CHAPTER TWO

ELECTRICAL SMART GRID

2.1 Introduction

Electrical system is a network of electrical devices connected to each other as an integrated system for the generation, transmission and distribution of electricity to its users [2].

A common example of a power grid is the central stations that generate energy using steam turbines, gas turbines, or water turbines. The electric transformers then raise the generating voltage to the transport voltage and transfer the energy by the transmission lines to the secondary power stations for the purpose of reducing the voltage back to levels that the user needs them in homes, factories and shops. Example of electrical power systems: networks that provide homes and factories with power in large areas [2].

The system is called a network and can be divided into generators which are the energy supply and transport system that transfers energy from generators to loads and distribution system that provides homes and factories and there is a smaller level of energy systems seen in some factories, hospitals and commercial centers Most of these systems are three phases of AC voltage and this is which is common in large systems [2].

2.2 Electrical Power System Grid

Fig (2.1) represents the electrical grid components.

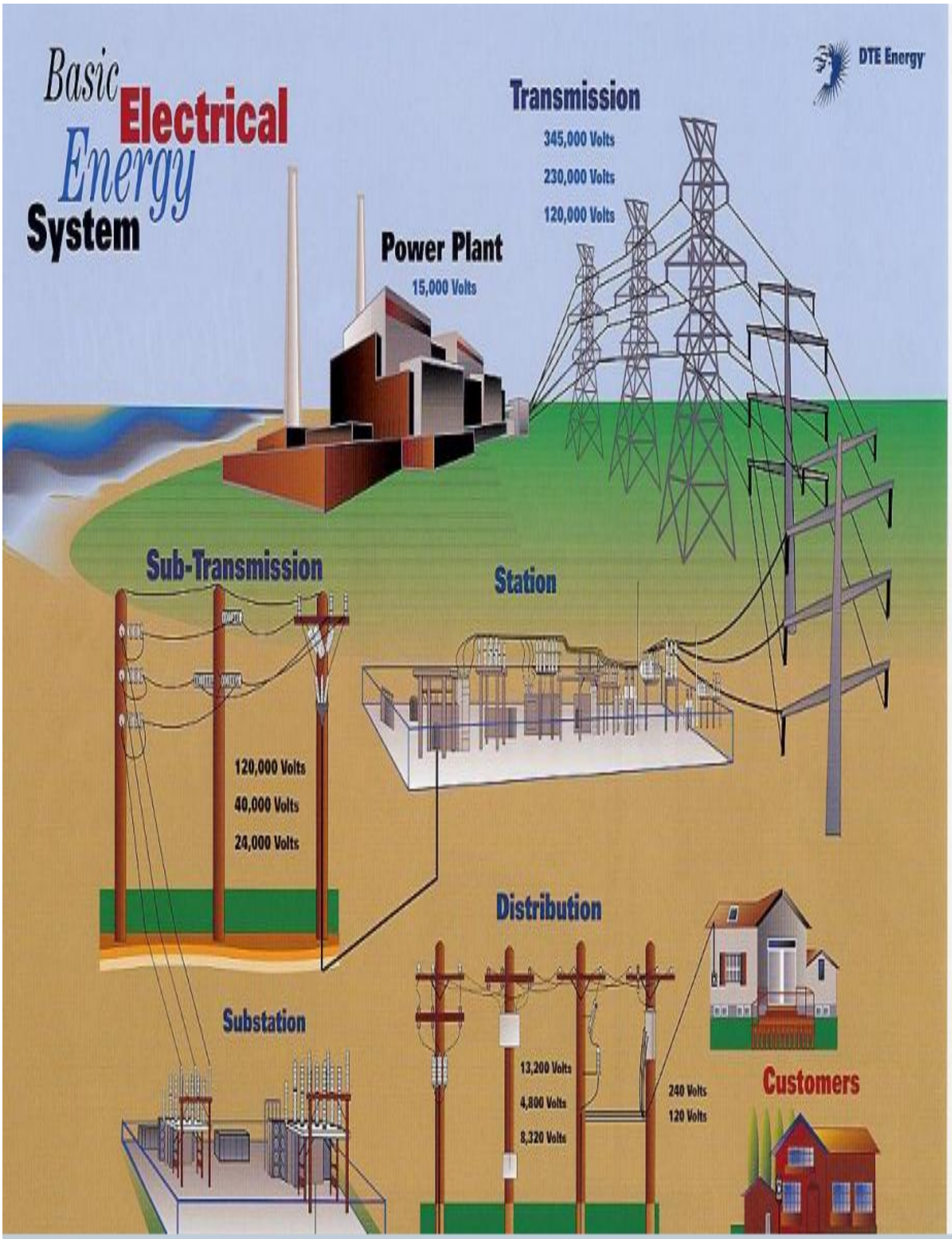

Fig (2.1) Electrical power system

2.2.1 Power plant

Power station depends on the three phase synchronous generator which converts mechanical energy to electrical energy. Synchronous machines can produce high power reliably with high efficiency, and therefore, are widely used as generators in power systems. A generator serves two basic functions. The first one is to produce active power (MW), and the second function, frequently forgotten, is to produce reactive power (MVAR) [6].

2.2.2Transformers

Power transformation stations and transmission lines are designed to transmit the electricity generated by the thermal power stations or hydropower stations which are usually situated far away from the inhabited areas, to the end-users. We are capable of designing, procuring, constructing and installing the power transformation stations and transmission lines as well as electricity grids and other necessary electricity meters and systems in order to transmit electricity to the inhabited areas for the use of all end-users [6].

2.2.3 Transmission and distribution

The equipment connecting the generated electrical energy from the generation to the distribution system is the transmission line. A transmission system is a massive interconnected network consists of mainly AC transmission lines with various high/extra high voltage levels. The main advantage of having higher voltage in transmission system is to reduce the losses in the grid.

Electrical energy is transported from generating stations to their loads through overhead lines and cables. Overhead transmission lines are used for long distances in open county and rural areas, while cables are used for underground transmission in urban areas and for underwater crossings. Because the cost for cables is much more expensive than the overhead lines, cables are used in special situations where overhead lines cannot be used [6].

2.3 Smart Grid Implementation

The electrical grid, consisting of power plants, miles of high voltage transmission, miles of distribution lines; it's one of the most complex machines in the world. However, the electrical grid has evolved surprisingly little over past 50 years while the population has grown and the equipment using electricity at the other end of the lines has become increasingly sophisticated. Today's electrical grid suffers from a number of problems, including that it is:

-Old (the average age of power plants is 35 years).

-Pollution (more than half of our electricity is generated from coal and oil).

-Inefficient.

-Vulnerable.

In addition, the electrical grid is not set up to handle the demands that are being placed on it by end-users or the changing generation mix of the 21st century. And the grid is ill-equipped to handle both renewable, which are intermittent and less predictable than fossil fuel-based generators, or distributed generation.

Since about 2005, there has been increasing interest in the Smart Grid. The recognition that ICT offers significant opportunities to modernize the operation of the electrical networks has coincided with an understanding that the power sector can only be de-carbonized at a realistic cost if it is monitored and controlled effectively [6].

2.3.1 Ageing assets and lack of circuit capacity

Recently the power system expanded rapidly and the transmission and distribution equipment that was installed then is now beyond its design life and in need of replacement. The capital costs of like-for-like replacement will be very high. The need to refurbish the transmission and distribution circuits is an obvious opportunity to innovate with new designs and operating practices.

In many countries the overhead line circuits, needed to meet load growth or to connect renewable generation, have been delayed for up to 10 years due to difficulties in obtaining rights-of-way and environmental permits. Therefore, some of the existing power transmission and distribution lines are operating near their capacity and some renewable generation cannot be connected. This calls for more intelligent methods of increasing the power transfer capacity of circuits dynamically and rerouting the power flows through less loaded circuits [6].

2.3.2 Thermal constraints

Thermal constraints in existing transmission and distribution lines and equipment limit of their power transfer capability. When power equipment carries current in excess of its thermal rating, it becomes over-heated and its insulation deteriorates rapidly. This leads to a reduction in the life of the equipment and an increasing incidence of faults.

If an overhead line passes too much current, the conductor lengthens, the sag of the catenary increases, and the clearance to the ground is reduced. Any reduction in the clearance of an overhead line to the ground has important consequences both for an increase in the number of faults but also as a danger to public safety. Thermal constraints depend on environmental conditions that change through the year. Hence the use of dynamic ratings can increase circuit capacity at times [6].

2.3.3Operational constraints

Any power system operates within specific voltage and frequency limits. If the voltage exceeds its upper limit, the insulation of components of the power system and consumer equipment may be damaged, leading to short-circuit faults. Too low a voltage may cause malfunctions of customer equipment and lead to excess current and tripping of some lines and generators. The capacity of many traditional distribution circuits is limited by the variations in voltage that occur between times of maximum and minimum load.

Renewable energy generation has a varying output which cannot be predicted with certainty hours ahead. A large central fossil-fuelled generator may require 6 hours to start up from cold. Thus maintaining the supply–demand balance and the system frequency within limits becomes difficult [6].

2.3.4 National initiatives

Many national governments are encouraging Smart Grid initiatives as a cost-effective way to modernize their power system infrastructure while enabling the integration of low-carbon energy resources. Development of the Smart Grid is also seen in many countries as an important economic/commercial opportunity to develop new products and services.

Smart grid definition:

The “grid” amounts to the networks that carry electricity from the plants where it is generated to consumers. The grid includes wires, substations, transformers, switches and much more.

Smart grid generally refers to a class of technology people are use to delivery electricity in the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses. They offer many benefits to utilities and consumers mostly seen in big improvements in energy efficiency on the electricity grid and in the energy user’s homes and offices.

The Smart Grid is defined as:

"A smart grid uses sensing, embedded processing and digital communications to enable the electricity grid to be observable (able to be measured and visualized), controllable (able manipulated and optimized), automated (able to adapt and self-heal), fully integrated (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources)" [6].

2.4 Smart Grid Characteristic

The main characteristics of smart grids are:

-It enables demand response and demand side management through the integration of smart meters and by providing customers with information related to energy use and prices.

-It accommodates and facilitates all renewable energy sources, distributed generation, residential micro-generation, and storage options, thus reducing the environmental impact of the whole electricity sector it will provide simplified interconnection similar to 'plug-and-play'.

-It optimizes and efficiently operates assets by intelligent operation of the delivery system (rerouting power, working autonomously) and pursuing efficient asset management. This includes utilizing asserts depending on what is needed and when it is needed.

-It assures and improves reliability and the security of supply by being resilient to disturbances, attacks and natural disasters, anticipating and responding to system disturbances (predictive maintenance and self-healing).

-It maintains the power quality of the electricity supply to cater for sensitive equipment that increases with the digital economy [6].

2.5 The Technology Required

Many smart grid technology areas – each consisting of sets of individual technologies –span the entire grid, from generation through transmission and distribution to various types of electricity consumers [6].

2.5.1 Wide-area monitoring and control

Real-time monitoring and display of power system components and performance, across interconnections and over large geographic areas, help system operators to understand and optimize power system components, behavior and performance. Advanced system operation tools avoid blackouts and facilitate the integration of variable renewable energy resources. Monitoring and control technologies along with advanced system analytics – including wide-area situational awareness (WASA), wide-area monitoring systems (WAMS), and wide-area adaptive protection, control and automation (WAAPCA) – generate data to inform decision making, mitigate wide-area disturbances, and improve transmission capacity and reliability[6].

2.5.2 Information and communications technology integration

Underlying communications infrastructure, whether using private utility communication networks (radio networks, meter mesh networks) or public carriers and networks (Internet, cellular, cable or telephone), support data trans7mission for deferred and real-time operation, and during outages. Along with communication devices, significant computing, system control software and enterprise resource planning software support the two-way exchange of information between stakeholders, and enable more efficient use and management of the grid [6].

2.5.3 Renewable and distributed generation integration

Integration of renewable and distributed energy resources – encompassing large scale at the transmission level, medium scale at the distribution level and small scale on commercial or residential building – can present challenges for the dispatch ability and controllability of these resources and for operation of the electricity system. Energy storage systems, both electrically and for thermally based, can alleviate such problems by decoupling the production and delivery of energy. Smart grids can help through automation of control of generation and demand (in addition to other forms of demand response) to ensure balancing of supply and demand [6].

2.5.4 Transmission enhancement applications

There are a number of technologies and applications for the transmission system. Flexible AC transmission systems (FACTS) are used to enhance the controllability of transmission networks and maximize power transfer capability. The deployment of this technology on existing lines can improve efficiency and defer the need of additional investment. High voltage DC (HVDC) technologies are used to connect offshore wind and solar farms to large power areas, with decreased system losses and enhanced system controllability, allowing efficient use of energy sources remote from load centers. Dynamic line rating (DLR), which uses sensors to identify the current carrying capability of a section of network in real time, can optimize utilization of existing transmission assets, without the risk of causing overloads. High-temperature superconductors (HTS) can significantly reduce transmission losses and enable economical fault-current limiting with higher performance, though there is a debate over the market readiness of the technology [6].

2.5.5 Distribution grid management

Distribution and sub-station sensing and automation can reduce outage and repair time, maintain voltage level and improve asset management. Advanced distribution automation processes real-time information from sensors and meters for fault location, automatic reconfiguration of feeders, voltage and reactive power optimization, or to control distributed generation.

Sensor technologies can enable condition- and performance-based maintenance of network components, optimizing equipment performance and hence effective utilization of assets [6].

2.5.6 Customer-side systems

Customer-side systems, which are used to help manage electricity consumption at the industrial, service and residential levels, include energy management systems, energy storage devices, smart appliances and distributed generation. Energy efficiency gains and peak demand reduction can be accelerated with in-home displays/energy dashboards, smart appliances and local storage. Demand response includes both manual customer response and automated, price-responsive appliances and thermostats that are connected to an energy management system or controlled with a signal from the utility or system operator [6].

Table(2.1) represents the smart grid technologies.

Technology area	Hardware	Systems and software
Wide-area monitoring and control	Phasor measurement unit (PMU) and other sensor equipment	Supervisory control and data acquisition (SCADA), Wide-area monitoring systems (WAMS), wide-area adaptive protection control and automation (WAAPCA), Wide-area situational awareness (WASA)
Information and communication technology integration	Communication equipment (Power line carrier, WIMAX, LTE, RF mesh network, cellular), routers, relays, switches, gateway, computers	Enterprise recourse planning software (ERP), customer information system (CES)
Renewable and distributed generation integration	Power conditioning equipment for bulk power and grid support, Communication and control hardware for generation and enabling storage technology	Energy management system (EMS), distribution management system (DMS), SCADA, geographic information system (GIS)
Transmission enhancement	Superconductors, FACTS ,HVDC	Network stability analysis, automatic recovery systems
Distribution and management	Automated re-closers, switches and capacitors, remote controlled distributed generation and storage, transformer sensors, wire and cable sensors	Geographic information system (GIS), distribution management system (DMS), outage management system (OMS), workforce management system (WMS)
Customer-side systems	Smart appliance, routers, in-home display, building automation systems, thermal accumulation, smart thermostat	Energy dashboards, energy management systems, energy applications for smart phones and tables

2.6 Smart Metering

Electricity meters are used to measure the quantity of electricity supplied to customers as well as to calculate energy and transportation charges for electricity retailers and network operators. 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. In recent years, industrial and commercial consumers with large loads have increasingly been using more advanced meters, Smart meters are even more sophisticated as they have two-way communications and provide a real-time display of energy use and pricing information, dynamic tariffs and facilitate the automatic control of electrical appliances.[6]

Fig (2.2): Evolution of meters

Smart metering consists of four main components: smart meters, a two-way communication network, a Meter Data Management system (MDM) and home area network (HAN) [6].

2.7 Smart Appliances

Smart appliances cycle up and down in response to signals sent by the utility. The appliances enable customers to participate in voluntary demand response programs which award credits for limiting power use in peak demand periods or when the grid is under stress. An override function allows customers to control their appliances using the Internet. Air conditioners, space heaters, water heaters, refrigerators, washers, and dryers represent about 20% of total electric demand during most of the day and throughout the year. Grid - friendly appliances use a simple computer chip that can sense disturbances in the grid's power frequency and can turn an appliance off for a few minutes to allow the grid to stabilize during a crisis [5].