necessitates a more flexible and adaptable grid infrastructure. Smart grid technologies enable the efficient integration of variable renewable generation by providing real -time monitoring, control, and optimization of power flows. This capability helps to mitigate issues related to intermittency and variability, ensuring grid stability while maximizing the utilization of renewable resources.

Secondly, the growing demand for energy efficiency and grid resilience drives the adoption of smart grid technologies. By implementing advanced sensors, monitoring systems, and automation, transmission operators can optimize grid operations, reduce losses, and enhance overall system reliability. Predictive analytics and machine learning algorithms enable proactive maintenance, minimizing downtime and improving asset management. Additionally, the deployment of flexible AC transmission systems (FACTS) and high-voltage direct current (HVDC) transmission technologies enhances grid flexibility and resilience to disturbances.

Thirdly, the need to modernize aging grid infrastructure and accommodate evolving consumer behaviors and preferences propels the development of smart grid technologies. Traditional grid systems were designed for one-way power flow from centralized generation sources to consumers. However, with the rise of distributed energy resources (DERs) and demand-side management programs, the grid must evolve to support bidirectional power flows and enable active participation of consumers in grid operations.

Smart grid solutions facilitate demand response, energy storage integration, and grid-edge intelligence, empowering consumers to optimize their energy usage and contribute to grid stability.

Lastly, regulatory mandates and policy initiatives play a crucial role in driving the deployment of smart grid technologies in transmission systems. Governments and regulatory authorities worldwide are increasingly focusing on promoting grid modernization, decarbonization, and energy transition objectives. Policies such as renewable portfolio standards, carbon pricing mechanisms, and grid modernization incentives encourage investment in smart grid infrastructure. Moreover, regulatory frameworks that support open standards, interoperability, and cybersecurity are essential for ensuring the effective deployment and operation of smart grid technologies while safeguarding grid reliability and security. Overall, these drivers collectively contribute to the advancement and widespread adoption of smart grid technologies in transmission systems, enabling a more resilient, efficient, and sustainable energy infrastructure.

SMART ENERGY RESOURSES:

In the context of smart grid transmission, smart energy resources play a pivotal role in optimizing grid operations, enhancing efficiency, and promoting grid resilience. These resources encompass a diverse range of technologies and strategies, including renewable energy sources, energy storage systems, demand response programs, and grid-edge devices. Integrating these smart energy resources into transmission systems enables dynamic control of power flows, grid balancing, and voltage regulation, thereby improving overall grid stability and reliability.

Renewable energy sources, such as solar and wind, are key components of smart energy resources in smart grid transmission. By harnessing these clean and abundant resources, transmission operators can diversify the energy mix, reduce dependence on fossil fuels, and mitigate greenhouse gas emissions. Additionally, energy storage systems, such as batteries and pumped hydro, complement renewable generation by storing excess energy during periods of low demand or high generation and releasing it during peak demand or low generation periods. Demand response programs engage consumers in actively managing their energy usage, allowing them to adjust consumption in response to grid conditions or price signals.

Grid-edge devices, such as smart meters and sensors, enable real-time monitoring and control of energy flows at the distribution level, facilitating the integration of distributed energy resources and enhancing grid resilience. Collectively, these smart energy resources contribute to a more flexible, efficient, and sustainable transmission infrastructure within the smart grid paradigm.

SMART SUBSTATION:

Smart substations play a critical role in modernizing power grids as part of smart grid technologies. In transmission systems, smart substations integrate advanced sensing, monitoring, and communication technologies to enhance grid efficiency, reliability, and flexibility. These substations utilize various sensors and intelligent devices to continuously collect data on voltage, current, temperature, and other parameters, enabling real-time monitoring and control of grid operations. Additionally, smart substations incorporate advanced communication protocols such as IEC 61850 to facilitate seamless exchange of information between different components of the grid, allowing for quicker response to disturbances and optimization of grid performance.

Furthermore, smart substations enable the implementation of advanced automation and control algorithms, including predictive maintenance and fault detection systems, which can proactively identify potential issues and mitigate downtime. By leveraging data analytics and machine learning techniques, these substations can analyze vast amounts of data to optimize grid operations, improve asset management, and enhance overall system resilience.

Ultimately, smart substations contribute to the evolution of transmission systems towards more adaptive, efficient, and sustainable grid infrastructures, capable of meeting the growing demands of modern society while integrating renewable energy sources and accommodating emerging technologies.

SUBSTATION AUTOMATION:

Substation automation is a pivotal component of smart grid technologies in transmission systems, revolutionizing the operation and management of substations. By integrating advanced control, monitoring, and communication technologies, substation automation enables remote monitoring and control of various substation equipment and processes.

Intelligent electronic devices (IEDs) play a crucial role in this automation, collecting real-time data such as voltage, current, and temperature, and facilitating the automation of switching operations and fault detection. Additionally, substation automation systems utilize standardized communication protocols like IEC 61850 to ensure interoperability and seamless data exchange between different components of the substation and the broader grid infrastructure.

Furthermore, substation automation enhances grid reliability and efficiency by enabling swift fault isolation and restoration, thereby reducing outage durations and improving overall system resilience. These systems are equipped with advanced analytics and predictive maintenance algorithms that can proactively identify potential issues before they escalate into major failures, minimizing downtime and optimizing asset management. By leveraging the capabilities of substation automation, transmission operators can achieve greater operational agility, enhance grid performance, and lay the groundwork for the integration of renewable energy sources and emerging technologies into the grid ecosystem.

FEEDER AUTOMATION:

Feeder automation is a critical aspect of smart grid technologies within transmission systems, focusing on improving the efficiency, reliability, and flexibility of power distribution at the feeder level. It involves the integration of advanced control, monitoring, and communication technologies to automate various aspects of feeder operation, such as fault detection, isolation, and restoration. By deploying intelligent electronic devices (IEDs) along the feeder network, real-time data on voltage, current, and other parameters can be collected, enabling quick identification of faults and abnormalities.

Furthermore, feeder automation systems utilize sophisticated algorithms and decision-making processes to analyze the collected data and automatically initiate appropriate responses to maintain grid stability and reliability. For instance, in the event of a fault, these systems can isolate the affected section of the feeder to minimize the impact on the rest of the network and swiftly restore power to unaffected areas.

Moreover, feeder automation enables utilities to remotely control and coordinate various devices, such as reclosers, switches, and capacitors, to optimize power flow, voltage levels, and load balancing along the feeder.

Additionally, feeder automation plays a crucial role in integrating renewable energy sources and accommodating the increasing penetration of distributed energy resources (DERs) into the grid.

By enabling more granular monitoring and control of feeder operations, utilities can better manage the variability and intermittency associated with renewable energy generation, improving grid stability and resilience.

Moreover, feeder automation supports the implementation of demand response programs, allowing utilities to adjust load patterns in response to supply fluctuations or grid constraints, ultimately enhancing overall grid efficiency and sustainability. In essence, feeder automation is essential for modernizing transmission systems and building a smarter, more resilient grid capable of meeting the evolving energy needs of the future.

Moreover, substation automation facilitates the implementation of advanced grid management strategies, such as demand response and dynamic pricing, enabling more efficient utilization of resources and better integration of distributed energy resources (DERs). With the ability to remotely monitor and control substations, operators can optimize grid operations in real-time, balancing supply and demand while maintaining grid stability and reliability. This level of automation and control is essential for the transition towards a more resilient, sustainable, and adaptive grid infrastructure capable of meeting the evolving needs of modern society.

EMS:

Energy Management Systems (EMS) play a crucial role in the operation and control of systems, serving as the nerve center for monitoring, analyzing, and optimizing grid operations. EMS integrates advanced software, hardware, and communication technologies to provide real-time situational awareness and control capabilities to grid operators. Through continuous monitoring of key parameters such as voltage, current, frequency, and power flow, EMS enables operators to detect and respond to grid disturbances and operational issues promptly.

Moreover, EMS facilitates the implementation of advanced control strategies to maintain grid stability, reliability, and efficiency. It utilizes complex algorithms and optimization techniques to optimize power flow, manage congestion, and coordinate the operation of various grid assets such as generators, transformers, and shunt devices. By leveraging EMS capabilities, transmission system operators can enhance grid resilience, improve asset utilization, and support the integration of renewable energy sources and emerging technologies into the grid infrastructure, ultimately ensuring the reliable delivery of electricity to consumers.

WIDE AREA MONITORING:

Wide Area Monitoring Systems (WAMS) are integral components of modern transmission systems, offering enhanced situational awareness and control capabilities over wide geographical areas. These systems utilize synchronized measurements collected from Phasor Measurement Units (PMUs) installed at various points across the grid. PMUs precisely timestamp voltage and current measurements, allowing for the synchronization of data across different locations. By analyzing the synchronized phasor data in real-time, WAMS can provide grid operators with a comprehensive view of system dynamics, including voltage stability, oscillations, and power flows. The insights provided by WAMS enable operators to detect and respond to emerging grid issues more effectively, such as voltage instability or oscillatory behavior, which can potentially lead to cascading failures. Additionally, WAMS facilitate the implementation of advanced control strategies, such as wide-area damping control and oscillation damping, to improve grid stability and mitigate the impact of disturbances. By leveraging the capabilities of WAMS, transmission system operators can enhance grid resilience, optimize system performance, and ensure the reliable and efficient operation of the electric power grid.

PROTECTION AND CONTROL:

Protection and control systems in smart grid transmission technology are essential for ensuring the reliable and safe operation of the electrical grid. These systems encompass a variety of devices, algorithms, and protocols designed to detect and mitigate faults and disturbances in the transmission network. Advanced protective relays, such as digital relays, are deployed at key points in the grid to rapidly detect abnormal conditions, such as overcurrent, overvoltage, or fault currents, and isolate faulty sections to prevent cascading failures and minimize disruption to the grid.

Furthermore, smart grid transmission technologies integrate intelligent control algorithms and communication protocols to enable coordinated control of grid assets and enhance system resilience. Remote terminal units (RTUs) and intelligent electronic devices (IEDs) equipped with communication capabilities facilitate real-time monitoring and control of transmission equipment. Additionally, advanced control strategies, such as adaptive protection schemes and wide-area control, leverage data analytics and communication networks to optimize grid performance and enhance fault response capabilities.

Overall, protection and control systems in smart grid transmission technology play a critical role in ensuring grid reliability, efficiency, and resilience. By integrating advanced sensors, communication technologies, and control algorithms, these systems enable transmission operators to detect and mitigate grid disturbances swiftly, optimize asset utilization, and support the integration of renewable energy sources and other emerging technologies into the grid infrastructure. Ultimately, protection and control systems are fundamental components of a modernized transmission grid, capable of meeting the evolving demands of the electric power system.

IV. SMART GRID TECHNOLOGIES (Distribution)

DMS, Volt/VAr control, Fault Detection, Isolation and service restoration, Outage management, High Efficiency Distribution Transformers, Phase Shifting Transformers, Electric Vehicles.

DMS:

Distribution Management Systems (DMS) are pivotal components of smart grid technologies, focusing on enhancing the efficiency, reliability, and flexibility of power distribution networks. DMS integrates advanced hardware, software, and communication technologies to provide utilities with real-time monitoring, control, and optimization capabilities over their distribution infrastructure. These systems enable utilities to manage a wide range of distribution assets, including transformers, switches, capacitors, and voltage regulators, to ensure optimal performance and grid stability.

One of the key features of DMS is its ability to collect and analyze data from various sensors and intelligent electronic devices (IEDs) deployed throughout the distribution network. By leveraging advanced data analytics and machine learning algorithms, DMS can identify patterns, detect anomalies, and predict potential failures, allowing utilities to take proactive measures to prevent outages and improve system reliability. Additionally, DMS facilitates the integration of distributed energy resources (DERs) such as solar panels, wind turbines, and energy storage systems into the grid, enabling utilities to manage and optimize the flow of power bidirectionally.

Moreover, DMS enables utilities to implement advanced control strategies to optimize grid operations and respond to changing grid conditions in real-time. These strategies include fault detection and isolation, load balancing, voltage regulation, and outage management, among others.

By automating routine tasks and optimizing grid performance, DMS helps utilities improve operational efficiency, reduce energy losses, and enhance customer satisfaction. Overall, DMS is a critical enabler of the transition to a smarter, more resilient, and sustainable distribution grid, capable of meeting the evolving energy needs of the 21st century.

VOLT/VAR CONTROL:

Volt/VAr control is a key feature of smart grid technologies in distribution systems, aimed at optimizing voltage levels and reactive power flow to improve grid efficiency, reliability, and voltage stability.

This control strategy involves the adjustment of voltage levels and reactive power (VAr) injections at various points in the distribution network to maintain voltages within acceptable limits and minimize power losses.

Smart grid technologies employ advanced sensors, communication systems, and control algorithms to implement Volt/VAr control in real-time. Voltage sensors deployed across the distribution network continuously monitor voltage levels, while control algorithms analyze this data to determine optimal Var settings for voltage regulation. This information is then communicated to distribution equipment such as voltage regulators, capacitors, and power factor correction devices, which adjust their operations accordingly to maintain voltages within desired limits.

By dynamically adjusting VAr injections in response to changing grid conditions and demand patterns, Volt/VAr control helps utilities optimize power flow, reduce energy losses, and improve voltage stability. Additionally, Volt/VAr control plays a crucial role in integrating renewable energy resources and accommodating distributed generation into the grid. By managing voltage levels and reactive power flow, utilities can mitigate voltage fluctuations caused by intermittent renewable generation and ensure grid stability and reliability. Overall, Volt/VAr control is an essential component of smart grid technologies in distribution systems, enabling utilities to enhance grid performance, optimize asset utilization, and pave the way for a more resilient and sustainable energy future.

FAULT DETECTION, ISOLATION AND SERVICE RESTORATION:

Fault detection, isolation, and service restoration (FDIR) are critical functions of smart grid technologies in distribution systems, aimed at minimizing outage durations, improving grid reliability, and enhancing customer satisfaction. These systems utilize advanced sensors, communication networks, and data analytics to detect and localize faults in the distribution network swiftly. By continuously monitoring parameters such as voltage, current, and power quality, FDIR systems can identify abnormal conditions indicative of faults, such as short circuits or line disturbances.

Once a fault is detected, FDIR systems employ sophisticated algorithms to isolate the faulty section of the distribution network accurately. This involves the coordination of switches, reclosers, and other protective devices to isolate the faulted area while minimizing the number of affected customers.

By isolating faults quickly, FDIR systems help utilities reduce the scope of outages and restore service to unaffected areas more rapidly.

Moreover, FDIR systems facilitate automated service restoration by rerouting power flows and remotely controlling switches to restore power to affected customers. Advanced control algorithms analyze network topology and load conditions to determine the most efficient restoration sequence, considering factors such as feeder capacity and customer priority.

By automating the restoration process, FDIR systems help utilities improve outage response times, minimize customer inconvenience, and enhance overall grid resilience. In summary, fault detection, isolation, and service restoration are essential components of smart grid technologies in distribution systems, enabling utilities to mitigate the impact of faults and disruptions and deliver more reliable and resilient electricity service to customers.

OUTAGE MANAGEMENT:

Outage management in smart grid technologies for distribution systems involves the integration of advanced monitoring, communication, and control capabilities to efficiently detect, analyze, and respond to outages. These systems utilize real-time data from sensors and intelligent devices deployed throughout the distribution network to promptly identify the location and extent of outages. By leveraging sophisticated analytics and algorithms, outage management systems can analyze outage data, assess the impact on customers, and prioritize restoration efforts based on factors such as outage duration, customer criticality, and available resources.

Furthermore, outage management systems enable utilities to streamline communication and coordination among field crews, dispatch centers, and customer service teams, facilitating a more coordinated and efficient response to outages. Automated outage notification systems keep customers informed about the status of their service restoration, reducing frustration and enhancing customer satisfaction.

By optimizing outage response processes and leveraging advanced technologies, smart grid outage management systems help utilities minimize outage durations, improve service reliability, and enhance overall grid resilience.

HIGH-EFFICIENCY DISTRIBUTION TRANSFORMERS:

High-efficiency distribution transformers are a key component of smart grid technologies in distribution systems, aimed at reducing energy losses, improving grid efficiency, and lowering carbon emissions. These transformers are designed with advanced materials, improved insulation, and optimized designs to minimize energy losses during the conversion and transmission of electricity. By reducing losses, high-efficiency transformers help utilities conserve energy resources and lower operating costs, contributing to a more sustainable and environmentally friendly grid infrastructure.

Moreover, high-efficiency distribution transformers play a crucial role in supporting the integration of renewable energy sources and accommodating the growing demand for electricity. As more distributed generation sources such as solar and wind power are connected to the grid, the need for efficient transformers becomes increasingly important to minimize losses and maximize the utilization of renewable energy.

Additionally, high-efficiency transformers help utilities meet energy efficiency goals and regulatory requirements, promoting the adoption of environmentally responsible practices within the power sector. In summary, high-efficiency distribution transformers are essential components of smart grid technologies, enabling utilities to enhance grid performance, reduce environmental impact, and meet the evolving energy needs of the future.

PHASE SHIFTING TRANSFORMERS:

Phase shifting transformers (PSTs) are critical components of smart grid technologies in distribution systems, offering advanced control capabilities to manage power flow and voltage levels within the grid. These transformers allow utilities to adjust the phase angle and control the power flow between different phases or sections of the distribution network. By dynamically altering the phase relationship between input and output voltages, PSTs enable utilities to optimize power flow, balance loads, and alleviate congestion in the distribution system.

One of the key benefits of PSTs is their ability to improve grid stability and reliability by mitigating voltage fluctuations and reducing overloads in heavily loaded sections of the network. Additionally, PSTs can facilitate the integration of renewable energy sources by enabling utilities to manage the variability and intermittency associated with renewable generation. By strategically deploying PSTs at critical points in the distribution network, utilities can enhance grid flexibility, increase system efficiency, and support the transition to a more resilient and sustainable energy infrastructure.

Furthermore, PSTs can play a crucial role in enabling advanced grid control strategies, such as voltage regulation and power quality management. By adjusting the phase angle and controlling power flow, utilities can optimize voltage profiles, reduce losses, and improve overall grid performance. Additionally, PSTs can support the implementation of demand response programs by enabling utilities to manage peak demand and balance supply and demand more effectively.

In summary, phase shifting transformers are essential components of smart grid technologies in distribution systems, providing utilities with greater flexibility and control over grid operations to meet the evolving challenges of modern energy distribution.

ELECTRIC VEHICLES:

Electric vehicles (EVs) represent a significant opportunity and challenge for smart grid distribution systems.

As the adoption of EVs continues to grow, they introduce both benefits and complexities to the grid. On one hand, EVs offer a potential solution for reducing greenhouse gas emissions and dependence on fossil fuels by enabling the electrification of transportation. Moreover, EVs can serve as distributed energy storage resources, capable of storing and supplying energy back to the grid through vehicle-to-grid (V2G) technology. This bidirectional energy flow can help utilities manage peak demand, integrate renewable energy sources, and enhance grid stability.

However, the widespread adoption of EVs also presents challenges for distribution systems, such as increased demand on local distribution networks, especially during peak charging times. This could lead to overloading of transformers and distribution lines, as well as voltage fluctuations and power quality issues. To address these challenges, utilities are exploring various smart grid solutions, including advanced metering infrastructure (AMI) for EV charging stations, demand response programs, and grid-integrated charging management systems. These technologies enable utilities to manage EV charging loads more effectively, optimize grid operations, and ensure grid reliability and stability.

Overall, the integration of EVs into smart grid distribution systems presents both opportunities and challenges. By leveraging smart grid technologies and implementing innovative solutions, utilities can maximize the benefits of EV adoption while mitigating the potential impacts on grid infrastructure. This requires collaboration among stakeholders, including utilities, regulators, automakers, and consumers, to develop and implement policies and strategies that support the transition to a more sustainable and resilient energy future.

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.

5.4.1 Ring bus topology: A series of devices connected to one another by unidirectionaltransmission links to form a single closed loop.

5.4.2 Star topology: The end points on a network are connected to a common central hubor switch by dedicated links.

5.4.3 Tree topology: Identical to the bus topology except that branches with multiple nodesare 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.

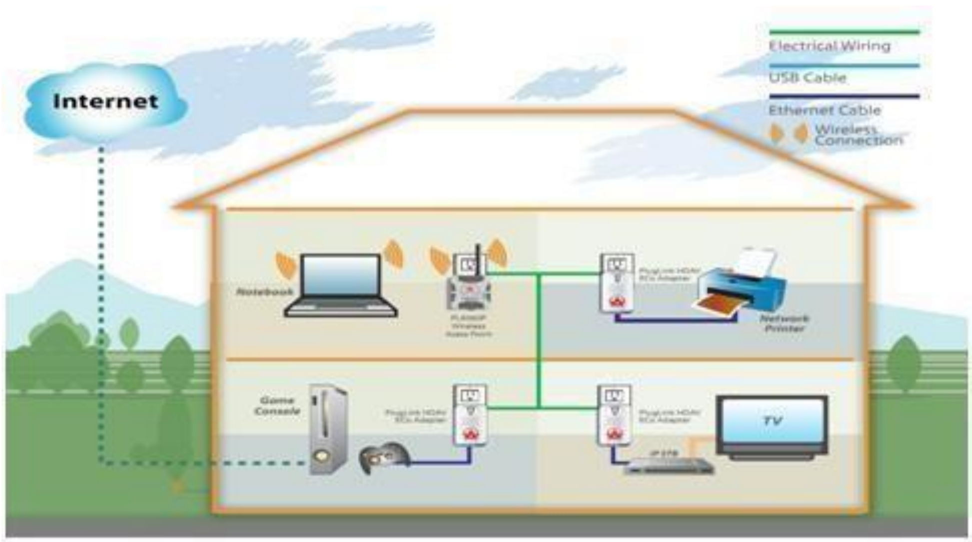

Figure 5.1: Home area network

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 overthe 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.

Requirements:

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.