UNIT 1

- **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.

- **Application of Smart Grid**

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

- **Give some of the benefits of Smart Grid**
    - Reduction in AT & C losses
    - Reduction in CO_2 Emission
    - Enabling Energy Audit
    - Reduction in Cost Billing
    - Remote Load Control

- **advantages of Smart Grid**
    - Improved Reliability
    - Higher asset utilization
    - Better integration of plug-in hybrid electric vehicles (PHEVs) and renewable energy
    - Reduced operating costs for utilities
    - Increased efficiency and conservation
    - Lower greenhouse gas (GHG) and other emissions

- Pillars of Smart Grid
    - Transmission Optimization
    - Demand Side Management
    - Distribution Optimization
    - Asset Optimization

- **Five Key Aspects of Smart Grid**

The Five Key aspects of smart grid development and deployment are,
    - Computational Intelligence
    - Power System Enhancement
    - Communication and Standards
    - Environment and Economics
    - Test-bed

- **Features of Smart Grid**
  - Reliability
  - Flexibility in Topology
  - Efficiency
  - Platform for advanced services

- **some of the challenges faced presently by the Indian Electricity System**

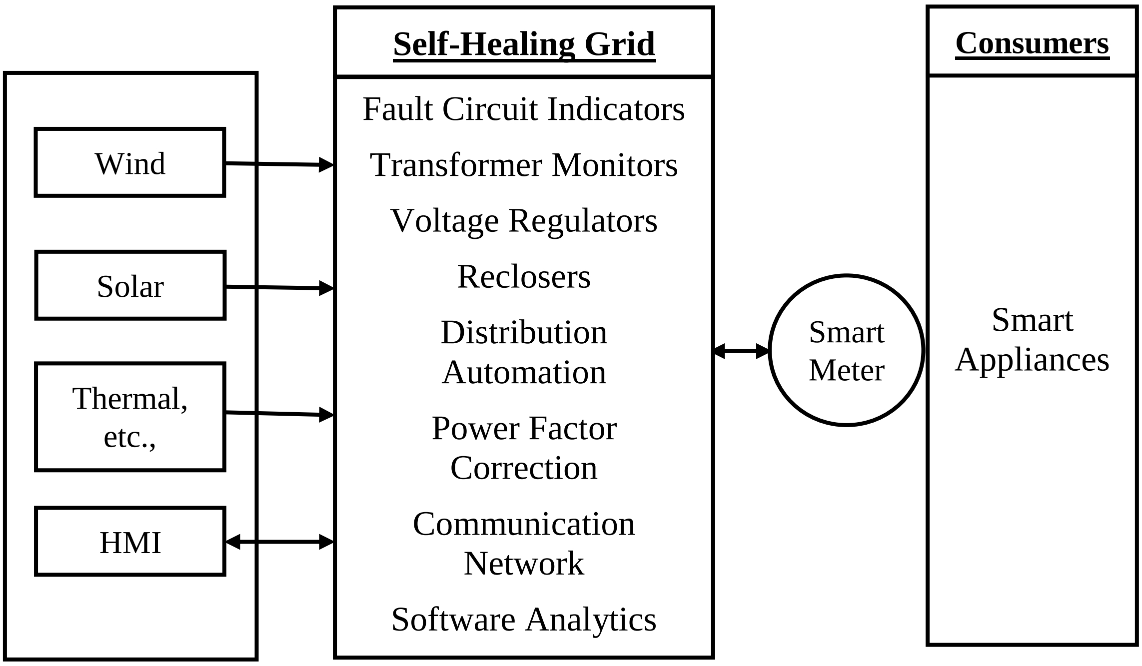
- Shortage of power
- Power Theft
- Poor access to electricity in Rural areas
- Huge losses in the Grid
- Inefficient Power Consumption
- Poor reliability

- **Self-Healing**

A smart grid automatically detects and responds to routine problems and quickly recover sif 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.



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

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.

Requirements of Self-HealingGrid:

System topology representation

- Feeders with single restoration path, generally open “tie switch”

Pre-fault system status

- Switch status (upstream and downstream information for devices)
- Pre-fault system loading (capacity check for the restoration)

Fault detection

- Based on recloser lockout status and reclosing counter value change, or substation breaker trip signal
- Downstream node of the lockout switch is the fault location

Fault isolation

- Downstream switch(es) of the fault location

Load restoration

- Start from the downstream node of the isolation switches

Benefits

- Allows utilities to focus investments on feeders that experience the most outages
- Fast implementation
- Initial low capital investment
- Target solution appropriate for problem feeders

Smart Grid and the need of Smart Grid?

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.

Need for establishment of Smart Grid:

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.

benefits of Smart Grid

- Self-Healing :A smart grid automatically detects and responds to routine problems 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.
- ProvidesPower Quality
- Optimizes Assets and Operates Efficiently
- Safety, Reliable and Efficient
- Improved National Security
- Improved Environmental Conditions
- Improved Economic Growth

Smart Grid drivers?

Drivers of Smart Grid

- **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: T**ransformers, 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)

Stages on Evolution of Smart Grid

	Elementary Stage	**Evolutionary Stage**	**Fully Integrated Smart Grid**
Metering	• Largely Manual Metering • Some automated Meters for large industrial users	• 100% Smart meters with automated meter reading with real time display	• Advance metering allowing real time rate changes and remote On/Off capability
Transmission Grid	• Zero automation in transmissionlines, switches and substations	• Ongoing automation of HV system and substations	• Full automation of HV System and Substations • All switches and flows remotely controlled
Distribution Network	• Zero automation of distribution network including substations & circuit breakers • Manual fault localisation	• Partly automated switches & circuit breakers along MV lines for fault identification • Manual LV Grid	• Fully remotely automated distribution network with remote sensing and voltage control capability
Integration	• Basic communication between grid components • Limited ability to control dispatch	• Online monitoring of flows in transmission grid and ability to balance system	• Total integration of supply and use of electricity • Ability to control dispatch and usage remotely

Comparsion between Conventional Grid and 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

Functions of Smart Grid Components

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

Smart Devices Interface Component

Smart devices for monitoring and control form part of the generation components real-time information processes.

These resources need to be seamlessly integrated in the operation of both centrally distributed and district energy systems.

Storage Component

Due to the variability of renewable energy and the disjoint between peak availability and peak consumption, it is important to find ways to store the generated energy for later use.

Options for energy storage technologies include pumped hydro, advance batteries, flow batteries, compressed air, super-conducting magnetic energy storage, super capacitors, and flywheels.

Transmission Subsystem Component

The transmission system that interconnects all major substation and load centers is the backbone of an integrated power system.

Transmission lines must tolerate dynamic changes in load and contingency without service disruptions.

Efficiency and reliability at an affordable cost continues to be the ultimate aims of transmission planners and operators.

MonitoringandControlTechnologyComponent

Intelligent transmission systems/assets include a smart intelligent network, self-monitoring and self-healing, and the adaptability and predictability of generation and demand robust enough to handle congestion, instability, and reliability issues.

This new resilient grid has to withstand and be reliable to provide real - time changes in its use.

Intelligent Grid Distribution Subsystem Component

The distribution system is the final stage in the transmission of power to end users. Primary feeders at this voltage level supply small industrial customers and secondary distribution feeders supply residential and commercial customers.

At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components, and AMI

Demand Side Management Component

DSM options provide reduced emissions in fuel production, lower costs, and contribute to reliability of generation. These options have an overall impact on the utility load curve.

Demand side management options and energy efficiency options developed for effective means of modifying the consumer demand to cut operating expenses from expensive generators and defer capacity addition.

The Challenges of Smart Grid Technology

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 outages and 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 wind penetration
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 not ease 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 and privacy 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 system stability with grid complexity
Power Quality	Disturbance Identification	Grid disturbances due to local faults in grids, load centres or sources
	Harmonics Suppression	System instability during sags, dips or voltage variation such as over-voltages, under-voltages, voltage flickers, etc.

the SWOT analysis of Smart Grid.

Strengths:

Self-healing systems are desirable to prevent dependence on human intervention at critical moments; by providing the systems with enough data, they can make smart decisions at the right moment: artificial intelligence (AI). With the tremendous growth of digital technologies, providing information faster and with fewer errors in communication, the smart grid will utilize a digital platform.

Demand and load management are critical parts of the concept, as they helps to optimize delivery and consumption by reducing customer demands at peak hours.

Another important feature of SG is that, due to the system transparency, we are able to see what is happening at all times in real-time.

Weaknesses:

Cyber security anticipates compromises of adjacent systems. This has been a major concern area addressed by IT under SG.

A smart grid contains so many sensors and devices that it increases the system complexity for maintenance and repairs. There could be failures in communications link, sensor and/or actuator, unplanned control center system failure, and nonexistent, late, or improper commands by untrained and/or distracted control room personnel.

As more modern and state of the art devices are integrated into the SG, there are possible compatibility issues.

Opportunities:

Cyber security controls will become more critical in future systems. Balancing demand and generation using SGD can achieve optimal flow.

An information security active defense model will not only protect but also defend the system from attacks and unexpected responses.

SG can have decentralized storage areas to achieve the desired system balance.

Threats:

Communication channels in the future may be more dedicated, creating a need for dedicated conduits for SG, affecting cost and reliability of the system. Due to the complexity of grid, it might not be easy to provide technical support from a single source.

As web applications are preferred targets of hackers, the SG might be attacked until its vulnerabilities are found. New regulations may have an impact on the grid as well.

SWOT analysis of Smart Grid.

Strength:	**Threats:**
◆ Anticipates compromises	◆ Dedicated communication

◆ Self-Healing ◆ Digitalised Platform ◆ Load Management ◆ Decentralised Controls ◆ Customised ◆ Renewable Resources ◆ Autonomous ◆ Transparency	channels ◆ Complex technical support ◆ Hackers attacks on Web applications ◆ New regulations
Weakness: ◆ Complexity ◆ Communications Link Failure ◆ Sensor/Actuator Failure ◆ Control System Failure ◆ Lack of Operator Response ◆ Late Human Response ◆ Improper Operator Command ◆ Compatibility Issues	**Opportunities:** ◆ Cyber Security in future ◆ Optimal Power Flow ◆ Defense Model ◆ Decentralised Storage.

technologies for Smart Grid

There are several technologies under the umbrella of Smart Grid Distribution (SGD); the most typical ones are

Advanced Metering Infrastructure (AMI): AMI is architecture for automated, two-way communication between a smart utility meter with an IP address and a utility company.

Demand Response (DR): Demand response is a change in the power consumption of an electric utility customer to better match the demand for power with the supply.

Distribution Automation (DA): It optimises a utility’s operations and directly improves the reliability of its distribution power system.

Electric Vehicles (EV): Electric Vehicles are being introduced in the market as an option for transportation so as to eliminate Carbon Foot Prints, etc.,

Distributed Generation (DG): Distributed generation (also known as Distributed Energy) refers to power generation at the point of consumption.

System Efficiency Improvement: By adopting Smart Sensors, AMI, IED’s, Automated control schemes, etc., enables cost reduction and improves the system Efficiency

Self-Healing: A smart grid automatically detects and responds to routine problems and quickly recovers if they occur, minimizing downtime and financial loss.

Cyber security: Cyber Security is the body of technologies, processes and practices designed to protect networks, Computers, Programs and Data from attack, damage or unauthorized access.

Distributed Storage: Energy storage to facilitate greater flexibility and reliability of the power system.

Information and communications technologies:

Two-way communication technologies to provide connectivity between different components in the power system and loads.

- Open architectures for plug-and-play of home appliances, Electric Vehicles and Micro Generation
- Communications, and the necessary software and hardware to provide customers with greater information,
- Software to ensure and maintain the security of information and standards

Sensing, Measurement, Control and Automation Technologies:

Intelligent Electronic Devices (IED) to provide advanced protective relaying, measurements, fault records and event records for the power system;

- Phasor Measurement Units (PMU) and Wide Area Monitoring, Protection and Control (WAMPAC) to ensure the security of the power system;
- Information and communication technologies provide rapid diagnosis and timely response to any event in different parts of the power system.
- Smart appliances, communication, controls and monitors to maximise safety, comfort, convenience, and energy savings of homes
- Smart meters, communication, displays and associated software to allow customers to have greater choice and control over electricity and gas use.
- Energy storage to facilitate greater flexibility and reliability of the power system.

UNIT 2

Feeder Automation

Feeder Automation Solution reduces capital investment in the distribution network by limiting the replacement of legacy devices. It contributes to more direct cost savings by facilitating preventative maintenance. Arctic Control is also ideally suited to retrofitting into existing disconnectors. It enables remote control of these devices and further extends the life cycle of the disconnectors themselves.

Feeder Automation Solution provides means for the utilities to reduce the frequency of power outages and faster restoration time by remote monitoring and control of medium voltage network assets such as disconnectors, load break switches and ring main units in energy distribution networks. It provides an always-on wireless connectivity together with the intelligence needed for disconnector control and monitoring.

Wireless connectivity is implemented via commercial mobile networks, thus reducing investment and operational costs. Used in conjunction with always-on communication from a SCADA system, this method achieves an ideal combination of local and centralized intelligence for real time systems in a cost-efficient way

Plug in Hybrid Electric Vehicles (PHEV)

Plug-In Hybrid Electric vehicles (PHEVs) are being introduced in the market as 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 result batteries 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 the distribution 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.

Types of PHEVs:

1. Series PHEV's or Extended Range Electric Vehicles (EREV's)
   Series PHEV's or Extended Range Electric Vehicles (EREV's): only the electric motor turns the wheels, the ICE is only used to generate electricity. Series PHEV's can run solely on electricity until the battery needs to be recharged. The ICE will then generate the electricity needed to power the electric motor. For shorter trips, these vehicles might use no gasoline.
2. Parallel or Blended PHEV's
   Parallel or Blended PHEV's: Both the engine and electric motor are mechanically connected to the wheels, and both propel the vehicle under most driving conditions. Electric only operation usually occurs at low speed.

the parts of DR system

DR system consists of the following major parts:
Prime movers, Power converters, Transformer, switches, relays, and communications devices

- Prime movers—this represents the primary source of power. There are several prime movers available today, such as reciprocating engines, CTs, microturbines, wind turbines, PV systems, fuel cells, and storage technologies.
- Power converter—this represents the way that power is converted from one entity to another. Synchronous generators, induction generators, double-fed asynchronous generators, inverters, and static power converters are examples of power converters.
- Transformer, switches, relays, and communications devices—these devices enable the protection of the DR from the distribution system and vice versa.

some of the Technologies of Smart Grid Distribution?

There are several technologies under the umbrella of Smart Grid Distribution (SGD); the most typical ones are

- Advanced Metering Infrastructure (AMI)
- Demand Response (DR)
- Distribution Automation (DA)
- Electric Vehicles (EV)
- Distributed Generation (DG)
- System Efficiency Improvement
- Self-Healing
- Cyber security
- Distributed Storage

Outage Management System (OMS)

Outage management system (OMS)

The OMS is a system which combines the trouble call centre and DMS tools to identify, diagnose and locate faults, then isolate the faults and restore supply. It provides feedback to customers that are affected. It also analyses the event and maintains historical records of the outage as well as calculating statistical indices of interruptions. The information flow of an OMS is shown in Figure 7.18. Outage management is important in distribution networks with goals (and sometimes penalties) to restore the supply to a faulted section of the network within a period of time. The main functions of each part of OMS are as follows.

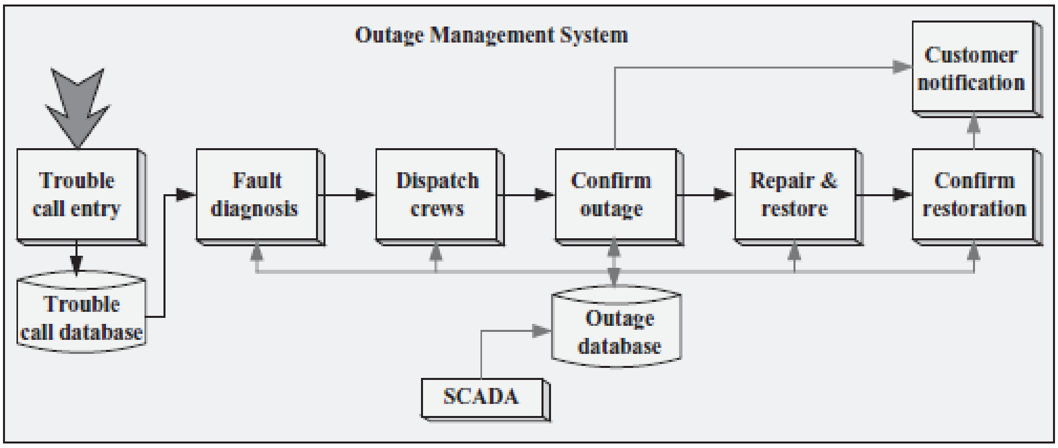


Figure 7.18 Information flow of the OMS

Fault identification

Fault identification is based on customer calls through telephone voice communication. It may also use automatic voice response systems (Computer Telephony Integration – CTI), automatic outage detection/reporting system, or SCADA detection of circuit breaker trip/lockout.

Fault diagnosis and fault location

Fault diagnosis and fault location are carried out based on the grouping of customer trouble calls using reverse tracing of the electrical network topology. It determines the protective device that is suspected to be open, for example, fuse, sectionaliser, recloser, or substation circuit breaker. Automatic feeder switching is also taken into account. The extent of the suspected outage will be calculated including the number of customers affected and the priority of the affected customers. Confirmation or modification of the fault diagnosis and its location is based on feedback from field crews.

Supply restoration

Remedial action depends on the severity of the problem. If the fault is a simple problem, the field crew can make the repair and restore supplies in a short time. If the fault causes a major outage, after the isolation of the faulted area, the un-faulted portions will be restored using normally open points. The OMS tracks partial restorations. Automated fault detection, isolation, restoration schemes with feeder automation is widely used. Computer aided modelin

Feeder Automation with its Application & Features

Feeder Automation Solution reduces capital investment in the distribution network by limiting the replacement of legacy devices. It contributes to more direct cost savings by facilitating preventative maintenance. Arctic Control is also ideally suited to retrofitting into existing disconnectors. It enables remote control of these devices and further extends the life cycle of the disconnectors themselves.

Feeder Automation Solution provides means for the utilities to reduce the frequency of power outages and faster restoration time by remote monitoring and control of medium voltage network assets such as disconnectors, load break switches and ring main units in energy distribution networks. It provides an always-on wireless connectivity together with the intelligence needed for disconnector control and monitoring.

Wireless connectivity is implemented via commercial mobile networks, thus reducing investment and operational costs. Used in conjunction with always-on communication from a SCADA system, this method achieves an ideal combination of local and centralized intelligence for real time systems in a cost-efficient way

Devices & Features:
Ultra High-speed Automatic Transfer Scheme (ATS) for Critical Loads
Fault Location, Isolation and Service Restoration (FLISR)
Communication and Networking Technology
Remote Terminal Unit
Remotely Operable Switch
Application Specific Integrated Circuit (ASIC)
DA software
Distribution Network Simulator

Flexible configuration
Quick, automated restoration
Multiple communication options
Use of any standard recloser
Small footprint
Integrated automation controller for local control
Protects critical loads

- Safety & Security:
  Proven & reliable solution with high degree of safety (Limited skilled staff) and data security.
- Reduce outage & improve consumer satisfaction:
  Introduce redundancies and reduce the down time during faults.
  Create infrastructure to implement Automated Outage Management System.

- Low operational cost:
  Low operational cost in terms of Communication rentals, Maintenance & Troubleshooting.
  Least or no reflection on tariff

Phase Shifting Transformer

Thyristor-controlled phase shifting transformer

Phase shifters are widely used in power systems for controlling the magnitude and direction of the active power flow, often over parallel circuits. The principle of operation of the conventional phase shifter is explained in Figure 11.12a.

Control of the magnitude and direction of active power flow on the line is achieved by injecting a voltage in series with the line, thus changing the phase angle of the receiving end voltage. A variable series voltage is obtained by a tap changer acting on the regulating winding. This voltage is in quadrature with the input voltage. It is then injected by the booster winding across the series winding. [8].

Rapid phase angle control can be accomplished by using a Thyristor Switching network to vary the injected voltage. One possible arrangement is shown in Figure 11.12b. In this case one choice would be, to select the number of turns in two regulating windings in the ratio 1 : 3. When winding 1 is connected, a series voltage, say, *V*, is injected in series with the line. The connection could be reversed, thus getting -*V* injected voltage. Winding 2 (gives injected voltage of ±3 *V*) and winding 1 (gives injected voltage of ±*V*) could be used to generate injected voltages from −4 *V* to +4 *V* in steps of *V*.

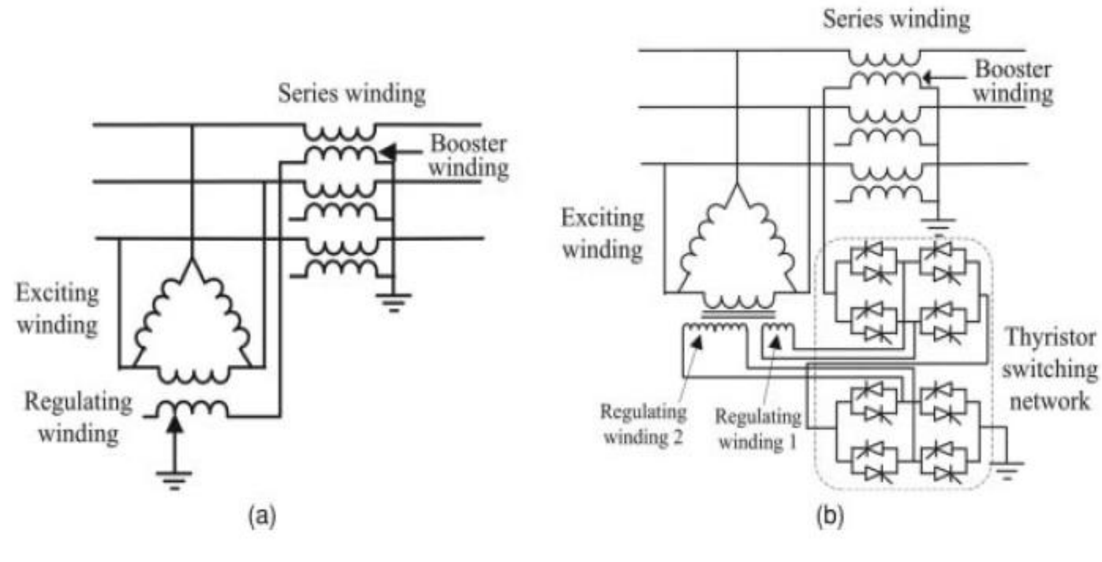


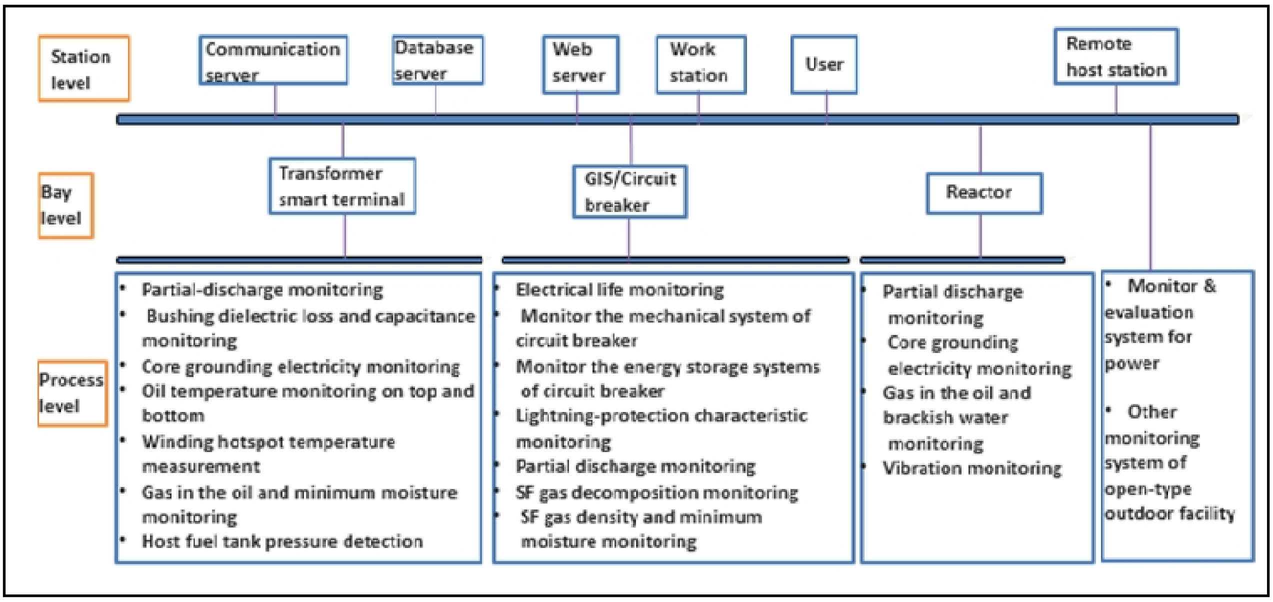
Figure 11.12 Phase shifter. *Note:* Only single phase connection to the booster winding is shown

Smart Substation

The number of distributed energy resources and new appliances with power electronics in the distribution grid rapidly grows. This leads to power quality problems and power flow fluctuations.

An Intelligent Distribution Station is designed to maintain power quality and reliability in an economic way.

Station level includes sub-system like automation system, control system for standing area, communication system and standard time system, etc. It is used to meet the function of the primary device, to detective and control the whole or more than one station device, and to perform the function of data collection, monitoring control(SCADA), lockout operation, and synchronous phase collection, electric energy collection, information protection and relevant function.



Features of the Smart Station:

1. Improving power quality, reliability and load profile
2. Control of voltage pollution
3. Demand Response,
4. A system for local control and remote monitoring
5. An electricity storage system, consisting of a battery and a bi-directional inverter (ESI)
6. Stepless control of the voltage level on the LV bus bar, performed by a smart transformer
7. Bidirectional communication between home appliances and the Smart MV/LV-station, using a home automation system .

Monitoring Device & Protection Device

Communication failure detector
SF6 gas leakage monitoring system
The electronic harmonic analyzer
Microcomputer protection devices
Current limiting intelligent protector
Intelligent circuit controller, etc.
Circuit breaker online monitoring
Standard time system
Low voltage motor protection controller
Smart electricity meter etc.

Energy management systems

An EMS monitors and manages flows in the higher-voltage transmission network.

A distribution management system (DMS) monitors and manages flows in the lower-voltage distribution network.

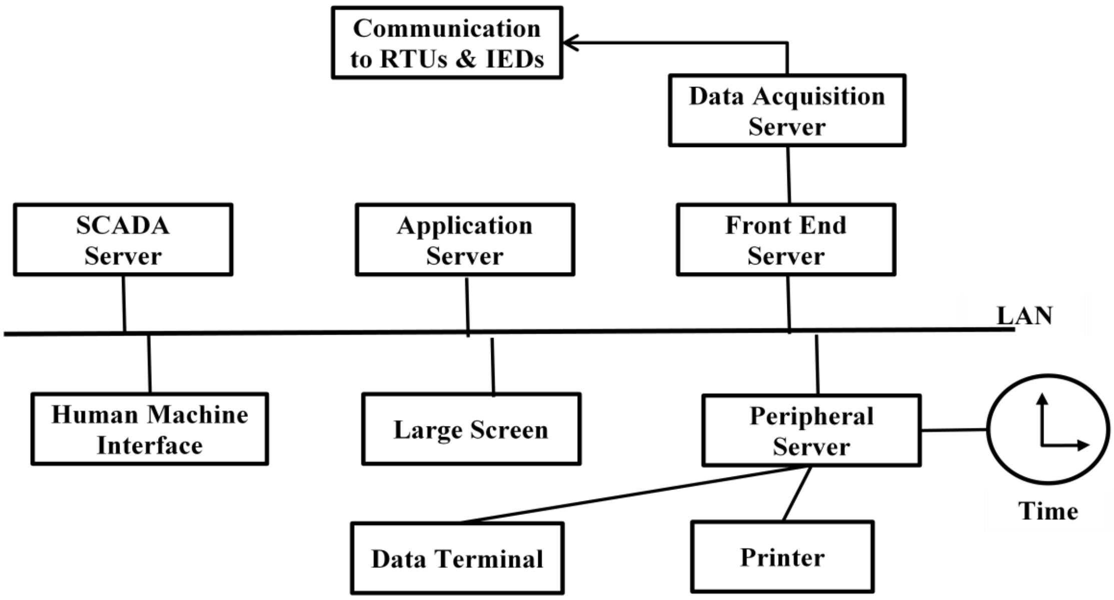
Real-time monitoring of grid conditions. The first EMS application placed in control centers across the country was known as the supervisory control and data acquisition (SCADA) system.

Energy management is doing more with the same amount of energy or less energy. Energy management saves money and makes buildings more comfortable, healthy, and safe.

Energy Management Systems (EMS) was designed originally at a time when the electrical power industry was vertically integrated and had centralised communications and computing systems.

With deregulation of the power industry and the development of the Smart Grid, decision-making is becoming decentralised, and coordination between different actors in various markets becomes important.

A typical EMS system configuration is shown in Figure



A Typical EMS System

System status and measurement information are collected by the Remote Terminal Units (RTUs) and sent to the Control Centre through the communication infrastructure. The front-end server in the EMS is responsible for communicating with the RTUs and IEDs. Different EMS Applications reside in different servers and are linked together by the Local Area Network (LAN).

EMS Applications include Unit Commitment, Automatic Generation Control (AGC), and security assessment and control. However, an EMS also includes

Applications similar to those of a DMS and most of the tools used in a DMS such as: topological analysis, load forecasting, power flow analysis, and state estimation.
The purpose of Unit Commitment within a traditional power system is to decide how many and which generators should be used and to allocate the sequence of starting and shutting down generators.
Similarly, in a power system, AGC carries out load frequency control and economic dispatch. Load frequency control has to achieve three primary objectives to maintain: (1) system frequency; (2) power interchanges with neighboring control areas; and (3) power allocation between generators at the economic optimum. AGC also performs functions such as reserve management (maintaining enough reserve in the system) and monitoring/recording of system performance.
The security assessment and control Application includes; security monitoring, security analysis, preventive control, emergency control, fault diagnosis and restorative control. The tools required include:

- Network topology analysis
- External system equivalent modeling
- State estimation
- On-line power flow
- Security monitoring (on-line identification of the actual operating condition – secure or insecure)
- Contingency analysis.

When the system is insecure, security analysis informs the operator which contingency is causing insecurity and the nature and severity of the anticipated emergency.

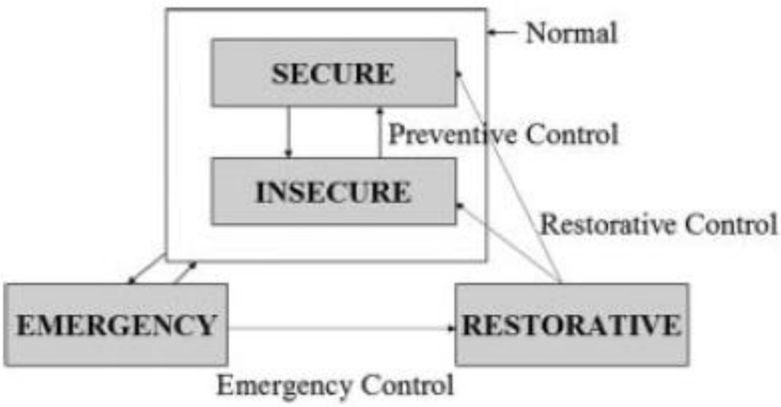


Figure 8.8 The Dy Liacco Framework for security assessment and control

The DyLiacco framework considers the power system as being operated under two types of constraint: load constraints (load demand must be met), and operating constraints (maximum and minimum operating limits together with stability limits should be respected). In the normal state, both these constraints are satisfied. The security assessment and control Application includes; security monitoring, security analysis, preventive control, emergency control, fault diagnosis and restorative control.

the Smart Sensor

A smart sensor is a device that takes input from the physical environment and uses built-in compute resources to perform predefined functions upon detection of specific input and then process data before passing it on.

A sensor that includes a microprocessor that conditions the signals before transmission to the control network. It filters out unwanted noise and compensates for errors before sending the data. Some sensors can be custom programmed to produce alerts on their own when critical limits are reached.

Smart sensors enable more accurate and automated collection of environmental data with less erroneous noise amongst the accurately recorded information. These devices are used for monitoring and control mechanisms in a wide variety of environments including smart grids, battlefield reconnaissance, exploration and a great number of science applications.

Sensors will be Key enabler for the Smart Grid to reach its potential. The idea behind the "Smart" Grid is that the Grid will respond to real-time demand, in order to do this, it will require sensors to provide real-time information.

Basic measurements:
Voltage Sensing, Current Sensing, Temperature Sensing,Moisture Sensing,Continuity Sensingand Phase Measurements

Wireless Sensor Networks for Automated Meter Infrastructure (AMI)
Smart Voltage Sensors
Smart Capacitor Control: That can Monitor and control Capacitor Banks Remotely
Smart Sensors for Outage Detection
Smart Sensors for Transformer Monitoring
High Voltage Line Temperature and Weather Condition Sensors
Distributed Generation Sensors for Load Balancing

Potential advantages of the smart-sensor concept include:

- Lower Maintenance
- Reduced Down Time
- Higher Reliability
- Fault Tolerant Systems
- Lower Cost
- Lower Weight

the Smart Meter

A smart meter is an electronic measurement device installed by the utility to maintain a two-way communication between the consumer and the utility and 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 thus facilitate real-time pricing, automated recording of the electricity consumption and a complete eradication of errors due to manual readings and reduce labor cost and enable instant fault detection.

Advantages of Smart Meters

1. 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.

2.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.

3. 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.

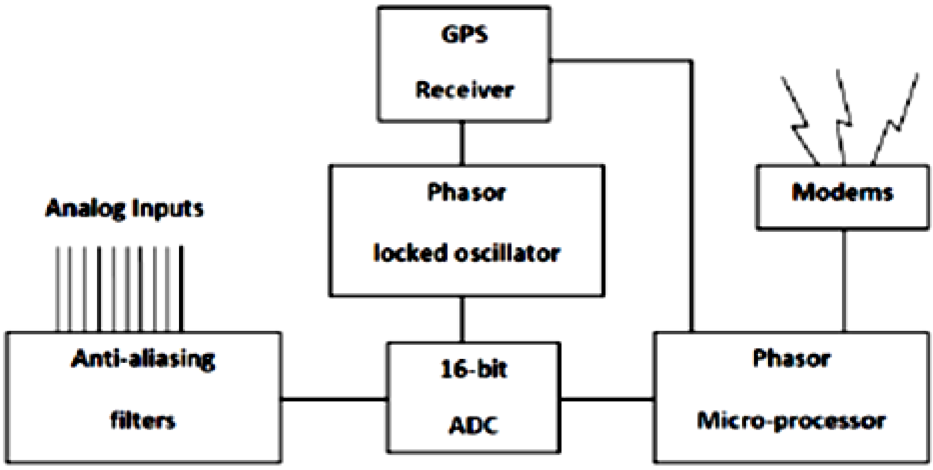
4. Automatic outage detection: A person having a conventional meter has to call the utility whenever there is a power outage whereas in case of smart meters, there is automatic outage detection as they are constantlysynchronised with the electric grid.

5. 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.

Phase Measurement Unit (PMU)

Phasor Measurement Units (PMUs) are electronic devices that use digital signal-processing components to measure AC waveforms and convert them into phasors, according to the system frequency, and synchronize these measurements under the control of GPS reference sources.

The analog signals are sampled and processed by a recursive Phasor algorithm to generate Voltage and Current Phasor. Different components of a PMU are shown by a block diagram in below fig.



Components of a Phasor Measurement Unit

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.

IED configuration consist of

1. Analog/Digital Input from Power Equipment and Sensors
2. Analog to Digital Convertor (ADC)/Digital to Analog Converter (DAC)
3. Digital Signal Processing Unit (DSP)
4. Flex-logic unit
5. Virtual Input/ Output
6. Internal RAM/ROM
7. Display

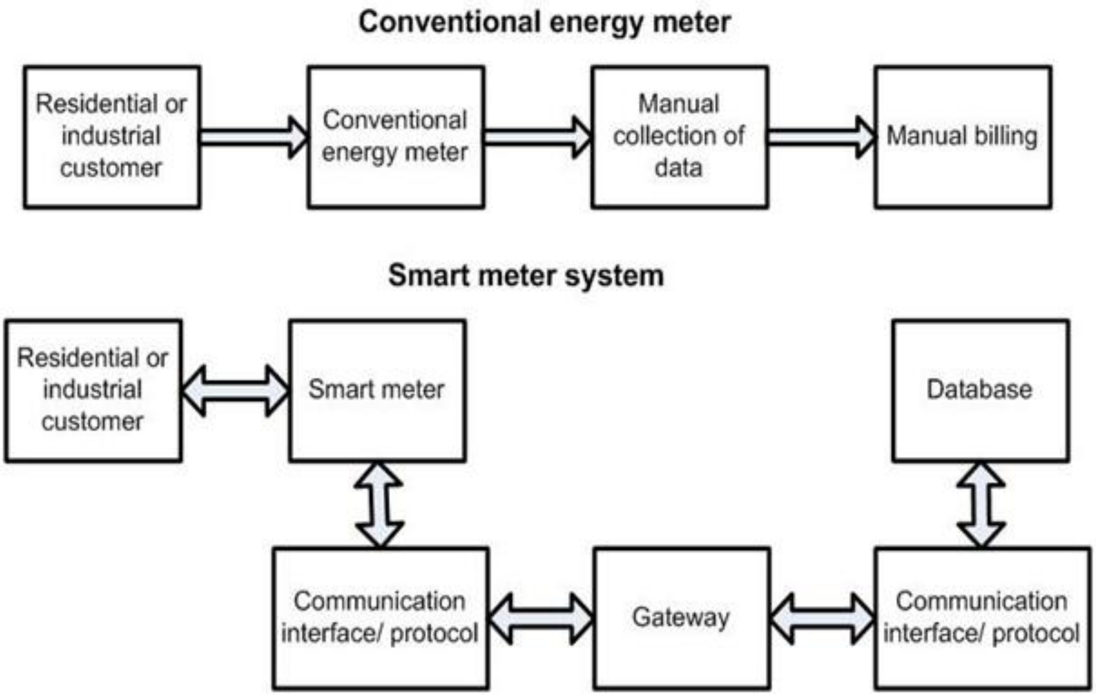
Intelligent electronic devices (IEDs) are Microprocessor-Based devices with the capability to exchange data and control signals with another device (IED, Electronic Meter, Controller, SCADA, etc.) over a communications link. IEDs perform Protection, Monitoring, Control, and Data Acquisition functions 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. Automation involves the deployment of substation and feeder operating functions and applications ranging from SCADA and alarm processing to integratedVolt/VArControl (IVVC) in order to optimize the management of capital assets and enhance operation and maintenance (O&M) efficiencies with minimal human intervention. 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.

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



Smart Meters and give its functions when deployed in domestic sectors

A smart meter is an electronic measurement device installed by the utility to maintain a two-way communication between the consumer and the utility and 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 thus facilitate real-time pricing, automated recording of the electricity consumption and a complete eradication of errors due to manual readings and reduce labor cost and enable instant fault detection.

Advantages of Smart Meters

1. **Accuracy in meter reading:**
2. **Data Recording:**
3. **Real time tracking:**
4. **Automatic outage detection:**
5. **Better service:**

The subsystems of a smart sensor include:

- A Primary Sensing Element
- Excitation Control
- Amplification (Possibly Variable Gain)
- Analog Filtering

- Data Conversion
- Compensation
- Digital Information Processing
- Digital Communications Processing
- Power Supply.

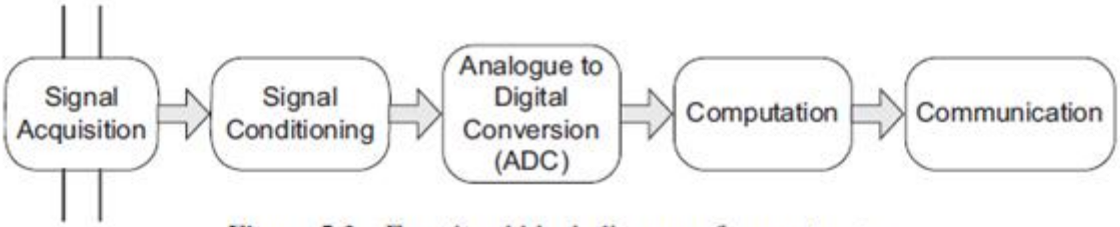


Figure 5.3 Functional block diagram of a smart meter

Evolution of Electricity Metering

The most common type of meter is an accumulation meter, which records energy consumption over time. Accumulation meters in consumer premises are read manually to assess how much energy has been used within a billing period. Smart meters are more sophisticated as they have two-way communications and provide a real time display of energy use and pricing information. Figure 5.1 shows the evolution of electrical metering, from simple electro-mechanical accumulation metering to advance Smart Metering.

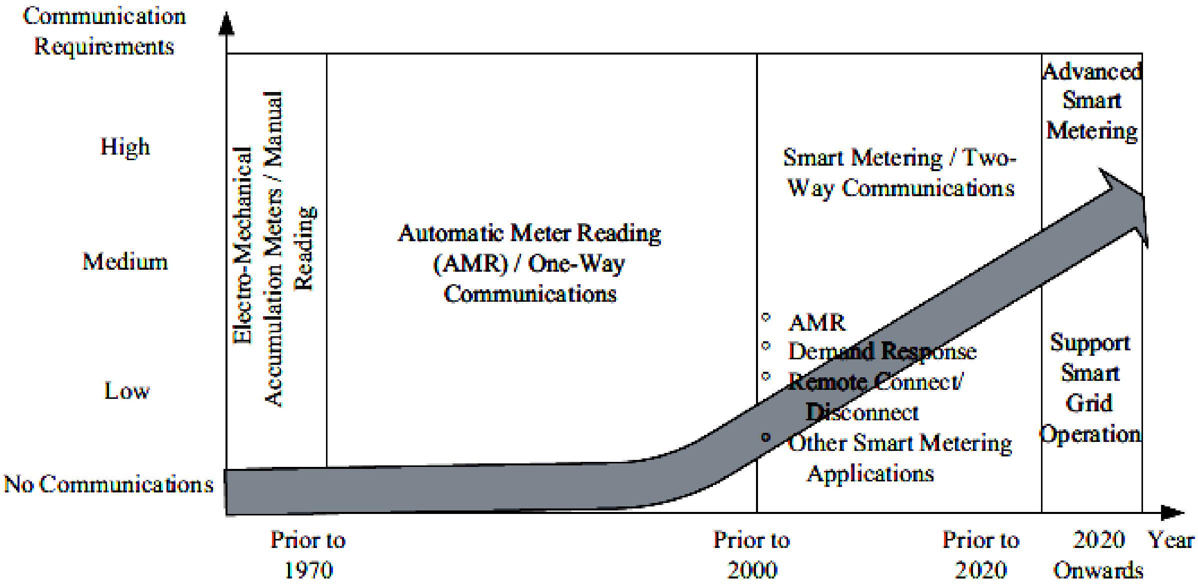
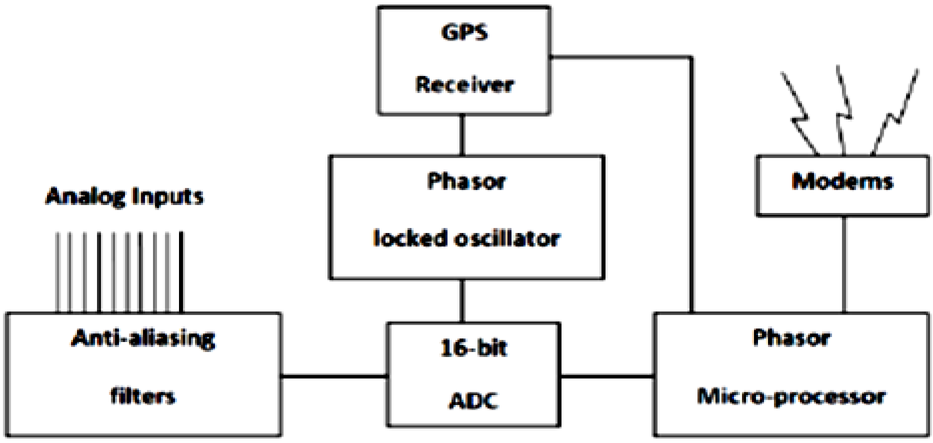


Figure 5.1 Evolution of electricity metering

Role of Phasor Measurement Unit in Smart Grid

Phasor Measurement Units (PMUs) are electronic devices that use digital signal-processing components to measure AC waveforms and convert them into phasor, according to the system frequency, and synchronize these measurements under the control of GPS reference sources. The analog signals are sampled and processed by a recursive Phasor algorithm to generate Voltage and Current Phasor. Different components of a PMU are shown by a block diagram in below fig.

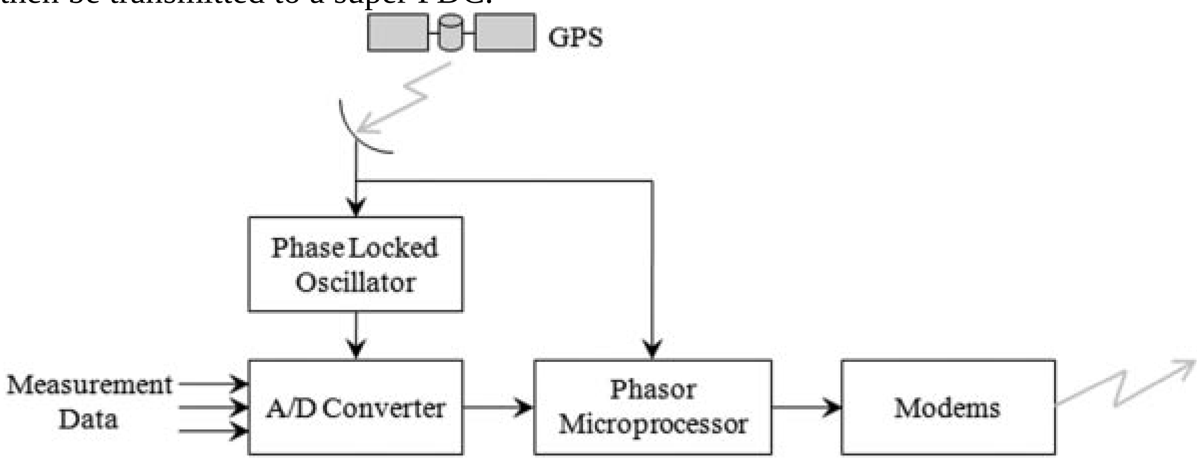


Components of a Phasor Measurement Unit

A Phasor network consists of Phasor measurement units (PMUs) dispersed throughout the electricity system, Phasor Data Concentrators (PDC) to collect the information and a Supervisory Control And Data Acquisition (SCADA) system at the central control facility. Such a network is used in Wide Area Measurement Systems (WAMS).

From the voltage and current samples, the magnitudes and phase angles of the voltage and current signals are calculated in the Phasor microprocessor of the PMU. As the PMUs use the clock signal of the Global Positioning System (GPS) to provide synchronised phase angle measurements at all their measurement points, the measured Phasor are often referred to as synchrophasors.

The data from different PMUs distributed in the grid is transmitted to a Phasor Data Concentrator (PDC) located at the control centre. The PDC collects and sorts the data by time stamp until the arrival of the slowest data. The data concentrated by the PDC is then utilised for different applications at the control centre. Data collected from several PDCs distributed over a particular area may then be transmitted to a super PDC.



A PDC collects phasor data from multiple PMUs or other PDCs, aligns the data by time tag to create a synchronized dataset, and then passes the data on to applications processors. For applications that process PMU data from across the grid, it is vital that the measurements are time aligned based on their original time tag to create a system-wide, synchronized snapshot of grid conditions. To accommodate the varying latencies in data delivery from individual PMUs, and to take into account delayed data packets over the communications system, PDCs typically buffer the input data streams and include a certain “wait time” before outputting the aggregated data stream.

PMUs often use phone lines to connect to PDCs, which then send data to the SCADA or Wide Area Measurement System (WAMS) server. Additionally, PMUs can use mobile (cellular) networks for data transfer (GPRS, UMTS, etc.,), which allows potential savings in infrastructure and deployment costs, at the expense of a larger data reporting latency.

Applications:
Phasor Measurement Technology and synchronized time stamping can be used for Security improvement through synchronized encryptions like trusted sensing base. Cyber attack recognition by verifying data between the SCADA system and the PMU data.

concept of Advanced Metering Infrastructure (AMI)

AMI is the convergence of the grid, the communication infrastructure, and the supporting information infrastructure. The network - centric AMI coupled with the lack of a composite set of cross industry AMI security requirements and implementation guidance, is the primary motivation for its development. The problem domains to be addressed within AMI implementations are relatively new to the utility industry; however, precedence exists for implementing large - scale, network - centric solutions with high information assurance requirements. The defense, cable, and telecom industries offer many examples of requirements, standards, and best practices that are directly applicable to AMI implementations.

The functions of AMI can be subdivided into three major categories:
Market applications: serve to reduce/eliminate labor, transportation, and infrastructure costs associated with meter reading and maintenance, increase accuracy GIS AND GOOGLE MAPPING TOOLS 23 of billing, and allow for time - based rates while reducing bad debts; facilitates informed customer participation for energy management

Customer applications: serves to increase customer awareness about load reduction, reduces bad debt, and improves cash flow, and enhances customer convenience and satisfaction; provides demand response and load management to improve system reliability and performance

Distribution operations: curtails customer load for grid management, optimizes network based on data collected, allows for the location of outages and restoration of service, improves customer satisfaction, reduces energy losses, improves performance in event of outage with reduced outage duration and optimization of the distribution system and distributed generation management, provides emergency demand response

Monitoring, control, and data acquisition will extend further down the network to the distribution pole-top transformer and perhaps even to individual customers by means of an advanced metering infrastructure (AMI) and/or demand response and home energy management systems on the Home Area Network (HAN).

More granular field data will help increase operational efficiency and provide more data for other smart grid applications, such as outage management.

AMI networks enable utilities to accomplish meter data collection, customer participation in demand response, and energy efficiency and support the evolution of tools and technology that will drive the smart grid future, including integration of electric vehicles and distributed generation.
Without the collection of AMI (interval) metering data, it is difficult to determine when customer consumption occurs in time

Smart meters and related sub meters that form the end points in the AMI architecture provide two critical roles. One is access to more granular interval usage data; Second a durable communications link that is bidirectional (two-way) to deliver messages/instructions to the meter.

The purpose of an AMI communications system is to provide electric utilities with a communications network permitting connectivity between grid devices such as electric meters and a head-end system.
AMI communications network options are numerous: they can be power line carrier (PLC), satellite, cellular (2G, 3G, or 4G), WiMAX, RF mesh, etc.

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.

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. Automation involves the deployment of substation and feeder operating functions and applications ranging from SCADA and alarm processing to integrated volt/VAr control (IVVC) in order to optimize the management of capital assets and enhance operation and maintenance (O&M) efficiencies with minimal human intervention.

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.

Smart Meters can play an important role to make a system Smart.
Smartmeters are even more sophisticated as they have twoway communications and provide a real-time display of energy use and pricing information, dynamic tariffs and facilitate the automatic control of electrical appliances.
Figure 5.1 shows the evolution of electrical metering, from simple electro-mechanical accumulation metering to advance smart metering.

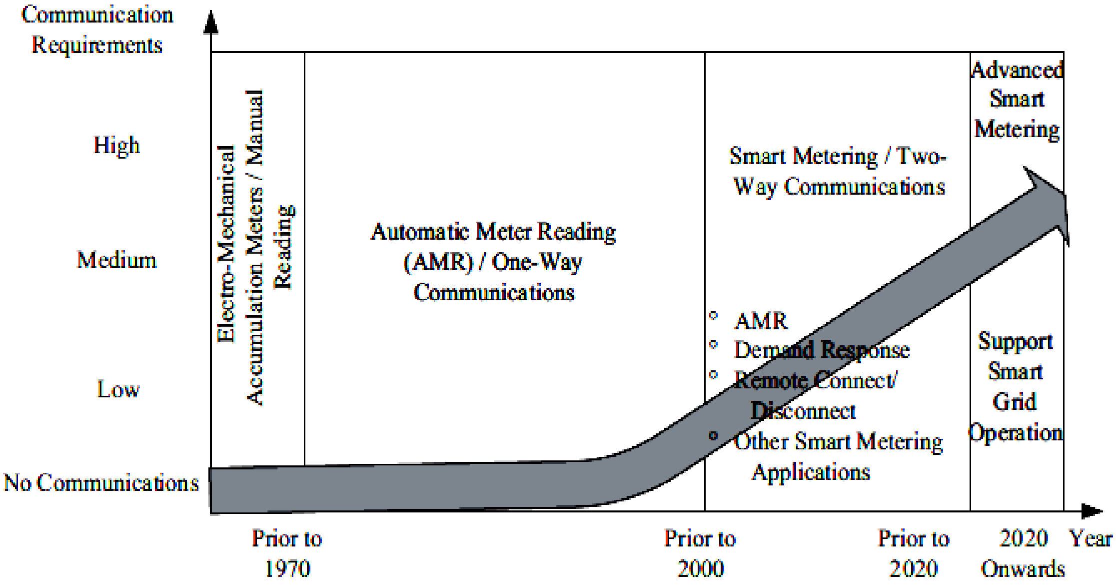


Figure 5.1 Evolution of electricity metering

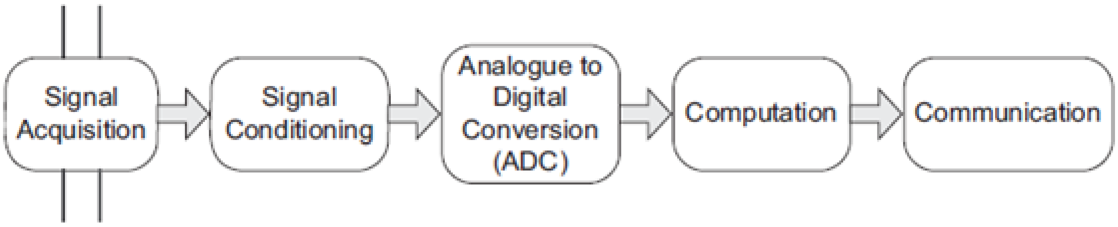


Figure 5.3 Functional block diagram of a smart meter

A smart meter has a display that presents information in the form of text and graphs for the human user. Liquid Crystal Displays (LCD) and the Light Emitting Diodes (LED) are preferred for their low cost and low power consumption requirements. Both display types are available in seven-segment, alphanumeric and matrix format.

Smart meters provide a small key pad or touch screen for [HMI] Human Machine Interface, to change the settings of a smart meter so as to select the smart appliance to be controlled or to select payment options.

As smart meters require calibration due to variations in voltage references, sensor tolerances or other system gain errors, etc., a calibration input is also provided. Some meters also provide remote calibration and control capability through communication links.

A traditional electro-mechanical meter has a spinning aluminium disc and a mechanical counter display that counts the revolutions of the disc. The disc is situated in between two coils, one fed with the voltage and the other fed with the current of the load.

The current coil produces a magnetic field, φI and the voltage coil produces a magnetic field, φV. The forces acting on the disc due to the interaction between the eddy currents produce a torque. The torque is proportional to the product of instantaneous current and voltage, thus to the power.

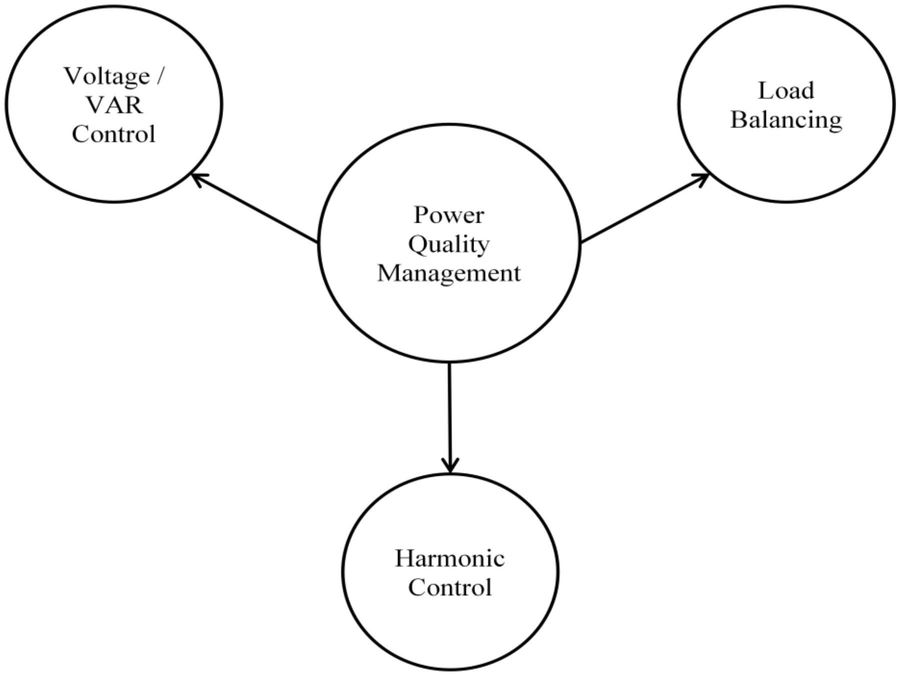
The number of rotations of the disc is recorded on the mechanical counting device that gives the energy consumption.

The replacement of electro-mechanical meters with electronic meters offers several benefits. Electronic meters not only can measure instantaneous power and the amount of energy consumed over time but also other parameters such as Power Factor, Reactive Power, Voltage and Frequency, with high accuracy. Data can be measured and stored at specific intervals. Moreover, electronic meters are not sensitive to external magnets or orientation of the meter itself, so they are more tamperproof and more reliable.
Early electronic meters had a display to show energy consumption but were read manually for billing purposes. More recently electronic meters with two-way communications have been introduced. Figure 5.3 provides a general functional block diagram of a smart meter. In Figure 5.3, the smart meter architecture has been split into five sections: signal acquisition, signal conditioning, Analogue to Digital Conversion (ADC), computation and communication.

Smart meters have two functions: providing data on energy usage to customers (end - users) to help/control cost and consumption, sending data to the utility for load factor control, peak load requirements, and the development of pricing strategies based on consumption informationand so on.

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.

role of EMC in Smart Grid

EMC – Electromagnetic Compatibility

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 Electro technical 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 “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.

Relation between Voltage Quality and EMC

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 and Conducted high-frequency phenomena

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:

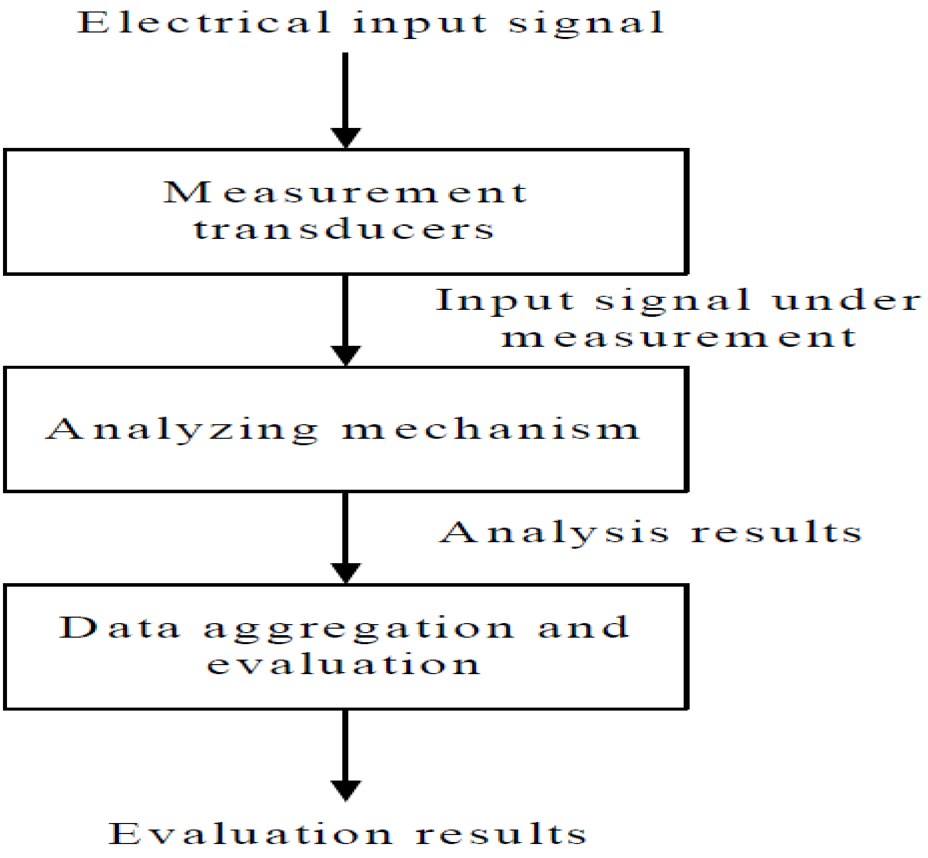
- The continuity of the power supply: i.e., that the power in the network is available on a regular basis and is able to ensure the efficient operation of the equipment
- The quality of the voltage: i.e., that there are no low or high frequency disturbances in the network capable of damaging the system 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.

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

the Flow Chart of Procedure for Monitoring Power Quality and Issues of Power Quality Monitoring

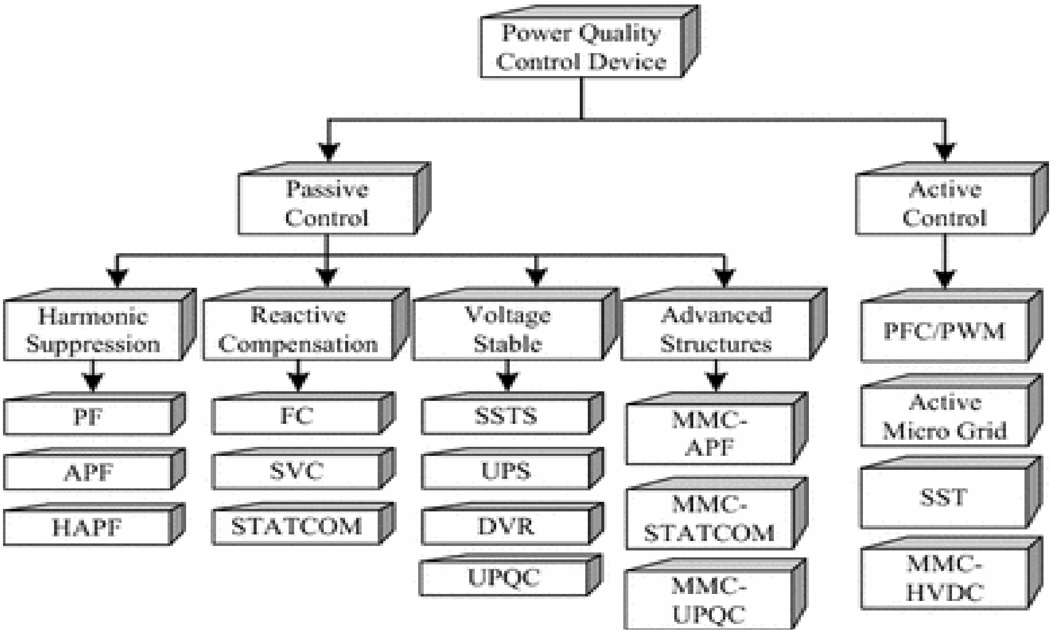
<u>**Flow Chart of Procedure for Monitoring Power Quality**</u>



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

Classification of Power Quality Compensator



<u>Classification diagram of power quality compensators</u>

the 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.

the Issues related to Power Quality Monitoring & PQ Measurement Issues in Smart Grid

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

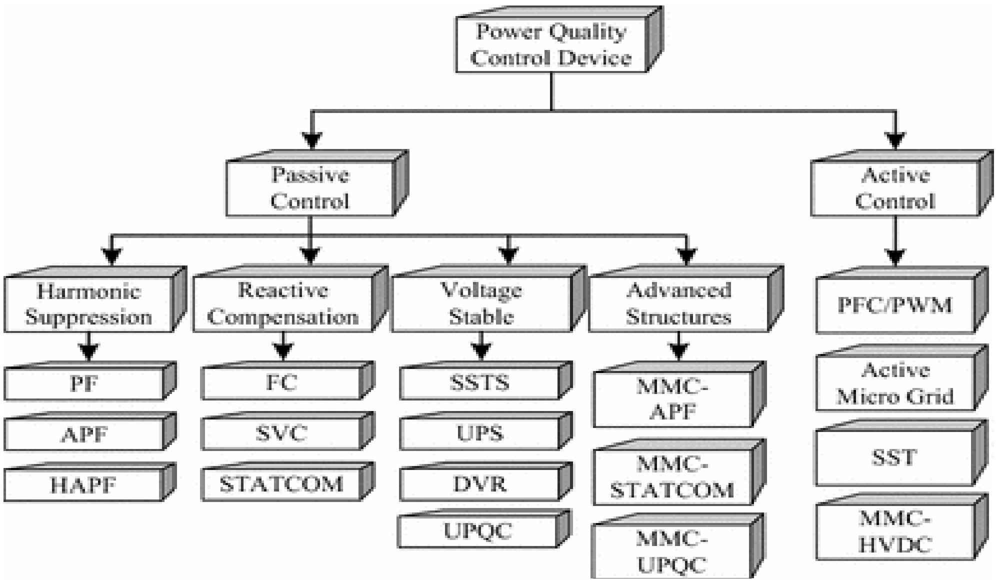
Smart Grid PQ Measurement Issues

1. Smart meter with Advance PQ Analysis Functions
2. Wide Area Monitoring Scheme with PQ Disturbance Identification and Remedy
3. Integration of Measured PQ Data and Database Design
4. Tracking PQ Disturbances and Real-Time PQ Analysis

5. Deployment of Advanced PQ Meters in Power Network
6. Embedding Advanced PQ Monitoring Functions in Substation/Feeder Automations
7. Communication Protocols for PQ Monitoring
8. PQ-related Standards Development
9. PQ Analytics

the Power Quality Compensator related to Smart Grid
Classification diagram of power quality compensators

It is important to improve the power supply quality on power consumer side by taking advantage of the power quality control technology and equipment.
The core principle of power quality control is to control and convert the electric energy to meet the requirement of quality conformance and optimal efficiency.
The classification of compensators is shown in Fig. below.



<u>**Classification diagram of power quality compensators**</u>

Power quality control technology can be divided into active control technology and passive control technology.

Passive control technology

The passive control technology is characterized by adding extra devices to eliminate or relieve the impact of existing power quality problems. The Harmonic Suppression techniques mainly contain the Passive Power Filter (PPF), Active Power Filter (APF), and Hybrid Active Power Filter (HAPF).

The reactive power compensator is capable of suppressing the voltage fluctuation and flicker.

The VAR compensators in distribution network include Fixed Capacitor (FC), Static VAR compensator (SVC) and Static Synchronous Compensator

(STATCOM). Among these devices, the STATCOM is widely used for its multiple functions.

Among the transient power quality problems, voltage sag and short interruption are perceived as the most common and harmful forms. The Solid-State Transfer Switch (SSTS) can effectively reduce the depth and time of voltage sag. Uninterruptable Power Supply (UPS) is the most effective tool to restrain the voltage fluctuation for low-power devices in the distribution network. The Dynamic Voltage Regulator (DVR) can directly and quickly compensate the instantaneous voltage sag and swell. The Unified Power Quality Controller (UPQC) comprised of the series APF and shunt APF, can make comprehensive compensation of voltage and current for the grid.

Cascade Power Converters based on Modular Multilevel Converter (MMC) comprising of APF, STATCOM, UPQC based on MMC greatly reduces the manufacturing difficulty and cost of high- and medium-voltage converters.

Active control technology
Active control technology is used to improve the impedance characteristics of the electrical equipment to prevent most power quality problems.

The Power Factor Correction (PFC) and Pulse Width Modulation (PWM) technology have improved the power quality of rectifier devices.

The distributed generation and microgrid inverter using the active control not only improve the quality of output voltage and current in distributed system, but also provide some extra compensation capacity for the adjacent grid.

The Solid-State Transformer (SST) will block the transmission and emission of power quality problems between the power consumer side and power distribution side.
The power quality level of the entire power grid will be enhanced due to the MMC-based High Voltage Direct Current (HVDC) Transmission and Multi-Terminal HVDC Technology.

Control method of power quality compensator
Power quality control equipment generally employs the voltage source converter or current source converter. The output of converters can be regulated to control the power quality according to the voltage or current reference. The control method of the converter has a significant impact on the effect on power quality control.

EMC and how it is role in Smart Grid
EMC – Electromagnetic Compatibility
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.
Relation between Voltage Quality and EMC
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:

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

Role of EMC in Smart Grid

1. EMC is essential for a robust Smart Grid; both with respect to radiated and to conducted disturbances.

2. Power Quality is a means to achieve EMC between the Smart Grid and connected equipment.
3. Protection requirements on networks and connected equipment should be economically fairly balanced.
4. With a view of EMC as a technical issue where cost optimisation to a large extent is made.

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.

Type
Short Duration Voltage Variation
Long Duration Voltage Variation

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.

Local Area Network (LAN) in Smart Grid

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

the 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.

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

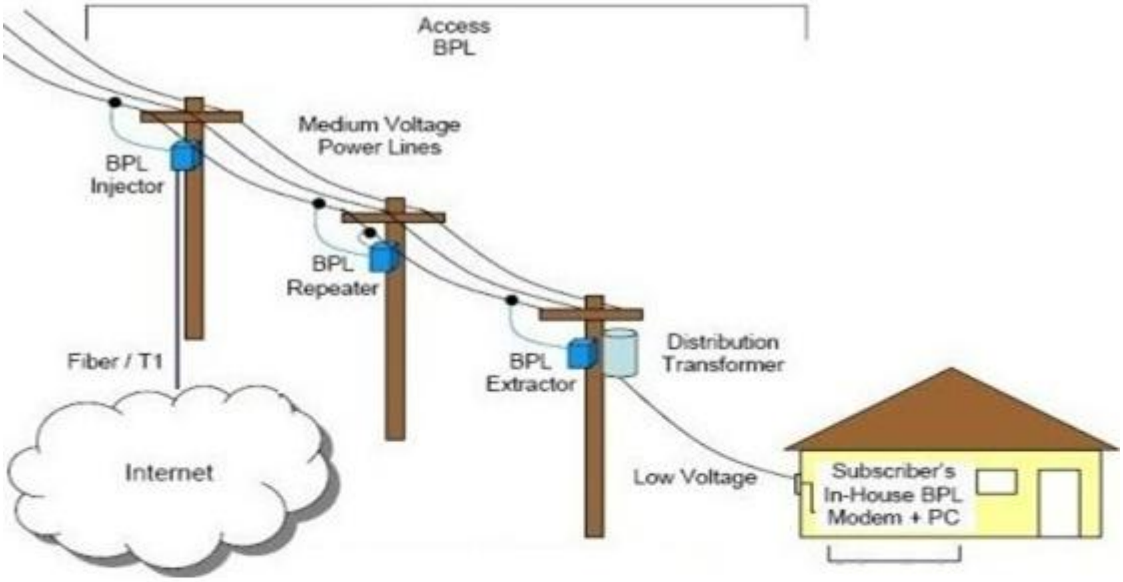
The most widely used version of IP today is Internet Protocol Version 4 (IPv4). However, IP Version 6 (IPv6) is also beginning to be supported. IPv6 provides for much longer addresses and therefore for the possibility of many more Internet users. IPv6 includes the capabilities of IPv4 and any server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

Broadband Over Power Line

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.



the House Area Network (HAN) in Smart Grid

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.

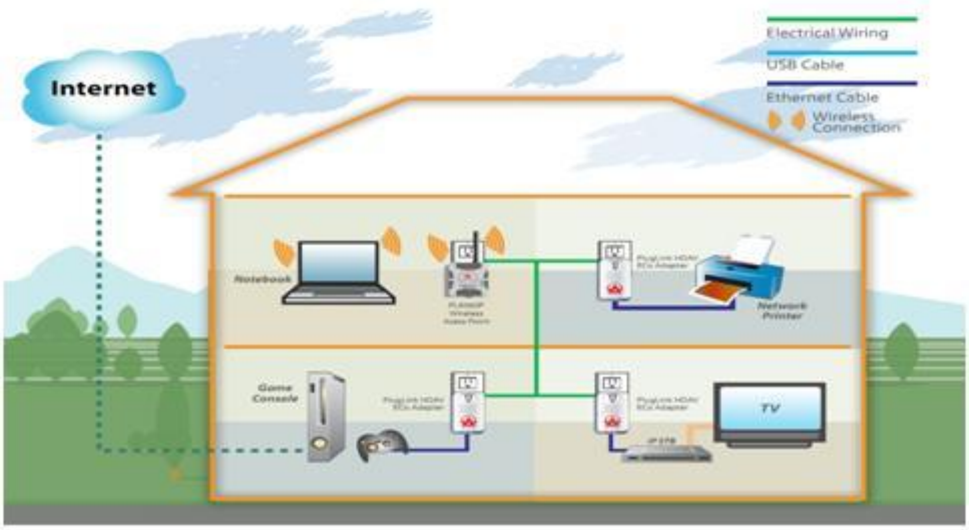


Figure 1: Home area network

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.

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.

Local Area Network (LAN) , Wide Area Network (WAN) and House Area Network (HAN) in Smart Grid

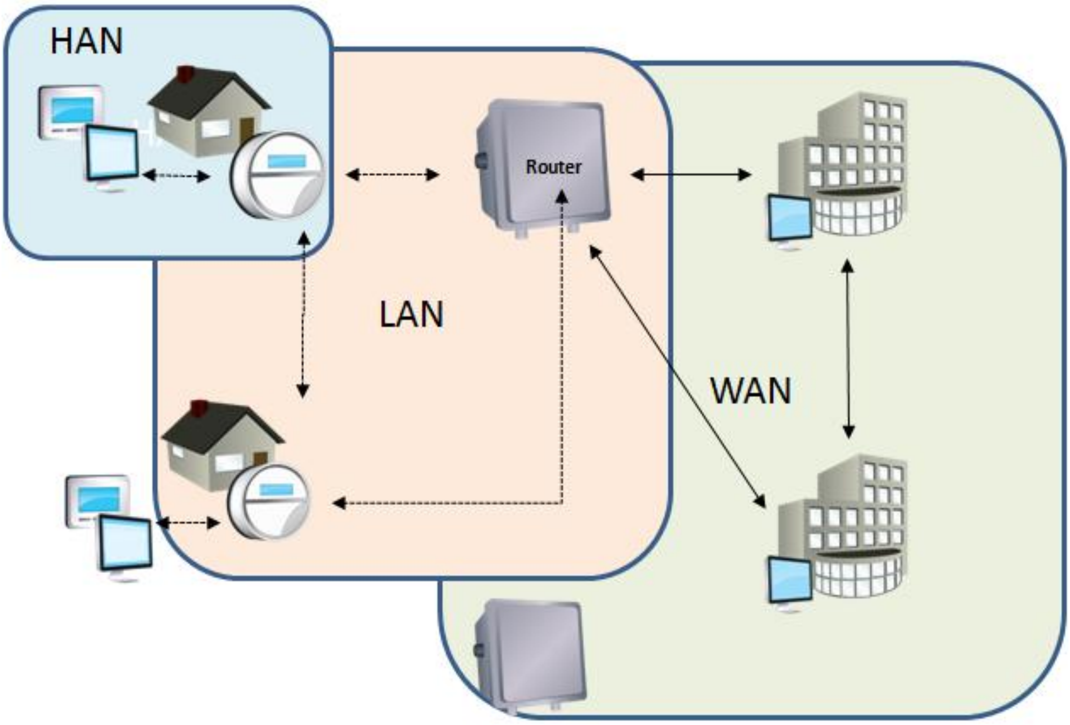
A local area network is a data communication network, typically a packet communication network, limited within the specific network. A local area network generally provides high-bandwidth communication over inexpensive transmission media. The information flow is between smart meters and sensors. For 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 given 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

WAN (Wide Area Network for Smart Grid): 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 centre and subsystems.

HAN (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.



Wide Area Network (WAN) related to Smart Grid

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."

Cyber Security is most important in Smart Grid and how it can be achieved

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.

importance of Cloud Computing in Smart Grid

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.

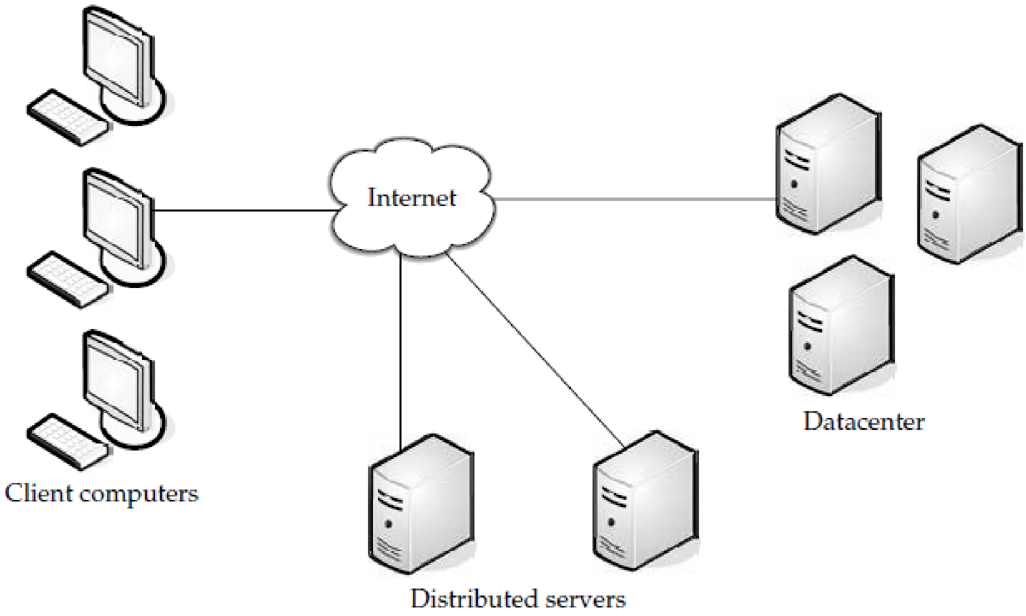
In order to balance the real-time demand and supply curves, rapid integration and analyzation of information that streams from multiple smart meters simultaneously is required that necessitates the scalable software platform. Cloud platforms are well suited to support huge data and computationally-intensive,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

- 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



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