UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION

INSTITUTE OF SCIENCE AND TECHNOLOGY

INVESTIGATION OF SMART GRID INTEROPERABILITY AND INTERCONNECTION STANDARDS TO TRANSFORM LIBYA ELECTRIC POWER NETWORK INTO SMART GRID

MASTER THESIS

Hamza Shelaf

THE DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

THE PROGRAM OF ELECTRICAL AND ELECTRONICS ENGINEERING

SEPTEMBER 2015

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I hereby declare that all the information in this study I presented as my Master's Thesis, called: INVESTIGATION OF SMART GRID INTEROPERABILITY AND INTERCONNECTION STANDARDS TO TRANSFORM LIBYA ELECTRIC POWER NETWORK INTO SMART GRID, has been presented in accordance with the academic rules and ethical conduct. I also declare and certify with my honor that I have fully cited.

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To My Family …

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LIST OF ABBREVIATIONS

AMR	Advanced Meter Reading
AMM	Advanced Meter Management
AC	Alternating Current
ABS	Accounting & Business Systems
BPL	Broadband over the Power Line
CIS	Customer Information Systems
CRM	Customer Relationship Management
DR	Distributed Resources
DG	Distributed Generation
DSL	Broadband Communications
EPS	Electric Power System
EVs	Electric vehicles
ERP	Enterprise Resource Planning
E&O	Engineering & Operations
FAN	Field Area Networks
GPTC	General Post and Telecom Company
GW	Gigawatts
GIS	Geographic Information Systems
GECOL	General Electric Company of Libya
HAN	Home Area Networks
I&C	Instrumentation and Modern Control
ICT	Information and Communication Technology
IED	Intelligent Electronic Device
IP	Internet Protocol
IT	Information Technology

IVR	Interactive Voice Response
KW	Kilowatts
LTE	Long Term Evolution
LTT	Libya Telecom & Technology
LAN	local Area Network
MW	Megawatts
MDM	Meter Data Management
NAN	Neighbourhood Area Networks
OMS	Outage Management System
PHEV	Plug-in Hybrid Electric Vehicles
PV	Photovoltaic
PDAs	Personal Digital Assistants
PLC	Power Line Carrier
PMSG	Permanent Magnet Synchronous Generator
PWM	Pulse Width Modulation
RE	Renewable Energy
R&D	Research and Development
SGIRM	Smart Grid Interoperability Reference Model
SG	Smart Grid
SCADA	Supervisory Control and Data Acquisition
Std	Standards
WAN	Wide Area Networks
WSN	Wireless Sensor Network
WAMPAC	Wide Area Monitoring, Protection, and Control
ZTE	Chinese Multinational Telecommunications Company

ABSTRACT

INVESTIGATION OF SMART GRID INTEROPERABILITY AND INTERCONNECTION STANDARDS TO TRANSFORM LIBYA ELECTRIC POWER NETWORK INTO SMART GRID

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September 2015, 84 Pages

Because of aging electric power grids and ever increasing demand for electric energy, countries need innovative ways to both generate electricity and manage how to consume it. In parallel with the developing technology, this creates new challenges and opportunities which can offer smarter ways to manage electricity from the utility to the individual consumers at the present time. These new technologies will become the building blocks of the future smart grids. In principle, smart grid is a simple upgrade of 20^{th} century power grids which generally "broadcast" power from a few central power generators to a large number of users to instead be capable of routing power in more optimal ways to respond to a very wide range of conditions. However, transformation to the smart grid appears as the main issue that needs good planning for the countries. In this thesis, the subject of how the classic power systems can be transformed to the smart grid is addressed. For this purpose, the main concept and main components about smart grids are investigated. After that, due to transform Libya electricity network to the smart grid, the available Libya electricity power network and communication infrastructure are presented and also, some of the main challenges and offered opportunities for applying suitable applications of the Smart Grid in Libya are discussed. At the end of the thesis, essential steps in order to implement the smart grid are introduced and various solutions and technologies are suggested.

Keywords: Smart Grid, Classical Power Network, Libya Electricity Grid, Transformation**.**

ÖZET

LİBYA ELEKTRİK GÜÇ SİSTEMİNİN AKILLI ŞEBEKEYE DÖNÜŞÜMÜ İÇİN AKILLI ŞEBEKE ORTAK ÇALIŞABİLİRLİK VE ORTAK BAĞLANTI STANDARTLARININ İNCELENMESİ

HAMZA SHELAF

Yüksek Lisans, Elektrik ve Elektronik Mühendisliği Bölümü

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Eylül 2015, 84 Sayfa

Elektrik güç şebekelerinin büyümesi ve artan elektrik enerjisi talebi nedeniyle, ülkeler elektriği üretmek ve tüketimini yönetmek için yeni yollara ihtiyaç duymaktadır. Gelişen teknolojiye paralel olarak, bu durum günümüzde elektriğin üretim tesisinden tüketiciye kadar daha akıllı yollarla yönetilmesi için yeni fırsatlar ve zorluklar yaratmaktadır. Bu yeni teknolojiler geleceğin akıllı şebekeleri için yapı taşları olacaktır. Prensip olarak, akıllı şebeke 20'nci yüzyılın birkaç merkezi üretim santralinden çok sayıda kullanıcıya dağıtım yapan klasik güç sisteminin, çeşitli durumlara karşı optimal yollardan güç dağıtımı yeteneğine sahip şebekeye güncellenmiş şeklidir. Bununla beraber, akıllı şebekeye dönüşüm, ülkelerin karşısına iyi bir planlamaya ihtiyaç duyan temel konulardan biri olarak çıkmaktadır. Bu tezde, klasik bir elektrik şebekesinin akıllı şebekeye nasıl dönüşebileceği konusu ele alınmıştır. Bu amaçla, akıllı şebeke kavramının başlıca özellikleri ve ana parçaları incelenmiştir. Daha sonra, Libya elektrik şebekesinin akıllı şebekeye dönüşümü için Libya'nın mevcut elektrik şebekesi ve üretim kapasitesi tanıtılmış ve Libya için uygun bir akıllı şebeke uygulaması için zorluklar ve fırsatlar tartışılmıştır. Tez çalışmasının sonunda, akıllı şebeke oluşumu için ana adımlar incelenmiş ve çeşitli çözümler ve teknolojiler önerilmiştir.

Anahtar Kelimeler: Akıllı Şebeke, Klasik Güç Şebekesi, Libya Elektrik Şebekesi, Dönüşüm.

CHAPTER ONE

SMART GRID

1.1 Introduction

The Smart Grid has become play a major role in the global energy system and a goal sought by all countries of the world with the increasing pace of energy demand. Smart Grid has a lot of descriptions and definitions which recall some of them as follows:

- Smart Grid means electricity network which uses digital and advanced technologies to transport of electricity to all users who connected with it [1,2].
- Smart Grid is the network that gives efficiency and reliability in the generation, transmission and distribution of electricity to its users.
- Smart Grid is the network that uses two-way communications for electric power transmission and distribution to its users [1].
- Smart Grid is the network that uses distributed computing technologies and advanced sensors for improve monitor and manage transmission electric power [1].
- Smart Grid is a network that can use all communication technologies like smart meters which collects and sends data to the control centers.
- Smart Grid is an electrical network which using renewable energy like wind and solar energy to meet the energy needs.
- Smart Grid is an electricity network that minimizes costs of generation, transmission and distribution and reduction of an environmental impacts.
- Smart Grid is an electricity network which operating all parts of the system as efficiently as possible [3]. Figure.1.1 shows the smart grid concept.

Figure 1.1 Smart Grid Concept [3]

1.2 History of Smart Grid

The idea of the establishment of a smart grid started in the late 1990 and the first model of the smart grid was introduced in the early 2000. The first Smart Grid implementation was in Italy in 2000 that presented by ENEL S.p.A. largest energy provider in Italy [4]. Smart Grid US started in 2003 that presented in Austin and Texas [5]. The Table 1.1 shows the comparison between the traditional and smart grid. Figure.1.2 also shows before and after smart grid.

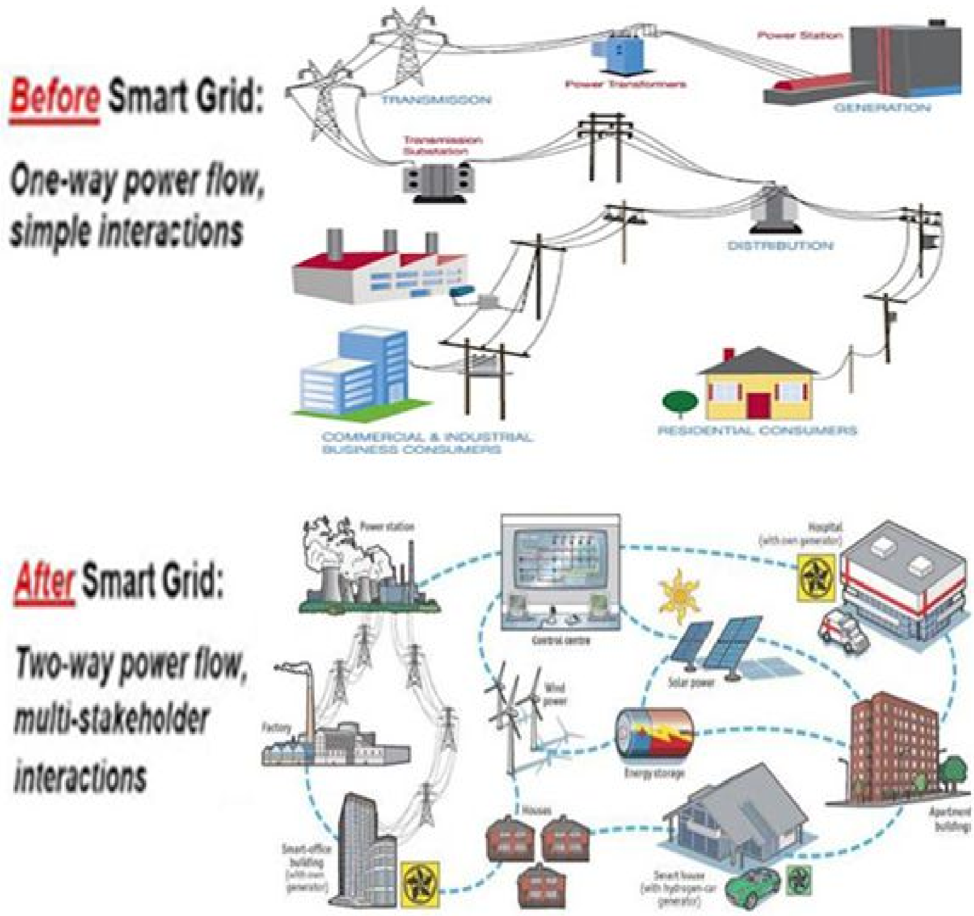

Figure 1.2 Before and After Smart Grid [6]

Traditional Grid	Smart Grid
Limited Control	Pervasive Control System
One-Way Communication	Two-Way Communication
Limited User Options	More User Options
Centralized Generation	Distributed Generation
Mechanization	Digitization
Solid State	Microprocessor
Radial Topology	Network Topology
Limited Pricing Information	Complete Pricing Information
Manual Checking	Monitor Equipment Remotely
Limited Protection	Adaptive Protection
Limited Monitoring, Control Systems	Pervasive Control System
Estimated Reliability	Predictive Reliability

Table 1.1 Comparison Between The Traditional and Smart Grid [1]

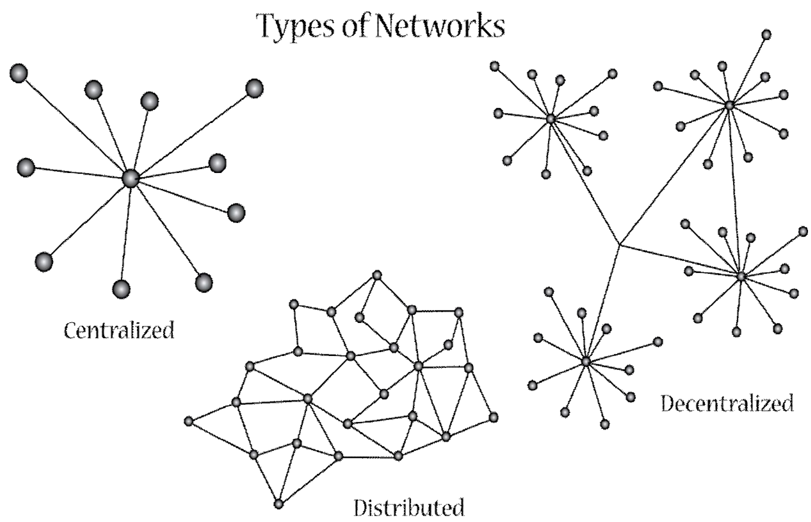

Figure 1.3 Types of Network [6]

1.3 The Importance of Smart Grid

Lies the importance of smart grid in the following:

- It gives efficiency and reliability in the generation, transmission and distribution of electricity to its users.
- It uses distributed computing technologies and advanced sensors for improve monitor and manage transmission electric power [1].
- It operating with all parts of the system as efficiently as possible [21].
- It able to integrate all types of electricity generation and storage systems which prevent power outages [7].
- It has the ability to predict problems before they occur such as surges, rain and snow, and thus heal itself.
- It incentivize and help customers to regulate demand in real time Which changes according to market and grid conditions.
- It is more secure, sustainable and energy efficient [8].
- Its ability to accommodating each generation sources and storage power options and it can integration all electricity networks on large geographic areas [9].
- It can use all communication technologies like smart meters which collects and sends data to the control centers.

- It using renewable energy like wind and solar energy to meet and fill its need of energy.
- It minimizes costs of generation, transmission and distribution and reduction of an environmental impacts.
- It provides flexibility, balance and stability system, thus gives more efficient to generation, transmission and distribution electricity.

1.4 Objectives of Smart Grid

The expected objectives from smart grid technology deployments include the following:

- Provide the best operation for generators of each sizes and technologies [10].
- Allows high utilization efficiency for customers of the system operation [10].
- Give all the information that will help consumers to choose the appropriate supply.
- Work to reduce the environmental impact of the system [10].
- Ensure the active participation of consumers in the wholesale market [10].
- Connect the consumer online, allowing rapid reaction to him on the supply.
- Identify network problems, allowing to processed quickly and efficiently.[10]
- Manage and store energy efficiently, including renewable energy (solar and wind energy).
- Increase production capacity that help to meet the shortfall in energy demand.
- The continued development of all of the network facilities including communications technologies.
- The provision of the appropriate operating system in time for including the generation, transportation, distribution.
- Use of the latest communication technologies to ensure the provision of better service to customers.
- Allow to the participation of all parties in the energy market Which gives the satisfaction of all these parties.

1.5 Functionalities of Smart Grid

There are three functions of the smart grid are as follows:

1.5.1 Smart Grid Management

Smart network management know as managing the massive amount of data that is obtained In order to control of energy and protect it and make use of them and managing of quality of supply within the network. This is done by Information and Communication technology (ICT) That helps to monitor and control of operate renewable energy sources with high efficiency [9].

1.5.2 Smart Integrated Generation

Smart integrated generation is provide appropriate solutions for energy storage and distributed generation and all elements that incorporated with grid [9]. This is important to the following:

- Power generation efficiently
- Optimizing power delivery
- Optimizing power generation

1.5.3 Smart Market

The task of the smart market is cover the following functions:

- load control
- demand response
- dynamic pricing

Smart market covers those functions by smart meters which allows exchange of information between the market and the customers [10]. Figure 1.4 shows the smart grid functions.

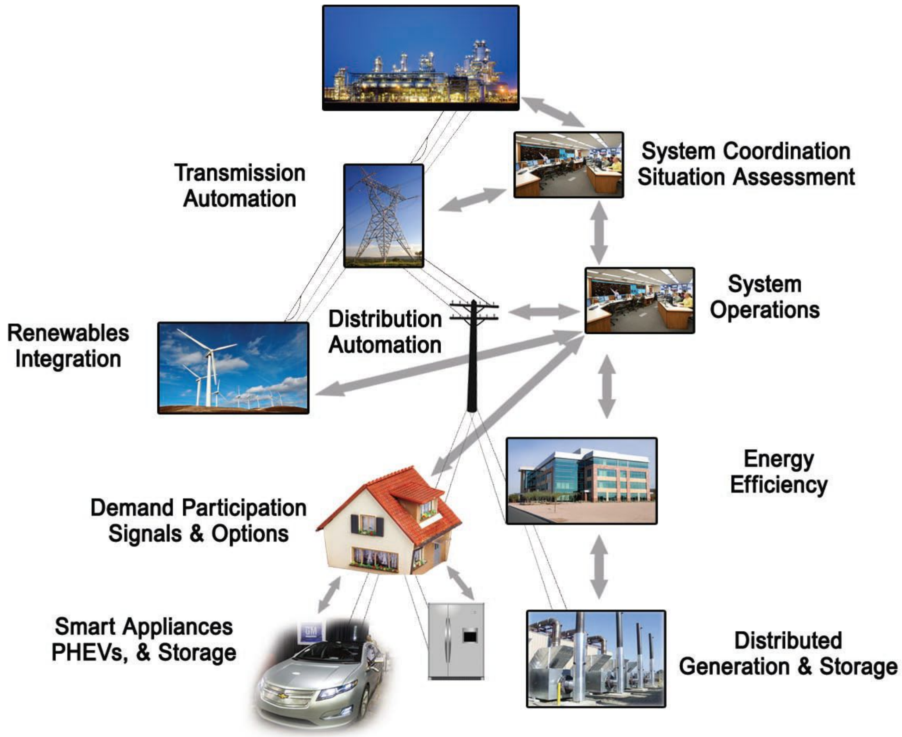

Figure 1.4 Smart Grid Functions [10]

1.6 Components of Smart Grid

1.6.1 Demand Management

The task of the demand management is cover the following functions:

- Reduce Electricity Consumption
- Continually monitoring for electricity consumption.
- Effectively managing for appliances in how to manage their energy consumption.
- Respond on variances of electricity pricing effectively.

1.6.1.1 Demand Response

Demand response helps consumers to reduce energy consumption by utility companies which send to them electronic alerts by smart meters during periods of peak and asking them to turning off appliances that are not necessary for them [11].

1.6.1.2 Variable Pricing

As is well known that electricity prices volatile, and it determined supply and demand. At this stage smart meters will inform the consumers about change prices that will able customers to choose the right price to them. By seeing the real cost of energy, consumers can consumed energy in the lowest prices periods [11,12].

1.6.1.3 Smart Meters

Smart meters is the main part of the demand management because it is the link between utilities and customers, and through which will alert customers to change prices during periods of peak and asking them to turning off appliances that are not necessary for them [11].

1.6.2 Distributed Electricity Generation

The main aim of distributed electricity generation is to make the grids more smarter, this is done through a transition from conventional generating power that generate from traditional sources to renewable energy generation that generate from renewable energy sources such as (wind and solar energy). However renewable energy generation has some problems. For example, when the sky becomes overcast or the wind stops blowing, in this case the generating power system will stop and shortfall in the electric grid. To compensate this deficit in time, utility companies must start up generate power from conventional power plants to temporarily offset the energy deficit. This smart grid features that is integration the conventional generating power with the renewable energy generation and create a balance of the grid [11,12]. Figure 1.5 shows distributed electricity generation future.

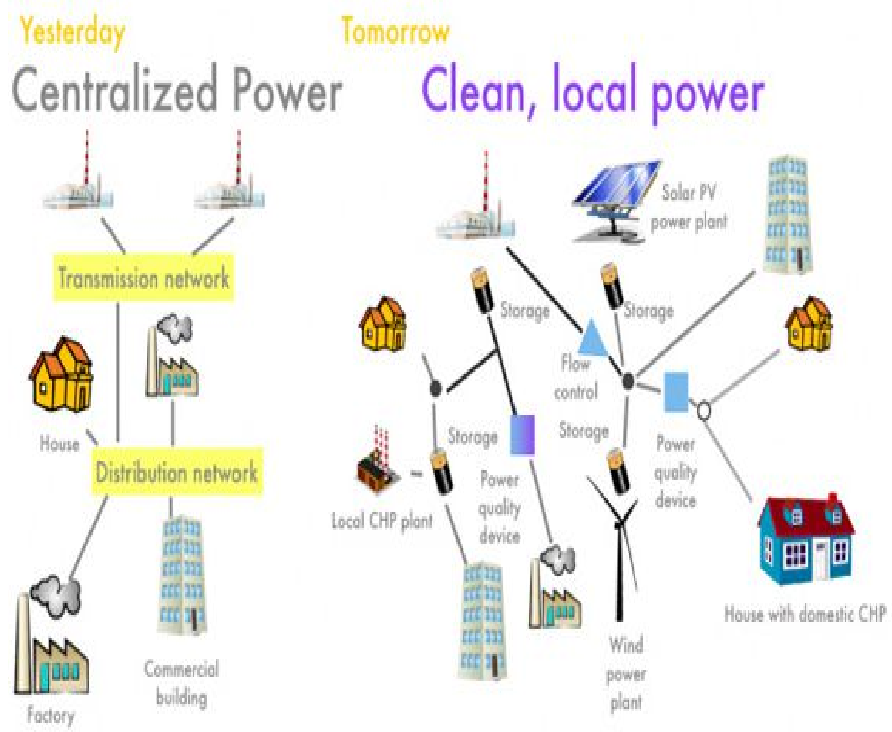

Figure 1.5 Distributed Electricity Generation Future [12]

1.6.3 Transmission and Distribution Grid Management

1.6.3.1 Grid Monitoring and Control

Grid Monitoring and Control allows to utility companies avoided expensive power outages by taking the appropriate decision quickly to isolate the cause of the outage. This can be achieved after installing sensors such as (SCADA system) to monitor and control the electrical grid to detect faults in time to respond. These monitoring and control systems are being extended from the beginning of transmission grid down to the distribution grid [11].

1.6.3.2 Grid Security and Surveillance

The function of Grid Security and Surveillance is protect the network from attacks and natural disasters by connected the substations, transformers, and power lines to data networks, allowing utility companies to monitor security by tamper sensors, live video, and active monitoring [12]. Figure 1.6 shows Smart grid components.

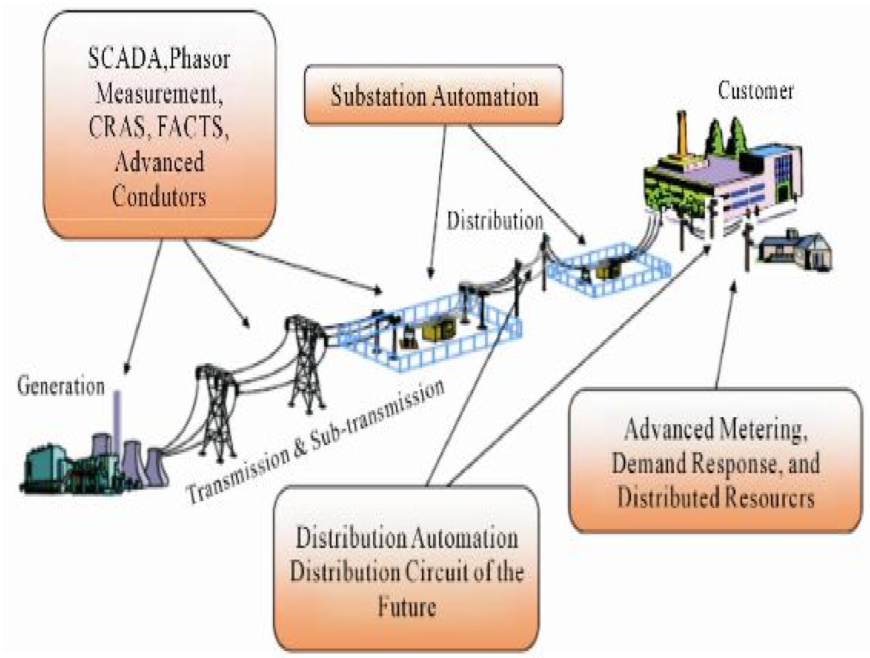

Figure 1.6 Components of Smart Grid [3]

2.7 Smart Grid and Environment

It is well known that the most important objectives of the deployment of smart grid is provide environmental benefits, through the minimizing of greenhouse gas emissions damage by increased energy conservation, improvements in end-use efficiency and integration of renewable energy projects into the grid [13].

CHAPTER TWO

MAIN TECHNOLOGIES IN SMART GRID

2.1 Information Technology in Smart Grid

2.1.1 Home Area Networks (HAN)

We can summarized the functions of HAN networks as follows:

- Gives motoring and control services to home automation networks.
- Gives demand response applications service to home automation networks.
- Gives users comfort by allowing power management efficiently.
- Gives access to smart devices and appliances in homes [14]. Figure 2.1 shows the main components of home area networks (HAN).

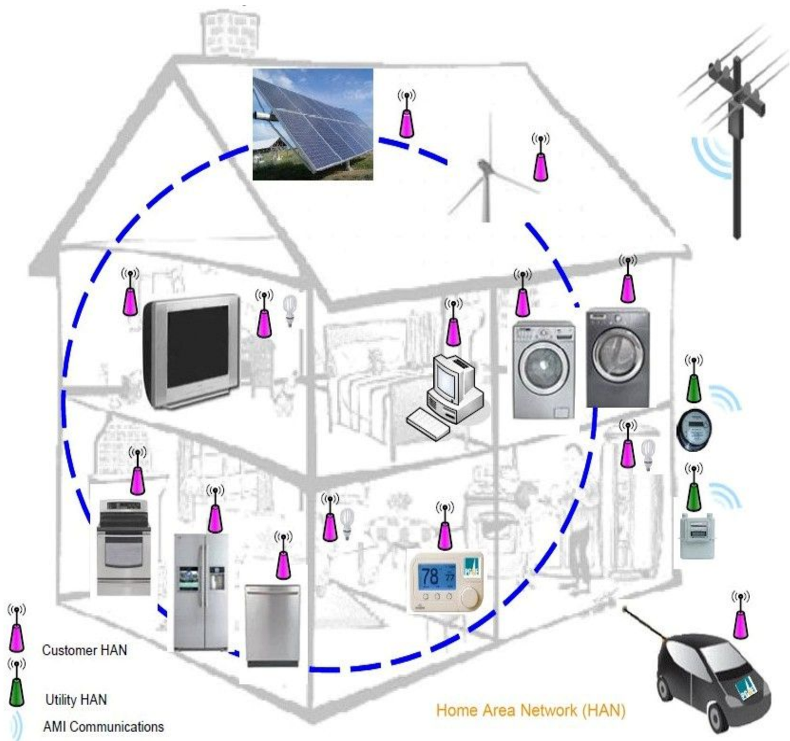

Figure 2.1 Home Area Networks (HAN) [14]

2.1.2 Local Area Network (LAN)

We can summarized the functions of LAN networks as follows:

- It is a computer network which connects computers and devices in the same building (in limited area).
- Gives the highest rate of data transfer in limited area.
- It does not need to leased telecommunication lines.
- Makes equipment of different companies compatible [15]. Figure 2.2 shows local area network (LAN).

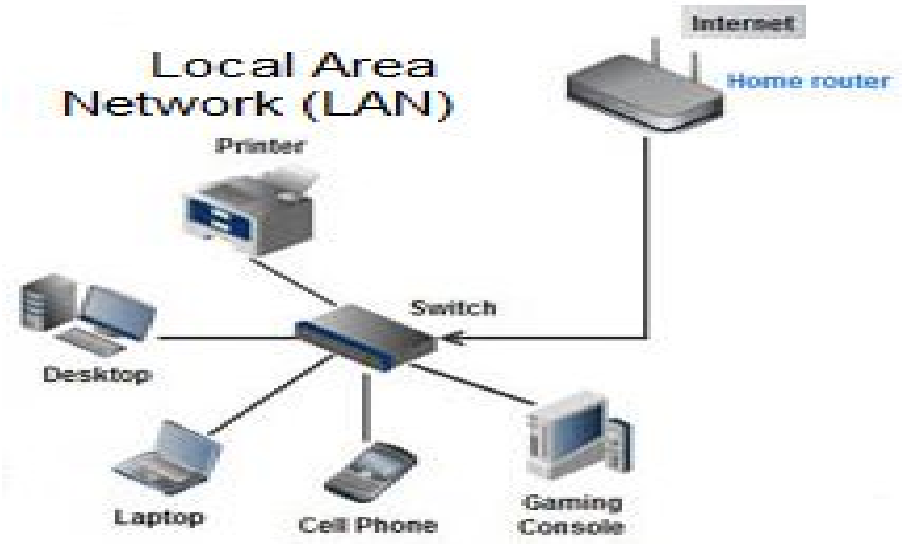

Figure 2.2 Local Area Network (LAN) [16]

2.1.3 Neighbourhood Area Networks (NAN)

We can summarized the functions of NAN networks as follows:

- Transmits information between customer premises and aggregation points.
- It is distribution domain network, it's also considered a mesh smart meters.
- Connects AMI applications access point to smart meters.
- It collects data from smart meters to monitoring and control.
- It appropriate for some networks such as (NAN networks WiMAX, LTE, 3G ,4G) [14]. Figure 2.3 shows neighbourhood area networks (NAN).

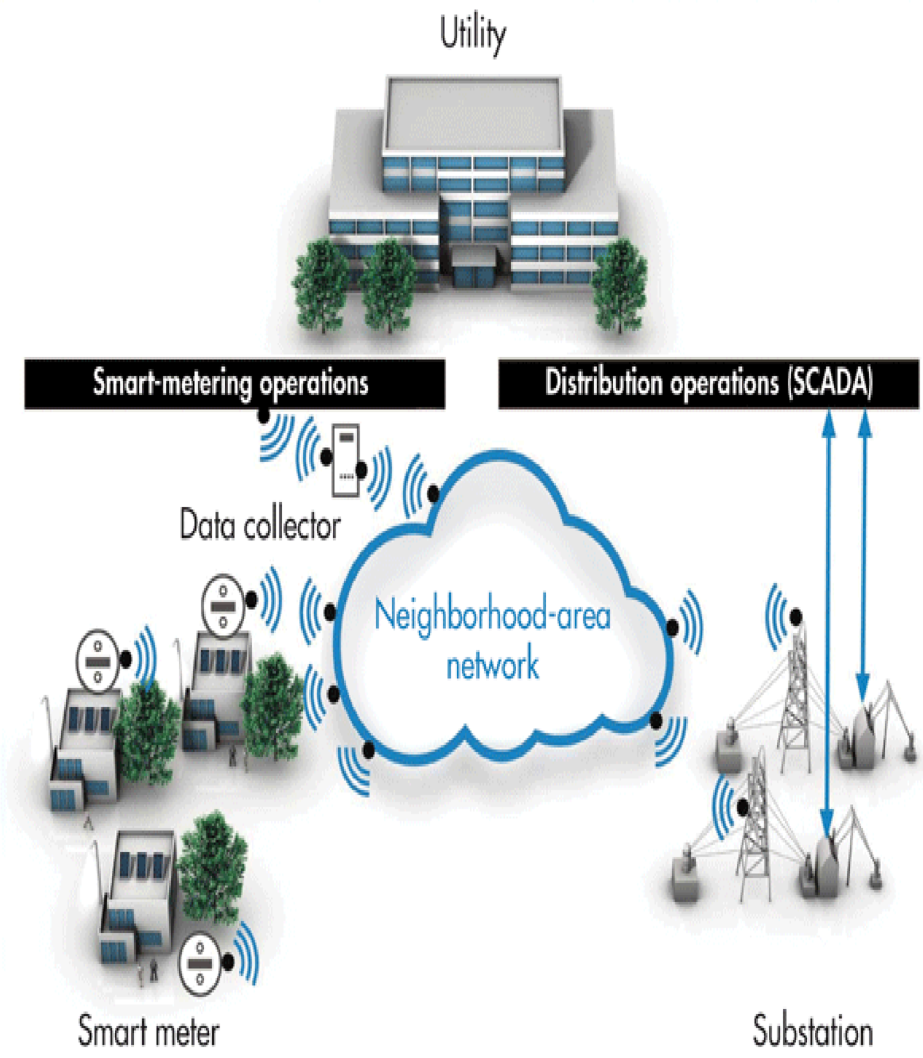

Figure 2.3 Neighbourhood Area Networks (NAN) [14]

2.1.4 Wide Area Networks (WAN)

We can summarized the functions of WAN networks as follows:

- It Plays an active role for communication between the data center and aggregation points.
- It gives communications systems between smart grid and utility system.
- It connects between substations and utility systems.
- (WiMAX, 4G,PLC, IP/MPLS) technologies could be used in its networks [14]. Figure 2.4 shows wide area networks (WAN).

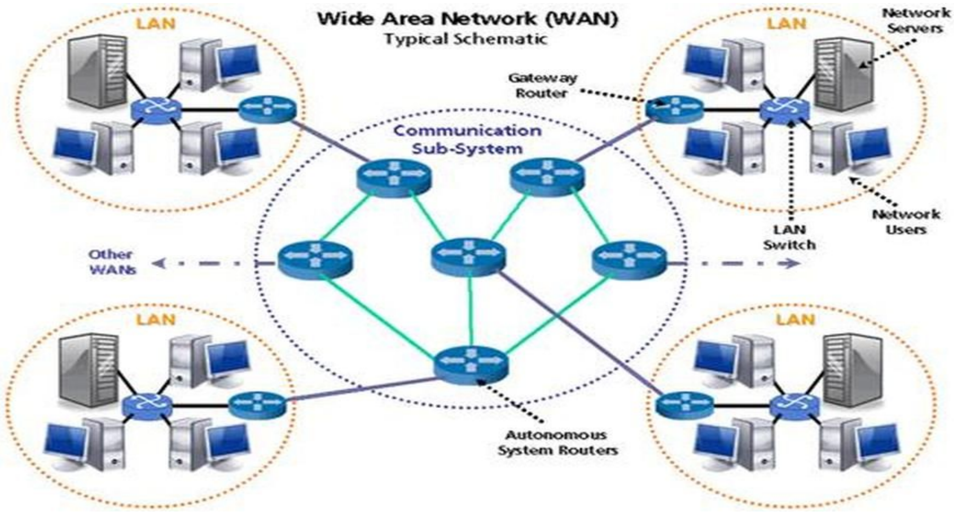

Figure 2.4 Wide Area Networks (WAN) [14]

2.1.5 Field Area Networks (FAN)

We can summarized the functions of FAN networks as follows:

- It is the communication network for the electrical power control centers.
- It is the communication network for distribution domain in the smart grid.
- It uses to collect data [14]. Figure 2.5 shows field area networks (FAN).

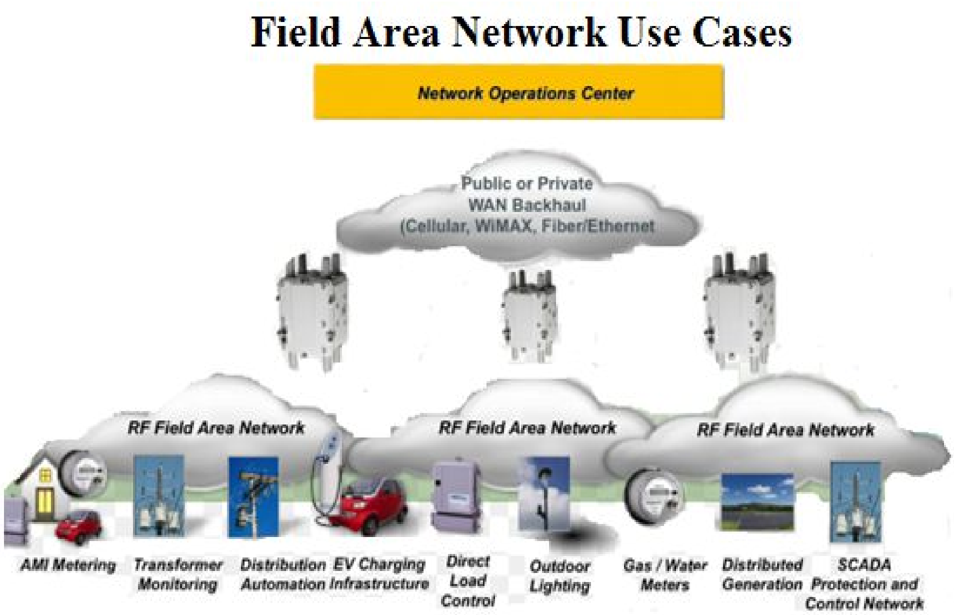

Figure 2.5 Field Area Networks (FAN) [15]

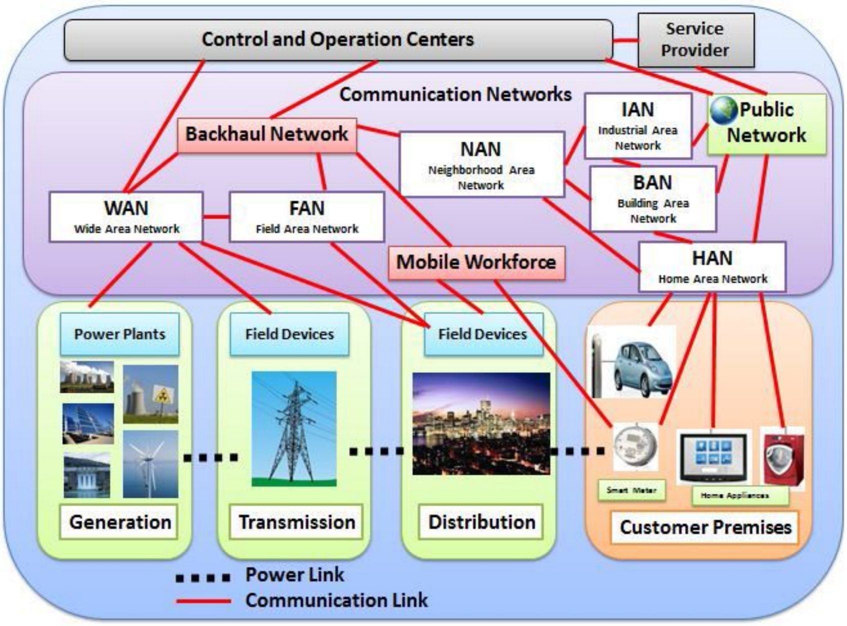

Figure 2.6 Multi-Tier Communication Networks for Smart Grid [17]

Smart grids distinguish three hierarchical subnetworks as depicted in Figure 2.7.

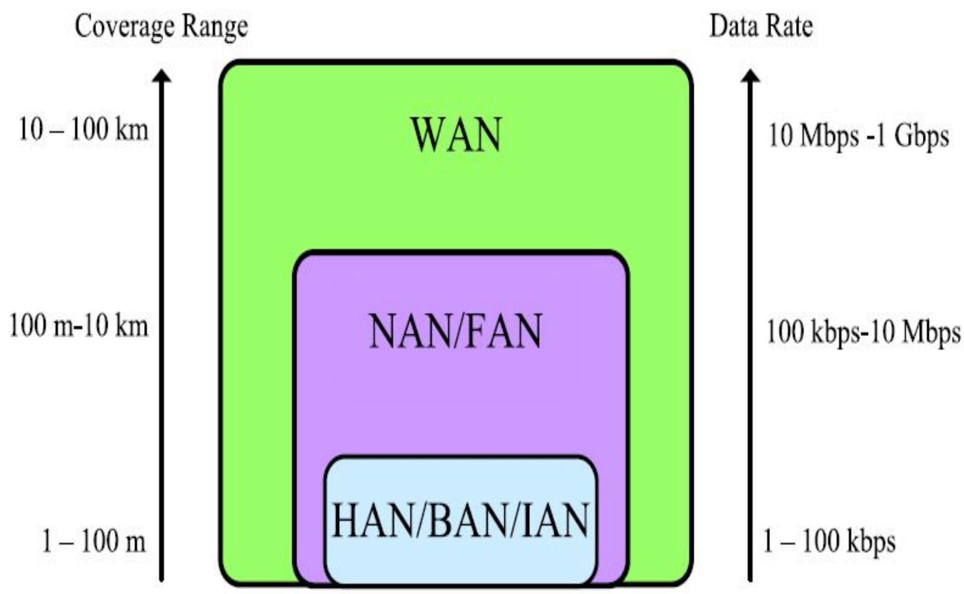

Figure 2.7 Smart grid communication sub-networks [18]

2.2 Communications Technologies in Smart Grid

2.2.1 Wired Communication Technologies

2.2.1.1 Dial-up Communications

Currently, Dial-up becomes little use. This technology still using for some AMI communications in some utilities and rural areas which there is no Internet available [19]. The Table 2.1 shows the advantages and disadvantages of Dial-up communications.

Advantages	Disadvantage
Cheap Compared to Other	Very Low Bandwidth
Very High Reliability	One User Per Line
Available Everywhere	Voice and data communications can't use at the same time
	Going on Long Outages

Table 2.1 Advantages and Disadvantages of Dial-Up Communications [19]

2.2.1.2 Power Line Carrier (PLC) Communication

Power Line Carrier (PLC) uses for transfer smart meter data to data concentrator. It gives high speed (2-3 Mbps) to transfer data signals from device to the other [19]. The Table 2.2 shows the advantages and disadvantages of power line carrier communications.

Advantages	Disadvantage
Existing Infrastructure	There is Noise on Power Lines
Overall System Pricing	Capacitors
There is no Radiated Signals	Data Injection Equipment Pricing
	Outages on power lines will cancels data transmission

Table 2.2 Power Line Carrier Advantages and Disadvantages [19]

2.2.1.2.1 Broadband over the Power Line (BPL)

PBL uses PLC technology, this technology allow access to the broadband Internet with higher data speeds by the electric utilities, that transmit the data signal over the medium electric power lines (PBL). This allow customers to have a higher upload speed [19]. Table 2.3 below shows the advantages and disadvantages of broadband over the power Line.

Advantages	Disadvantage
Provide using the Internet Service	On power line is low attenuation
Gives an Internet Service for the Utility	Passing the BPL signal by the distribution transformer
High speed throughputs	Equipment's cost to offer service

Table 2.3 Broadband Over The Power Line Advantages and Disadvantages [19]

2.2.1.3 Fiber Optic Communications

The optical fiber creates the optical signal including the use of a transmitters, sending the signal, ensuring that the signal will not be very distorted or weak. It's also the component that actually transmits the data by the fiber optic cable to a long distance with high data rates [19]. The Table 2.4 shows the advantages and disadvantages of fiber optic communications.

Advantages	Disadvantages
Lightweight and Small	Fiber cost
Low (no Signal Loss)	Installation cost
No Crosstalk	Maintenance cost
Bandwidth is Very High	Taps off Built by Existing Fiber Networks
Data Speeds are Very High	
there is no noise components	
High Security	To Installation needs Right of Way
Uses for long distances to data transfers	

Table 2.4 Fiber Optics Advantages and Disadvantages [19]

2.2.1.4 DSL Broadband Communications

DSL means communication technologies that permit data transmit by telephone lines. It gives a higher throughput speed and larger bandwidth over dial-up communications. It gives speed for download and upload data [19]. The Table 2.5 shows the advantages and disadvantages of DSL broadband communications.

Advantages	Disadvantages
can use existing Infrastructure	Utilities cannot control on Outages
Low cost compared to other	Right of the way removal
Does not use equipment investment	Equipment service that dependent on distance
High speed	
Reliability	Outages is extensive

Table 2.5 DSL/Broadband Advantages and Disadvantages [19]

2.2.2 Wireless Communications Technologies

2.2.2.1 Satellite Communications

Satellite communications provides Internet connectivity over long distances. It gives a high speed rate to access the Internet in anywhere including rural areas [19]. Satellite communications include the following:

- Ground Segment
- Space Segment

The Table 2.6 shows the advantages and disadvantages of satellite communications.

Advantages	Disadvantages
Gives a higher speed internet in rural areas	Low in transmission control
Wide area Coverage	Delay in Transmission time
No needs for right of way	High operational costs
Operates on many frequency bands	Daily Download is limited and known

Table 2.6 Satellite Communications Advantages and Disadvantages [19]

2.2.2.2 Radio System Communications

Radio communications operates in the range (900 MHz - 2.4 GHz). It cannot give the utility direct access to the Internet [19]. Table 2.7 below shows the advantages and disadvantages of radio communication systems.

Advantages	Disadvantages
Low monthly cost	Wireless Propagation Line of Sight is badly
System Designs by Contractors	Initial Cost is high
Higher in transfer data	No Internet services
Independent of Power Lines	Wireless interference with different systems

Table 2.7 Radio Communications Advantages and Disadvantages [19]

2.2.2.3 Microwave Communications

Microwave communications is type of sight communication lines. It allows transmit and receive information by antennas over long distances and does not depend on cables [19]. Table 2.8 shows the advantages and disadvantages of Microwave communications.

Advantages	Disadvantages
Channel Capacity is High	High Cost
does not depend on Power Lines	Signal Quality
Designs System from Contractor	Interference Problems
does not use any cables	

Table 2.8 Advantages and Disadvantages of Microwave Communications [19]

2.2.2.4 Cellular Data Communications

Cellular Data Communications uses cellular communications that is provides by cellular network. It provides the cellular technologies to be used with (AMR, SCADA, AVL) [19]. Table 2.9 shows the advantages and disadvantages of Cellular Data Communications.

Advantages	Disadvantages
Set Cost	The range (Carrier Coverage Areas)
Potential fast	Data Over fees
data speeds	Carrier cannot provide the customers equipment
high bandwidths	Gives an allowable data usage limit
	Equipment investment

Table 2.9 Cellular Communication Advantages and Disadvantages [19]

2.2.2.5 WiFi Communication

WiFi networks give operation and redundancy for fixed applications easily. It used for WLANs networks as IEEE 802.11 standard refers [20]. Table 2.10 shows the advantages and disadvantages of Wi-Fi Communications.

Advantages	Disadvantages
easy create Wi-Fi	Sensitive to electromagnetic radiation
can merge multiple devices together	Interfere with each other
ideal for buildings	
very convenient and allows you to connect to the internet almost anywhere	Call quality influenced by the environment
can access the network easily	

Table 2.10 WiFi Communication Advantages and Disadvantage [20]

2.2.2.6 WiMAX Communication

IEEE 802.16 standard known as (WiMAX). It gives data rate around 100Mbps and supports long distance around 10 Km broadband [20]. Table 2.11 shows the advantages and disadvantages of WiMAX Communications.

Advantages	Disadvantages
Standardized	Operational cost
High speed of connectivity to long distance	needs line of sight for longer connections
Infrastructure is flexible	Requires strong electrical support
Single station can serve a hundreds users	The rain could interrupt the signal
provides maximum reliability	Big installation
The same frequency equipment works together	Other wireless equipment could cause interference

Table 2.11 WiMAX Communication Advantages and Disadvantages [20]

2.2.2.7 ZigBee Wireless Mesh Technology

IEEE802.15.4 standard known as (ZigBee) is for low cost and power, and short range over tens of meters. It has power consumption is low which making a devices operate for months on AA batteries [14]. Table 2.12 shows the advantages and disadvantages of ZigBee Wireless Mesh Technology.

Advantages	Disadvantages
Relatively Inexpensive	No more secure
Power consumption is low	Short Range
Appliances compatibly operate on the same network	Replacement with Zigbee compliant appliances can be costly
Eliminates dependence on Infrared devices	Can be confusing at first for the homeowner
Manage home appliance network remotely	

Table 2.12 ZigBee Wireless Mesh Advantages and Disadvantages [14]

2.2.2.8 Long Term Evolution (LTE)

The 4G standard known as LTE, it uses for (NAN) networks like end to end quality of services. It is good chose for Smart Grid because it offers (100 Mbps of peak speeds, 10 Mbps of average user throughput speeds and download rates 300 Mb/s) [19,20]. Table 2.13 shows advantages and disadvantages of long term evolution (LTE).

Advantages	Disadvantages
Facilitates the applications to perform on better speed	High cost
Allows many users to use the same frequency	multiple-input multiple-output (MIMO)
Separates frequencies to different channel	Need to use additional antennas
Offers faster data rate transfer	only supports packet switching with its all-IP network
Supports more data capacity	

Table 2.13 LTE Advantages and Disadvantages [19,20]

2.2.2.9 DASH7

The ISO standard known as Dash 7 is a technology for wireless sensors networks and active radio frequency identification devices (RFIDs). It operates at a rate 28-200 kbps and coverage around 250 M to 5 KM [14,21]. Table 2.14 shows the advantages and disadvantages of Dash 7.

Advantages	Disadvantages
Permitting less nodes and communication time	Cannot handle high-bandwidth data transfers
Sensor and security support	
Penetration of concrete walls and water	Transmission of multiple
Interoperability	Not suitable for large networks
Robustness and low cost	Consecutive packets may occur
Multi-year battery life	Contrasts with some wireless data technologies
Ability to bend around metal objects	

Table 2.14 Dash7 Advantages and Disadvantages [14,21]

2.3 Communication Technologies That Used In Smart Grids

Satellite, fiber optic, Cellular and WiMAX communications are used in high range and data rate WAN applications, others are used in low and middle range such as (HAN,BAN,AN,NAN and FAN) applications. However, 3G and 4G/LTE cellular communication techniques have not used in smart Grids applications right now. The Table 2.15 shows communication technologies that can be used in the sub-networks of smart grids [18].

Communication Technologies	**Sub-Networks**		
	HAN/BAN/IAN	**NAN/FAN**	**WAN**
Wired			
Fiber optic	-	-	x
Coaxial Cable	-	x	-
DSL	-	x	-
Ethernet	x	x	-
PLC Communication	x	x	-
Wireless			
Z-wave	x	-	-
Bluetooth	x	-	-
WiFi	x	x	-
ZigBee	x	x	-
WiMAX	-	x	x
Wireless Mesh	x	x	-
Cellular (2G)	-	x	x
Satellite	-	-	x

Table 2.15 Communication Technologies Used In Smart Grid [18]

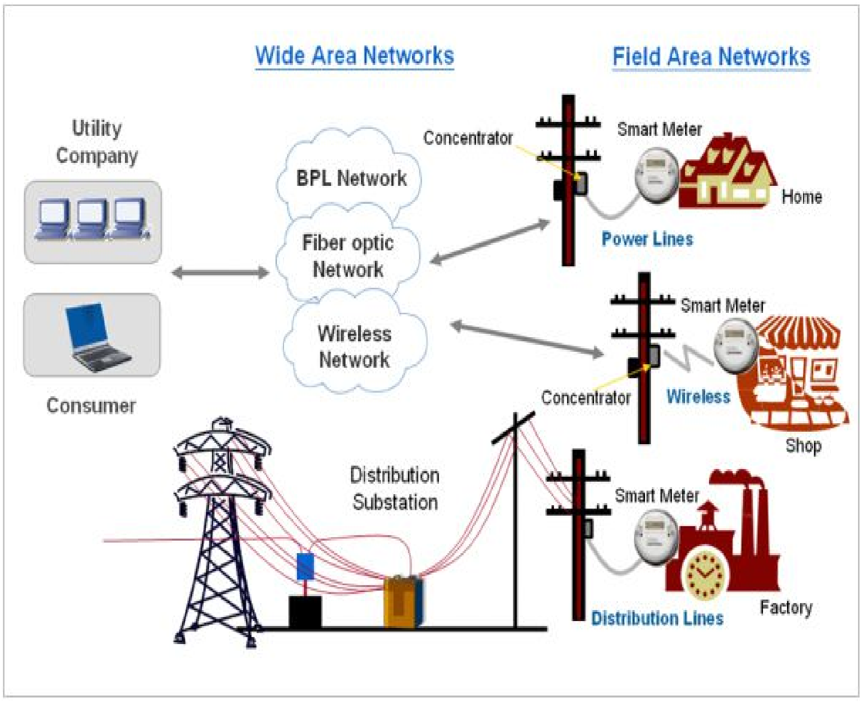

Figure 2.8 Use of Communications in Smart Grid [22]

2.4 Metering Technologies in Smart Grid

Automatic Metering Infrastructure (AMI) technology in Smart Grid system allows read automatically for meters instead of using reading eye or otherwise of meter readers. This is done by two way communications systems that enable information interchange between the utilities and consumers [19]. Figure 2.9 shows AMI system.

Figure 2.9 AMI System [23]

Figure 2.10 shows how smart meter monitoring works.

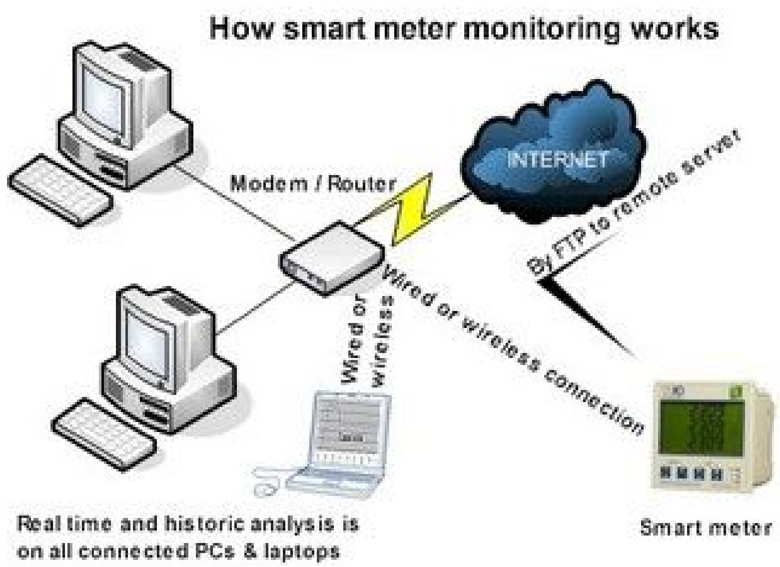

Figure 2.10 Smart Meter Monitoring Works [23]

2.4.1 Advanced Meter Reading (AMR)

The most important part of the (AMI) technology is automatic meter reading (AMR). This technology gives the utilities a huge amount of information and quick access every minute of the day. AMR system can gives reports to the utilities about power thefts [19]. Figure 2.11 shows AMR system.

Figure 2.11 AMR System [19]

2.4.2 Advanced Meter Management (AMM)

Advanced Meter Management (AMM) is the ability to receive control signals from the operator and to switch off local electric appliances. AMM enables distribution grid operators to take appropriate measures more quickly in emergency situations to avoid blackouts [24]. Figure 2.12 shows AMM system.

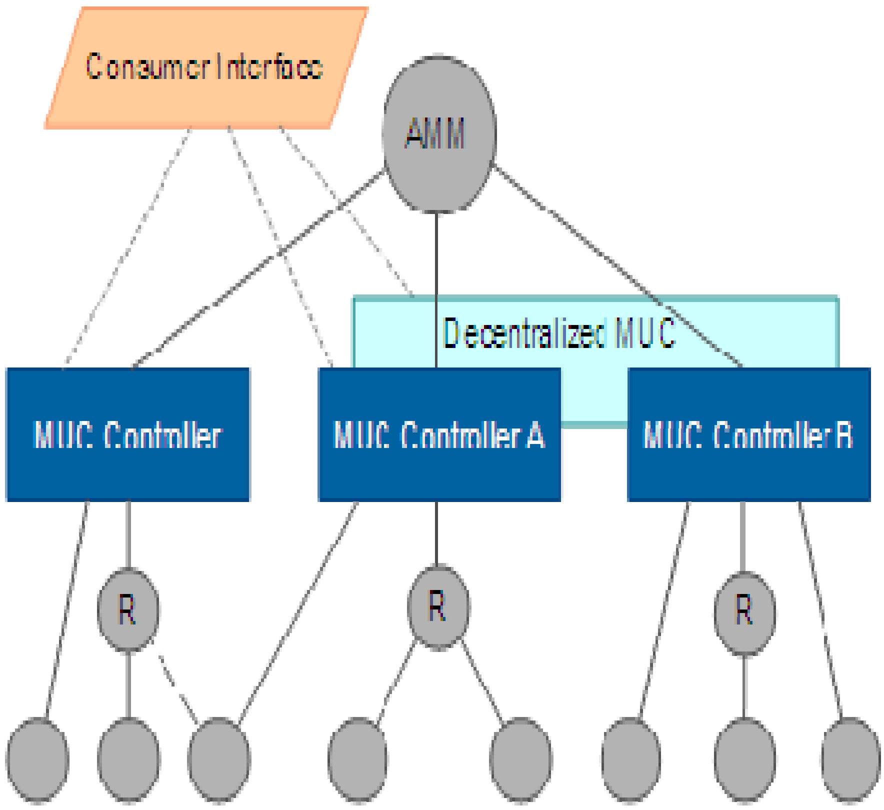

Figure 2.12 AMM system [25]

2.4.3 Meter Data Management (MDM)

MDM helps utilities to manage a huge quantity of customers energy. It's center for all data and information, and allows processing of all data types [26]. Figure 2.13 shows Meter Data Management MDM.

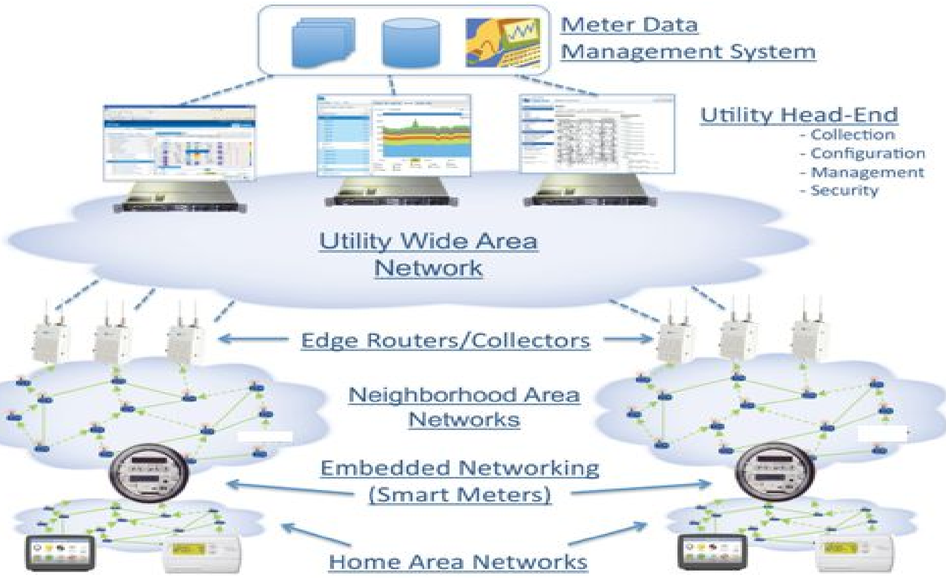

Figure 2.13 Meter Data Management MDM System [26]

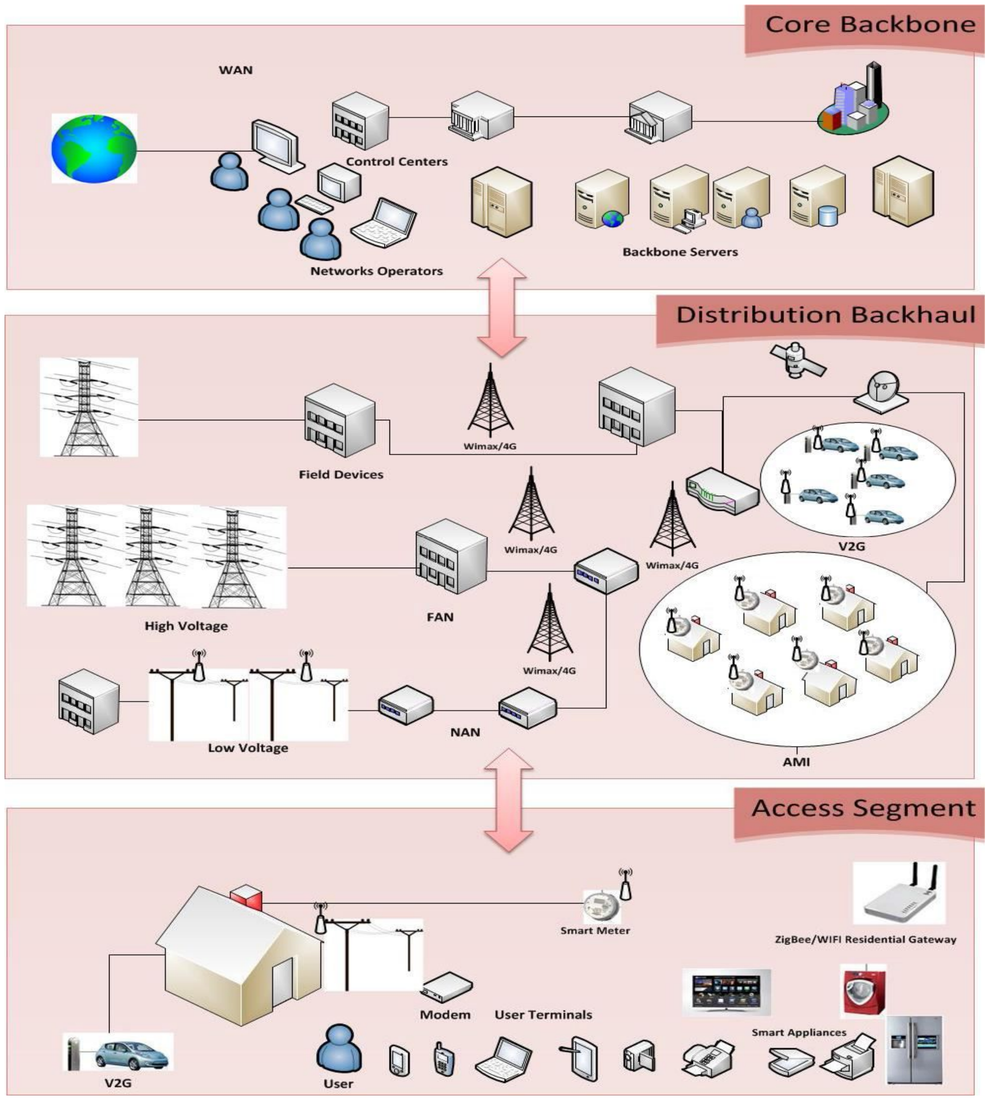

Figure 2.14 End to End Smart Grid Communication Architecture [17]

Type	Coverage	Applications
PLC	NB-PLC: 150 km BB-PLC: 1.5 km	NB-PLC: AMI, FAN, WAN BB-PLC: HAN/AMI
Fiber	Between10 Km and 60 Km	WAN, AMI
DSL	Between 300 m and 7 km	AMI, FAN
WiFi	Between 300 m and 1 Km	V2G, HAN, AMI
WiMAX	Between 10 km and 100 km	AMI, FAN, WAN
3G, GSM, GPRS, EDGE	HSPA+: 0–5 km	V2G, HAN, AMI
4G / LTE	0–5 km up to100 km	V2G, HAN, AMI
ZigBee	Up to 100m	V2G, HAN, AMI
Cognitive Radio	Up to 100 Km	AMI, WAN
Dash7	from 250 m to 5km	V2G, HAN, AMI

Table 2.15 Summary of Communication Technologies for Smart Grid [17]

CHAPTER THREE

SMART GRID STANDARDS

3.1 Introduction

Smart grid standards are important to:

- Determine Smart grid equipment
- Handling information data management, communications and control in smart grid.
- Flexible smart grid system interoperability
- Development of a body of interoperability smart grid [27].

3.2 Interoperability

Interoperability means the ability of a product or a system to exchange data and interpret that shared data with other products or systems without special effort on the part of the user [27].

3.2.1 IEEE Standard 2030 Series

3.2.1.1 IEEE Standard 2030

Scope and Purpose: [28]

- Provide guidelines to understanding and defining smart grid interoperability.
- Provide integration of energy technology, information and communications technology.
- Provide functional performance.
- Provide a knowledge base addressing terminology.
- Provide evaluation criteria.

- Establishes the (SGIRM)
- Provide Characteristics
- Provide guidelines for smart grid interoperability.
- Power generation usage.
- Digital information management.
- Communications and linkages
- Data Flows
- Design Criteria
- Logical Connections

3.2.1.2 IEEE Standard P2030.1

Scope and Purpose: [28]

- Applications for electric sourced vehicles.
- Related support infrastructure.
- Provide a knowledge base addressing terminology.
- Planning Requirements
- Methods and Equipment

3.2.1.3 IEEE Standard P2030.2

Scope and Purpose: [28]

- Guide for smart grid interoperability of energy technology.
- Guide for smart grid interoperability of information technology operation with (EPS).
- End-use applications and loads.
- Functional Performance
- Testing And Operations
- Evaluation Criteria

3.2.1.4 IEEE Standard P2030.3

Scope and Purpose: [28]

- Establishes test procedures for (EPS) applications.
- Establishes tests procedures for electric energy storage equipment.
- Smart Grid Definitions.
- Systems Approach
- Functional and performance attributes.
- Interoperability
- End-use
- Interfaces and Integration
- Test and Verification Methods

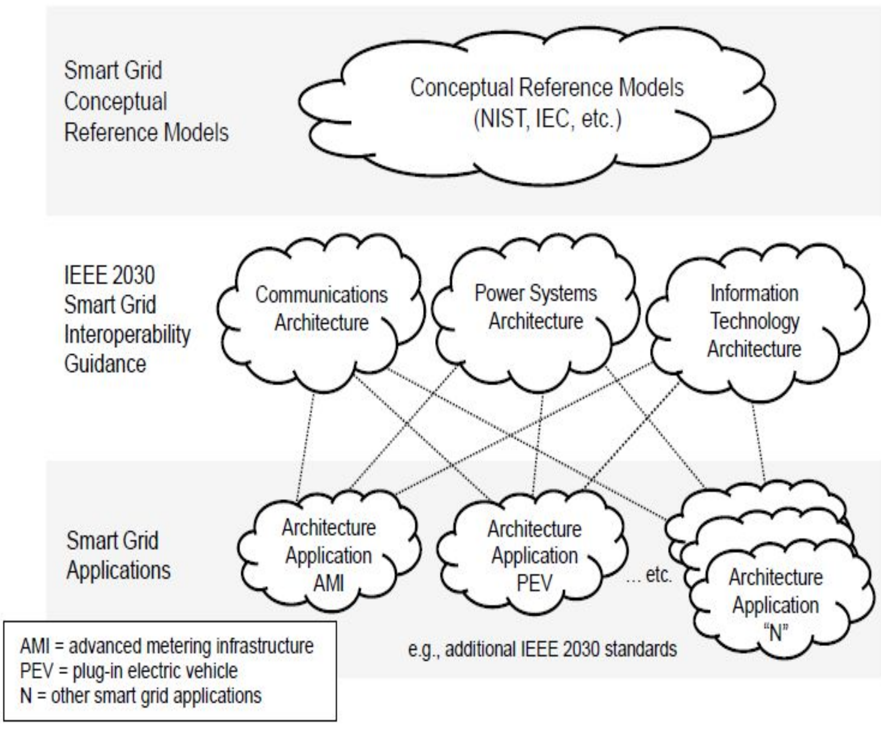

Figure 3.1 Evolution of Smart Grid Interoperability Source: IEEE Std 2030 [28]

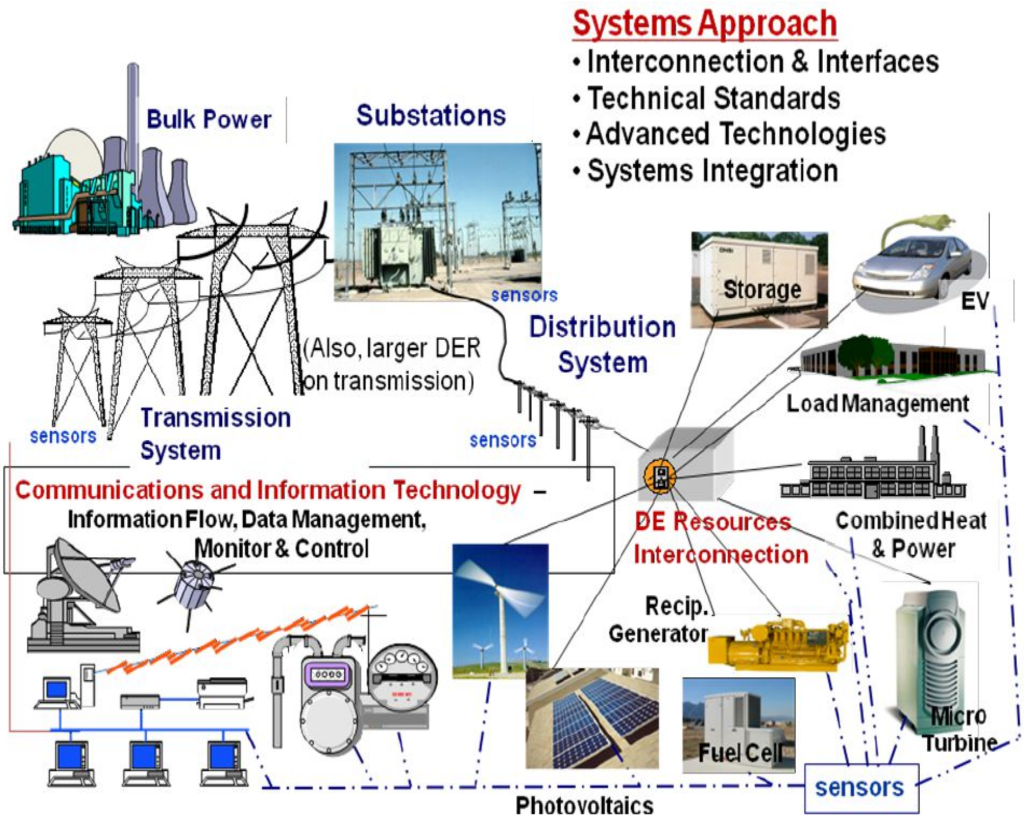

Figure 3.2 IEEE P2030 Standard Interoperability Smart Grid Concepts [28]

3.3 Interconnection

Interconnection is the logical and physical linking of a carrier's network with facilities or equipment that not belonging to that network [29]. It means the linking of telecommunications networks so that makes customers of one network communicate with customers of another network [30].

3.3.1 Interconnection Function

- Interconnection cancels the need for a customer to subscribe to multiple networks in order to be able to communicate with all other customers [29].
- Controlling carriers can hinder or cancel competition by delaying interconnection, degrading the quality of interconnection, or charging high prices for interconnection [29].

3.3.2 The IEEE 1547 Series of Standards

3.3.2.1 IEEE Standard 1547

Scope and Purpose: [28,31]

- Distributed Resource (DR)
- Electric Power System (EPS)
- Interconnection
- Interconnection Equipment
- Interconnection System
- Point of common coupling (PCC)

3.3.2.2 IEEE Standard 1547.1

Scope and Purpose: [31]

- Interconnection Equipment connects (DR) to (EPS).
- Specifies The Type
- Specifies The Type
- Production
- Commissioning Tests
- Accommodate a Variety of DR Technologies.

3.3.2.3 IEEE Standard 1547.2

Scope and Purpose: [32,33]

- Application Guide for IEEE1547 Standard
- Interconnecting (DR) to (EPS)

3.3.2.4. IEEE Standard 1547.3

Scope and Purpose: [31,34]

- Provides Guidelines for Monitoring.
- Information Exchange
- Control For (DR) Interconnected With (EPS)
- Facilitates The Interoperability
- Describes Functionality
- Methodologies For Monitoring
- Parameters

3.3.2.5 IEEE Standard 1547.4

Scope and Purpose: [31]

- Provides Alternative Approaches
- Good Practices For The Design
- Guide for Operation
- Guide for Integration of (DR) Island Systems with (EPS).

3.3.2.6 IEEE Standard 1547.5

Scope and Purpose: [31,34]

- Provide guidelines for technical requirements such as (construction, acceptance testing, including design , maintenance / performance requirements).
- Provide Technical Information.
- Correct Guidance For Interconnection Technically.

3.3.2.7 IEEE Standard 1547.6

Scope and Purpose: [28]

- Interconnection of (DR) into distribution secondary network systems.
- Establishes criteria that bespoke such as (provides guidance, requirements, tests).

- Addresses the technical issues and concerns of (EPS) area.
- Identifies communication and control.

3.3.2.8 IEEE Standard 1547.7

Scope and Purpose: [34]

- Describes engineering studies extent of the impact on (EPS) area of (DR).
- Impacts Study Scope
- The Interconnection

3.3.2.9 IEEE Standard 1547.8

Scope and Purpose: [28]

- Identification Of Innovative Designs
- Processes And Operational Procedures
- Provide More Flexibility
- Determining The Design
- Implementation strategies that use to interconnecting (DR) with (EPS).

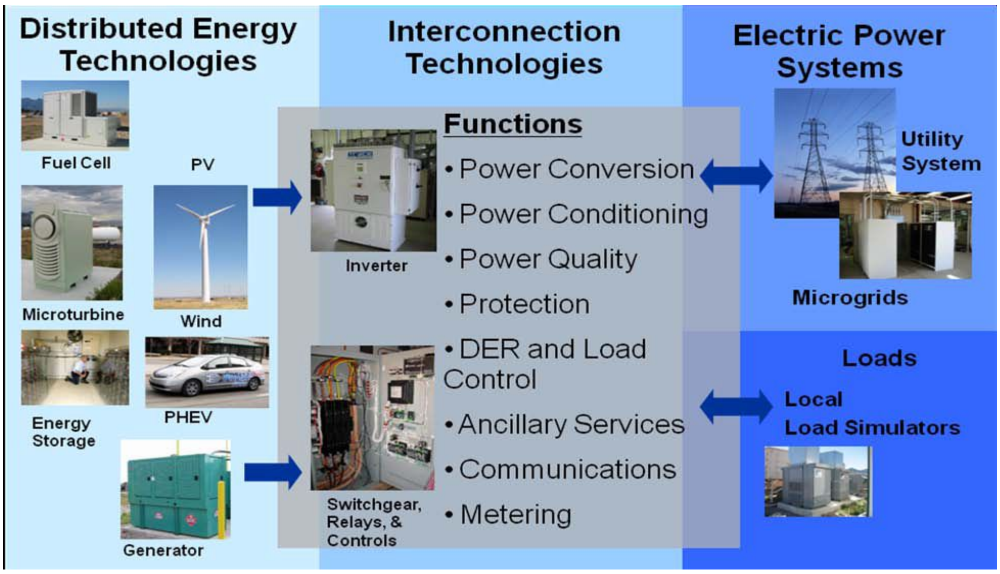

Figure 3.3 Distributed Energy Technologies and Interconnection Technologies [34]

CHAPTER FOUR

ELECTRICITY AND COMMUNICATIONS INFRASTRUCTURES OF LIBYA

4.1 Electricity Infrastructure of Libya

Currently, Libya's electric power production capacity around 4.6-4.7 GW, with peak load of about 3.3 GW. Libya's power grid consists of around 13860 KM of 220 kV lines, 14476 KM of 66 kV, 16226 KM of 30kV lines and 16700 KM of 11 kV lines and 400 kV grid are in the works, involving installation of 3360 KM of new power lines. The installed capacity is 5600 MW with a peak Load of 3650 MW. Power demand in Libya is growing rapidly about 6%-8% yearly, and is expected to reach 8 GW by 2020 [35].

Peak Load	5,759 MW
Installed Generation Capacity	8,907 MW
Generated Energy	32.6 TWh
400 kV Transmission system	2,823 km
220 kV Transmission system	13,782 km
30, 66 kV Subtransmission	23,132 km
11 kV distribution	52,260 km
Customers	1,224,193
Per-Capita Consumption	4,351 kWh
Urban & Rural Electrification Rate	~99%

Table 4.1 Key Figures [35]

Consumption type	Percentage
Residential	36%
Commercial	14%
Agriculture	12%
Industrial	11%
Others	27%

Table 4.2 Electricity Consumption Per Sector [35]

4.1.1 Overview of Power Sources in Libyan Transmission Network

Substation name	Fuel	No. of units	Unit capacity	Total capacity
Homs	Heavy oil/Gas	4	120 MW	480 MW
Tripoli West	Heavy oil	5	65 MW	325 MW
		2	120 MW	240 MW
Derna	Heavy oil	2	65 MW	130 MW
Tobruk	Heavy oil	2	65 MW	130 MW

Table 4.3 Steam Power Plants [36]

Substation name	Fuel	No. of units	Unit capacity	Total capacity
Abu Kamash	Light oil	6	15 MW	90 MW
Homs	Light oil/Gas	4	150 MW	600 MW
Tripoli South	Light oil	5	100 MW	500 MW
Zwitina	Light oil/Gas	4	50 MW	200 MW
Kufra	Light oil	3	25 MW	75 MW

Table 4.4 Gas Power Plants [36]

Substation name	Fuel	No. of units	Unit capacity	Total capacity
Zawia	Gas	4	165MW	660MW
		2	165MW	330MW
Bengazi North	Gas	3	150MW	450MW
		1	165MW	165MW
	Steam	2	195MW	390MW

Table 4.5 Combined-Cycle Power Plants [36]

Substation name	Fuel	No. of units	Unit capacity	Total capacity
Misurata Steel	Heavy oil/Gas	6	85 MW	510 MW
Nahr	Heavy oil/Gas	6	15 MW	90 MW

Table 4.6 Private Power Plants [36]

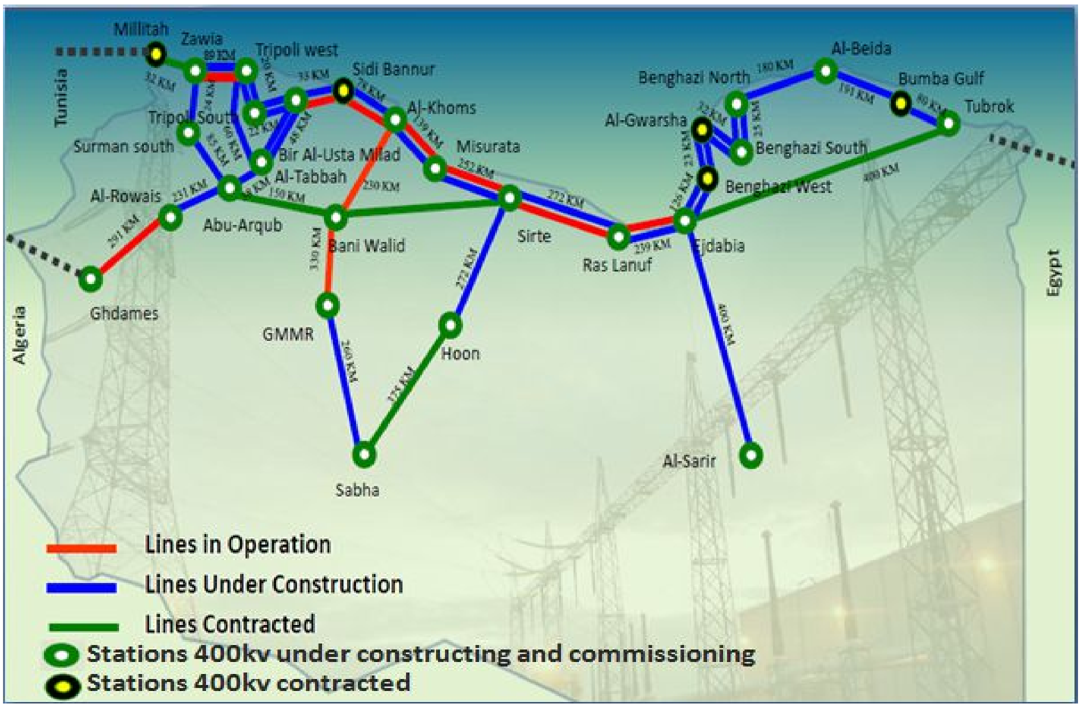

Figure 4.1 400/220kv Substations and Ultra-High Voltage (400kv) Network [35]

4.2 Libya's Renewable Energy Resources

4.2.1 Libya's Wind Energy

Libya has started the construction of a 62 MW wind farm at its north east coast. Libya want to obtain 20% of renewable energy in 2020. Wind energy, will help it to achieving this. Large wind power projects which will be implemented in Libya should increase wind power capacity to 500 MW by 2015 and 1000 MW by 2020. Table 4.7 shows program of Libya's wind energy projects [37].

Region	Farm Name	Capacity	Project status
Green Mountain	Dernah 1st stage	60 MW	Contracted
Green Mountain	Dernah 2st stage	60 MW	Contracted
Benghazi	Almqrun 1st Stage	120 MW	Contracted
Benghazi	Almqrun 2st Stage	120 MW	For investment
Western Mountain	Trhuna – Mislatha – Assaba	250 MW	Offer prepare

Table 4.7 Wind Energy Program [37]

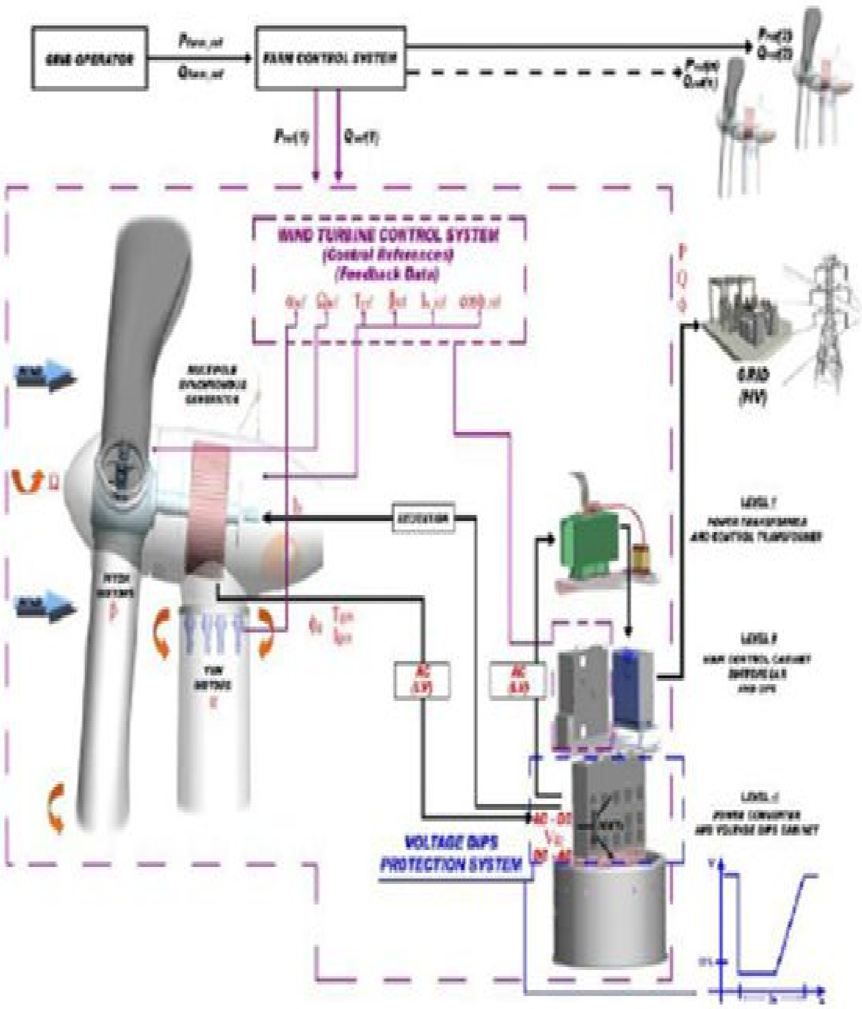

Figure 4.2 Wind Generation Modeling [37]

4.2.2 Libya's Solar Energy

Libya has the possibility to be a renewable energy giant according to Studies conducted on climate change. It has a very high daily solar radiation rate on a coastal areas it is about 7.1 kilowatt hours per square metre per day (kWh/m²/day) and in the south areas it is about 8.1kWh/m²/day [38]. If we covered just 0.1% of Libya's land mass of solar panels, it can generate from solar power about five times the amount of energy that it currently produces of crude oil as stated by the journal Renewable Energy [39].

4.2.2.1 Photovoltaic

The total installed PV capacity in Libya divided to [40]:

- PV for Rural Electrification
- PV for Water pumping
- PV for street lights
- PV for Communication Networks
- PV for Roof top systems
- PV for Cathodic protection

Table 4.8 presents the total installed capacity as PV.

Applications	Number of systems	Total power [KWp]
Communication	100	420
Cathodic protection	300	540
Rural Electrification	510	345
Water pumping	40	110

Table 4.8 Total Installed Capacity as PV [41]

4.2.2.2 Thermal Conversion

The use of thermal conversion in Libya started in 1983. Since then has been installed about 2000 of solar heaters [35].

4.2.3 Current and Future Plans for Developing The Renewable Energy in Libya

Based on the plan that is (National Renewable Energy) with the aim of bringing Renewable energy into the main stream of the national energy supply system with a target contribution of 10-20% of the electricity demand by the year 2020. The proposed plan that call to encouragement use a wide spectrum of renewable energy applications [35].

4.2.3.1 Short-Term Projects (2013 - 2015)

Field	Total Capacity	Name of Project	Capacity of Project
Projects of wind power	260 MW	Darnah wind farm	60 MW
		Al-Magron wind farm1	80 MW
		Al-Magron wind farm2	120 MW
Projects of solar PV	85 MW	Plant Al-Jofra	14 MW
		Plant Sabha	15 MW
		Plant south green mount	50 MW
		Roof systems	3 MW
		Rural electrification	2 MW
Projects of Concentrated solar power	25 MW	Plant south Sabha	25 MW
Projects of solar water heating	60 MW	Different sits	60 MW

Table 4.9 Short-Term Projects [42]

4.2.3.2. Medium-Term Projects (2016 – 2025)

Field	Total Capacity	Notes
Projects of wind power	340 MW	Based on the results of technical and economical, Site selection will be conducted feasibility studies with the follow up reports of the short term projects.
	400 MW	
Projects of solar PV	220 MW	
	500 MW	
Projects of CSP	125 MW	
	250 MW	
Projects of SWH	250 MW	

Table 4.10 Medium-Term Projects [42]

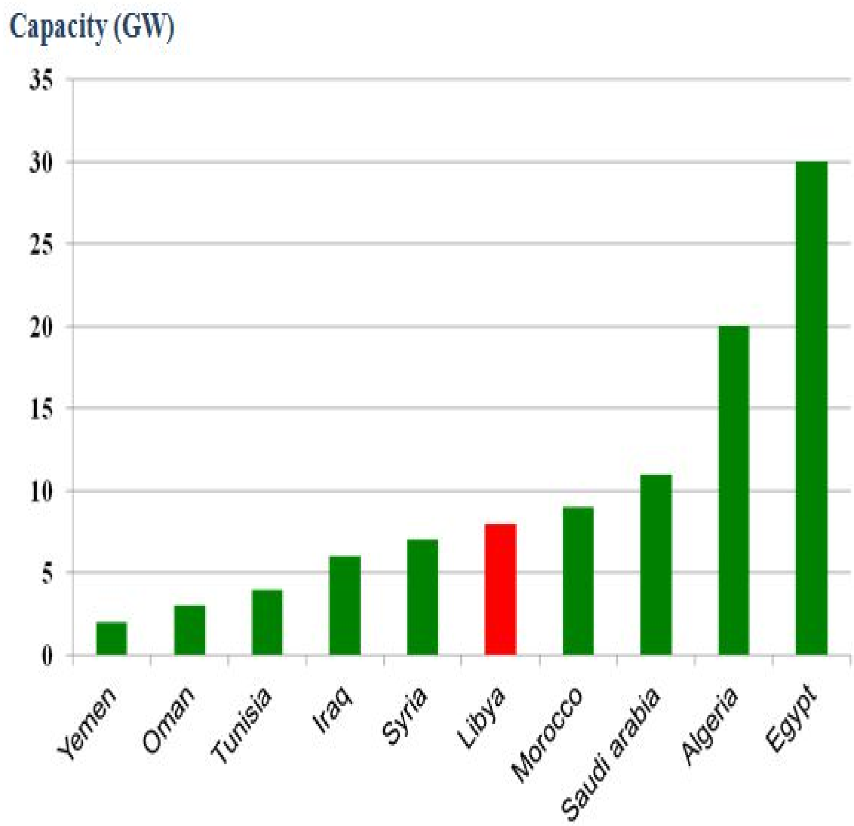

Figure 4.3 Wind Energy Potential In Comparison [42]

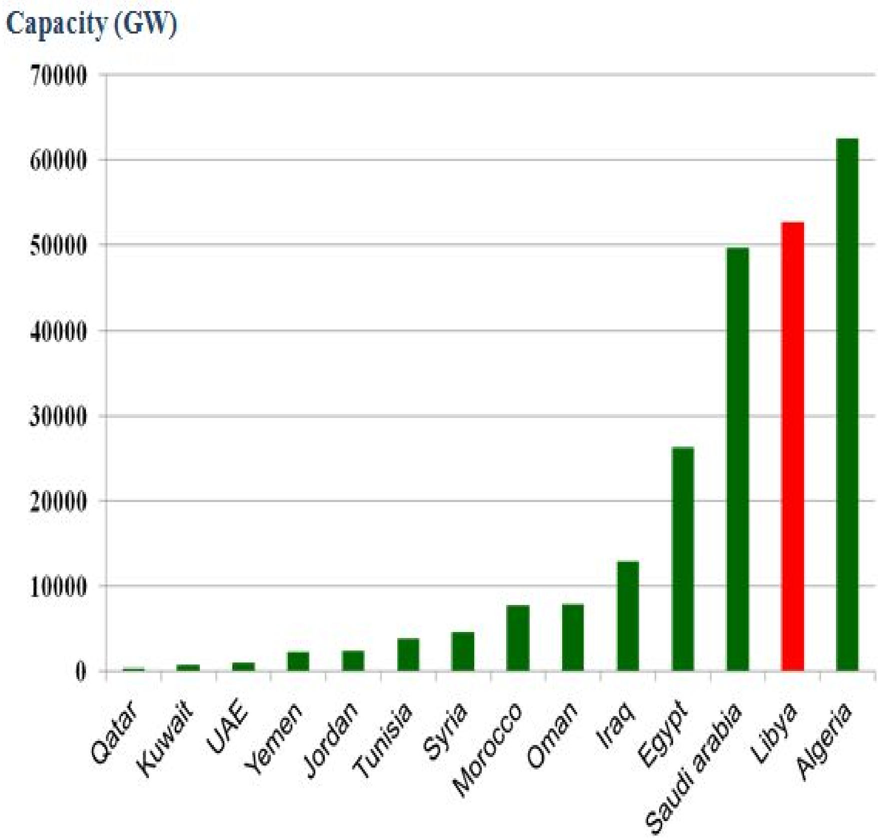

Figure 4.4 Solar Energy Potential In Comparison [42]

4.3 Communications Infrastructure in Libya

Communications infrastructure in Libya has grown quickly by General Post and Telecommunications Company (GPTC) that is owned to the public sector. It owns Libya Telecom and Technology Company (LTT) [43,44]. It is the only company specializing in providing data services such as (Internet, and the two mobile operators, Almadar and Libyana for Mobile Phone Network) [45]. LTT has been Libya's main provider of communications and Internet services since 1997. In 2007, LTT selected ZTE to build the first WiMAX network in Africa. Now, it become superior to those in most other African countries [43,44]. Table 4.11 shows communication technologies that used in Libya.

Communication Technologies in Libya	
Wired Communication	**Wireless Communications**
Power line carrier (PLC)	satellite
Broadband over the power line (BPL)	Radio System
Fiber Optic	3G
DSL/Broadband	WiFi
	WiMAX

Table 4.11 Communication Technologies in Libya [43,44]

CHAPTER FIVE

TRANSFORM LIBYA ELECTRIC NETWORK INTO SMART GRID

5.1 Setting Standards That Will Use to Implementation Smart Grid

In the first step towards a smart grid we must set standards that will help us to make smart grid reality such as smart grid systems and devices , identify an initial set of standards to support implementation, and list plans to set standards needs. Figure 5.1 shows the standards that will we use.

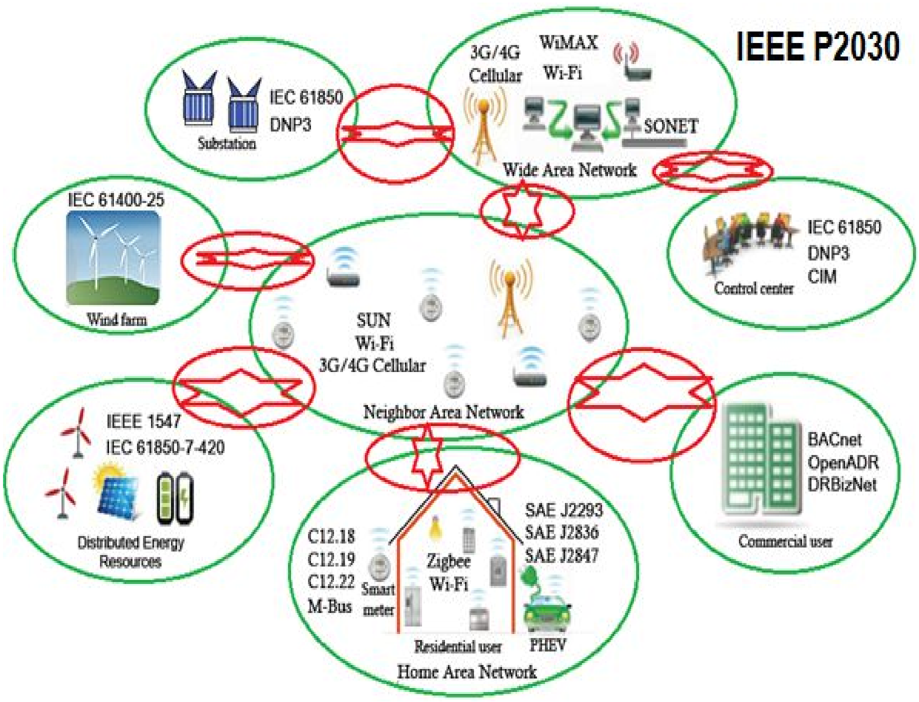

Figure 5.1 Main Standards That Will Use

5.2 Digital Communication System

Two-way digital communications will make the smart grid an interactive, dynamic [46]. This critical “interoperability” depends on a coordinated framework of protocols and standards like IEEE Standard 2030 and 1547 that is in a very early stage of planning as shown in Table 5.1.

Item of Standards	Libya Available Status	Smart Grid Requirements	
		Technology	Applications
IEEE Standard 2030	PLC , BPL, LAN,NAN, WAN Used in Libya , but some applications do not use like FAN, HAN and Little of AMI as test	PLC BPL	NB-PLC: AMI, FAN, WAN BB-PLC: HAN/AMI
IEEE Standard 1547	Fiber, Cognitive Radio Used in Libya, and Little of AMI as test	Fiber Cognitive Radio	AMI WAN
IEEE standard 1547.3	DSL Used in Libya, but some applications do not use like FAN, and Little of AMI as test	DSL	AMI, FAN
IEEE standard 1547.6	WIFI , 3G , 4G, GSM , GPRS Used in Libya but some applications do not use like ZigBee, LTE/LTEA , Dash7, HAN and Little of AMI as test	WIFI, 3G, GSM, GPRS, EDGE, 4G, LTE/LTE-A, Dash7, ZigBee	V2G, HAN, AMI
IEEE standard 1547.8	WIMAX Used in Libya but some applications do not use like FAN, And Little of AMI as test	WIMAX	AMI, FAN, WAN

Table 5.1 Integrated Digital Communicated Systems for Smart Grids

5.3 Modern Devices

Devices have an effective and important role in determining the electrical behavior of the grid. These type of modern devices apply the latest research [46]. These type of modern devices include as following:

Modern Hardware	Fixed devices	Mobile devices
Materials	SCADA Devices	Voice And Data Dispatch Radios
Superconductivity	Distribution Automation Devices	Other Mobile Communications
Distributed Generation	AMR Devices	Automatic Vehicle Location Devices
Energy Storage	Smart Meters	Mobile Computing Devices
Power Electronics	RETAIL Premises Monitoring	Cell Phones
	Control Systems	GPS Devices.
Microelectronics	Energy Management Systems	Web Access Devices
	Monitoring And Control Technologies	Voice And Data Dispatch Radios

Table 5.2 Modern Devices [46]

Table 5.3 summarized such devices according to specifications IEEE Standard2030, 1547:

Item of Standards	Libya Available Status	Smart Grid Requirements	
		Type	Technology
IEEE Std 2030 IEEE Std 2030.3 IEEE Std 1547 IEEE Std 1547.4 IEEE Std 1547.6	• Unified Power Flow Controller (UPFC) • DVAR or DSTATCOM • Static Voltage Regulator (SVR) • Static VAR Compensator (SVC) • Solid State Transfer Switch • Dynamic Brak • AC/DC inverter	Power Electronic Devices	• Unified Power Flow Controller (UPFC) • DVAR or DSTATCOM • Static Voltage Regulator (SVR) • Static VAR Compensator (SVC) • Solid State Transfer Switch • Dynamic Brake • AC/DC inverter
IEEE Std 1547 IEEE Std 1547.1 IEEE Std 1547.8 IEEE Std 1547.7 IEEE Std 1547.6	• First Generation wire • HTS cable •Second Generation wire	Superconductivity	• First Generation wire • HTS cable •Second Generation wire
IEEE Std 1547.3	Microturbine Used in Libya ,but, Fuel Cell,Wind Turbine do not use and Little of PV	Distributed Generation	• Microturbine • Fuel Cell • PV • Wind Turbine
IEEE Std 2030 IEEE Std 2030.2 IEEE Std 2030.3 IEEE Std 1547 IEEE Std 1547.2 IEEE Std 1547.3 IEEE Std 1547.8	Do not use	Distributed Storage	• Nas battery • Vanadium Redox Battery (VRB) • Ultra capacitors • Superconducting Magnetic Energy Storage (SMES)
IEEE Std 1547 IEEE Std 1547.1 IEEE Std 1547.8 IEEE Std 1547.7 IEEE Std 1547.6	Do not use	Composite Conductors	• Aluminum Conductor Composite Core Cable (ACCC Cable) • Aluminum Conductor Composite Reinforced Cable (ACCR Cable) • Annealed aluminum, steel supported (ACSS)

Table 5.3 Modern Devices for Smart Grids

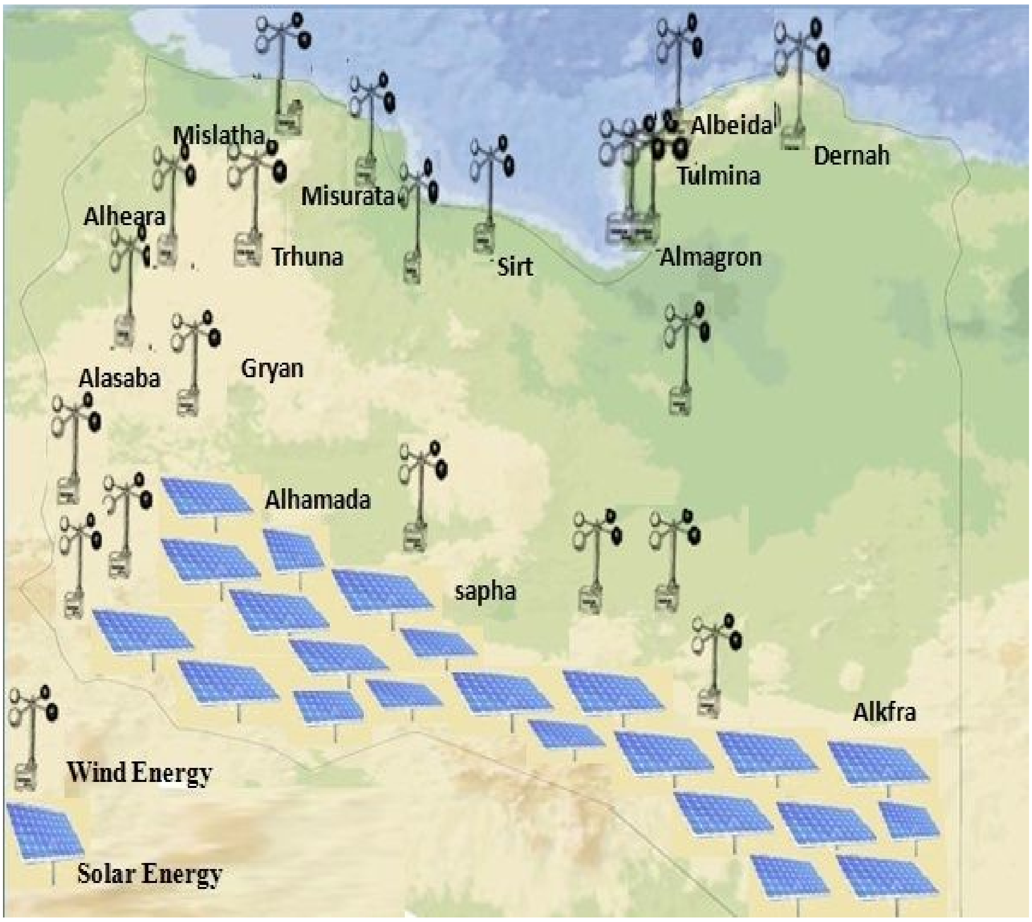

Figure 5.2 Overview of Renewable Energy Future for Smart Grid Libya

5.4 Instrumentation and Modern Control (I&C)

I&C can provides the components of monitor power system, which helps rapid diagnosis and timely, and gives appropriate response. It contain devices that will diagnose and predict conditions with the determination, also to take the corrective actions that will be use to prevent faults. Figure 5.3 shows that this control components present in all parts of grid. Measurement technologies will support frequent meter reading, reduce billing estimation and prevent illegally energy usage. Some of the technologies in these areas are described according to specifications IEEE Standard 2030, 1547 in Table 5.4 [46].

Item of Standards	Libya Available Status	Smart Grid Requirements	
		Type	**Technology**
IEEE Std 2030 IEEE Std 1547.4 IEEE Std 1547.6 IEEE Std 1547.7	• Digital Relays • Intelligent tap changer • Energy management system • Grid friendly appliance	Distributed Intelligent Agents	• Digital Relays • Intelligent tap changer • Energy management system • Grid friendly appliance controller • Dynamic distributed power control
IEEE Std 2030 IEEE Std 1547.4 IEEE Std 1547.5 IEEE Std 1547.6	• System performance monitoring and control • Phasor measurement analysis • Fast load flow analysis • Distribution fault location • High speed commutating	Analytic Tools	• System performance monitoring and control • Phasor measurement analysis • Weather prediction • Fast load flow analysis • Market system simulation • Distribution fault location • High speed commutating
IEEE Std 2030.1 IEEE Std 1547.4 IEEE Std 1547.6 IEEE Std 1547.8	• SCADA • Substation Automation • Transmission Automation • Demand Response • Outage management • Asset optimization	Operational Application	• SCADA • Substation Automation • Transmission Automation • Distribution Automation • Demand Response • Outage management • Asset optimization

Table 5.4 Modern Control Methods for Smart Grid

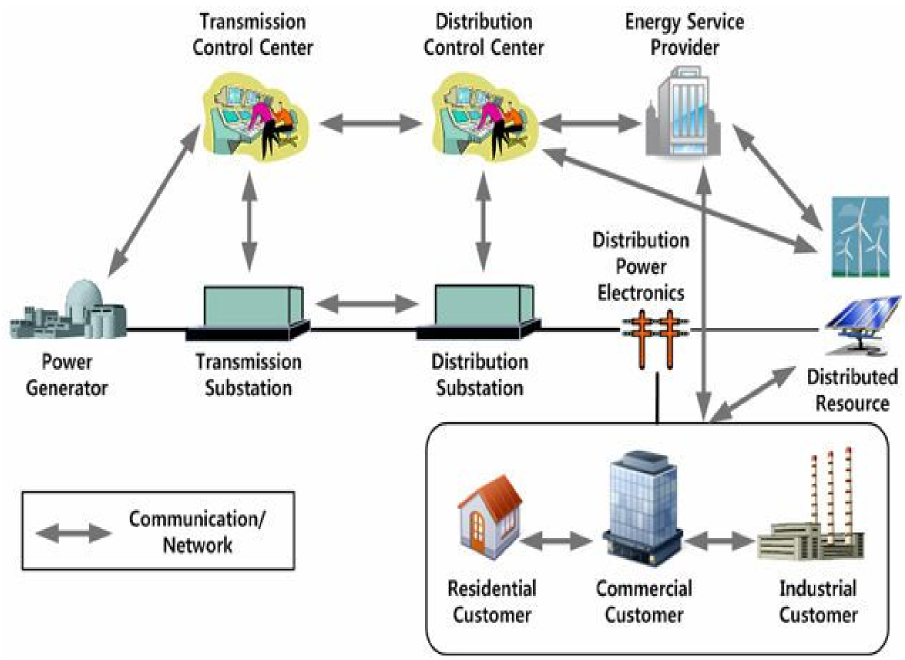

Figure 5.3 Control Center in All Parts of Grid [46]

5.5 Smart Software, Decision and Control Software

According to specifications IEEE Standard 2030 and 1547, the modern grid will require wide, seamless, often real-time use of applications and tools that enable grid operators and managers to make decisions quickly. Huge amounts of data will have to be organized, analyzed and acted upon. This needed to decision software [46]. This software include to:

- Decentralized Software
- Back Office Software

5.5.1 Decentralized Software

The amount of devices and data prevent centralized data collection and computation. So, the devices such as intelligent electronic devices (IED) that will increasingly be collect, and analyze data and perform computations to determine data that should be communicated [46].

5.5.2 Back Office Software

Some back office software is used by Most utilities. These back office software solutions becomes more effective and powerful by the deployment of intelligent electronic devices (IEDs) and two-way digital communications. These back office software include to:

Interactive Voice Response (IVR)	Enterprise Resource Planning (ERP)
Accounting & Business Systems (ABS)	Customer Billing & Payment
Customer Information Systems (CIS)	Work & Workforce Management
Outage Management System (OMS)	Engineering & Operations (E&O)
Customer Relationship Management (CRM)	Real-Time Distribution Analysis
Geographic Information Systems (GIS)	Engineering Analysis
Performance & Productivity Management	Circuit Modeling & Analysis
Active Distribution Grid Management	Reliability Analysis

Table 5.5 Back Office Software [46]

5.6 Smart Meters an Important Step Towards Libya's Smart Grids

Smart Meters technology have an effective and important role in the smart grid that will modernize the electrical system to be smarter and more efficiently. In Libya, we used the traditional meters until right now. So the biggest challenge in this process is the establishment of smart power grids. Smart meters are an important interface between customers and smart grids. Smart meters able to make power consumption more transparent and clearly; moreover detect the ways of save an energy in the households. This depend on an efficient management of huge amounts of data that gathered and processed by smart meters in very short time periods. We must working on practically solution to make this vision become more reality.

In the first step, We have to work on the installation of smart meters in the Libyan electrical networks, also we need to know the smart meters number that will be installed. This is done by identifying the number of customers who connected to the electric network. As we see in Tables 5.6, 5.7

Customer Type	No. of Customers
Residential	905970
Small Agriculture	116199
Big Agriculture	966
Light Industrial	33409
Heavy Industrial	39
Commercial	142270
Public Utilities	7061
Total	1205914

Table 5.6 Number of Customers 2015 [47]

Total No. of Smart Meters	1205914

Table 5.7 Number of Smart Meters That Will Installed

5.6.1 Smart Meters Contribute To Energy Conservation

Research with energy reports ,that provided by the energy suppliers, about actual effectiveness of savings achieved with customers who use smart meters in Aruban countries, the result was 4-8 % less electricity after a full consumption year, compared to of customers who without a smart meters [48]. In this case we will apply these research relating to the use of smart meters on the Libyan network.

5.6.2 The Situation Before The Installation Of Smart Meters

In Libya, the energy consumption is divided into two parts as following:

- Normal customers are spending 73% of energy Consumed in Libya. Those who we will Install smart meters to them.
- Public sectors are spending 27% of energy Consumed in Libya.

Table 5.8 shows number of customers and Energy Consumed 2015.

Customer Type	**No. of Customers**	**Energy Consumed (KWH)**
Residential	905970	4651063064
Small Agriculture	116199	757119912
Big Agriculture	966	736784897
Light Industrial	33409	643373818
Heavy Industrial	39	805605305
Commercial	142270	1841023672
Total	1198853	9434970668

Table 5.8 Number Of Customers And Energy Consumed 2015 [47]

Figure 5.4 shows energy consumption Before The Installation Of Smart Meters.

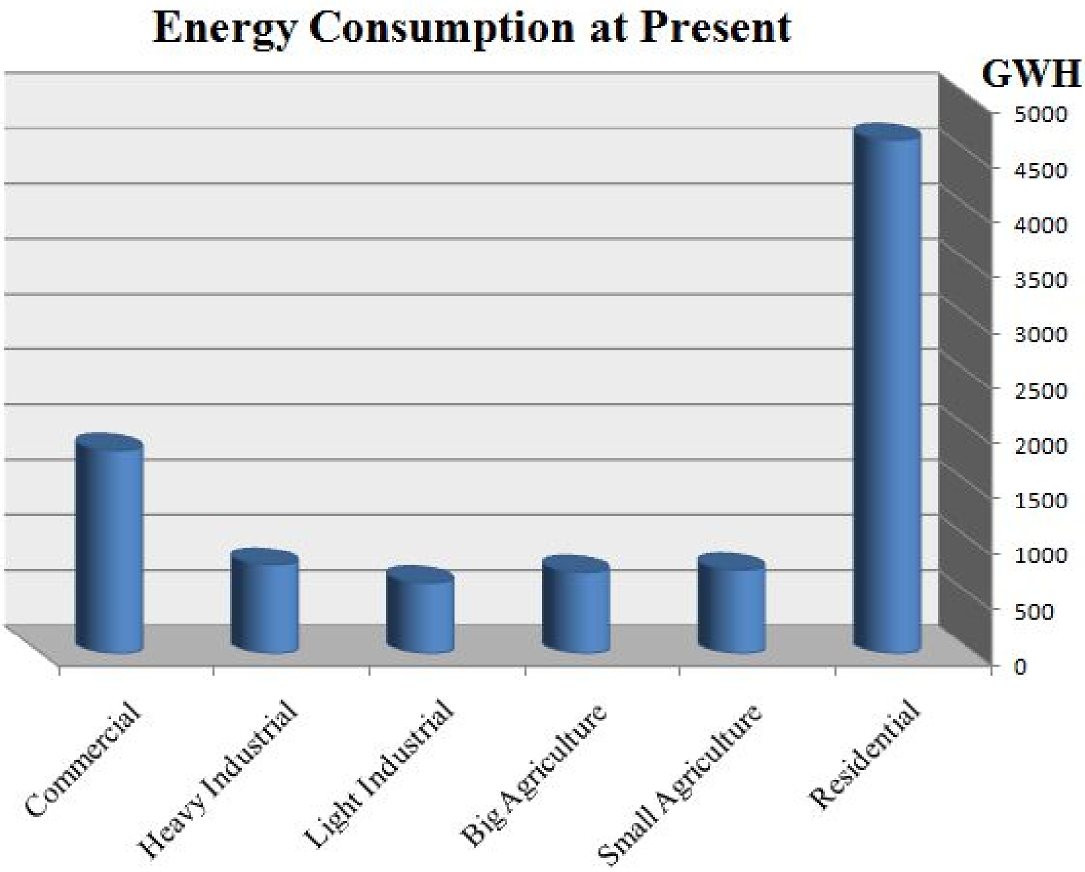

Figure 5.4 Energy consumption Before The Installation Of Smart Meters

5.6.3 The Situation After The Installation Of Smart Meters

According to studies conducted on smart meters that they can help in saving energy from 4% to 8% [48]. So we will take the average value of which is 6% to calculate how much you will save smart meters of energy in Libya. In this step, we will divide the customers who will install smart meters to them into four phases such as (25%, 50%, 75%, 100%).

5.6.3.1 Saving Energy, After Installed Smart Meters to 25% Of Customers

Customer Type	No. of customers who have smart meters at 25%	Energy consumed without smart meters (KWH)	Energy consumed with smart meters (KWH)	Saving Energy (KWH)
Residential	226493	1162765766	1092999820	69765946
Small Agriculture	29050	189279978	177923179	11356799
Big Agriculture	242	184196224.25	173144451.235	11051773.015
Light Industrial	8353	160843454.5	151192847.47	9650607.03
Heavy Industrial	10	201401326.25	189317246.235	12084080.015
Commercial	35568	460255918	432640563	27615355
Total	299716	2358742667	2217218106.94	141524560.06

Table 5.9 Energy Consumption After 25% Of Customers Used Smart Meters

In table 5.9 we note that 25% of customers with smart meters after responding in the peak periods per year, could be saved energy amount to (141524560.06 KWH per year). This mean that smart meters helped customers to save energy.

Figure 5.5 shows energy consumed and saved energy per year for 25% of customers types without and whit smart meters.

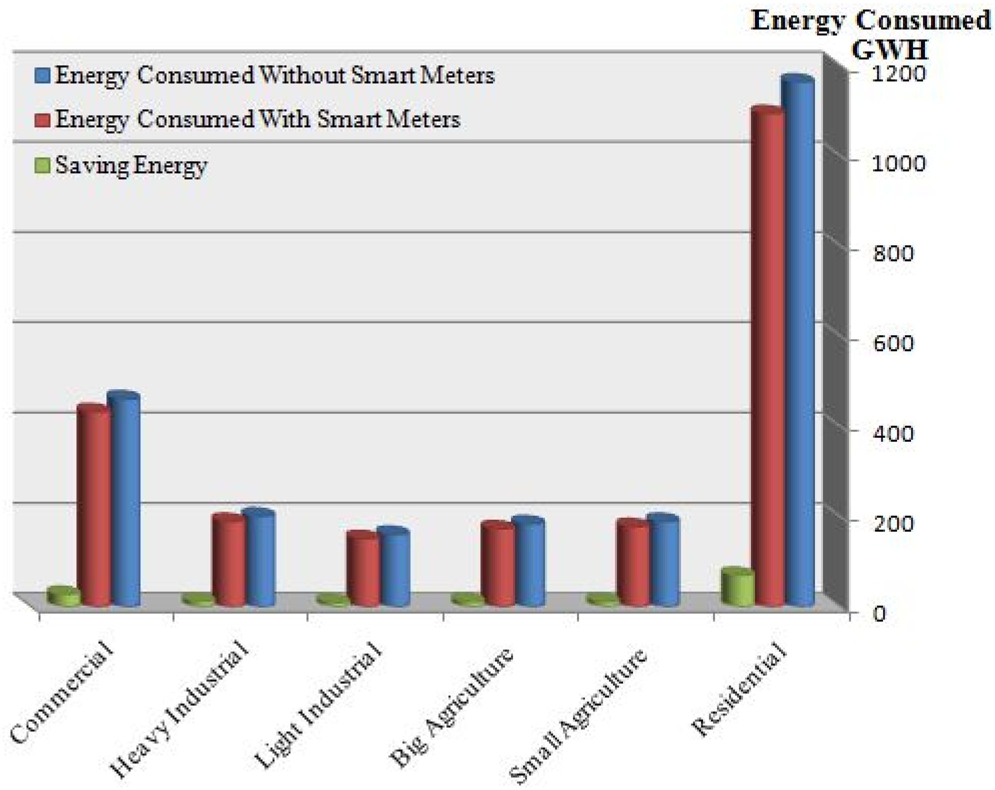

Figure 5.5 Energy Consumption Before and After 25% Of Customers Used Smart Meters

Figure 5.6 shows total of energy consumption per year without and with smart meters and total of saving energy per year for 25% of customers.

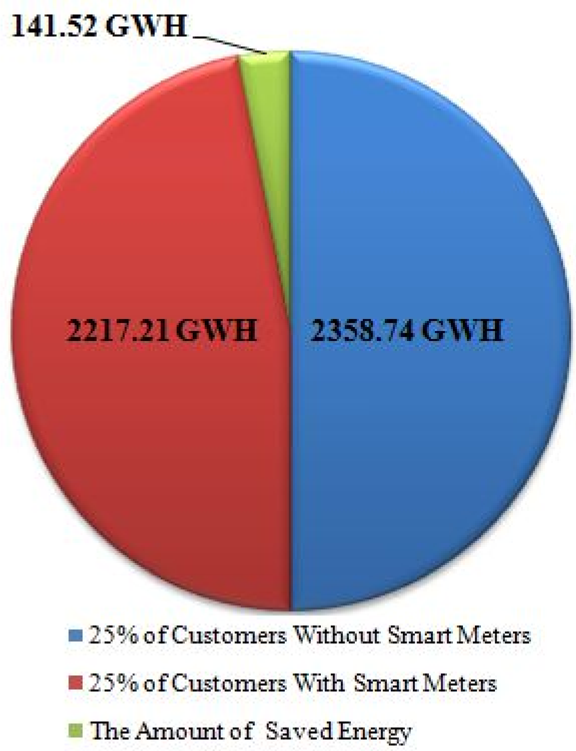

Figure 5.6 Saving Energy When 25% Of Customers Used Smart Meters

5.6.3.2 Saving Energy, After Installed Smart Meters To 50% Of Customers

Customer Type	No. of customers who have smart meters at 50%	Energy consumed without smart meters (KWH)	Energy Consumed With Smart Meters (KWH)	Saving Energy (KWH)
Residential	452985	2325531532	2185999640	139531892
Small Agriculture	58100	378559956	355846359	22713597
Big Agriculture	483	368392448.5	346288901.47	22103547.03
Light Industrial	16705	321686909	302385694	19301215
Heavy Industrial	20	402802653	378634494	24168159
Commercial	71135	920511836	865281126	55230710
Total	599428	4717485334.5	4434436214.47	283049120.03

Table 5.10 Energy Consumption After 50% Of Customers Used Smart Meters

In table 5.10 we note that 50% of customers with smart meters after responding in the peak periods per year, could be saved energy amount to (283049120.03 KWH per year). This mean that smart meters helped customers to save energy.

Figure 5.7 shows energy consumed and saved energy per year for 50% of customers types without and whit smart meters.

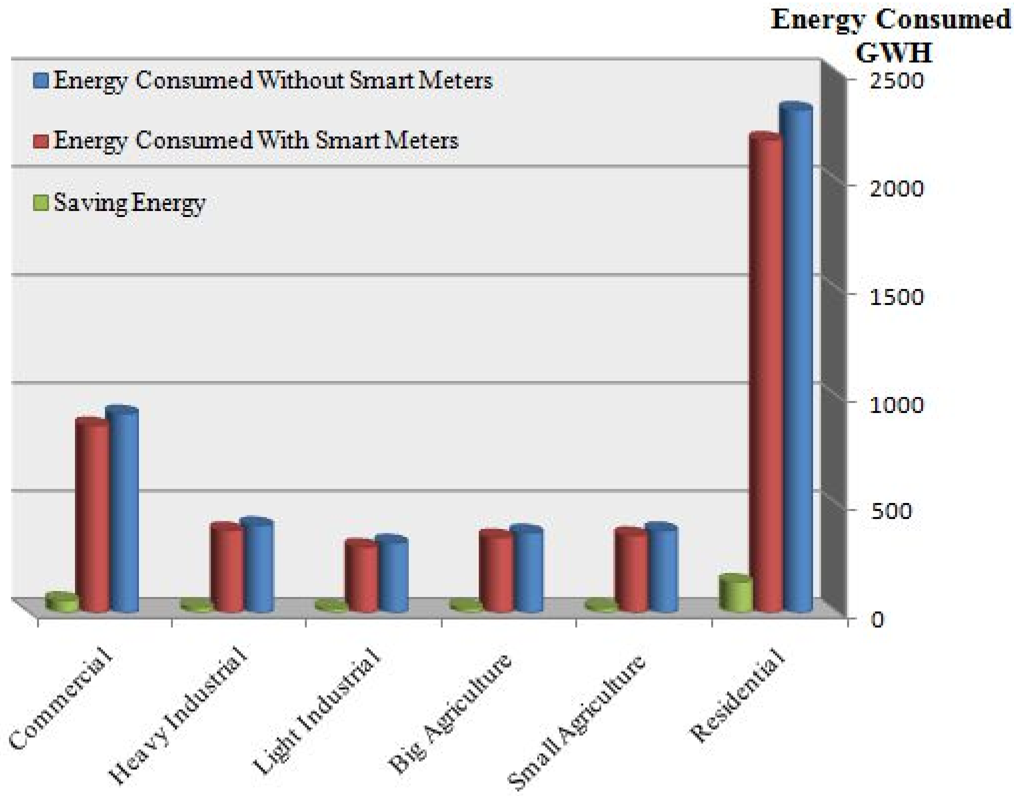

Figure 5.7 Energy Consumption Before and After 50% Of Customers Used Smart Meters

Figure 5.8 shows total of energy consumption per year without and with smart meters and total of saving energy per year for 50% of customers.

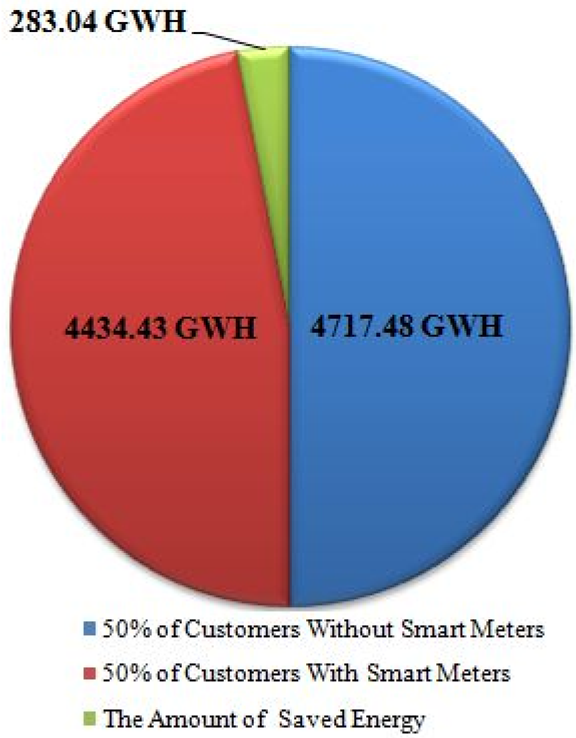

Figure 5.8 Saving Energy When 50% Of Customers Used Smart Meters

5.6.3.3 Saving Energy, After Installed Smart Meters To 75% Of Customers

Customer Type	No. of customers who have smart meters at 75%	Energy consumed without smart meters (KWH)	Energy consumed with smart meters (KWH)	Saving Energy (KWH)
Residential	679477	3488297298	3278999460	209297838
Small Agriculture	87149	567839934	533769538	34070396
Big Agriculture	724	552588672.75	519433352.705	33155320.045
Light Industrial	25056	482530363.5	453578541.47	28951822.03
Heavy Industrial	29	604203978.75	567951739.705	36252239.045
Commercial	106702	1380767754	1297921689	82846065
Total	899137	7076228001	6651654320.88	424573680.12

Table 5.11 Energy Consumption After 75% Of Customers Used Smart Meters

In table 5.11 we note that 75% of customers with smart meters after responding in the peak periods per year, could be saved energy amount to (424573680.12 KWH per year). This mean that smart meters helped customers to save energy.

Figure 5.9 shows energy consumed and saved energy per year for 75% of customers types without and whit smart meters.

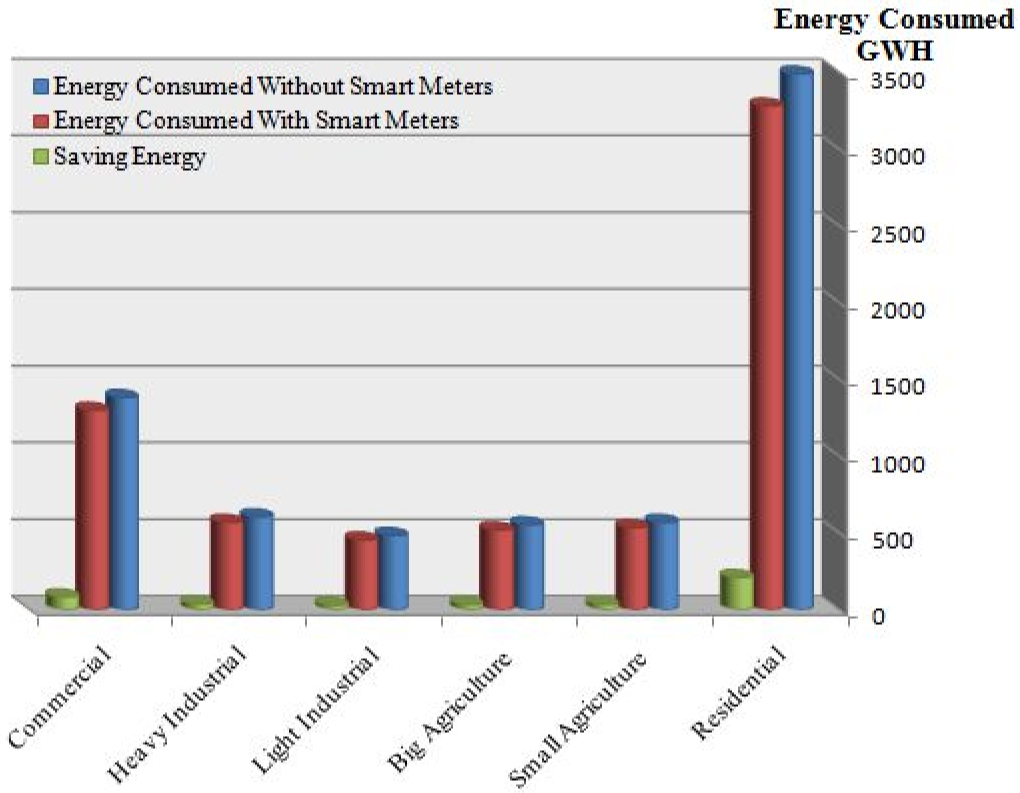

Figure 5.9 Energy Consumption Before and After 75% Of Customers Used Smart Meters

Figure 5.10 shows total of energy consumption per year without and with smart meters and total of saving energy per year for 75% of customers.

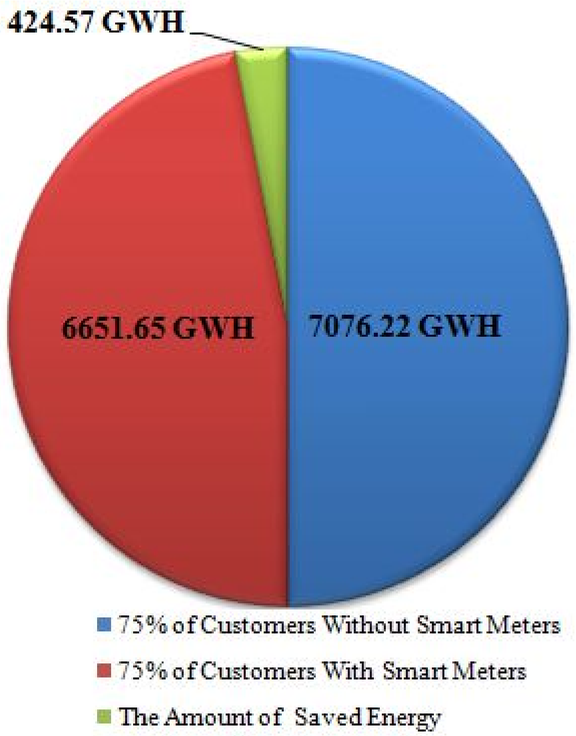

Figure 5.10 Saving Energy When 75% Of Customers Used Smart Meters

5.6.3.4 Saving Energy, After Installed Smart Meters To 100% Of Customers

Customer Type	No. of customers who have smart meters at 100%	Energy consumed without smart meters (KWH)	Energy consumed with smart meters (KWH)	Saving Energy (KWH)
Residential	905970	4651063064	4371999280	279063784
Small Agriculture	116199	757119912	711692717	45427195
Big Agriculture	966	736784897	692577803	44207094
Light Industrial	33409	643373818	604771389	38602429
Heavy Industrial	39	805605305	757268987	48336318
Commercial	142270	1841023672	1730562252	110461420
Total	1198853	9434970668	8868872428	466683240

Table 5.12 Energy Consumption After 100% Of Customers Used Smart Meters

In table 5.12 we note that 100% of customers with smart meters after responding in the peak periods per year, could be saved energy amount to (466683240 KWH per year). This mean that smart meters helped customers to save energy.

Figure 5.11 shows energy consumed and saved energy per year for 100% of customers types without and whit smart meters.

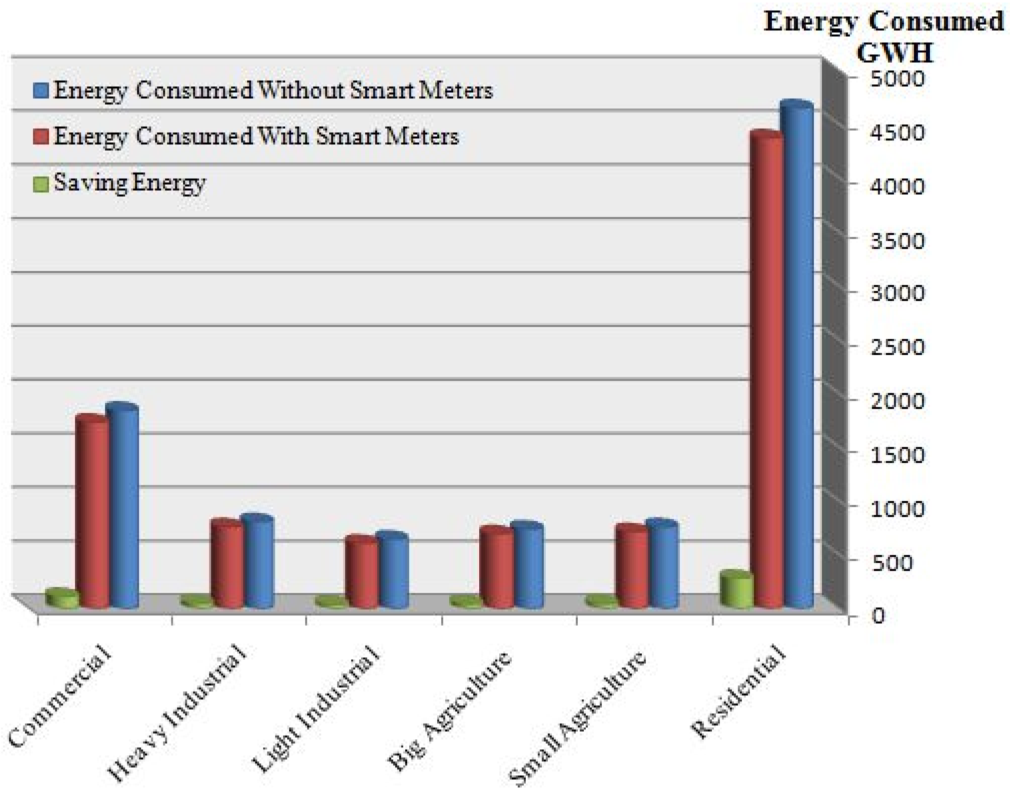

Figure 5.11 Energy Consumption Before and After 100% Of Customers Used Smart Meters

Figure 5.12 shows total of energy consumption per year without and with smart meters and total of saving energy per year for 100% of customers.

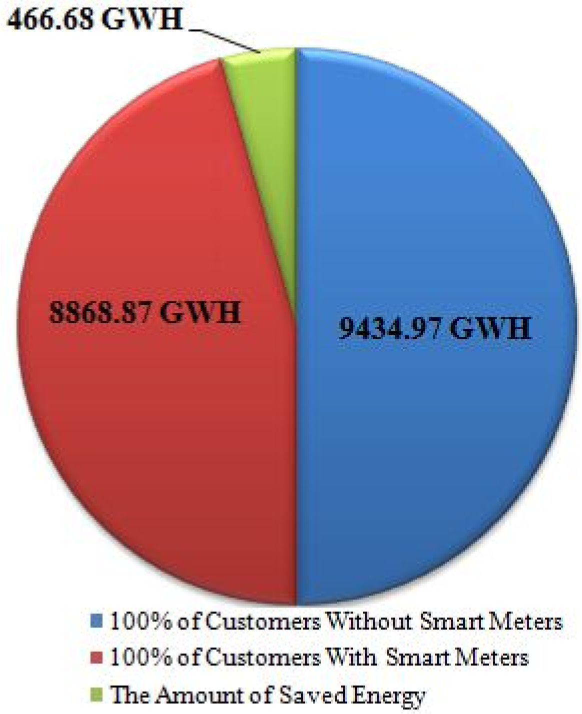

Figure 5.12 Saving Energy When 100% Of Customers Used Smart Meters

Table 5.13 and figure 5.13 show all the stages of the installation of smart meters with the amount of energy that was saved at every stage.

Customers Ratio	Total of Energy Consumed Without Smart Meters (KWH)	Total of Energy Consumed With Smart Meters (KWH)	Saving Energy (KWH)
25% of Customers	2358742667	2217218106.94	141524560.06
50% of Customers	4717485334.5	4434436214.47	283049120.03
75% of Customers	7076228001	6651654320.88	424573680.12
100% of Customers	9434970668	8868872428	466683240

Table 5.13 Energy Consumption Before and After Customers Used Smart Meters

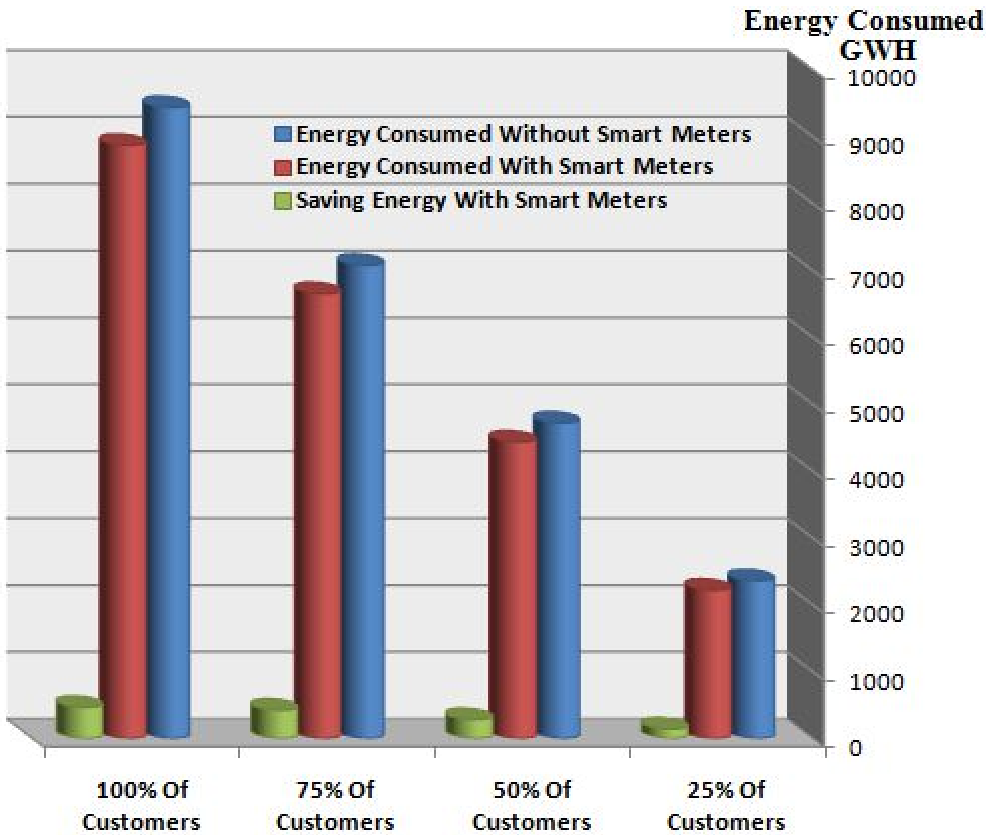

Figure 5.13 Energy Consumption Before and After Customers Used Smart Meters

Conclusion

We conclude from the previous study that smart meters play an active role in contributing to the reduction of energy consumption and helps utilities and customers to save energy.

5.7 Renewable energy Step Towards Libya's Smart Grids

In this study we will focus on wind energy only, and we will examine the possibility to take advantage of wind speed in Libya, where proven studies that conducted on the climate, Libya has a wind speed rate 8.3 M/S in Darnah city [49]. Through this information we will implement the simulation to generate power from the wind speed in Darnah city.

5.7.1 Wind Energy

Wind energy is one of the main renewable energy sources and the fastest growing sector of the energy industry in the world today. Wind turbines is that generate electricity by kinetic energy resulting from the wind which pushes directly against the blades of the turbine, than converts the linear motion of the wind to the rotary motion necessary to spin the generators rotor, into electrical energy producing (as defined by Faraday's law of magnetic induction) [50].

5.7.1.1 Wind Turbine Generator (WTG)

Wind Turbine Generator is the electrical machine which used to generate the electricity by conversion of the rotational mechanical power that generated by the rotor blades (the prime mover) to electrical power then transmitted to the grid by the stator and the rotor windings. There are two main types of wind generators as follows:

- Generator With Vertical Axis
- Generator With A Horizontal Axis

The main types of rotational electrical machines that commonly used in a wind power generating systems:

- (DC) machine, that known as a Dynamo.
- (AC) synchronous machine, that known as an AC Generator.
- (AC) induction machine, that known as an Alternator.

All these electrical machines work on Faraday's law of electromagnetic induction, through the interaction of a magnetic flux and an electric current, or flow of charge [50]. Figure 5.14 shows wind turbine, power flow and operating principle.

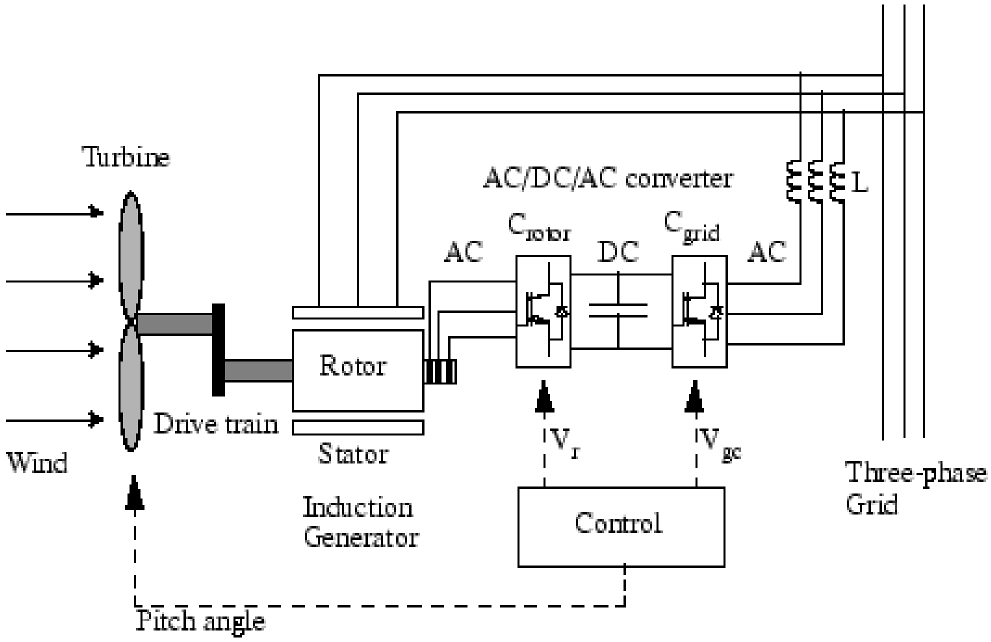

Figure 5.14 Wind Turbine, Power Flow and Operating Principle [51]

In figure 5.14 the followings parameters are used:

- The mechanical power and the stator electric power output are computed as follows:

$$P_m = T_m \omega_r$$
$$P_s = T_{em} \omega_s$$

- For a lossless generator the mechanical equation is:

$$J\frac{d\omega_r}{dt} = T_m - T_{em}$$

- In steady-state at fixed speed for a lossless generator

$$T_m = T_{em} \; and \; P_m = P_s + P_r$$

It follows that:

$$P_r = P_m - P_s = T_m\omega_r - T_{em}\omega_s = -T_m\frac{\omega_s - \omega_r}{\omega_s}\omega_s = -sT_{em}\omega_s = -sP_s$$

Where s is defined as the slip of the generator:

$$s = (\omega_s - \omega_r)\omega_s$$

Figure 5.15 below shows the power flow

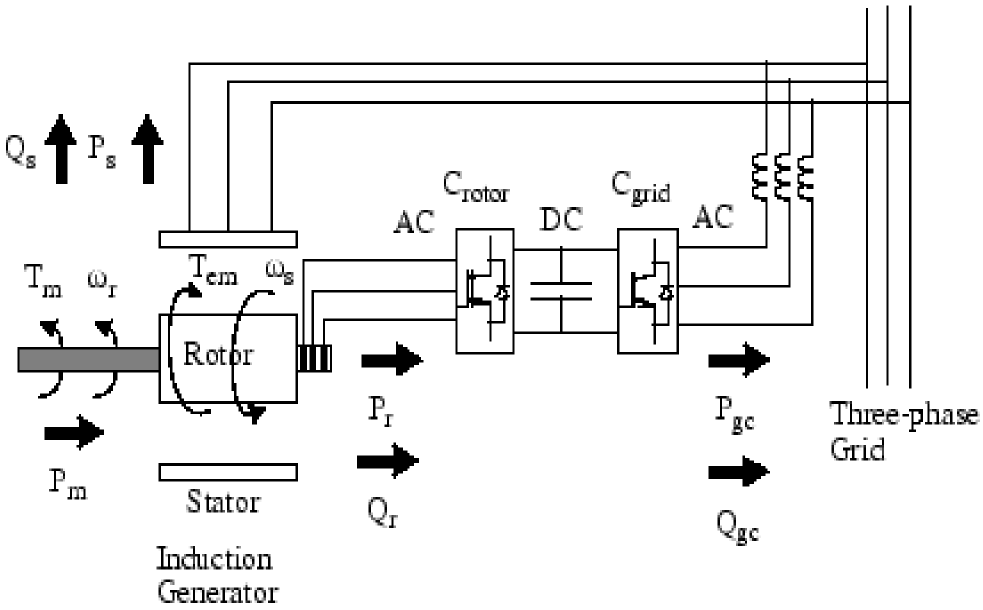

Figure 5.15 The Power Flow [50]

Whereas: (P_m) is mechanical power captured by the wind turbine and transmitted to the rotor, (P_s) is stator electrical power output, (P_r) is rotor electrical power output, (P_{gc}) C_{grid} electrical power output, (T_m) is mechanical torque applied to rotor, (T_{em}) is electromagnetic torque applied to the rotor by the generator, (ω_r) is rotational speed of rotor, (ω_s) is rotational speed of the magnetic flux in the air-gap of the generator, (J) is combined rotor and wind turbine inertia coefficient, (Q_r) is rotor reactive power output, (Q_s) is stator reactive power output, (Q_{gc}) C_{grid} reactive power output [50].

5.7.1.1.1 Synchronous Generators

This type of wind generator is connected directly with the rotor blades without gearbox. the operation of a Synchronous Generator based on Faraday's law of electromagnetic induction. It is working in a similar fashion to an automotive type alternator [50]. The main Components of a Synchronous Generator as follows:

- The Stator: It carries the three separate (3-phase) armature windings physically and electrically by 120 degrees producing an AC voltage output.
- The Rotor: It carries the magnetic field connected to an external DC power source via slip rings and carbon brushes.

This type of generator is the one that will use it in the design of wind turbine in this thesis. Figure 5.16 below shows Synchronous Generator.

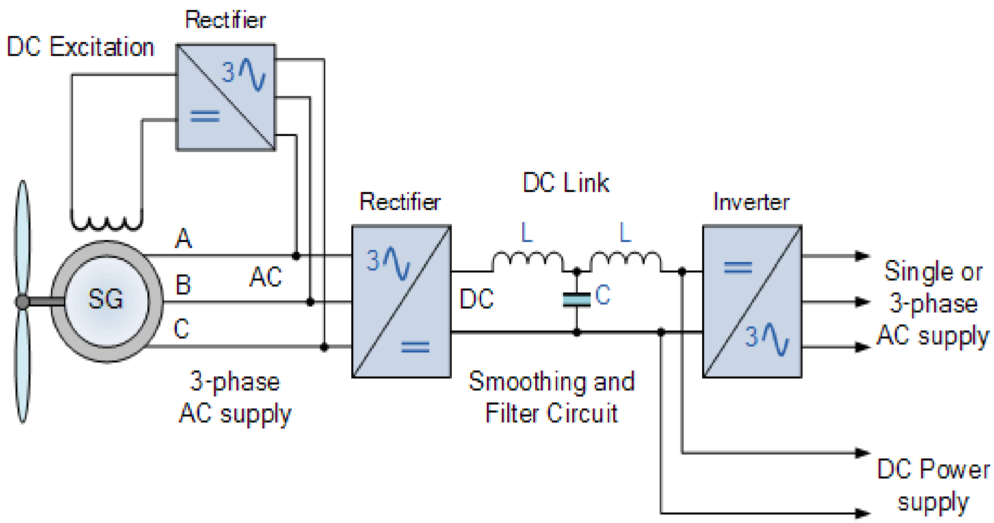

Figure 5.16 Synchronous Generator [51]

5.7.1.2 AC-DC Three-Phase Converter (Rectifier)

The simplest type of rectifier circuit uses a diode bridge circuit to convert the AC generated by the generator into a fluctuating DC supply whose amplitude is determined by the generators speed of rotation as shown in figure 5.17, the generator's three phase output is rectified to DC by a three phase rectifier [50].

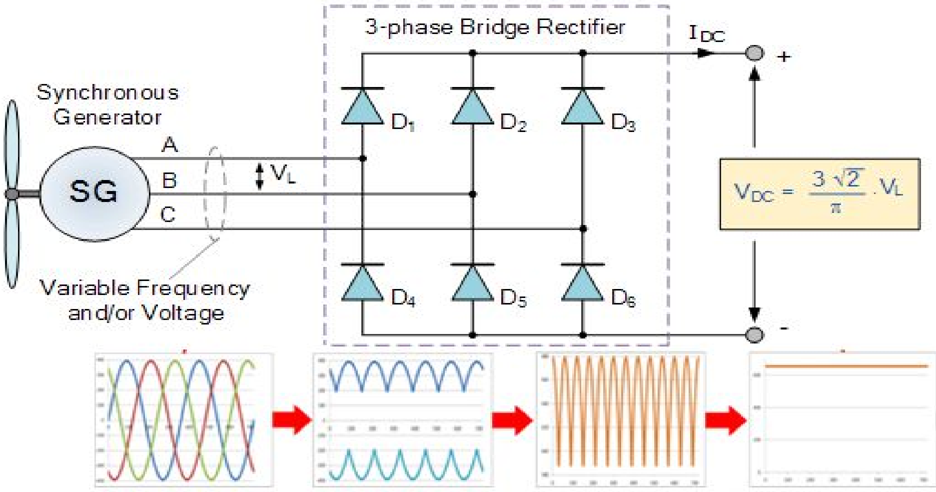

Figure 5.17 The Full-Bridge, Three-Phase, AC To DC Rectifier [50]

The circuit diagram of the full-bridge, three-phase, AC to DC rectifier is shown above. In this configuration, the wind turbine can operate the generator at a frequency independent of the synchronous frequency as changing the generator speed varies the generator frequency [50].

5.7.1.3 Inverter

It is an electrical device that converts DC power to AC (DC to AC converter) . May be inverter electrical electromechanical mechanism (moving members) or electronic (static members). Figure 5.18 shows simulation model of inverter that will use in wind turbine.

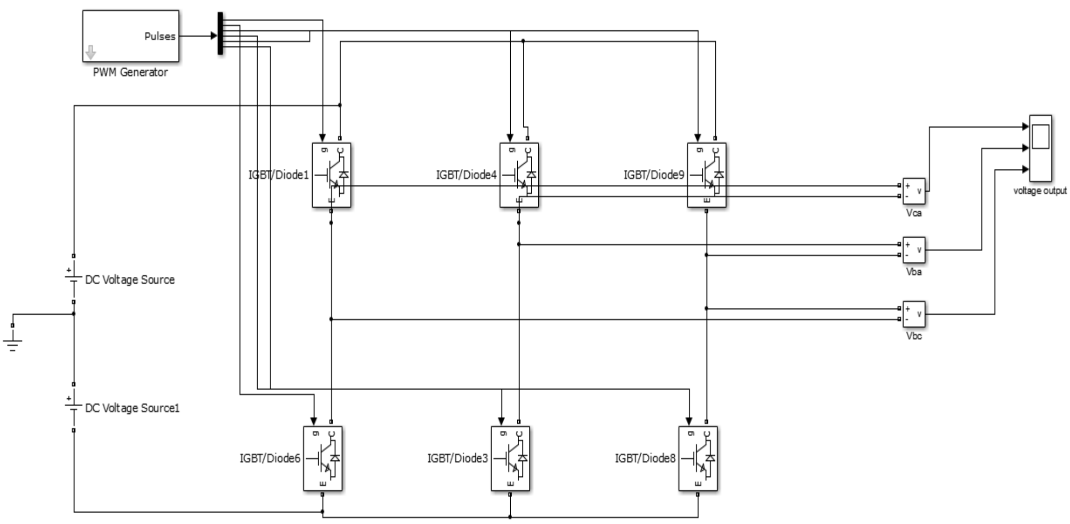

Figure 5.18 Simulation Model of Inverter That Will Use in Wind Turbine

After we run the inverter to make sure that it runs, it gives us a signal as we see in figure 5.19. This means that the inverter operates as required.

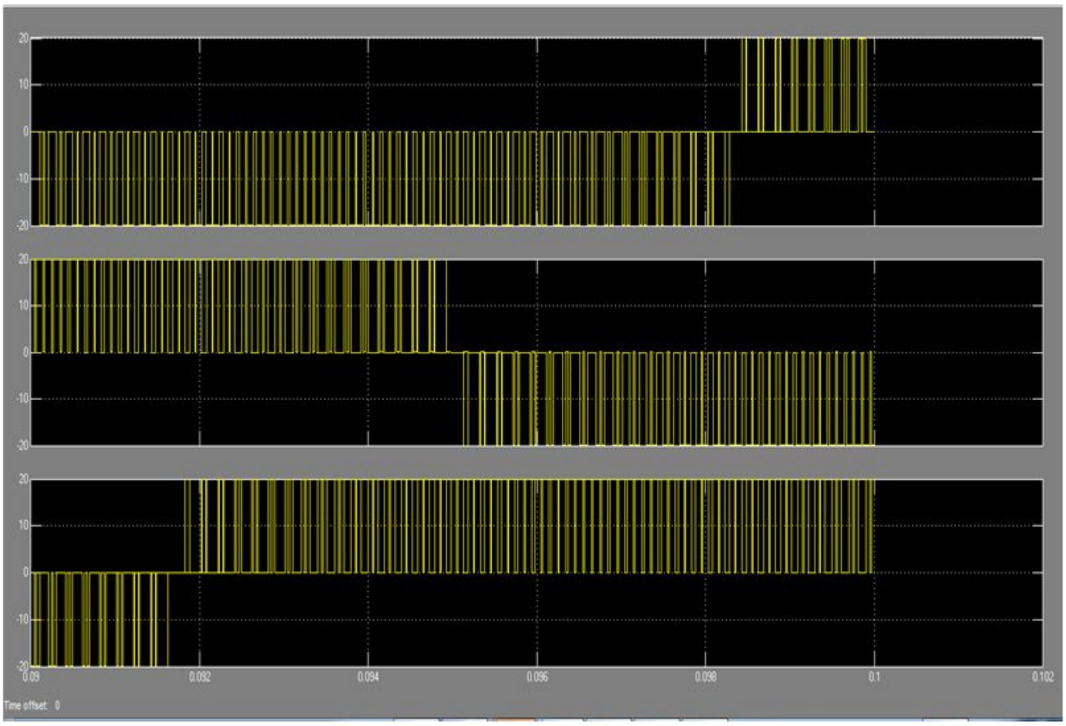

Figure 5.19 Inverter Test Run

5.7.1.4 Simulation and Results

We built a simulink model of a wind turbine with Synchronous Generators PMSG (direct drive) by using MATLAB /SIMULINK environment. In this simulation model, wind turbine shaft is mechanically connected with direct drive PMSG and then connect it to the network as we can see in Figure 5.20.

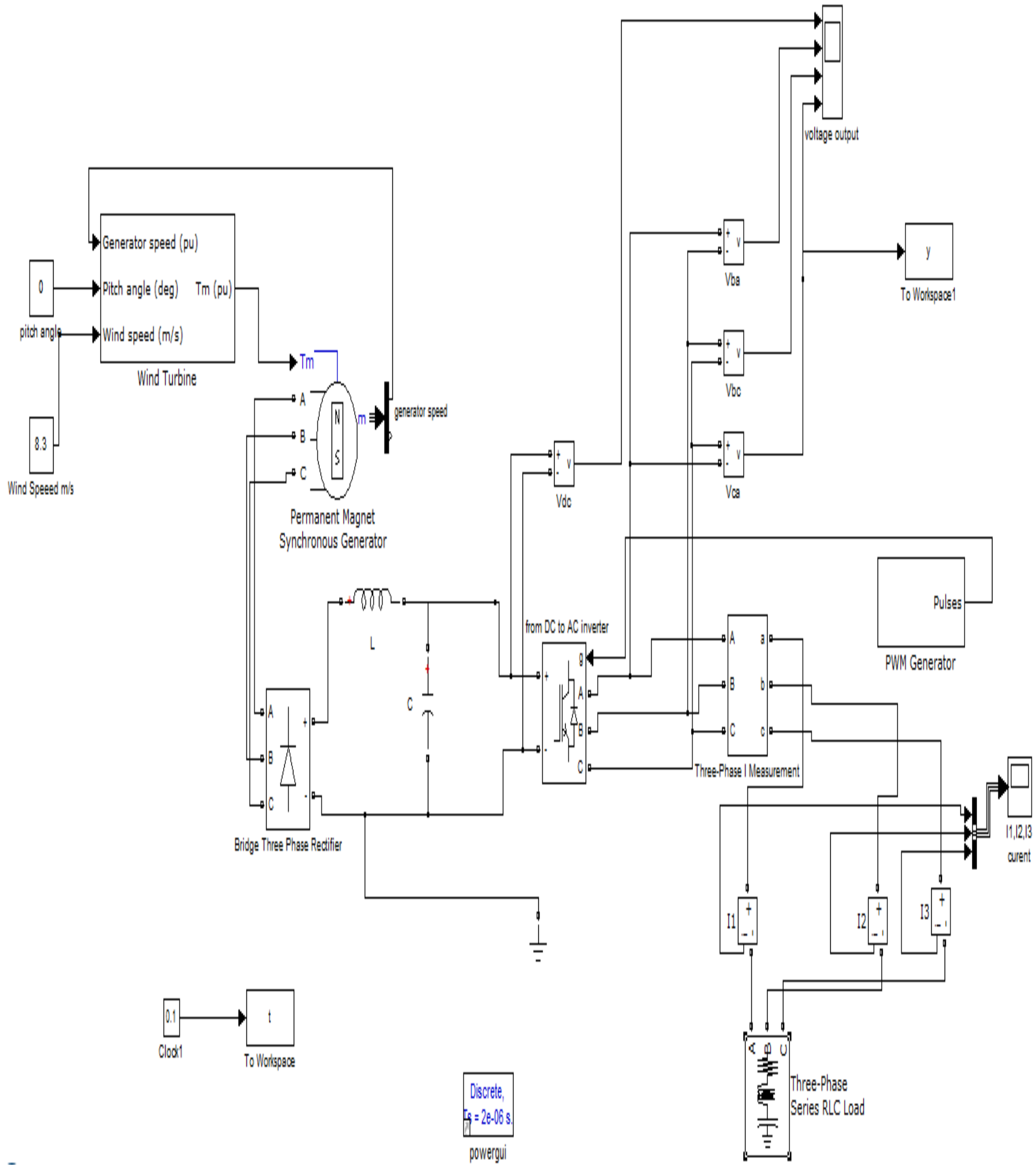

Figure 5.20 Simulation Model of Wind Turbine

After we run the wind turbine with wind speed 8.3 m/s which is the wind speed in Derna city, it gives us a signals as we see in figure 5.21 and figure 5.22 . This means that the wind turbine operates as required and the results very satisfactory.

Figure 5.21 shows DC link voltage and PWM output voltage at wind speed 8.3 m/s.

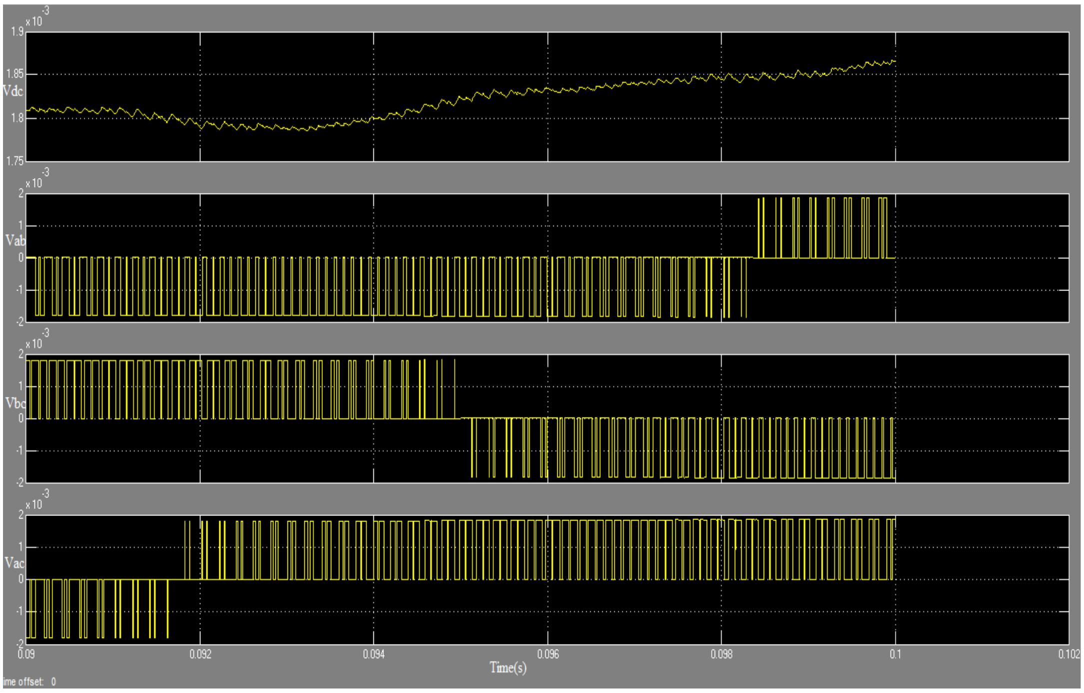

Figure 5.21 DC Link voltage and PWM output Voltage at wind speed 8.3 m/s

Figure 5.22 shows three phase sinusoidal current with three phase load star connected.

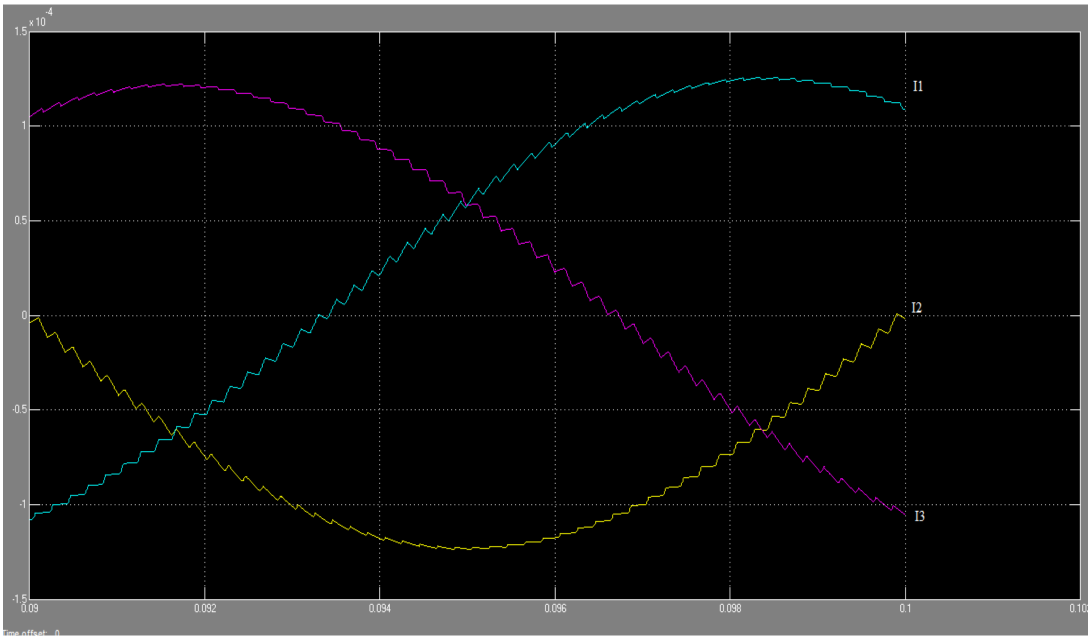

Figure 5.22 Three Phase Sinusoidal Current With Three Phase Load Star Connected

AC output voltage of PMSG is rectified to DC voltage that changes with wind velocity after that DC voltage will converts to obtain an AC output by a Pulse Width Modulation (PWM) Inverter. The output voltage increases with increasing wind speed.

CONCLUSION

In this wind turbine model uses the Permanent Magnet Generator (PMSG) that does not have a gearbox so cost of gear box and its maintenance is eliminated. thus the use of this type of wind turbines in Libya has many advantages such as Maintenance cost will be very few because no gearboxes and the output voltage increases with increasing wind speed. This will help to meet the annual increasing of 6-8% power demand in Libya.

CHAPTER SIX

CASE STUDY

TO PRESENT ONE OF THE BASIC PREMIUM OF SMART GRID

6.1 Introduction

In this chapter, the basic case study is realized in order to show the benefits of transformation of Libya electricity power network into smart grid.

Currently, Libya's electric power production capacity around 4.6-4.7 GW, with peak load of about 3.3 GW. The installed capacity is 5.6 GW with a peak Load of 3.65 GW. Most of electricity produced is made from Libya's existing oil-fired and natural gas power stations. Libya has a lot of renewable energy sources, for example, its average sun duration is more than 3500 hours per year and it has a high-speed winds of up to 8.3 in Derna city [35]. The usage of renewable energy sources of Libya will be able to provide the important amount of decreasing for the budgets of establishing new power plants.

On the other hand, Libya's power demand is growing rapidly and is expected to reach 8 GW in 2020. It is around 6-8 % annually. It is mean that these new power demands will be required to establish new electric power plants, to realize new investments and also to allocate the new budgets for these investments. To cope with this challenge, the smart grid concept has also an important role. By using smart grid components, the cost of establishing new power plants for the new peak demands in the future can be decreased. The tools of smart grid such as smart management, integration of renewable energy plants, smart metering, demand management and especially smart marketing and dynamic pricing can be used in order to take under control the consumption of electricity.

6.2 The Use of Dynamic Pricing

By using dynamic pricing, the electricity demands in a day are spread from the more usage hours to less usage hours, in this way. Also, the leakage power is decreased and at last, the peak power demand in a day can be decreased. This process is called demand smoothing and it is presented in Figure 6.1.

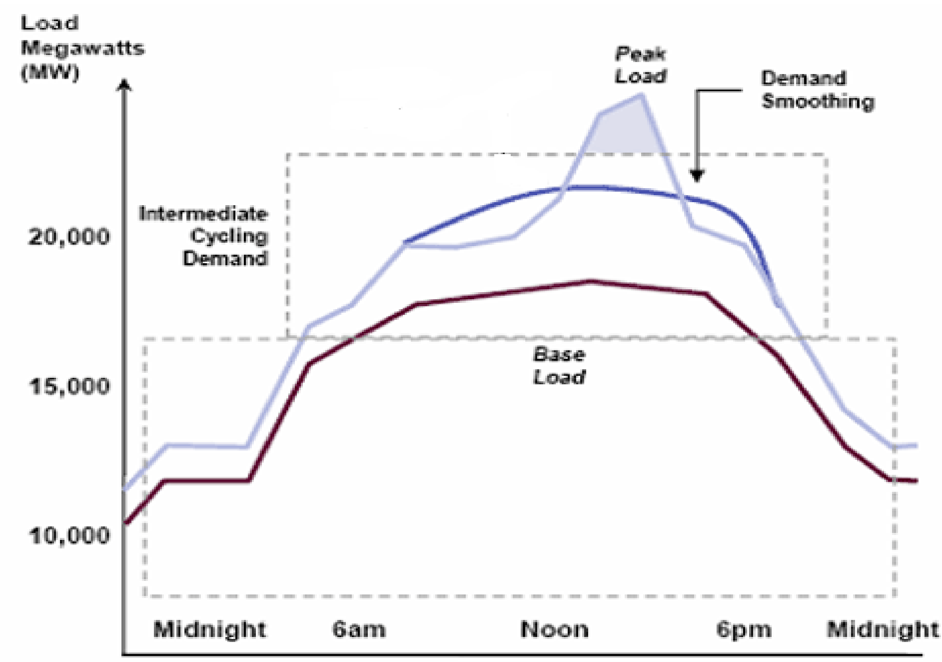

Figure 6.1. Decreasing Peak Demand By Applying Demand Smoothing

In this study, the basic case study is computed in order to show decreasing the peak demand by using dynamic pricing. In this way, it is evaluated that the new power plant investments and also the allocation of the new budgets for these investments to meet annual increasing of 6-8% power demand in Libya can be greatly decreased.

In the case study:

Case-1

First of all, the annual electric power demand is computed for Libya;

Present peak load demand : 3.65 GW
Annual increase (acceptance) : 7%
A year later load demand : 3.65 GW x 1.07 = 3.90 GW

Annual increase in MW : 3.90 – 3.65 = 250 MW

For example,

If the building cost of a 100 MW Natural Gas Combined Cycle Plant is accepted as $80 million

Then the needed cost for 250 MW plant (rough calculation) is

2.5 x $80 million = $200 million

Case-2

If the electricity demand in a day is spread from the more usage hours to less usage hours by applying dynamic pricing in smart grid, the peak power demand in a day can be decreased by as approximately as 15%:

15% decreased peak load
demand after dynamic pricing: 3.10 GW
Annual increase (acceptance) : 7%
A year later load demand : 3.10 GW x 1.07 = 3.31 GW
Annual increase in MW : 3.31 – 3.10 = 210 MW

For example,

If the building cost of a 100 MW Natural Gas Combined Cycle Plant is accepted as $80 million

Then the needed cost for 210 MW plant (rough calculation) is

2.1 x $80 million = $168 million

If the demand smoothing is accepted as 15% after dynamic pricing in smart grid in Libya, the annual cost reduction between two cases for the first year is,

$210 million – $168 million = $32 million

This result of this case study is showed that only even one component of the smart grid, dynamic pricing, is enough to decrease the country's power plant investments.

CHAPTER SEVEN

CONCLUSION

In this thesis, is explain of concept and components smart electric grid with its possible application in Libya.

Smart Grids becoming the most important technology during recent years because of its benefits such as ensuring energy security, optimizing economic development, realizing low-carbon economy, and the speed of coping with climate change. It attracts a lot of attention of the world.

7.1 Findings

In this thesis, by meticulously analyzing the current status of electricity grids in Libya from the aspects of technologies, research work, pilot regions and organizations. At the end of these investigations, it can be seen that:

- Libya communication and information infrastructure is enough and ready for transformation into smart grid.
- The modern power electronic hardware capacity of Libya is enough for transformation, but the energy storage and effective conducting technologies must be developed.
- The usage of modern control technologies for power system control and management such as energy management system, substation / transmission / distribution automations, demand response in Libya are also enough for transformation into smart grid, but may be some academic studies can be realized for smart grid applications.
- Usage of renewable energy resources should be increased. In this way, the usage of patrol to produce electrical energy can be decreased and this patrol may be used another purposes which have high premium.

It is concluded that Libya has a great potential and opportunity to transition to smart grid. However, there are still obstacles that hold back transition Libya to smart grids. To overcome these barriers, we must increase the capacity of the electricity network by connected it with the latest technology systems and speed up the ending of renewable energy projects.

7.2 Future Studies

This thesis has only focused on the smart grid and related issues in transform Libya electric network into smart grid. However, the future steps will be expanded to include solar energy and other quality standards which will help to speed the transition to the smart grid.

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APPENDICES A

CURRICULUM VITAE

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