Study The Prospect Of Smart Grid Technology In Bangladesh

A Thesis Submitted In Partial Fulfillment Of The Requirements For The Degree Of Bachelor Of Science In Electrical And Electronic Engineering

Undertaken By

AVIJIT ADHIKARY

ID: 173-33-549

MD. EMRUL KAYES

ID: 173-33-573

Supervised by

DR. MOHAMMAD TAWHIDUL ALAM

Associate Professor

Department of EEE

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

FACULTY OF ENGINEERING

DAFFODIL INTERNATIONAL UNIVERSITY

May 2021

Certification

This is to certify that this thesis entitled "**Study The Prospect Of Smart Grid Technology In Bangladesh**" is done by the following students under my direct supervision and this work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering. The presentation of the work was held on 31^{st} May 2021.

AVIJIT ADHIKARY
ID: 173-33-549

EMRUL KAYES
ID: 173-33-573

____

DR. MOHAMMAD TAWHIDUL ALAM

Associate Professor

Department of Electrical and Electronic Engineering

Daffodil International University

BOARD OF EXAMINERS

Md. -------------
Designation
Department of EEE, DIU

Coordinator

Dr. -----------------
Designation
Department of EEE, DIU

Internal Member

Dr. ----------------------
Designation
Institution

External Member

Dedicated to

Our Parents

&

Respected Teachers

DECLARATION

We do hereby declare that this thesis is based on the result found by ourselves. This thesis is submitted in partial fulfillment of the requirement for the degree of B.Sc. in Electrical and Electronic Engineering. This thesis neither in whole nor in part has been previously submitted for any degree.

Signature of the Candidates:

____

AVIJIT ADHIKARY
ID: 173-33-549

____

MD. EMRUL KAYES
ID: 173-33-573

ACKNOWLEDGEMENT

First and foremost, we express our gratitude to Allah. Then we have to thank our parents for their love and there support throughout our life.

Then, we would like to sincerely thank our supervisor, **Dr. Mohammad Tawhidul Alam, Associate Professor of Department of EEE**, for his guidance and support throughout this study.

We also want to convey our thankfulness **to Dr. Md. Shahid Ullah, professor & Head of the Department of EEE** for his help, support and constant encouragement.

We are also grateful to the faculties of Electrical and Electronic Engineering Department for offering their helpful hands during the course of our thesis. Apart from that, we would like to thank our entire friends for sharing knowledge; information and helping us in making this thesis a success.

To our beloved family, we want to give them our deepest love and gratitude for being very supportive and also for their inspiration and encouragement during our study in this University.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Abbreviations

kWh	Kilo Watt Hour
MW	Mega Watt
kV	Kilo Volt
TWh	Tera Watt Hour
MVA	Mega Volt Ampere
PV	Photovoltaic
BPDB	Bangladesh Power Development Board
DESCO	Dhaka Electric Supply Company Limited
DPDC	Dhaka Power Distribution Company Limited
WZPDCL	West Zone Power Distribution Company Limited
NESCO	Northern Electricity Supply Company Limited
BREB	Bangladesh Rural Electrification Board
IDCOL	Infrastructure Development Company Limited
IPP	Independent Power Producers
GoB	Government of Bangladesh
MAGS	Microgrid Agent Control System
FIPA	Foundation for Intelligent Physical Agents
ACL	Agent Communication Language
ESS	Energy Saving System
DSM	Demand Side Management
BESS	Battery Energy Saving System
SG	Smart Grid
GDP	Gross Domestic Product
GHG	Greenhouse Gas
RE	Renewable Energy
ICT	Information, Communication and Technology
IEC	International Electro-technical Commission
OpenADR	Open Automated Demand Response

ABSTRACT

Bangladesh is a middle class developing country and its GDP growth rate is increasing at a very fast rate. GDP growth of Bangladesh largely depends on its industry, especially on export-oriented industries, which is totally dependent on the power sector of this country. The grid system of Bangladesh have not implemented properly for a long time. As a result, Bangladesh power sector facing huge power wastage.

Smart grid technology is such a digital technology that can greatly reduce power wastage with a great extent. Smart Grids are being deployed to make grid system more intelligent and secure. If smart grid system can be implemented properly, the grid operations will open up new channels and prospects with considerable financial consequences. This thesis represents the implementation possibility of smart grid technology based on geographical location, amount of energy resources and feature plan of Bangladesh. It also discusses numerous Smart Grid (SG) projects and their consequences in the light of evolving power market of Bangladesh. It also reviews the current progress report of achieving smart grid technology and different statistics that shows the future of smart grid implementation in Bangladesh. This thesis also discusses in detail on expanding power sector of Bangladesh toward smart grid. A final review on financial benefit also presented in this thesis. There are also some illustrations on the basis of present and potential problems associated with Smart Grid technologies in Bangladesh power sector for future needs.

CHAPTER 1

INTRODUCTION

1.1 : Introduction

Bangladesh is one of the most populous countries in the world, with a population of 160 million. Farming used to be the country's primary source of revenue. But the Gross National Product (GDP) in 2019-20, Bangladesh stood at 8.2% [1]. In 2020–21, the World Bank forecasts a 3.6% rise in Bangladesh's Gross Domestic Product (GDP) [2]. Rapid urbanization, driven by steady economic growth, has led to tremendous energy demand. Power is well known to play a crucial role in reducing hunger, economic prosperity, and sustainable development and country's growth and protection. The most popular source of energy in Bangladesh is electricity. Thus, future economic development relies substantially on energy supply. The government of Bangladesh should make electricity accessible to people at an inexpensive and environmentally sustainable cost. However, the country has struggled to produce ample energy to satisfy demand since becoming independent from Pakistan in 1971. There is a major energy deficit in public electricity. In addition, the electricity market has also not drawn sufficient private investments in power industry due to weak pricing policies and other bottlenecks.

1.2 : Thesis Objectives

This thesis has following objectives;

1. To know about the position of power production of Bangladesh toward the world power production scenario.
2. To know about existing power grid of Bangladesh and how it’s extend day by day.
3. To know the future of Bangladesh power grid and implementation of Smart grid system.
4. To know the implementation prospect of Smart grid in Bangladesh and its advantages and drawbacks.
5. To reduced Transmission and Distribution loss using smart grid technology.

6. To Merging renewable energy system with micro-grid or hybrid-grid technology replacing one way conventional grid system.
7. To analysis and calculate generation, transmission and distribution side framework of smart grid technology system.

1.3 : Literature

The demand is much higher than the power generation of Bangladesh. To meet this insufficient demand superficial load shedding is required during the day. The amount of load shedding increases especially during peak hours. Which on the one hand creates such a stagnant situation, on the other hand, power is wasted commercially. Power shortages can be largely eliminated, if the conventional energy resources can be used properly. Various case studies show that there is huge potential for renewable energy in Bangladesh. In particular, solar PV systems and wind power can be a major source of renewable energy. Due to the large sea area of Bangladesh, there is a possibility of more renewable energy resources like tidal energy, wave energy. According to the power system master plan of 2041 Renewable energy generation of about 10% of the power sector of Bangladesh is crucial for achieving capacity.

Combining smart grids with renewable energy will reduce the growing demand for fossil fuels, in the same way. Smart grids are closely related to micro grids and hybrid grids. If the grid systems are installed in small steps, it will be possible to eliminate the power loss for transmission and distribution. Excessive power saving will greatly reduce the amount of electricity generation. Similarly, the amount of load shedding during peak hours will be reduced. Bangladesh Smart Grid has already started its journey through net energy metering and smart metering. Electricity is considered as the bearer and carrier of the development of not only Bangladesh but also all over the world. The socio-economic growth rate is also depending on the global power system. Therefore, the demand of electricity is increasing day by day. New power plants are being installed every day to increase the demand for electricity in the developed world. Power stations which are outdated cause many of environmental occurrences, such as Greenhouse Gases (GHGs) emission, climate changes etc. In adding the oldest model of power plant, price hike of useable fuel, insufficient space to install and as a result an unstable power system. For the safety of future generation, it is the high time to recognize the green technology for a sustainable and full proof future. Brief problem statements of using of traditional grid system are described below;

1.3.1 : Limited Conventional Fuel

Mainly coal, oil, natural gas etc. are used for generating power that named as fossil or conventional fuel. These fossil fuels are limited into the Earth. At a time, it has been finished, but the demand of electricity has not been finished. For the huge dependency of fossil fuel the market price of this type of fuel is also be increasing and in local market it create a huge price hike. Avoid deep drilling on earth is also costly and it create many of side effect (e.g. Earthquake, Landslide, Rising of latent Volcano etc.) of our environment. The changeover of fossil fuel is more superior for creating a pollution free environment. The green energy that gets from the surface of earth is the most safety and low constable energy resources. Renewable Energy (RE) can take place to decrease the dependency of fossil fuel.

1.3.2 : Threat of Climate Change

Currently the rising of world average temperature are the most crucial things. The effect of climate change is being very costly in running 21^{st} century. Climate change effect broke the chain of stability of world economy, natural resources and all type of social activity. In today’s world, most of the nations are suffer this dangerous effect of climate change. More than 17 billion people are gets an abnormal daily life activity for that’s circumstances. In every year 2^oC of temperature is rising in overall world temperature. Carbon Dioxide (CO_2) emission is the main reason for increasing temperature of earth to creating house effect. It has been believes that, if this huge CO_2 emission not been controlled immediately, at the end of 21^{st} century the sea level area has been submerged permanently. In the West Atlantic and the Greenland area has been melt for rising of temperature around $0.8\text{-}3.8^oC$ above the rising of current temperature. It can be controlled by reducing the overall carbon emission.

1.3.3 : Nuclear Peril

Nuclear technology can be used for controlling carbon emission (CO_2). A report from International Energy Agency (IEA) was published for the perspective on Nuclear energy. The report describes the blue print of Nuclear energy plan from now to 2050. To achieve the ongoing electricity demand about in average 32 large reactor (1,000 MW each) are installed in every year. Those can decrease the CO_2 emission less than 5%. But there is another problem; the temperature index from catastrophic aftermath shows that, the hazard has been produced by nuclear plants is very expensive. From the past violations and for secured future it is also being a threat for environment. Many of the nuclear hazards were happened; such as Japan's nuclear incident at Fukushima in 2011 and also a remarkable incident were happened in "Cheronbyl Nuclear Power Plant" in Russia. Their situation will not been change after 25 years later. Other Problems are unsafe technology and the safety that does create another major problem. Then the price of raw material of nuclear plant is so expensive and waste management of nuclear plant is also expensive and risky, where the renewable energy is not ruinous and a safe technology indeed.

1.3.4 : Efficiency Incrimination

Energy sector is one of the most costly sectors for any nation. The model of any power project is so complex that, at the last point the efficiency is on threat. But this type of threat can be achieved by many modern innovative power technologies. The balance between energy produce and supply is so important. From the increasing demand power system architecture should be updated with smart grids, micro-grids, hybrid technology and sometimes clops with super-grids. This type of technology can be supervised and remodeling the future grid system. These energy system also be increased the power market stability and decrease the footprint of carbon emission and provide a GHGs free environment.

This whole problem can be solved by implementing smart grid technology by promoting renewable energy (RE) sources. In that case the existing grid system needs some refinement and expansion. The fourth chapter (Chapter 4) focuses on smart grid technology and then shown (Chapter 5-6) the implementation process.

1.4 : Energy Review of Bangladesh

Day by day the market of electricity is increase. To minimize the issue of demand and generation difference, the Government of Bangladesh is planning various strategies for the inclusion of a new generation system. In fiscal year 2019-20, the power industry saw substantial developments in power production. Over the fiscal year, BPDB (Bangladesh Power Development Board) installed 1,033 MW (including the IPPs (Independent Power

Producers) contracted capacity) of this new capacity expansion with the remaining 118 MW installed by EGCB (Electricity Generation Company of Bangladesh), and the BCPCL (Bangladesh-China Power Company (Pvt.) Limited) installed 622 MW of this new capacity expansion, bringing the overall generation capacity up to 20,383 MW and annual generating capacity up to 7.0%. The proposal currently comprises 43 power generation projects with capacity of 15,294 MW. By 2025, the proposal envisages a new generation of roughly 21,977 MW. Selling of commodities BPDB's system losses (without 132 kV of consumers) dropped to 8.99% from 9.12% last year. The Collection/Import ratio is down by 92.87% to 90.19%. The generation and usage per capita in Grid amounted to 426.23 kWh and 378 kWh, compared with 426.05 kWh and 375 kWh in the previous year respectively [3]. Table 1.1 introduced the recent ten year history of Bangladesh power sector:

Table 1.1 Recent Ten year history of Bangladesh Power Sector

S/L No.	Fiscal Year	Particulars						
		Installed Capacity (MW)	**Maximum Peak Generation (MW)**	**Maximum Peak Demand (MW)**	**System Load Factor (%)**	**Transmission Loss (T) (%)**	**Distribution Loss (D) (%)**	**Total T&D Loss (%)**
01.	2010-11	6,639	4,890	6,765	70.82	3.31	13.06	15.21
02.	2011-12	8,100	6,066	7,518	62.85	3.22	12.15	14.65
03.	2012-13	8,537	6,434	8,349	64.73	3.11	11.95	14.36
04.	2013-14	9,821	7,356	9,268	62.53	2.72	11.89	14.13
05.	2014-15	10,939	7,817	10,283	63.87	2.74	11.17	13.55
06.	2015-16	12,365	9,036	11,405	63.41	2.73	11.01	13.10
07.	2016-17	13,555	9,479	12,644	66.65	2.72	9.27	12.74
08.	2017-18	15,953	10,958	14,014	63.33	2.76	9.89	11.87
09.	2018-19	18,961	12,893	13,044	60.75	3.15	9.12	11.96
10.	**2019-20**	**20,383**	**12,738**	**13,300**	**62.41**	**2.93**	**8.99**	**11.23**

1.4.1 : Position of Bangladesh in Global Energy Sector

In global energy markets, developed countries play a rising part. Nearly 60% of global primary energy usage was in 2018 accounted for by countries outside the organization for International Cooperation and Deutschland (OECD). The share is projected to increase as these countries reflect 90% of potential energy demand by 2040 [4]. Electricity demand has outpaced to primary energy use growth in Bangladesh.

Subject to economic growth, constant energy supplies are a requirement. There is, however, a deficit in electricity generation in almost all SAARC (South Asian Association for Regional Cooperation) countries. The thinking of a SAARC grid has long been in the minds of the regional policy planners, however development on the idea has been slow, commonly because some nations lack of political issue. Some member Countries have occasionally been impacted by using anxiety and mistrust, with some individuals building strength flowers and transmission traces in the place thru bilateral and trilateral agreements. Some countries have been preventing cooperation between them. However, a number of domestic grids were cross-border linked, which could potentially appear as a SAARC power grid.

Bangladesh's industrial electricity comprises with natural gas, imported power, coal, oil, hydro, solar and some of other renewable energy source. The government constructs massive power stations based on imported coal, LNG (Liquefied Natural Gas) and nuclear power. There is a plan for importation into Bangladesh and India of natural gas from Myanmar. In vast numbers in rural areas, small solar panels are used.

India currently supplies Bangladesh with approximately 1160MW (about 5.69% of Electricity from the Annual Report of BPDB 2019-20) of electricity. In the near term, this number is expected to rise. In 2010 Nepal and Bhutan agreed to export 2,000 MW of energy to Bangladesh gradually 1,000 MW each to Nepal and Sankosh in Bhutan. In 2011, the company officially agreed to export 2,000 MW of power to Nepal. By a 400 kV HVDC line between Bheramara, Bangladesh and Baharampur, Bangladesh is now interconnected to India. One of the biggest organizations named Bay of Bengal Initiative for Multi-Sectoral and Economic Co-operation (BIMSTEC) is likely to connect Bangladesh to the Bhutan, Nepal, Tripura (India) grids as well as to Myanmar and Thailand. Here is the Table 1.2 that represents the South Asian electricity Producing chart with the Position of Bangladesh [5];

Table 1.2 Current position of Bangladesh Power sector in SAARC countries

Rank of Power Consumption	Nations	Electricity Production (GWh)	Data Taken	Total Production (GWh)	Production Percentage (%)
01.	India	1,309,000			85.85%
02.	Pakistan	120,392			7.90%
03.	**Bangladesh**	**62,925**			**4.13%**
04.	Sri Lanka	14,150	2018	1,524,743	0.93%
05.	Bhutan	7,630			0.50%
06.	Nepal	5,057			0.33%
07.	Afghanistan	4,981			0.32%
08.	Maldives	608			0.040%

Prediction of FY2030 approximate generation of Electricity is illustrated below:

Table 1.3 Prediction of Power Generation of SAARC Countries

Rank of Power Consumption	Nations	Electricity Production (GWh)	Data Taken	Total Production (GWh)	Production Percentage (%)
01.	India	2,657,000			87.08%
02.	Pakistan	191,828			6.30%
03.	**Bangladesh**	**122,061**			**4.00%**
04.	Sri Lanka	28,473	2030	3051104	0.93%
05.	Bhutan	23,619			0.77%
06.	Nepal	15,836			0.52%
07.	Afghanistan	8,575			0.28%
08.	Maldives	3,712			0.12%

1.4.2 : Policy of International Organization for Climate Change

There is now recourse to procurement and financial security top of the program for climate reform. Slowly moving oil markets have to do with a combination of many events, while rare and expensive availability of all fossil fuels is one reason for these price fluctuations. Certain 'unconventional' commodities like shale oil, which have catastrophic effects for the natural climate, have become economical. Only a scarce resource is Plutonium, the radioactive fuel. By contrast, the worldwide available supplies of renewable power are 40 times more powerful than the earth, according to the IPCC on Special Renewables Report (SRREN). In only the past two years, cost reductions have radically altered the economy of renewables, particularly photovoltaic (PV) wind and solar power, along with common features such as low to no emission of GHG, and are a practically inextricable resource. There have also been competitive technologies, with the solar market and the wind sector sustaining double digits for ten years, leading to faster implementation of technologies worldwide.

In 1961, the forum for democratic and market economy nations was set up to promote economic development and world exchange and provide a venue for contrasting the political perspectives, seeking responsibilities for common issues such as global warming, recognize best practices and co-ordinate their members' national and foreign policies, such as sustainable energy enhancement. This helped create the OECD with high-income economies, which are considered developed countries, which have a very high Human Development Index (HDI). The organization has been formed in the OECD. In addition, the 1992 Kyoto Protocol signatories to the United Nations Framework Convention on Climate Change (UNFCCC) voted in 1997 to accept global threats to climate change. The Face in the beginning of 2005, the Protocol came into force and its 193 members regularly held meetings to continue to discuss refined and develop the agreement. In 2009, the UNFCCC was unable to conclude an ambitious and fair cut in emissions under a revised climate change deal. The Conference of 2012 agreed to enter into a new contract by 2015 and to accept a second engagement period by the end of 2012. The mitigation pledges introduced by the government are likely to increase global temperatures to at least 2.5 to 5 degrees above the pre-industrial era.

1.4.2.a : International Policy for Preventing The Effect of Climate Change

In order to make the Energy Transition feasible and avoid negative climate change, Greenpeace, GWEC, EREC, MNRE, CERC, etc., call for the following energy policy and activities:

- Both fossil oil and nuclear plant subsidies must be phased out.
- Ensure that all energy consuming equipment, construction and cars are expected to follow stringent performance requirements.
- Set legally binding clean energy goals and integrated heat and electricity generation.
- Reforming the energy markets and ensuring that solar generators have preferential access to the grid.

- Plan for grid access to the new grid for steady RE interconnection.
- Provide investors with specified and predictable returns, such as by feed-in tariffs.

- Creation of stand-alone, micro-grid, hybrid, and energy storage technologies.
- The inclusion in the prevailing electricity grid of information, communication and technology (ICT).

This study presents a detailed debate on the important generation of renewable energy that can operate contrary to the current power grids, and the introduction of advanced smart grid management elements into distributing systems in Bangladesh. It also clarified is the role of the infrastructure supporting, automation and communications for smart grid sustainability growth. This research also discusses micro-grid and hybrid-grid energy system development initiatives and various examples of new Bangladesh automation systems. It also reviews how numerous public and private sector organizations, funded by leading foundations worldwide, intervene in R&D in such technologies. The emphasis has also been questioned on the present and potential challenges for Smart Grid infrastructure implementation for future demands.

CHAPTER 2

ENERGY RESOURCES OF BANGLADESH

2.1 : Electrical Energy

Electrical energy is an energy which is generated from kinetic energy or electrical potential energy. Electrical energy refers to energy that has been transformed from electrical potential energy as used loosely. The mixture of electric current and electrical potential delivered by an electrical circuit provides this electricity (e.g., provided by an electric power utility). It ceases to be electric potential energy at a time when this electric potential energy has been transformed to another form of energy. Therefore, all electrical energy until it is transmitted to the end-use is potential energy. Electrical energy will still be considered another form (e.g., heat, light, motion, etc.) of energy if converted from potential energy.

Typically, electrical energy is sold in kilowatt hours (1 kWh = 3.6 MJ), a product that is a product of a kilowatt capacity compounded in hours by an operating time. Electric utilities use a power meter to calculate energy to maintain total electricity provided to a consumer.

2.2 : Types of Energy Resources

Both kinds of fuel used for heating, producing electrical energy, and other types of energy transfer processes in the industrial world are energy supplies. Roughly three groups can be marked as energy resources: green, fossil and nuclear.

Out of dead plant and animal deposits that were formed over the years the world has been using fossil oil supplies. These services are comprehensive, but finite and cannot be renewed. Until recently, the bulk of human energy needs were fulfilled by fossil fuels. Mainly coal, oil and natural gas are these commodities.

Renewable energy supplies are types of energy natural to our world. Hydropower and biomass are examples of unconventional renewable resources (e.g., plant fuels such as wood traditionally have been used throughout history, mostly for heating). Winds, wave, tidal, solar and geothermal are modern renewable energy. This group also includes some types of fuel made from biomass (plants and animals).

2.2.1 : Conventional or Non-renewable Energy

Conventional energy resources are renewable energy supplies that are small in quantity and have been used for a long time. They are called non-renewable sources as they cannot be produced at the pace that can support their consumption rate until they are exhausted. They are produced over hundreds of millions of years from decaying matter.

Owing to their ongoing exploitation, these commodities have been exhausted to a significant degree. It is believed that in a few decades, the petroleum deposits in our country will be depleted and the coal reserves will last for a hundred years. Coal, oil, natural gases are some typical examples of traditional sources of energy.

2.2.2 : Non-conventional or Renewable Energy

The energy supplies which are constantly replenished by natural cycles are non-conventional energy sources. These cannot be quickly depleted, can be continuously produced, and can be used repeatedly, such as solar energy, wind energy, tidal energy, biomass energy, geothermal energy, etc. Non-conventional energy is defined as energy derived from non-conventional sources. These outlets are not environmentally polluting and do not require heavy spending. As they can be supplemented by natural processes at a rate equal to or greater than the rate at which they are used, they are considered renewable resources.

2.3 : Conventional or non-renewable Energy Sources

Examples of non-renewable products include rocks from the soil and metal ores. Metals themselves are found in large quantities in the Earth's crust, and human production happens only where natural geological processes (such as fire, friction, organic activity, weathering and other processes) are necessary to make them commercially feasible for extraction to be concentrated. Via plate tectonics, tectonic subsidence and crustal recycling, these cycles typically take tens of thousands to millions of years.

In human time frames, the localized concentrations of metal ores close to the surface that can be commercially mined by humans are non-renewable.

2.3.1 : Fossil Fuels

Fossil fuel is a fuel that is a source of natural processes, such as the anaerobia decomposition of buried, dead organisms that produce organic molecules from aged, combustible photosynthesis. These species and the fossil fuels that are produced appear to be millions of years old and sometimes over 650 million years old. Oil, coal, natural gas, and fossil fuels produce high carbon percentages. Kerosene and propane are common derivatives of fossil fuels. Fossil fuel ranged from low-carbon to hydrogen (such as methane), volatile materials and liquids (such as petroleum), and nearly pure carbon-composed non-volatiles [6].

Bangladesh has three types of fossil fuel energy sources. They are;

a. Coal
b. Natural Gas and
c. Imported Oil

As from 2018, the largest source of primary energy in the world was petroleum (34%), coal (27%) and gas (24%), which constituted 85% of fossil fuels in the world's main energy usage. In 2019-20 fiscal years for power generation Bangladesh uses Natural Gas (53.86%), Furnace Oil (27.18%), Diesel (6.33%) and Coal (5.62%), a total of 92.99% fossil fuel are used for power generation [7].

2.3.2 : Nuclear Fuel

The material for heat-to-power generators at nuclear power plants is nuclear fuel. Heat is produced by nuclear fuel fission.

Naturally occurring radioactive material is a fuel for the application of fission-based nuclear energy. Uranium, the most common fission fuel, is comparatively poor and mined in 19 countries on the ground. This extracted uranium is used to fuel fissionable uranium-235 (U-235) nuclear power reactors that produce heat, which is eventually used for power turbines. The highest energy density for nuclear fuel is all functional fuels.

Currently Bangladesh is working on Nuclear Power Station named as “Rooppur Nuclear Power Plant”, which may be goes on service in 2024 with the installed capacity of 2160MW (Name Plate) [7] .

2.4 : Renewable Energy Availability

Gas supplies are in decline, while new factories, manufacturing, households etc. are increasing and the fast use of gas is improving. If no new sector is found, the country will face gas supply shortages. Furthermore, 20% of the power plants are too older to operate properly (fuel running). As a result, these devices are abruptly shut down and need a high cost of maintenance.

More than 2/3 of the overall production of electricity is gas dependent. In total, 2.5% of total energy outputs come from renewable resources such as solar, hydro, wind, biogas and biomass. On the other hand, non-renewable sources of energy often lead to a substantial part (97.5 percent) of the electricity generated, causing sluggish air, water, land and organic emissions. The burning of energy-generating fossil fuel has an impact on the nation's sustainability and is responsible for high carbon emissions. If this doesn't improve, future generations will face intense power shortages, environmental threats and other countries are lagging behind. For this purpose, renewability is necessary if these concerns and threats are to be mitigated. Renewable energy means power generation from Bangladesh. Current renewable energy options include solar, wind, hydro, biogas and biomass. The following Figure 2.1 introduced the renewable energy mix:

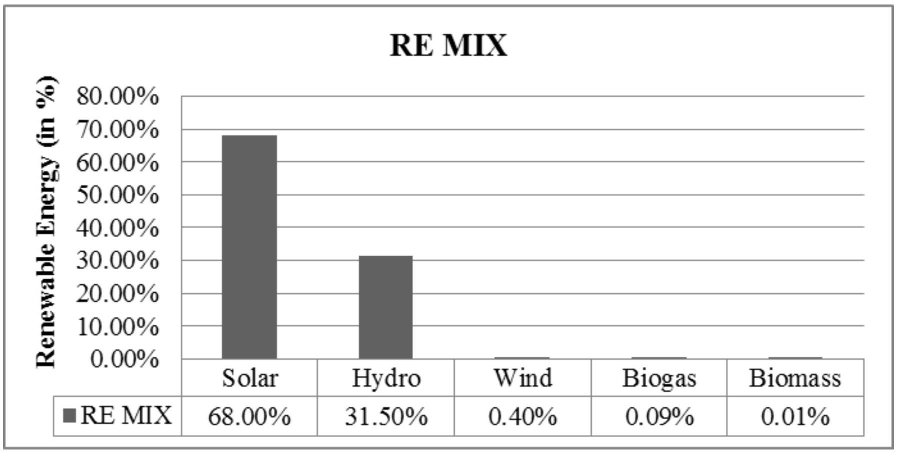


Figure 2.1 Renewable Energy Generation Mix

The Government of Bangladesh has made a strong contribution towards to boosting the production of renewable electricity. In order to promote renewable energy and energy efficiency in 2014, the Government has established a Sustainable and Renewable Energy Development Authority (SREDA). Bangladesh has become one of the first members of the International Renewable Energy Agency (IRENA) to strengthen international cooperation. Renewable sources of energy currently have a very small share (<2%) of overall generation. The Bangladeshi government is trying to promote the use of renewable energies and formulates a policy on renewable energy.

One of the main focuses of this policy is the increase in renewable energy contributions to the production of electricity. The initial objective was to produce 5% renewable energy by 2015, and 10% by 2020. Due to its geographic characteristics, solar Photovoltaics (PV) are the basis of most renewable energy projects. In the course of the 2003 Solar Home System (SHS) program was initiated by a public development financial institution to support/finance infrastructure and green energy ventures in Bangladesh called 'Infrastructure Development Company Limited' (IDCOL) to secure the access of Bangladesh's hungry rural electricity off-grid areas to clean electricity. The policy complements the Government's view that "Electricity for All" will be promised by 2021. Until April 2016, about 4 million SHSs were deployed inside the program in Bangladesh's out-of-grid rural areas. As a result, nearly 18 million consumers receive solar power, comprising 11% of Bangladesh's overall population.

Renewable energy is a renewable resource that plays a crucial role in fulfilling Bangladesh's energy demand. Bangladesh's current renewable energy options are solar, biomass, wind, hydro and geothermal and these are renewable energy potentials in Bangladesh to reduce energy problems. In total, hydro, solar and wind energy share of the national energy consumption by 3% are 60%, 48.2% and 0.6% respectively. The other off grid energies are Biomass and Biogas with the percentages are respectively 0.1% and 0.2% [7]. The most rapidly developing green energy market in Bangladesh, however, is solar energy.

So, renewable energies available in Bangladesh are;

i. Solar or Solar PV

ii. Hydro Power

iii. Wind

That’s the major and grid connected renewable energy sources of Bangladesh.

The minor and off grid energy sources are Biomass and Biogas. Currently, Bangladesh Government and Power Division are also working on Waste Energy.

2.5 : Solar Energy

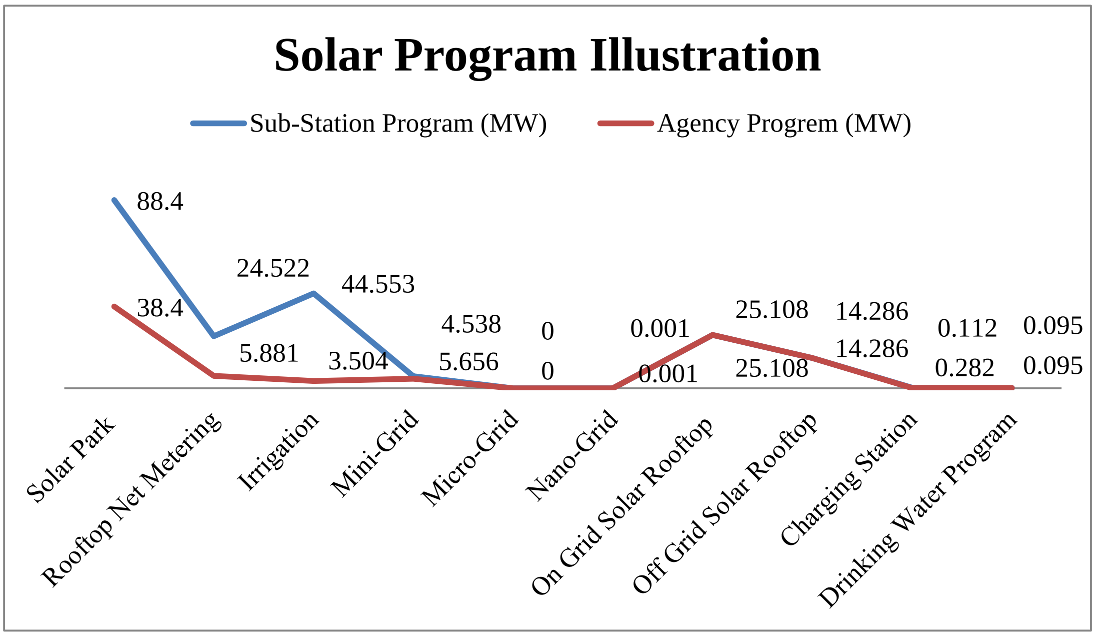
Bangladesh's limited portion of demand for electricity partly filled with solar Photovoltaic (PV) system and Bangladesh's location vision in view of solar radiation 241 0' 0'' N and 901 0' 0'' E latitude. But the combined solar power generation and clean energy share in Bangladesh are 500 MW and 39.5%. By supplying renewable electricity to more than 13 million rural residents, Bangladesh's state owned IDCOL has now deployed 3 million solar home systems (SHSs). The average daily radiation obtained by Bangladesh is 4-5 kWh/m [8].

2.5.1 : Installed Capacity of Modern Solar PV System

The amount of new solar power generation linked through the grid again exceeded the volume of separate facilities. 2019 announced the National Development Agency for Sustainable and Renewable Energy (SREDA) that there have been 24.99 MW of new grid-connected photovoltaic power, compared to 18.26 MW of off-grid projects. These estimates marked a deeper difference between the two projects after a total of 27.34 MW in 2018, as compared to 26.32 MW in stand-alone projects, were added in Bangladesh's network. In Bangladesh SREDA reports that about 5.8 million solar homes were built. Of the approximately 25 MW of solar power supplied to the grid last year, an official from the senior Power Division reported that 10,827 kW was connected to the roof top PV. A new portion of the new grid power was created at an 8 MW facility in the “Panchaghar” district in November, 2020. Huawei Smart PV solution, in which it is connected with the national grid since the start of October 16, 2020 is completely installed in the largest Bangladesh-based solar plant in Mymensingh. The 73 MW photovoltaic power stations will help to full-fill the government's goal to produce 10% renewable energy of the country by 2021 [9].

Bangladesh is a typical country of South Asia where up to 2500 hours per year of sunlight, with a lush and hot climate, are enjoyed. Mymensingh Power Plant use Huawei’s Smart PV system included SUN2000-185KTL with IP66 high level Protection and Anti-PID technologies.

At that shown path Solar PV system are classified in Bangladesh are Ten Categories [10]:



** Data Taken on 30 April, 2021*

Figure 2.2 Solar Program illustration respect to Bangladeshi Solar PV System Scenario

2.5.2 : Solar PV Targets from 2021 to 2041

In this portion, the bases (or business as usual; on short BAU), medium and high cases are the three targets of deployment of solar photovoltaic power between 2021 and 2041. Different levels of RE share are aimed in the power mix built. However, during the three examples, the following points should be taken into account;

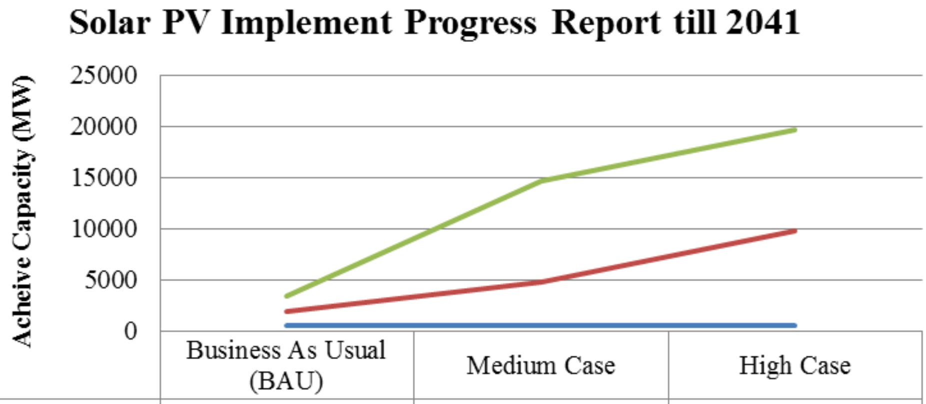
a. Both cases are based on current infrastructure or on technology growth. There is no consideration of the potential to build totally new or unknown technology.

b. All the scenarios were suggested with respect to the Power Sector Master Plan (PSMP) 2016 goals for power production.

c. There have been variations among solar photovoltaic projects in energy scale and solar hubs.

d. Land demand and other forecasts are based on state-of-the-art industry technologies.

The selling of solar cells with higher efficiencies, affordable and more efficient storage systems, etc. will alter the whole landscape dramatically in the next decades. The higher efficiency of panels or solar cells, especially in a small, densely populated country, like Bangladesh, will result in lower land demands which are today one of the key cost components. The overall result will be found by following compressed Figure 2.3 [11]:



	Business As Usual (BAU)	Medium Case	High Case
Untill 2020	546	546	549
2021-30	1961	4795	9743
2031-40	3439	14659	19711

Figure 2.3 Potential of Solar PV till 2041

2.6 : Wind Power Station

The energy from the wind can be collected continuously using wind turbines to transform the wind into kinetic energy from mechanical energy and then electricity been produce. Wind is an outstanding green energy source.

Bangladesh is ideal for a long coastline region. Wind blows here in various seasons multiple patterns. The strong south-west wind from Bangladesh flows across the Indian Ocean during the Monsoon. Therefore, the average wind speed between March and September is 3 m/s and 6 m/s and accordingly. The wind speed between October and February remains lower. The highest wind intensity can be seen in June and July. It would also be safer for a wind turbine to be set up on the coast and the solution to satisfy our national grid requirement.

2.6.1 : Typical Capacity of Installation

Under the plan of 10% electricity from renewable source, there are many of project are ongoing on renewable energy. In a preliminary study conducted in 1982, data from 30 meteorological stations in the country showed that Chittagong and Cox's Bazar districts were suitable for wind power generation. After further experimentation, as part of a pilot project to generate electricity from wind energy, the first wind power plant in Bangladesh was set up in 2005 on 6 acres of land in “Lamchi Mouza” of “Khojaj” along the banks of “Mahuri River” and “Sonagazi Char” in Feni. At present, under the PDB project, Pan Asia Power Service Limited has made arrangements to generate 200 kilowatts and 900 kilowatts of electricity by using wind through four turbines. Its maximum generation capacity is 0.90 MW. Another wind power plant in Bangladesh is at “Kutubdia” in Cox's Bazar. The power generated from the center was also distributed experimentally to 600 customers on 14th April, 2007; where there were 50 turbines. Each has a capacity of 20 kilowatts In other words; the power generation capacity of this center is 1 MW [12].

2.6.2 : Wind Energy Potential in Bangladesh

A one year assessment of wind energy in the area of Feni, Mognamaghat and Anwara Parky Beach of Chittagong, Kepupara of Borguna and Kuakata of Patuakhali, the measures were taken for the construction of 15 MW Wind power plants in the coastal regions of Bangladesh. Wind maps are being carried out at Feni's Muhuri Dam and Regen Powertech Ltd. of India's Mognamaghat Cox'sbazar. The plant will be set up in Kurushkul, southeast of Moheshkhali River, by US DK Group Green Energy (BD), a joint venture between the USA Taylor Engineering Group, a Denmark ph.-consulting group and the Bangladesh Multiplex Green Energy Group. The $120 million project will start business by May, 2022. The wind speed was measured in different west-south side in Bangladesh. A report shows the following result that concluded the wind speed data [13]:

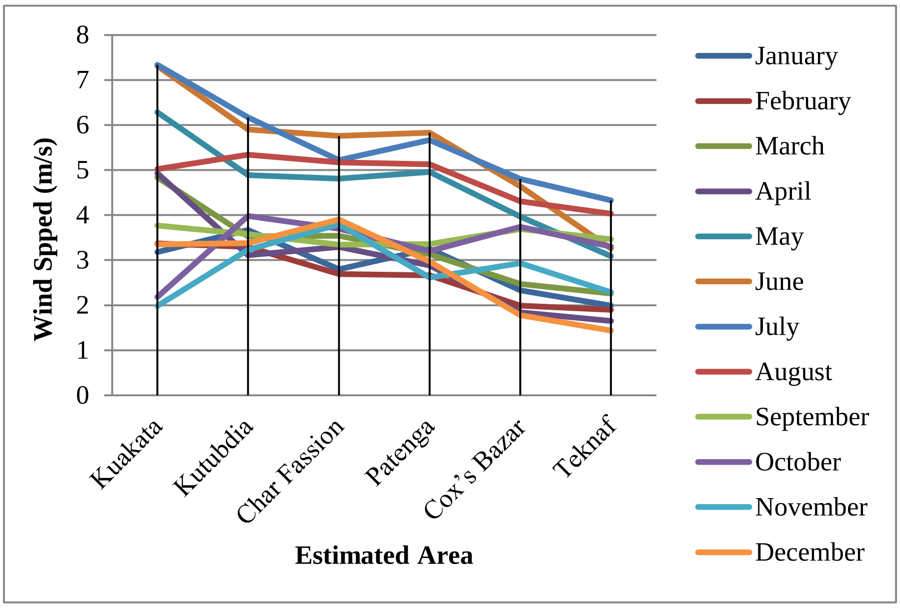


Figure 2.4 Wind Speed (m/s) potential (estimated in 1996-97) of different places in Bangladesh

From this graph, the wind speed rises over 7meter per seconds at the months are June, July and August but on the other time of the year wind speed goes to under 3m/s.

Here is graph of the average speed of these estimated 6 places data [13]:

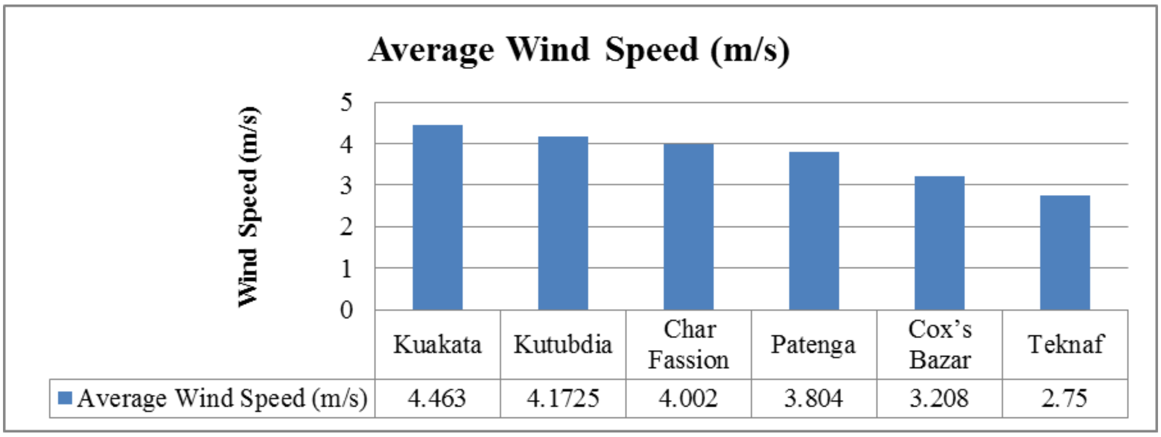


Figure-2.5 Average Wind Speed (m/s) of estimated places in Bangladesh

2.7 : Hydroelectric Power Plant

Hydropower or water energy is energy derived from falling or fast-running water, and can be used for produce electricity. Hydropower has been used as a renewable energy source for the irrigation and functioning of different mechanical devices such as gristmills, scratch mills, textile mills, travel hammers, dock cranes, house elevators and ore mills since ancient times.

In comparison with global hydropower production, Bangladesh has lower hydropower resources. Hydroelectric production capacity was 230 MW in Bangladesh in 2020 and global sharing is extremely insignificant.

2.7.1 : Typical Installed Capacity of Hydroelectric Power Plant

Kaptai Dam is only one of Bangladesh's dams in which hydropower are producing electricity. It is at the banks of Kaptai Karnaphuli and at Rangamati it is 65 km from Chittagong. The building of the Kaptai Dam began in 1962. The water storage capacity of the reservoir is 6,477 million cubic metres with energy of 230 megawatts when it operates completely.

2.7.2 : Hydro Power Potential in Bangladesh

A recent survey by US advisory company STI showed that there are theoretically 140 MW can be find on the two river in Chittagong hill Tracts. The analysis found that the Sangu and the Matamuhury could produce 58.33 MW defined by BPDB. The BPDB and BWDB have identified a number of possible small hydro sites. There are also two sites which can probably be found at the Sangu and the Matamuhuri for other hydro power plants. Table 2.1 shows the planned schemes for micro hydropower [14]:

Table 2.1 Proposed future micro grid Hydro Plant Project

Serial No.	**River Name**	**Electrical Energy Potential (MW)**
01.	Lohajari	4.5
02.	Mohamaya	65*
03.	Matamuhuri	100
04.	Shangu	100
05.	Kaptai	100
Total		**369.5**

** Approximate Value (can be varied from 23-65 MW)*

2.8 : Further Available Major Non-Conventional Energy

Bangladesh, as a developing nation, needs more demand-dependent capacity. Bangladesh needs further generation with a modern small and large power plant in order to reduce the power shortage. With this in mind, the governments of Bangladesh and certain private firms have undertaken certain schemes. Mainly Biofuel, Geothermal Energy, Tidal Energy, Waste Energy can be dominate the future renewable prospect of Bangladesh.

2.8.1 : Biofuel

Biofuel used for bio-product, bio-energy and bio-power production. Biofuel generates environmentally-friendly green fuel oil, which is made specifically from (tallows, lard, poultry and fish oil) and mainly from natural vegetable oils. The method of extracting gas and liquids from biomass called biofuel processing and crop oil. More common in Bangladesh are biogas and biomass. Bangladesh has more than 350 possible oil-bearing plants that are considered alternating source of fuel in Bangladesh to manufacture biodiesel such as j.

curcas, sunflower, sesame, beaver and groundnut oils. In Bangladesh, the Table 2.2 illustrates the biogas capacity [15].

Table 2.2 Technical Potential of Biogas

Serial No.	Division	Technical Potential (MWh)*		Estimated Capacity Potential (kW)**	
		Only Commercial Organic Waste			
		Cattle and Buffalo	Fowl and Duck	Cattle and Buffalo	Fowl and Duck
01.	Dhaka and Mymensingh	18,452	188,138	421	4,295
02.	Chattagram	11,364	69,243	259	1,581
03.	Rajshahi and Rangpur	15,999	33,193	365	758
04.	Khulna	11,095	26,983	253	616
05.	Barisal	1,989	16,189	45	370
06.	Sylhet	1,383	18,946	32	433
Total		**60,282**	**352,692**	**1,376**	**8,052**

**Heating Rate assume 10,000 btu/kWh*
***Assume efficiency 50%*

2.8.2 : Geothermal Energy

Earth's hot center perhaps the most clean, green energy is called geothermal energy. However, it has the opportunity to derive energy from geothermal sources and has a geothermal geographic gradient of 19.8 to 29.5°C/km in the North-West, of the area between 20.8 and 48.7°C/km, and a geothermal gradient of 110-153°C inside the Earth from 304km. However, the major reservoirs of geothermal energy are the Rangpur Saddle (700 m deep), Madhupur Clay (20 m), the Single, Kuchma and Bogra (60-125 kilometres). In coordination with Anglo MGH, the Bangladesh government has already planned the establishment of a 200 MW geothermal power station in Thakurgaon [16].

2.8.3 : Tidal Energy

The Bay of Bengal and the long coastal belt, approximately 740 kM, are truly a good thing in Bangladesh. Tidal power is a good source of power in Bangladesh's coastal region as a sustainable renewable energy. Through the tidal stream generator the tidal power can be generated. Although it is not commonly used, it has a future power generation capacity. Thus, tidal energy is much needed from wind and solar power. The current supply of tidal power will be better and higher than the previously expected power if turbine technologies and strategy have been developed and established recently. By applying two technologies: low head tidal movement (2 - 5 metres) and medium head tidal movement (5,000 feet or more), Bangladesh with a sea in the south can obtain more energy from the tidal waves.

In coastal areas such as Khulna, Satkhira, Barishal, Bagerhat or Cox's Bazar with sluice gates and levees, the tidal flow of lower head can be determined. This is the case here. If the water is stuck in a coastal reservoir where there is a dead difference while the turbine is powered by the low tide, it can be quickly deployed. This approach is used by many developing countries [17].

2.8.4 : Waste Energy

The rapid urbanization and population growth of the city of Bangladesh is primarily responsible for the increasingly growing rate of MSW (Municipal Solid Waste) production. The production per capita of waste and the heat value of different waste components are the most relevant data to calculate the capacity of MSW in electricity generation. The average waste per capita production of 8300 tons of waste is produced daily by the total population of the Dhaka, Chittagong, Rajshahi and Khulna city corporations and by 0.5 kg per day. MSW's annual recuperation rate is 70%, which is 2.12 million tons a year.

The government has launched the construction in Dhaka of two waste power plants using everyday waste to make Dhaka a safe and clean environment. One of the plants at Aminbazar and the other in Matuail will be mounted. This is the country's first attempt to produce waste electricity. In order to produce at least 35MW energy, two plants would need 3,000 tons of waste each [18].

In the meantime, a private bidder's proposal for the installation of a waste-based construction company (BOO) in Narayanganj was adopted by the Cabinet Public Purchasing Committee on 16th September, 2020. One private company and a Joint Undertaking of the Consortium of UD Environmental Equipment Technology Ltd, Changzhou, and SABS Syndicate, will set-up the 6 MW power plants in Narayanganj, Jalkuri. The Private bidder will operate.

Bangladesh Power Development Board (BPDB) will purchase electricity generated in the plant for a term of 20 years, equal to Tk17.60, at USD 20.91 cents per kilowatt hour (each unit). The plan will create two separate plots of waste, build the necessary infrastructures for plant growth, and also provide the residual as required, in the context of both Dhaka South City Corporation (DSCC) and Dhaka North City Corporation (DNCC) [19].

CHAPTER 3

TRADITIONAL GRID ANALYSIS AND REFORMES

3.1 : Hierarchy & Blue Print of a General Power Grid System

An electrical power grid is a network of interconnected power lines that transports electricity from producers to consumers. An electrical control grid is another name for it. Generating stations (power plants), transmission systems, and delivery systems make up a power grid.

Power plants are built in the most practical locations, such as where there is enough fuel, where there is a river, or where renewable energy can be used efficiently. As a result, they're often found far from the city and populated areas. This is very practical since transmitting electrical power over longer distances is far more cost-effective than transmitting any other electricity. A hydroelectric project must either be sited in accordance with a suitable dam site, or a wind power plant can be sited off-shore to harvest additional wind energy. To transmit the produced electricity to populated areas, a long-distance transmission system is needed. A distribution system is also needed to transmit power to each customer at the proper voltages.

3.1.1 : Working Procedure of a general Power Grid System

The power system includes the devices connected to the system like the synchronous generator, motor, transformer, circuit breaker, conductor etc. The power plant, transformer, transmission line, substations, distribution line, and distribution transformer are the six main components of the power system.

The Figure 3.1 below depicts a typical electrical power grid configuration:

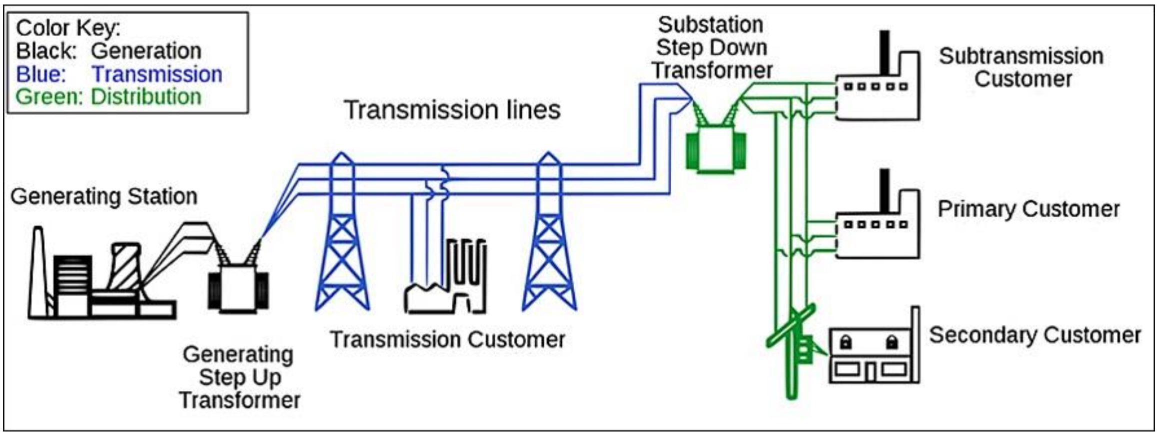


Figure 3.1 Typical one way grid system

Power generation, transmission, and distribution are the three phases of a power grid. Each of these stages is described in greater depth further down.

3.1.1.a : Power Generation

Energy is generated in power plants, which are regularly situated a long way from populated territories. Thermal, nuclear, hydro, solar, and wind power plants are examples of different types of power plants. A power plant can have two or more paralleled 3-phase alternators. Voltages ranging from 11kV to 25kV are used to produce electricity in power plants. Owing to technological constraints, generation voltage cannot be any higher.

In Bangladesh power mainly generates by Coal, Natural Gas, Oil, Hydro and Solar Power. “Payra Thermal Power Plant” is the biggest thermal power plant in Bangladesh. It has two plants with 1320MW installed capacity each.

3.1.1.b : Power Transmission

The generated voltages are ventured up to a lot more significant level for transmission of control over longer distances. This is accomplished with the aid of a step up transformer, which raises the voltage while lowering the current. Stepping up the voltage is needed to improve transmission efficiency by lowering resistive (I^2R) losses in transmission lines. The higher the transmission voltage, the lower the current consume. So, as a result, the lower I^2R loss occurred. Transmission voltages are usually 220 kV or higher, with a maximum of 400 kV. Transmission lines are often seen on the outskirts of cities, passing over tall buildings.

The power transfer is usually done using 3-phase AC power at a very high voltage. However, owing to advancements in power electronics, HVDC (High Voltage DC) has shown to be a

viable option for longer-distance transmission. As a result, for very long distance power transmission, HVDC transmission systems are used. For transmission, AC power is converted to HVDC at a converter station, then back to AC at the other end. Furthermore, for interconnecting grids with different frequencies, HVDC links are currently the only option.
"Power Grid Company of Bangladesh (PGCB)" is the only power transmission company of Bangladesh. By the report of PGCB till 2020 was 12,283 ckt. km.

3.1.1.c : Power Distribution

Using a step-down transformer in a main step-down substation, power from the transmission grid is stepped down to a much lower voltage (33kV or lower). The electricity is either sent to storage substations or directly to major industrial customers. Control is stepped down even lower at delivery substations (e.g. 11kV). Overhead or underground distribution cables, which are normally interconnected in a ring or mesh network type, are used to distribute electricity. Distribution transformers are used to lower the voltage to the use voltage (120 volts or 230 volts) and supply several customers through secondary distribution lines.
Six power distribution companies are distribute electricity all over Bangladesh. They distributes electricity in Bangladesh with different areas; such as "DPDC and DESCO" are distribute electricity only in "North and South Side in Dhaka", "WZPDCL" distribute electricity in "South-West side of Bangladesh named Khulna and Barishal", "REB" distribute electricity with "80 PBS" in the rural area of Bangladesh etc.

That was the short description of three sector of general power grid system but the real system is more complex than it.

3.2 : Power Generation Scenario of Bangladesh

The combined public and private sector power generation capacity in June, 2019 was 22,051 MW with 20% capacity reserved for maintenance and forced outages. Without fuel constraints, the available generation capacity should be around 17641 MW. Up until June 30, 2019, the maximum generation achieved was 12893 MW, which was less than the target of 17641 MW. It's possible that it happened because of a lack of fuel. The public and private sectors share 52 percent and 43 percent of total generation capacity, respectively, with imports accounting for 5%. Bangladesh began importing 500 megawatts of electricity from

India in October 2013, with an additional 100 megawatts added in March 2016 and 560 megawatts added in December 2018, accounting for 5.69 percent of total power generation.

3.2.1 : Energy Generation

After the independence of Bangladesh, the government of Bangladesh established BPDB for the expansion of power industry. BPDB's (Bangladesh Power Development Board) accomplishment in the period of 1972 to 1995 was as follows; total 2,818 MW installed capacity; a high tension transmission line of 2469 km (132 kV) and 419 km (230 kV); a transmission line with the high tension line (230kV) capacity of the country of East-west (Tangi-Ishurdi) in December 1982. BPDB established electricity throughout the district and urban area, but the government needed electricity in rural areas, particularly for irrigation, to develop the whole country.

From the present grid scenario (FY2019-20) total net energy generation is 71,419GWh, which is 1.26 percent higher than the previous year. The public power plant generated 35,316GWh of net energy, while the private sector generated 29,429GWh (including REB). Through the interconnection in Bheramara and Tripura, another 6,674GWh was imported from India. The following history Figure 3.2 is a breakdown of total net energy generated by public and private sector power plants by fuel type [20]:

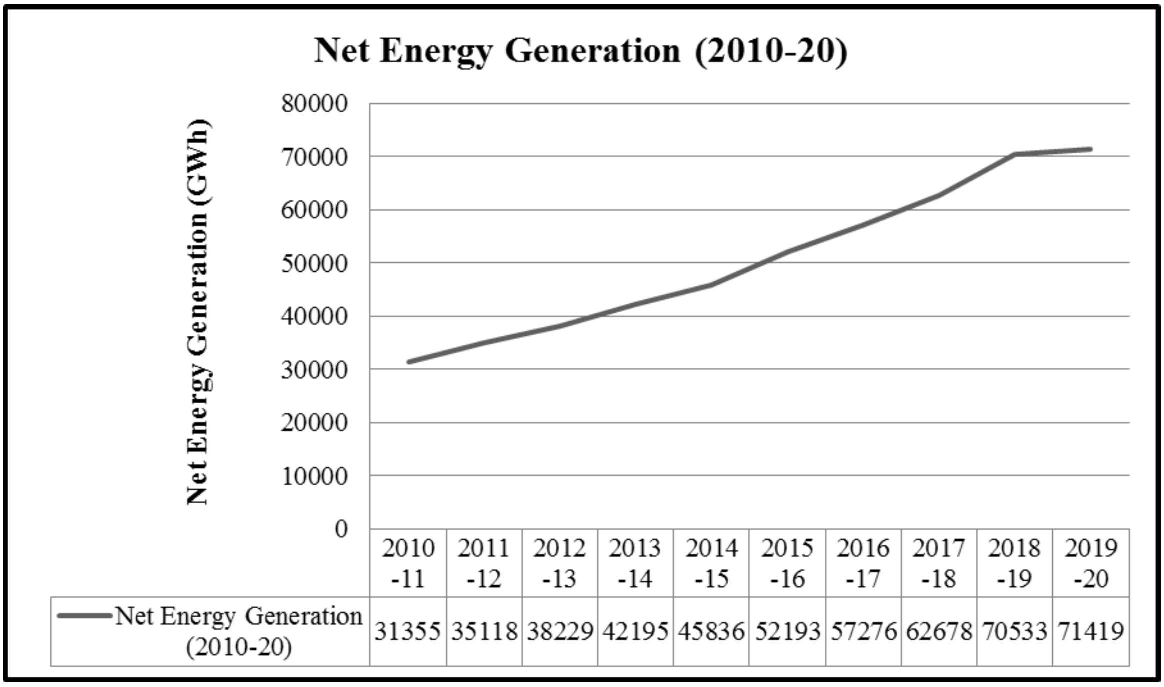


Figure 3.2 Historical Net Energy Generation (GWh) in Bangladesh

3.2.2 : Current Installed Capacity

The total installed capacity (FY-2019-20) of power plants is 20,383 MW, with 9,717 MW from the public sector, 622 MW from joint ventures, 7,332 MW from IPP/SIPPs, 1,301 MW from rental power plants, 251 MW from REB (for PBS) and 1,160 MW from India. The maximum peak generation (FY-2019-20) was 12,738 MW that is less than 1.20 percent from the previous year (FY-2018-19) [21]. But the maximum power generation of May, 2021 is 13,289 MW. The following Figure 3.3 and Figure 3.4 is the Generation Capacity mix:

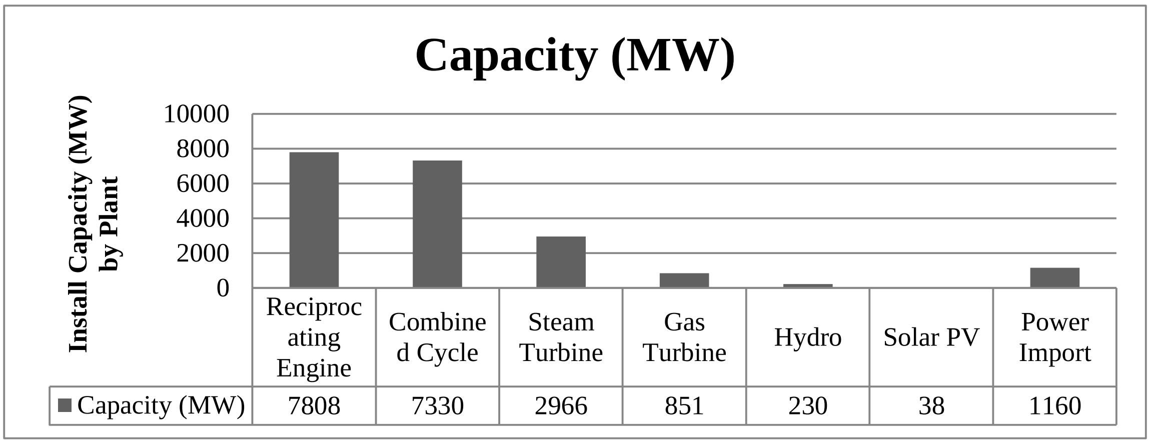


Figure 3.3 Installed Generation Capacity of Power Plant

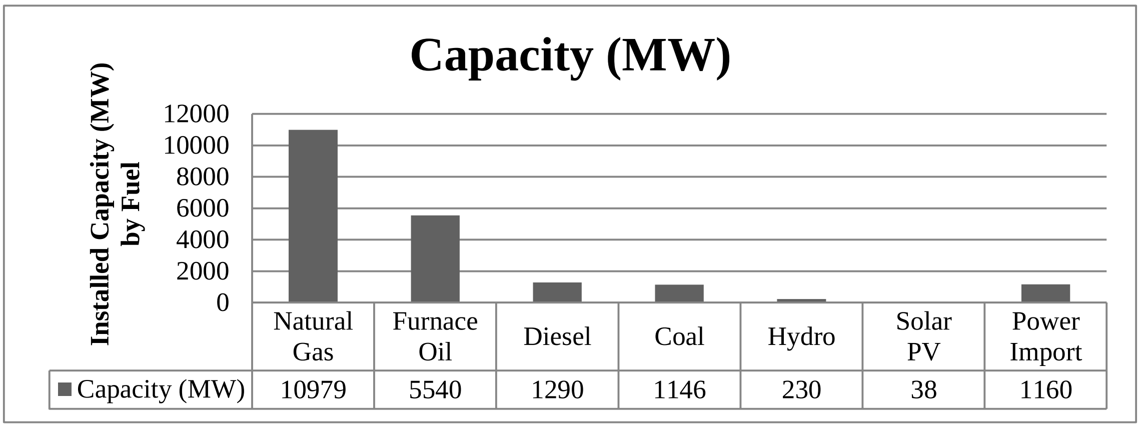


Figure 3.4 Installed Capacity of Power Plant by Fuel

3.2.3 : Opportunities of extension of Power Plant

Bangladesh may have substantial reserves of untapped natural gas in the offshore blocks of Bay of Bengal. The prospects for location of gas have been suggested by geologists, but marketable reserves have yet to be proven. After a seismic survey is complete, more specific information is possible [22]. As well as offshore deep-water exploration, there are also possibilities for the reinvigoration of ageing brown fields, the further development of onshore gas fields, the refurbishment of roads, waterways and fuel transport networks and the construction of terminals and of pipelines, which transport imported LNG and drilled natural gas to hubs. Changes in energy policies and legislation, including renewables, distributed energies and energy sources, energy-efficient technology, efficiency, stable energy solutions, off-grid solutions to energy supplies, sustainable construction technologies, and management of air emissions can also be given commercial opportunities over long periods.

3.2.3.a : Planning of Power Generation of Bangladesh

The power generation capacity of the country has seen an increase over the last decade, but no substantial progress in medium and long-term projects has yet been observed: Over the past decade, Bangladesh's government has given priority to enhancing the capabilities immediately (but at high cost), which have provided short-term solutions to some of Bangladesh's rental or quick rental power projects on a private-owned basis. The government has also approved several private sponsors, to decrease the legislative delay, to set up electricity generation stations within the time frame stated. Most of these plants were awarded under the Speedy Supply and Energie (Special Provision) Act 2010, on the basis of unsolicited offerings.

Still superfluous long-term electricity generation plans need cautious reassessment: The demand forecast for PSMP -2010 was based on a GDP growth rate of 7 percent per year. The highest demand in FY2020 is estimated at approximately 17,304 MW and in 2030 at 33,708 MW based on this report. In addition, Bangladesh's government plans, in 2030 to boost its fast-growing economy, to raise its power generation capacity to 40,000 MW above its projected demand. But as in the current situation, the real scenario differs somewhat from what was previously envisaged. According to the latest PSMP, peak demand was expected to be 15,809 MW in 2020. Nevertheless, up to now the reported maximum power consumption was 12,893 MW, and in 2020 it produced 12,536 MW of the highest power. While reduced economic activity has slowed consumption demand due to the COVID-19 pandemic, over 45 percent of generation capacity still remains unused.

In recent years, more than clean power, coal power has become more expensive. Thus, by adding more LNG power contribution instead of Coal, the government has revised its master plan of long-term energy systems. As per the PSMP-2016 revisit, the share of capacity generation in the gas/LNG power plants is now going to be greater compared to coal-based capacity. The Power Division has proposed converting coal-based plants into LNG-based plants that have made little to no progress. Minister of Energy, Power and Minerals already sought the Prime Minister's approval to transform into pure liquefied natural gas (LNG) plants thirteen major coal-fuel projects out of 18 ongoing projects. In the meantime, a total of five GLG-based projects are in progress and funded by local and international organizations with a power capability of 8,750 megawatts. Currently, the government imports LNG from two floating storage units of 1000 mmcf (million cubic feet) a day. Nevertheless, by 2030, Bangladesh expects to increase its LNG import ability to 2,000 mmcf of gas a day.

However, for long-term power generation, there has been limited success: Renewable energy can be a better alternative: Bangladesh is presently generating approximately 365 MW of clean energy electricity. The potential for solar and wind is immense in Bangladesh. However, Bangladesh's prime restrictions on the availability of land and land weather are not suitable for hydroelectricity generations are limited. According to energy specialists, the overall projected capacity for renewable energy is up to 3,700 MW in Bangladesh. By 2020, the government aimed to account for 10% of overall renewable energy production. But the current situation is a long way from the plan as most facilities have failed, within the specified time period, to complete their installation [23]. Few solar projects under implementation include a solar park with 200 MW in Tekhnaf, a solar power project of 500 MW in Feni, a grid-connected electric power plant of 100 MW Solar Photo Voltaic in Feni, a 200 MW grid-tied solar photovoltaic power plant in Latshal, a power plant of 60 and 30 MW in Cox's Bazar and 1 MW waste plant in Keraniganj and other projects in the fields of solar power. There are currently some more ventures in Bangladesh for the production of renewable energy. If all projects proceed according to their plans, a mentionable contribution to electricity generation from renewable energy expansion will be made. The government also aims to produce 4,000 MW of electricity from a nuclear power source, as part of the long term energy production strategy.

3.2.4 : Power Import

The first Interconnection Project Bangladesh-India Regional Grid has already been implemented and is now importing 1,160 MW of power into Bangladesh along this route. 100 MW of power is imported from 2016 to Tripura, India, from July to Cumilla, another 60 MW of power is imported from the same stage and another 500 MW from September 2018 are imported by "Bohorampur-Bheramara". BPDB is planning to import 340 MW of Tripura power until 2021. Another 1496 MW of power is to be imported by 2022 from Jharkhand, India [24].

3.3 : Power Transmission Scenario of Bangladesh

Power requirements have progressively increased in order to rapidly expand the communications infrastructure, manufacturing, agriculture, human resources, modern lifestyles, and extension of the Bangladesh health service. The government of Bangladesh has implemented a lot of time-limited energy generation plans. Significant achievements have been made in this field in the last 10 years. The capacity for power production in 2020 increased from 4,942MW in 2009 to 23,548MW. The generation of electricity per person has risen from a maximum of 220 KWh to 512 KWh. The number of individuals with electricity has grown from 47% to 98%. According to the government's master plan, power production will be 24,000MW by 2021 and 40,000MW by 2030. Power Grid Company of Bangladesh Limited (PGCB) worked for the expansion of the transmission network and the development of the transmission capacity in order to establish cooperation with electricity production.

Bangladesh's Power Grid Company was formed to build, run and sustain power transmission networks across the country through Bangladesh's Power Development Board's assets and liabilities for power transmission systems under the power reforms. In reality, from last 2000, PGCB was in charge of transmitting power to the region. New transmission lines and sub-stations, i.e. transmission infrastructure, have been used to keep pace with both legislative and electricity generation technologies and the 2021 vision. In building transmission networks, enormous amounts of local and foreign currencies are needed per year.

By Power System Master Plan (PSMP-2016) PGCB is progressively stressing the construction work to create a solid grid network, including meeting the government's SDG goals in the power sector. PGCB brings projects under the sponsorship of GoB, its own construction partners and various partners to efficiently undertake constructing works for 132 kV, 230 kV, 400 kV, 765 kV (on going) sub-stations and transmission lines. The power generation has improved tremendously over the last nine years. In order to transmit extra power and surplus power, which will be produced in tomorrow, PGCB has adopted a sustainable development strategy.

In the financial year 2019-20, the delivery companies earned 65,384 million kilowatt hours of transmission infrastructure. This is about 2.76% higher than the current fiscal year. The high voltage transmission will be increased further in the coming years by keeping track with the growth in overall production capability in the country and the growing regional electricity demand [25].

3.3.1 : Power Transmission Scenario

During fiscal year 2019-20 the system was supplemented with a very large amount of transmission components due to the completion of various projects. The length of the transmission line (Ckt. km) has risen 5.15% from the previous year. Total transmission line length of 400 KV is up to 861 km of the circuit from 697.76 km of FY2018-19. The overall transmission line length of 230 kV was up from last year by 3406.69 kilometers to 3658 kilometers. The overall transmission line length of 132 kV was up 7,764 circuits of 7,545.5 km from FY2018-19. The following Table 3.1 shows figures for the past five years of the financial year 2015-16 on the net power generation and delivery via the transmission network of PGCB:

Table 3.1 Last five financial year Net power Generation V/S Transmission history of many of organization that's are connected with PGCB

Serial No.	Financial Year	Net Power Generation (MKWh)	Distribution Organization Power Transmission (MKWh)
01.	2015-2016	47,759	46,413
02.	2016-2017	52,738	50,846
03.	2017-2018	57,226	55,741
04.	2018-2019	65,427	63,628
05.	2019-2020	67,357	65,384

The expected preservation efforts have also been continued in the last financial year 2019-2020, to keep the transmission mechanism active as before. The demand for electricity in Bangladesh is normally poor during the dry winter season. At the time, i.e., annual maintenance exercises typically take place between December and March. The transmission network has been kept working by effective conservation practices although it faces some minor problems. In 2019-2020, total transmission line availabilities were 99.99% and grid sub-station capacity was 99.99%. The energy transmission failure has hit 2.93% in FY2018-19 [26]. Transmission interruptions of this financial year 2019-2020 from the 2015-2016 and loss figures have been listed in the Table 3.2 below:

Table 3.2 PGCB's power interruption history of (2015-2020) Fiscal Years

Serial No.	**Financial Year**	**Transmission System Power Interruption**		**Transmission Loss (%)**
		Number	**Duration**	
01.	2015-2016	1	5 hours 10 minutes	2.86
02.	2016-2017	14	20 hours 37 minutes	2.67
03.	2017-2018	14	16 hours 32 minutes	2.60
04.	2018-2019	19	32 hours 51 minutes	2.75
05.	2019-2020	13	15 hours 27 minutes	2.93

Here is the illustrated summary of PGCB's transmission final report of FY2019-20 which is provided by PGCB:

Table 3.3 PGCB's grid connection history in 2019-20 Fiscal Years

Serial No.	**Transmission Line Type**	**Transmitted Line (Circuit Km)**
01.	400KV Transmission Line	861.31
02.	230kV Transmission Line	3,651
03.	132kV Transmission Line	7,764
Total Transmission Line		**12,283.31**
Transmission Loss (%)		**2.93%**

Table 3.4 PGCB's Sub-station connection history in 2019-20 Fiscal Years

Serial No.	**Sub-Station Type**	**No of Sub-Station (Nos.)**	**Capacity (MVA)**
01.	400 kV HVDC Sub-station (MVA)	1	1,111
02.	400/230 kV Sub-Station Capacity (MVA)	4	3,770
03.	400/132 kV Sub-station Capacity (MVA)	2	1,300
04.	230/132 kV Sub-station Capacity (MVA)	25	13,075

05.	132/33 kV Sub-station Capacity (MVA)	145	26,222
Total		**177**	**45,478**

3.3.2 : PGCB's Transmission Scenario

PGCB play the most important role of transmitting power line all over Bangladesh. In previous ten years it provides a great knock in electricity sector. Here is Table 3.5 summary of PGCB's last ten years power transmission scenario [27]:

Table 3.5 Progress Report of PGCB of last 5 years (2015-2020) infrastructure

Year	**Transmission Line (Ckt. Km)**			**Substations**									
	400 kV	**230 kV**	**132 kV**	**HVDC**		**400/230 kV**		**400/132 kV**		**230/132 kV**		**132/33 kV**	
				No.	**Capacity (MW)**	**No.**	**Capacity (MVA)**	**No.**	**Capacity (MVA)**	**No.**	**Capacity (MVA)**	**No.**	**Capacity (MVA)**
2015-16	220.7	3185.166	6401.63	1	500	1	520	*	*	19	9,375	90	12,656
2016-17	559.76	3324.99	6465.75	1	500	2	1560	1	650	19	9,675	91	14,155
2017-18	697.76	3342.62	6994.79	1	500	3	2600	1	650	19	10,275	96	16,598
2018-19	698	3407	7545	1	1000	3	3770	1	650	21	11,475	105	19,907
2019-20	861	3,658	7,671	1	1000	3	3770	2	1,300	22	12,075	114	22,055

3.4 : Power Distribution Scenario of Bangladesh

Despite numerous challenges, Bangladesh has maintained a GDP growth rate of more than 7.5 percent for quite some time. Its economy expanded by 5.24 percent in the previous fiscal year (2019-20). This economic growth has resulted in an increase in the demand for electricity, which is expected to continue to grow in the near future. The country's electricity capacity needs to be upgraded in order to meet increased demand and sustain economic growth. In Bangladesh, approximately 97 percent of the population has access to electricity, and per capita generation (including captive power and renewable energy) is 512 kWh. As a result, the government has set a target of supplying electricity to all by 2021, as well as ensuring a consistent and high-quality supply at a fair and affordable price.

3.4.1 : Current Power Distribution

During fiscal year of 2021, the company sold bulk energy of 67,668 GWh, which was 1.68 percent higher than last year, to distribution utilities, including BPDB regions. BPDB's four distribution areas' retail sales were 10,308 MkWh, down by 2.50 percent from the previous year. BPDB's system losses (without 132 KV of consumers) decreased by 9.12% to 8.99%. The production and consumed per person (Grid), from 426.05 kWh to 375 kWh from the previous year, has risen to 426.23 kWh and 378 kWh respectively. BPDB extended its distribution transformer in 2019-20 with a capacity of 551 MVA to around 1,992 nos. for its continuous system improvement. The BPDB covers electrification within its four zones (Chattogram, Cumilla, Mymensing, Sylhet) up to the end of the fiscal year in 242 thanas/upazilla and 4,957 villages.

3.4.2 : Power Distribution by Companies

The power generation capacity of the country has seen an increase over the last decade, but no substantial progress in medium and long-term projects has yet been observed: Over the past decade, Bangladesh's government has given priority to enhancing the capabilities immediately (but at high cost), which have provided short-term solutions to some of Bangladesh's rental or quick rental power projects on a private-owned basis. The government has also approved several private sponsors, to decrease the legislative delay, to set up electricity generation stations within the time frame stated. Most of these plants were awarded under the Speedy Supply and Energy (Special Provision) Act 2010, on the basis of unsolicited offerings.

Except for Dhaka Metropolitan City and its adjoining areas under Dhaka Power Distribution Company Limited (DPDC) and Dhaka Electric Supply Company Limited (DESCO), areas under West Zone Power Distribution Company Limited (WZPDCL), and some rural areas under Rural Electrification Board (REB), BPDB is responsible for electricity distribution in most of Bangladesh's urban areas.

Six distribution utilities are responsible for electricity distribution: (i) BPDB, (ii) DPDC, (iii) DESCO, (iv) WZPDCL, (v) BREB (that have 80 PBSs as of 2021), and (vi) NESCO. In 2017, the overall number of consumers served by these six delivery utilities was estimated to be about 27.4 million. Around 1980 and 1992, the delivery losses of BPDB, DPDC, and DESCO ranged from 25% to 35% and DESCO, DPDC, and WZPDCL had distribution losses of less than 10% in 2017, while BPDB, BREB, and NESCO had losses ranging from 10 percent to 12 percent. Upgrading overwhelmed modules and reducing commercial losses were two significant factors in this change.

Table 3.6 illustrates total distribution report of distributions companies of Bangladesh [7, 28-32]:

Table 3.6 Power Distribution report by Companies

Serial No.	Particulars	BPDB (2019-20)	DESCO (2019-20)	DPDC (2019-20)	BREB*	WZPDCL (2018-19)	NESCO (2019-20)
01.	Total Substations (Nos.) (132/33 kV, 33/11 kV)	0/137	5/44	15/57	0/1136	0/69	19/64
02.	Maximum Demand (MW)	1876	1031	1633.20	7100	622	810
03.	Distribution Transformer (Nos.)	24012	7,185	20,270	Unidentified	8,403	9072
04.	System Loss (%)	7.30	6.32	6.58	10.22	8.83	10.66
05.	Consumer (Nos.)	3236886	1,001,799	1,367,137	31,280,532	1,169,584	1,568,982
06.	Total Distribution Line (km)	33,641	5,234.157	11,482.12	5,56,663	11,593.70	211,252.12

**Data taken 12th May, 2021*

CHAPTER 4

SMART GRID TECHNOLOGY

4.1 : Preface of Smart Grid System

In order to improve network efficiency and integrate different smart grid services, such as; renewables energy sources, demand response, electricity storage and power transport smart grids is mostly proposed as the fundamental exploiting connectivity and IT (Information Technology). It strengthens competitiveness between suppliers, encourages the expanded usage of intermittent power supplies, develops the broad-based automation and tracking capacity for both large-scale and distributed power generation delivery, enables effective failure management and promotes the use of energy market expansion to push retail requests Smart Grid technology emphasizes considerations such as industry policy, regulations and performance, costs and benefits and facilities that standardize the marketing campaign by complex transformation of the world power scenario. Moreover, issues like safe correspondence, uniform protocols, advanced database administration and reliable architecture for the sharing of ethical data complement their requirements.

The ICT development has modified the technology by promoting complex re-evolving electricity and knowledge exchange in real time, enabling the inclusion of green energy sources in the grid, motivating customers by Advance Metering Infrastructures (AMI), the Virtual Power Plant (VPP) and other some digital system implementation [33]. Furthermore, it allows Grid to constantly track and adapt to self-healing, in order to monitor all types, compensate, redeploy the power stream, prevent accident intensification and allow various intelligent devices to achieve the network connectivity topologies. In this way it monitors and adjusts itself.

Power engineers all over the country have built curiosity to decarbonize electricity while minimizing fossil fuel dependence. The renewable energy development, resulting in the efficiency and economy of power grids, was strengthened by such interest. Integrated distributed electricity sources including fuel cells, photovoltaic cells, wind turbines and micro-hydro power generators could increase energy stabilization requirements, boost grid reliability, employ plugin electricity, benefit customers by shifting energy consumption habits, cutting electric power use and save costs. High-power electronics is another primary technique for eventually building smart grid infrastructure by connecting modern DC networks, AC VAR sources and backbones to current grids at T&D level [34]. Figure 4.1 demonstrates a common paradigm and distinguishing characteristic of Smart Grid Technology.

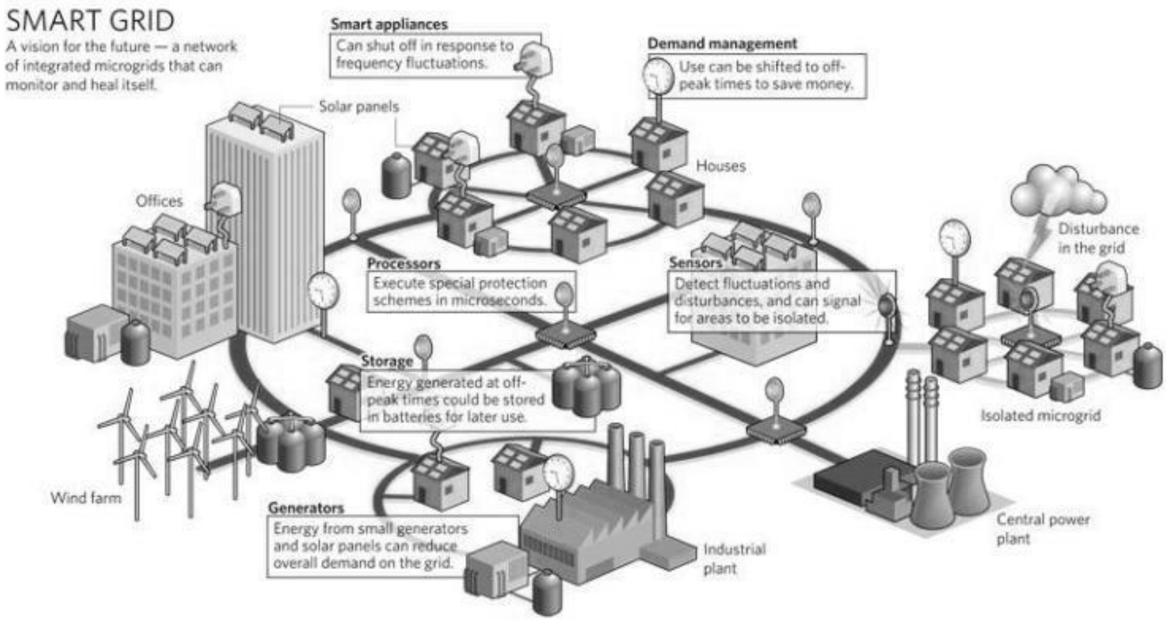


Figure 4.1 Deminstration scheme of Smart Grid System

Contrary to these unavoidable advantages Smart Grid infrastructure has emerging technological and non-technical problems. Researchers and power engineers are invaded to address these main problems in order to apply technologies correctly and effectively over a broad network. Under the R&D (Research and Development) department, this strategy will be initiated in association with a number of world-class institutes as well as multinational corporations.

4.2 : Global Outline for Smart Grid Technology

Broad electricity power stations were built and distributed via HV transmission lines through various energy-deprived regions to increase socio-economic growth and to meet energy demand. But, in addition to enormous spending, such a consolidation still calls for various non-technical concerns focused on environmental and judicial issues. The energy markets thrive with the launch of innovative technological advances, non-technical concepts, such as Energy Management System (EMS) and Demand Side Management (DSM), optimized asset management, etc. in order to control the global electricity market and reduce ambiguous incidents in power systems. Furthermore, new advanced innovations such as the Wide Area Monitoring System (WAMS), Phase Measurement Units (PMUs), Distributed Energy Resources (DER), Flexible AC Transmission System (FACTS), and others enrich the existing power system and open up new possibilities [35].

By the next decade, the world population is expected to increase by a factor of 1.4 billion, with a power demand expectation of 27,000 TWh. The numbers was expressed by both emerging and developed nations, respectively with a ratio of 45% and 55% [36].

We must deal with a tension between supply reliability, environmental protection, and economic productivity in order to satisfy the demands of an increasingly growing global population while simultaneously reducing fossil fuel usage. This can be achieved by ideas, clever solutions and creative technology that offer the worldwide strategy and power engineers with today's and tomorrow's challenges.

4.3 : General Infrastructure of Smart Grid Technology

The intelligent Grid has been used in different nations with the influence of state-of-the-art technologies, and quite a few things are necessary to focus on an integrated operating system. This segment discusses three extremely incipient and critical developments in depth.

4.3.1 : Transmission system for Smart Grid

The transmission network, which serves as the conduit for delivering electric power from generators to loads and customers, has played an important role and is a well-known body in power system engineering. After the beginning of Direct Current (DC) transmission, the spectrum of the transmission has expanded to include HVAC, HVDC transmission at varying voltage speeds and a plethora of dynamic network topologies. Upgrading the transmission network by installing high-capacity multi-circuit/bundle conductor lines, High Surge Impedance Loading (HSIL) lines, high-capacity HVDC networks and High Temperature Low Sag (HTLS) lines among other aspects increases the efficiency of power transmission while preserving grid stability and economy [37]. However, today's transmission network continues to address problems and concerns such as environmental issues, demand forecast, technical and technological challenges.

It has quarried a unique view of the future smart transmission grids by defining the main smart characteristics and efficiency features to tackle the problems using state-of-the-art technological advancements in the fields of sensing, connectivity, power, computation, and information technology. The following Table 4.1 emphasis the whole smart grid system in a raw:

Table 4.1 System information of Smart grid transmission system

Characteristics	**System Visualization**
Flexibility	Diverse generation systems, adaptability, various control strategies, and system up-gradation innovation and diversification.
Digitization	Sensing, connectivity, efficient security, and user-friendly visualization are all fast and accurate.
Customization	Smart consumers, price freedom, openness, energy efficiency.
Sustainability	Environmentally sustainable, renewable energy resources, carbonization prevention, congestion.
Reliability	Fast reactions, ruggedness, review in real-time.
Intelligence	Auto consciousness, online surveillance, reliability of the machine, self-healing, protected system.

Three key interactive and smart components are listed in detail for the smart transmission grid development: smart control centers, smart transmission networks and smart substations. In this one-of-a-kind vision of a smart transmission system, it seeks to foster technical advancement in order to achieve low-cost, efficient, scalable, and long-term electric power distribution. It also unlocks some of the most critical functions including:

- Increased monitoring, service, and extension flexibility;
- Creation of embedded intelligence;
- Grid stability and sustainability and
- Enhance consumer benefits and service efficiency.

4.3.2 : Information and Communication Technology (ICT)

Consistent and real-time knowledge are critical in the smart grid for the efficient supply of electric power from the generating station to the end-users. The classical power system had many flaws, including a lack of automatic analysis, low vision, slow reaction of mechanical switches, and a lack of situational awareness. The smart grid architecture, which incorporates advanced technology and applications, enhances the network's capability and functionality while also providing advanced sensing and control through modern communication protocols and topologies. For data and knowledge transfer and connectivity between smart customers and the service industries, wired and wireless modems are compliant [38]. Each of the communication modes has its own advantages and drawbacks; based on different factors such as geographical area, investment in resources, use economy, etc. Following Figure 4.2 illustrate the two way communication system:

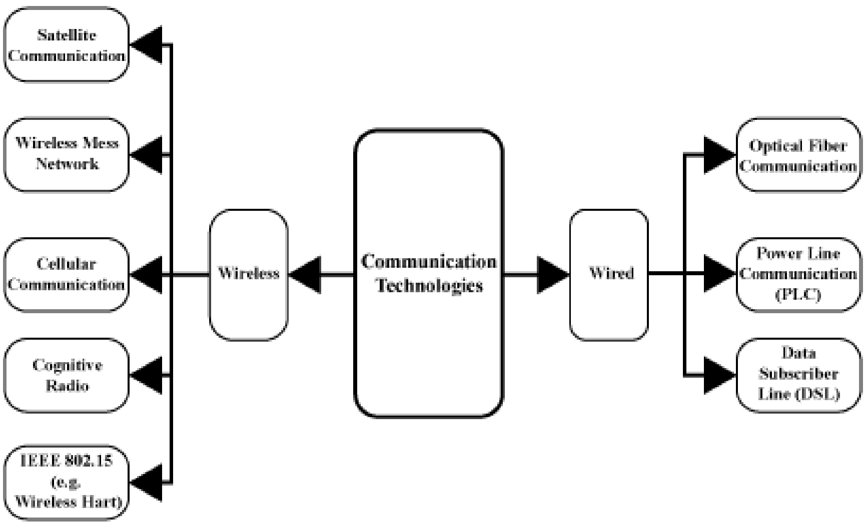


Figure 4.2 Different types of Information and Communication Technology (ICT)

The architecture of smart grid is built on the basis of two-way power and data flows. The Smart Grid infrastructure's smart networking subsystem or ICT is a diverse market. The infrastructure predominantly portrays the connectivity pattern in two conduits, namely, sensor and electrical appliance to smart meters, and smart meters to service data center. The network system between energy generation, storage, delivery, and use necessitates two-way communication, interoperability between advanced applications, and end-to-end efficient and safe communication with low latencies and adequate bandwidth [39]. It's enhanced the essential evolution of system protection and robustness against cyber-attacks, which offers system integrity and functionality with advanced control.

On the one hand, wired technologies such as DSL, PLC and optical fiber are expensive to install over a large area, but they have superior transmission capability, reliability, and data protection. Wireless systems, on the other hand, help minimize installation costs while highlighting latency and security limitations. While secure and efficient information sharing is vital to the success of future smart grid systems, network infrastructure must meet system quality of operation, data efficiency, wide reach, signal fidelity, and information protection and privacy.

4.3.3 : Smart Metering Technology

The smart metering scheme has been hailed as a cost-effective way to improve energy consumers' power usage patterns and productivity, thus lowering their electricity bills. It is a combination of electricity, telecommunications, and a number of other technologies. Clearly, as research and cutting-edge technologies have progressed, further services have been introduced to this field. In comparison to a conventional energy meter, a smart meter tests a consumer's energy usage and gives additional input to the utility provider. The ability to capture information in advance of network networks and control devices is allowed by bidirectional data communication.

Smart metering technology that includes a range of smart meters, connectivity modules, LAN, data collectors, WAN, Network Management System (NMS), Outage Management System (OMS), Meter Data Management Systems (MDMS) and other subsystems is known as Advanced Metering Infrastructure (AMI). The system provides a clean, stable, fast, and self-upgradable vision of reliable and versatile access to electricity consumption with an advanced feature of data collection.

Energy and distribution grid are used for customers. Figure 4.3 shows a planned architecture for an open smart metering scheme, which also provides a short rundown of how AMI and other subsystems are used. The model predicted outcomes and created a coherent method for power delivery system acquisition and management. Digital Meters are used in the Data Model, which is part of a broader term known as Virtual Power Plant (VPP) [40].

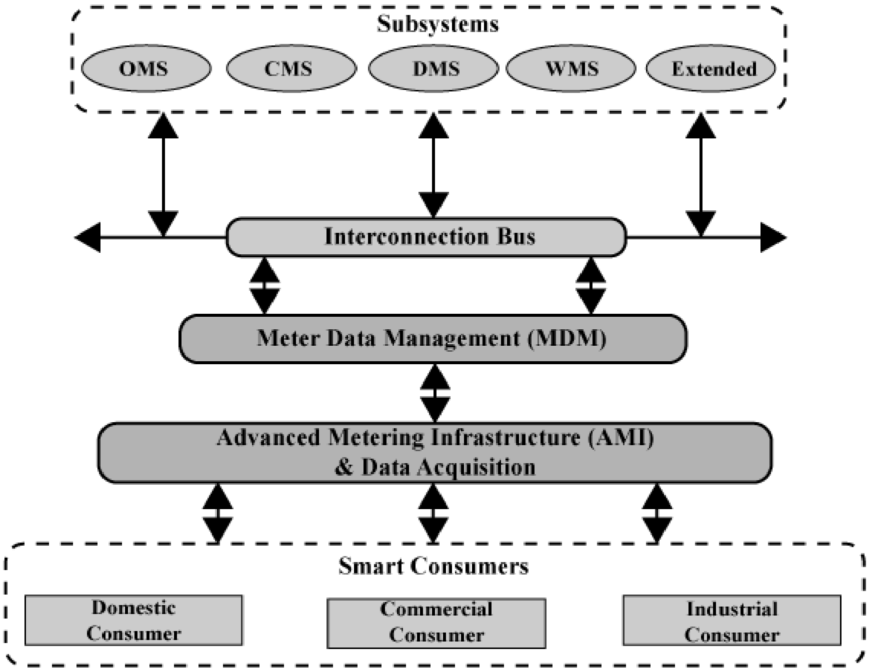


Figure 4.3 Schematic Diagram of Advanced Metering Infrastructure

The introduction and deployment of the Smart Metering Scheme is imperatively essential to a critical technical product, called the In-Home Display (IHD). In the Table 4.2, a briefing is disclosed. In the context of a meter data management scheme, the proposed architecture was applied to shown value.

Table 4.2 In-Home Display (IHD) used in Smart Metering

Smart Metering System	**AMI-Related System**	**EMS-type System**
Principle	Induces power savings by time-varying tariff.	By providing accurate statistics on energy usage over time, it encourages self-power savings.
Key Feature	Controlling power peak and demand response improves the reliability of the power supply chain.	Controlling the electricity demand of customers improves the reliability of the power delivery network.
Benefits	In a single format, information on power use and market changes.	Information of power consumption, higher resolution color display.

Because of the vast variety of benefits and uses, intelligent meters solutions are being developed and deployed on a large scale worldwide. Renowned power providers, such as Austin Energy (USA), Centerpoint Energy (Houston), Enel (Italy), Ontario (Canada), KEPCO (Korea) etc. are at a high speed to incorporate the smart metering technology within the scheduled and anticipated deadlines. Smart metering technologies are on the rise. In North America, approximately $50 billion was spent with an 89 percent goal in 2012 [41]. In various developing or industrialized nations, various organizations and venture capitalist corporations are also making immense investments.

4.3.4 : Smart Control and Monitoring System

A dynamic, stochastic, computational and scalable (DSCS) with innovative control technologies can be a promising trait for a stable, safe and productive power network, particularly with the invasion of very complex adaptive systems in smart power grids. Through distributed convergence of green energy sources and various types of energy storage, the electric power grid's sophistication and interconnectivity is increasing. Occasionally, in the grids, various approaches to conventional modeling, monitoring, and optimization may be supplemented or relieved for accelerated adaptation, complex foresight, self-healing, power system islanding, fault-tolerance, and robustness to fluctuations and randomness. Global Dynamic Optimization (GDO) is a critical component of a DSCS strategy for grid smart management, with Computational Intelligence (CI) and Adaptive Critic Designs (ADCs) being the most promising and promising methods. These are adaptive mechanisms influenced by natural phenomena and based on the AI paradigm, which allow cognitive and intelligent action in dynamic, unpredictable, and evolving environments. These CI paradigms, such as neuro-fuzzy systems, neuroswarm systems, fuzzy-PSO systems, fuzzy-GA systems, neuro-genetic systems, and others are the combination of superior to any single paradigm [42]. Furthermore, the ADCs are built using neural network-based designs for optimization and are based on a mixture of reinforcement learning and approximate dynamic programming. The Table 4.3 below illustrates the control technologies that make use of the GDO.

Table 4.3 Global System Optimization (GDO) for smart control and Metering

Control Technology	Fixtures
Neural Networks and Fuzzy System	Non-linearity of power networks and smart grids is captured.
Neural Networks	Smart grids use behavioral analytics to make fast, complex decisions.
Fuzzy and Neuro-Fuzzy	During times of confusion and invariability in the system, make fast and correct decisions.
Artificial Immune Systems	Provides fault-tolerance by protecting against transients caused by disruptions and faults in smart grids.
Swarm Intelligence and Evolutionary Computation	Allows for large-scale smart grid service optimization offline.
Adaptive Critic Designs (ACDs)	Allows for dynamic planning and scheduling, as well as the design of stable, adaptive, and optimal controllers in a competitive, unpredictable, and variable smart grid environment.
Computational Intelligence (CI)	Power grids with self-healing properties.

4.4 : Comparison between Existing & Smart Grid

The existing general power grid is made up of synchronous equipment, power transformers, transmission lines, transmission substations, control lines, distribution substations and various kinds of loads that are all interconnected. They are situated far from the power consumption field, and electricity is delivered through long transmission lines.

The smart grid is a modernized version of the conventional power grid that provides more stable and efficient electricity. It is, in effect, a two-way connection between the utility and the purchaser of electricity. The smart grid will track grid-connected device operations, user desires for energy use, and provide real-time updates on all incidents. Smart switches, smart substations, smart meters, and integrated synchrophasor systems are all main components of the smart grid. On the basis of infrastructure, power delivery & generation, controls, tracking, restoration service, equipment, control, and consumer choices, the main distinctions between the Traditional Power Grid and the Smart Grid are illustrated below in Table 4.4 [43];

Table 4.4 Comparisons between Existing grid and Smart Grid System

SL	Characteristics	Existing Power Grid	Smart Grid
01.	Infrastructure	**Electromechanical :** Electromechanical infrastructure is used in traditional electricity infrastructure. This implies that it is of, referring to, or denoting an electrically powered mechanical unit. This type of technology is often referred to as "retarded" because it lacks contact between machines and has no internal control.	**Digital :** Digital infrastructure is used in the smart grid, allowing for improved connectivity between machines as well as remote control and self-regulation.
02.	Generation	**Centralized :** Alternative energy sources cannot be readily incorporated into the grid as a result of this.	**Distributed :** Power can be delivered from several plants and substations using smart grid systems to help balance the demand, reduce peak time pressures, and reduce the number of power outages.
03.	Distribution	**One-Way Distribution :** Conventional electricity infrastructure can only be used to transmit fuel from the main facility.	**Two-Way Distribution :** Although electricity is always supplied from the primary power station, in a smart grid environment, power from a secondary supplier can be sent straight up the lines to the main plant. Individuals with renewable energy sources, such as solar panels, will potentially return energy to the grid.
04.	Control by Sensor	**Few Sensor :** This makes pinpointing the root of an issue more challenging and can lead to longer downtimes.	**Much Sensor Used :** Multiple sensors are mounted on the lines of a smart grid infrastructure scheme. This aids in pinpointing the source of an issue which can assist in rerouting electricity to where it is required while minimizing the areas impacted by the outage.
05.	Tracking	**Manual :** Energy delivery must be manually supervised due to shortcomings of conventional infrastructure.	**Self :** Using modern infrastructure, the smart grid can keep track of itself. Without the need for manual supervision from a technician, it will balance power loads, troubleshoot outages, and

			control delivery.
06.	**Restoration Service**	**Manual :** Technicians must physically travel to the site of the breakdown to make repairs on conventional energy systems. Because of this, outages can last longer.	**Self-Healing :** Sensors can diagnose line issues and perform basic troubleshooting and maintenance without the need for human interference. When there is an issue with the infrastructure, the smart grid will alert technicians at the testing center automatically so that fixes can be made.
07.	**Equipment**	**Failure and Blackout :** Conventional electricity infrastructure is vulnerable to collapse due to ageing and restrictions. Infrastructure breakdown may result in blackouts, which arise when a customer's device receives no electricity, causing downtime.	**Adaptive and Islanding :** Power can be rerouted around any problem areas using a smart grid system. This can be done on a per-residence basis, limiting the area affected by power outages.
08.	**Control**	**Limited :** Energy is difficult to manage by using conventional electricity infrastructure. Companies have no discretion over electricity delivery until they leave the power plant or substation.	**Widespread :** Energy firms now have greater leverage over electricity generation than ever before thanks to the increased use of sensors and other smart infrastructure. Energy and energy usage can be tracked all the way down the road, from the power plant to the end user.
09.	**Consumer Choice**	**Less :** Customers do not have a say in how they generate their electricity because the conventional power grid system technology is not designed to do so. Alternative electricity sources, for example, must be isolated from conventional grid systems and power plants. This is also one of the reasons why electric utilities were founded as a public utility.	**Much :** This helps more businesses and renewable energy sources to link to the grid, providing people more choices on how they get energy.

4.5 : Key Advantages of Smart Grid

As mentioned, Smart grids use Internet of Things (IoT) to share data and power, allowing utilities and their customers. It is a network of communications, computers, sensors, automation and other emerging technology that work together to improve the performance, safety and greener energy production and delivery.

These grids facilitate the exchange of data among power generation, distribution faculty and end users. This two-way relationship enables stable and cost-effective flow of seamless and uninterrupted energy flow. Such benefits provided by the smart grid in the delivery of electricity are;

4.5.1 : Self-Healing

A self-healing power network is characterized as one that uses real-time information from embedded sensors and automatic control to predict, identify, and respond to system problems in order to ensure grid reliability and enhance supply efficiency, prevent or minimize power outages, power quality problems, and service interruption. Such programmers are devoid of user input, with assessments made on information gleaned from pre-calculated and pre-monitored data. In general, self-healing is divided into two levels: physical (monitored hardware) and conceptual (monitored application/system) self-healing, depending on the condition of concern.

4.5.2 : Real Time Data Acquisition

The smart grid will be made up of a variety of different structures and subsystems, each with its own data collection needs. Data collection specifications for power generation and transmission, for example, may vary from those for a smart meter built in a consumer's home. In addition, for intelligent response and decision support in the smart grid, a vast volume of data must be collected, checked, processed, and converted in near real time. In order to accommodate the necessary volumes of data volume and complexity, data sensing in the smart grid must scale up. To assess the efficiency of power supply, a PMU (Phase Measurement Unit), for example, must submit up to 30 reports per second. Decentralized aggregation techniques for sensor calculation and distributed computing techniques for actuator parameters are required because the sensing nodes deployed in different locations of the power grid pose scalability challenges [44]. The network's scalability can be increased, for example, by grouping or domaining the collections of sensors and actuators into a hierarchical topology. These domains are controlled by a domain manager, who is in charge of aggregating the sensed data and setting the domain's actuator parameters.

4.5.3 : Wide Area Monitoring and Control (WAMC)

The use of system-wide information and the communication of relevant local information to a distant location to combat the dissemination of major disturbances in a system are known as Wide-Area Monitoring and Control (WAMC) and Wide-Area Monitoring, Protection, and Control (WAMPAC). A WAMC framework comprises four basic components: PMU, PDC, PMU and NASPI communication network.

PMUs, PDCs, a PMU-based application system, and a networking network to connect the interfaces are the basic components of a WAMC system. A WAMC structure has three levels, similar to conventional SCADA schemes. A standard schematic of various layers and components of a simple WAMC framework is shown in Figure 4.4.

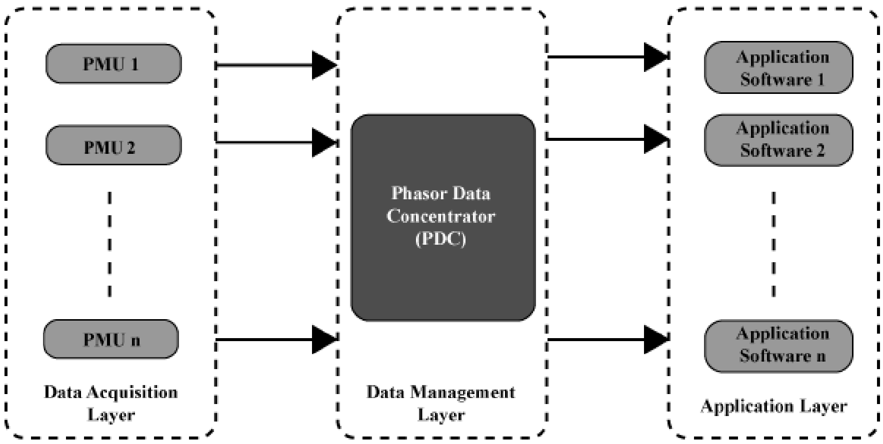


Figure 4.4 Wide Area Monitiring (WAM) and Control System

The data acquisition layer is the layer 1, where the WAMC system communicates with the electricity system on the substation bars and power lines, and the PMUs are installed.

The layer 2, which is known as the Data Management Layer, collects and sort PDC PMU measures and produces a single, synchronized data collection.

Layer 3 is also the application layer which shows the PMU-based application functions in real time, which process the time synchronized measurements made by the previous layer. The coordination network is used to transact information within these three levels.

The infrastructure of connectivity is a key component of WAMC systems architecture. In the majority of instances, PMU instruments are spread over a wide range. According to the operating principle, the PMU systems are attached to a single control center or to a series of control centres. The transmission network is also a potential bottleneck of the design of these networks, as the data quality of PMU measurements from distant locations will be highly dependent on the capacity and layout of the communication infrastructure.

Dedicated fiber optic connections (as the primary contact medium for PMU communication networks) has been proposed by many studies. The key justification for using point-to-point optical fibers is to reduce latency. The output of PMU-based applications is determined by the amount of delay. Sharing the current wide area networking network with SCADA and other apps, on the other hand, is a cost-effective solution. PMU traffic would be mixed in with traffic from substation RTUs and other network uses in such a network, and traffic would be prioritized due to its value [45].

These systems face a greater range of problems and restrictions because they channel real-time sub-second incoming continuous streams of measurement data. If the data is incorrect or corrupted, it may cause the program to crash or, worse, provide false results that deceive the operators. Another factor to consider is the massive amount of incoming data that a client device would deal with, which will slow it down. Future work will concentrate on introducing further algorithms and reviewing such ICT problems and restrictions as a top priority.

4.5.4 : Power System Islanding

When the power grid is out of step, it must be felt quickly and the system must be insulated to protect against the general blackout of the system. Due to the system's transient voltages which lead to a large division in the rotor angles of the generators, large voltage or current fluctuations and accordantly to a loss of synchronization between the generating systems or between the adjacent utility systems for such severe disruptions two or more "Islands" have to be deliberately divided into to preserve the greater part as soon as possible.

An islanding scheme is widely used in “Microgrid”, mostly in distribution grids that are decoupled from the main grid and can function under regulated, deliberate insulating conditions. Some limitations must be met to break operations as such to support a smooth islanding scheme;

- Pre-scheduled division should be received, and the system should be disconnected during fault at predestined division locations.
- The synchronicity of generators on each island should be integrated and the asynchronous generator groups isolated from separate islands and
- The balancing of power in each island should be preserved.

As previously discussed, the smart electricity grid is much more dynamic than the classic grid as time differs energy sources and emerging technology are incorporated. Many organizations and structural supports are apparently involved in designing and developing streamlined and irresponsible dynamic reaction control algorithms for smart grid operation.

4.6 : Worldwide Supervision of Smart Grid and Further Advantages

Modern and future power systems are none different from classic, as the systems contain some advanced and intelligent equipment using state-of-the-art technologies like RE (Renewable Energy) integration, power storage, and energy management systems for Microgrid and Hybrid, mega smart grids as well as a wide-ranging information and communications infrastructure application [46].
An estimate of around 2100 TWh/year of tidal or wave power potential can be generated in the area of Northern Europe, South Chile, South Africa, South West Australia and Alaska because of the high value of wave energy flows recorded at the US Electric Power Research Institute (EPRI) in 2005. However, the huge and devastating impacts of such energy will cost billions of investments in both technique and non-technical aspects are faced with greater challenges. Through their vast theories, academics and energy engineers aim to intensify their optimization strategies. Furthermore, owing to the influence of chemical, material and biological research, biomass and construction of fuel cell are at the forefront of development. An elegant view of the conceptual broad range electricity infrastructure, "Super Smart Grid"

(SSG), which unites different national grids and renewable sources in countries such as North Africa, the Middle East, Turkey, and the IPS/UPS Commonwealth of Independent States (CIS) countries; It initiates a wide-ranging use of renewable energies and calls for improved energy efficiency in Europe [47].

Due to the diffusion and dissemination of advanced technology, numerous emerging and advanced nations across the globe have taken over smart grid with projects conducted with the help of government and NGOs (Non-Government Organizations). Huge investments in the initiation and establishment of distributed demand side control, smart metering, substation automation, PHEVs etc. have been committed from different countries.

Countries like China are also transmission-centered and are to be developed in near future by acquiring WAMS and PMU sensors in each generator unit and substation. The implementation of the Smart Grid technology platform for electricity networks around the country, compared to countries likes the US and European Union becomes concerned. Some 100 million dollars are being spent on constructing smart grids and creating Grid Modernization Commissions (GMC) to analyses the advantages of the solution to demand and prescribe the appropriate protocol specifications [48]. Countries like Korea and Saudi Arabia are also making significant progress investments and preparation.

CHAPTER 5

IMPLEMENTATION OF SMART GRID TECHNOLOGY IN BANGLADESH

5.1 : Vision of Smart Grid Technology

Due to cutting-edge technologies, the focus has been the mottoes such as energy efficiency and carbon control, renewable energy, economic growth, security aspect, reduction of T&D losses and an optimum use of properties. Smart grids will help better manage the power shortage and optimize power grid status across the country; provided India struggles to meet their energy demands both in terms of energy usage and peak load. A Smart Grid is a perception of reworking the national electricity grid scenario by a combination of knowledge and electrical grid operating technologies, providing consumers with lasting choice and improved stability, reliability and utility performance. Smart Grid (SG) technology's elite vision makes for more effective generation, transmission, distribution and exploitation of electricity.

Demand side management (DSM), in particular in the developing countries such as Bangladesh, is an important activity for optimized and efficient electric power usage in which demand exceeds usable power generation. Such non-technical losses can be resolved by electrical grid information, based on integrated control and connectivity protocols installed into the utility to offer the entire package for "Smart Grid" requirements.

Every classified rendering was briefly highlighted by a vivid study of the power scenario. The entire scheme was regulated and managed in the past, by means of a strictly blue-collar telephonic medium, with power strategy regulation. Only a single generation or interconnected substation was responsible for the grid. The device is tracked around the clock by advanced data transmission protocols for more advances in research and technology. The substation also features an insulating system and direct power backups to keep the grid secure.

The situation of the power structure is changed exponentially in Bangladesh as a developing nation. In addition, with its development towards data exchange and analysis, the system is supposed to be efficient and more scalable. The Figure 5.1 indicates improvement and immediate outcomes during potential implementation. A definite solution to the Bangladeshi smart grid with the current technical development and broad characteristics as seen in the Figure 5.2 will be visualized accordingly.

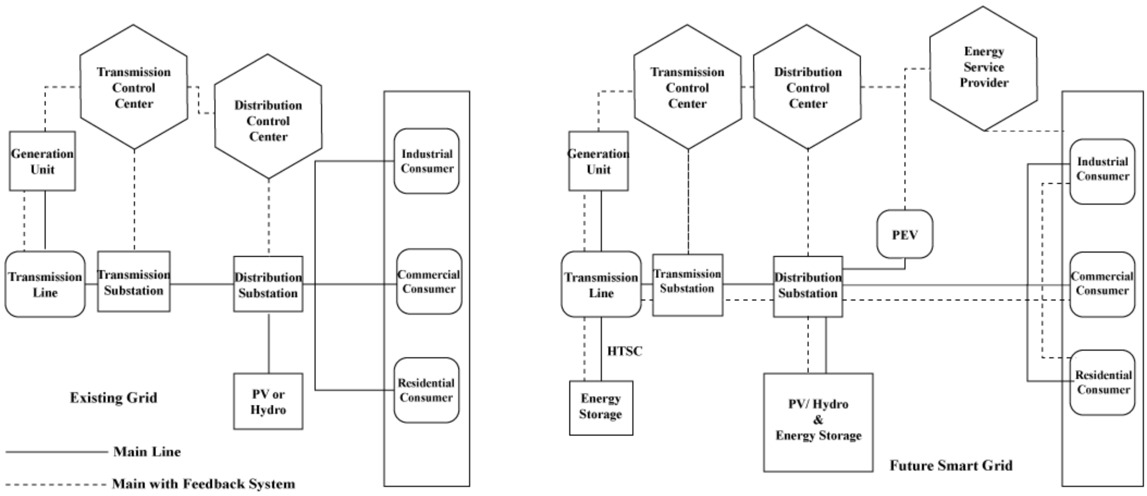


Figure 5.1 Toward Smart Electricity from Traditional Grid System

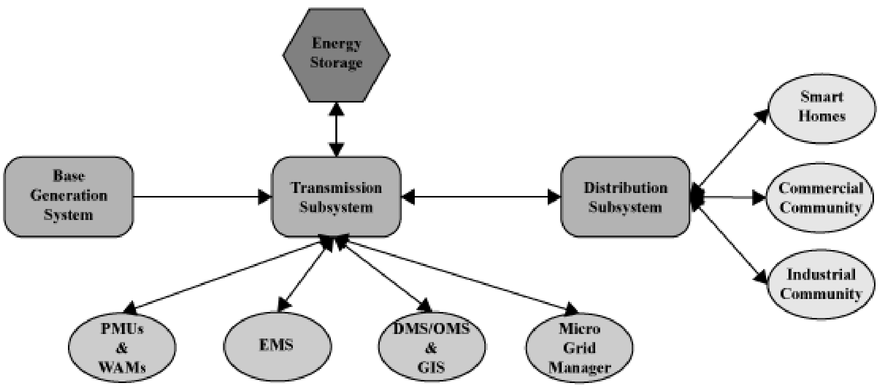


Figure 5.2 Hierarchy of Bangladeshi Smart Grid

5.2 : Advantages of Smart Grid toward Renewable Energy

Environmental concern has heightened interest in the advancement of new smart grid technology and its convergence of renewable and clean energy as a result of coal-fired power plants.

The Table 5.1 below gives a brief overview of renewable energy production in India, as expected by the Bangladesh government (Power System Master Plan-2016) and the SREDA (National Solar Energy Roadmap – 2021-2041) [49-50]. With the understanding of green market, the energy converges to; lower carbon footprints, a healthier atmosphere, plug-in electric vehicles, and decentralized electricity, both of which improve the quality of life and the grid network's reliability.

Table 5.1 Renewable energy according to 25 year plan

Renewable Energy Resources	Till 2017 (in MW)	Through 2021 (in MW)*	PSMP – 2041 (in MW)
Solar Power	266.59	490.18	2,750
Hydro Electricity	230	230	900
Wind Energy	2.9	2.9	1,350
Biomass (Biogas, Waste etc.)	0.51	1.03	1,000
Total	**500 MW**	**724.11 MW**	**6000 MW (10% of 60 GW)**

**Data Taken on 24 April, 2021*

However, the efficiency of power also presents several possible problems, including voltage control, transient and harmonic power system, dynamic power compensation, grid synchronization, energy conservation, load handling and misconduct for switching, etc. The challenges are mostly visualized for large sources of renewable energy such as solar and wind. There is no such major issue with the grid convergence of other energy sources, as biomass, hydro and geothermal sources. Integrating renewables with the Smart Grids enhances the system's reliability and flexibility in the delivery of economic loads not just at a specific location but also around the world, including amongst nations. Scale-up between neighboring nations has taken place in Nordic countries and potential implementation is still centered. However, several research analytics teams build forecasting methods, architecture algorithms and other models and must be developed in many parts of the country. The following Figure 5.3 provides for a short overview of smart grid infrastructure requests for renewables in the power system innovation network.

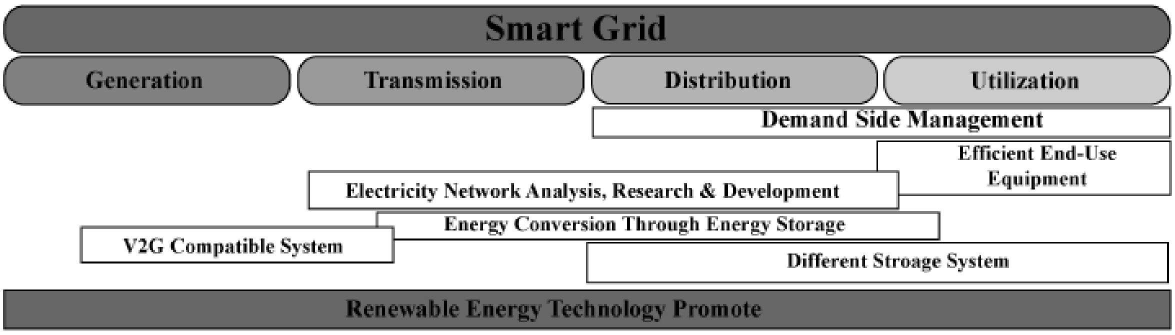


Figure 5.3 Renewable Energy Promote in Smart Grid Technology

Fossil fuel instability has paved the way for alternative and sustainable sources of electricity. The wind and photovoltaic cells can be enabled by upcoming developments such as the micro grid and hybrid grid with their inherent unpredictability. Such new technology will play a significant role in economic insolence in the healthy living standard. Large scale clean energy deployment has to be guided by well-determined government policy and standards. The governing consideration for a deficient and developing nation like Bangladesh is proper financial assistance.

5.3 : Smart Grid Integration with Rural Electrification

Smart delivery technologies that allow for higher levels of distributed generation have a high potential to meet rural electrification needs while reducing the erection costs, transmission delays, and maintenance costs associated with large transmission grids. The Bangladesh Rural Electrification Board (BREB) and the Bangladesh Power Development Board (BPDB) are infrastructure financiers in Bangladesh's power sector, financing and promoting rural net metering electrification projects across the country, with installing 1358* solar power plants. These net metering power plants are providing about 24.502MW* power to develop the stability of power system in grid. That was the first step to achieving smart grid system in Bangladesh [51]. **Data Taken on 24 April, 2021*

The current rural electrification scenario in the country is still unclear, and the Ministry of Power, Energy, and Mineral Resources (MPEMR) has yet to investigate and verify it. As a result, the Bangladesh government and business community will need to invest in more low-footprint technology, clean energy options, smart metering, and resource-efficient infrastructure projects and schemes.

5.4 : Micro-grid & Hybrid System Integration

Renewable resources do not perform well in an absolutely stand-alone fashion due to reliability problems caused by asymmetrical activity and environmental conditions. In such situations, the generators are backed up by another generating technology and/or storage devices that combine two or more distributed generation systems, such as wind-PV, wind-diesel, and so on, to meet a typical load. Hybrid energy is the name given to such a technology. A more ethical solution is to congregate all such technologies into Micro Grid. Hybrid connection with multiple services and/or storage systems increases the system's stability and is physically and economically viable. Smart Grids and Micro Grids, or smart Micro Grids, have some similarities. However, the size of the issue, the types of decision-makers involved, and the expected pace of growth are all different in both cases. Smart Grids are implemented at the utility and national grid level when it comes to massive transmission and distribution poles, while smart Micro Grids incorporate different Distribution Generator systems into energy distribution networks and are more quickly implemented. The goals of the Smart Micro Grid are to build a perfect power system with smart technology, redundancy, distributed generation and storage, cogeneration (which mixes heat and power), improved voltage profile, cost savings, reduction in carbon credits, and smart control of appliances and loads, among other things. Bangladesh has only recently begun this endeavor with two minor Micro Grid programs. Public-private partnerships, such as Bangladesh Power Ministry and Infrastructure Development Company Limited (IDCOL), are supporting these schemes.

Solar Mini-Grid, Micro-Grid, Nano-Grid, and Pico-Grid have been described as follows [52]:

Table 5.2 Installed Capacity of Different Tiny Grid System

Serial No.	System Type	System’s Capacity
01.	Mini Grid	5 MW > System Size ≥ 100 kW
02.	Micro Grid	100 kW > System Size ≥ 10 kW
03.	Nano Grid	10 kW > System Size ≥ 3 kW
04.	Pico Grid	3 kW > System Size ≥ 500 W

To achieve the grid compatibility must obey these rules;

a. Renewable Generation system must have at least 10 consumers.
b. Commercial operation with consumer or contributory participation among prosumer.
c. Isolated from National Grid Network.

Providing power to rural areas are difficult, because the grid cannot be extended to cover them or the amount of ‘ability to pay’ consumers are insufficient to warrant this extension. The government of Bangladesh issued a Remote Area Power Supply System (RAPSS) Guideline in 2007 to make electricity more accessible to underserved areas. The guidance has established a business model for implementing the mini grid project through the private sector. However, the strategy was based on traditional power generation, mostly diesel. The government has allocated 25 MW to the private sector to build solar mini grids in remote areas, in line with the concept of building mini grids in remote areas. Each project will be introduced as a Distributed Utility, with solar-powered generation and distribution management. The government would help by offering fiscal and financial assistance. Initially, 30 remote areas where grid expansion is not expected in the next 15-20 years were established.

The government has launched a number of initiatives and made significant strides to improve rural economic mobility. Solar mini-grids in off-grid areas are one of the projects. Under the current scheme, the government will provide the required fiscal and financial assistance to IDCOL in order to reduce the initial investment expense and make energy tariffs more attractive to customers. Under the current scheme, the government will provide the required fiscal and financial assistance to IDCOL in order to reduce the initial investment expense and make energy tariffs more attractive to customers. A proposed mini grid proposal is also included. Many of mini grid project are executed by GOB with the help of IDCOL [53]. Here is a small Table 5.3 of mini grid that’s are implements by IDCOL:

Table 5.3 Major Mini-Grid Implementation by IDCOL

Serial No.	**Location of Implement**	**Purpose of Implementation**	**Installed Capacity (kW)**
01.	Baghutia Char, Daulatpur, Manikganj		228
02.	Chilmari, Daulatpur, Kushtia		188
03.	Monpura, Bhola	Solar Home Lighting,	177

04.	Narayanpur, Nageshwari, Kurigram	Workshop, Electricity Supply for Local Market, Small Project, Irrigation, Solar Drinking Water Project etc.	158
05.	Godagari, Rajshahi		149
06.	Bagha, Rajshahi		141
07.	Paratoli, Rajpura, Narshingdi		141
08.	Sirajganj Sadar, Sirajganj		130
09.	Kutubdia, Cox's Bazar		100
10.	Enam Nahar, Sandwip, Chittagong		100

Solar PV-based mini-grids are being deployed in rural parts of the country where grid extension is unlikely in the immediate future. These projects deliver grid-quality energy to households and small businesses, promoting economic activity in the project regions. Solar PV-based mini-grids are being deployed in rural parts of the country where grid extension is unlikely in the immediate future. These projects deliver grid-quality energy to households and small businesses, promoting economic activity in the project regions. BPDB, on the other hand, has constructed the largest solar mini grid project in South Asia at Shalla, Sunamganj.

IDCOL has so far funded the construction of 26 solar mini-grids with a total generation capacity of 5 MW. Around 16,000 people in rural Bangladesh now have access to low-emission electricity as a result of the mini-grid projects [52]. Over the project's lifespan, they are also expected to contribute a CO2 reduction of 29,300 tons. IDCOL's Solar Mini Grid Project is supported financially by the World Bank, KfW (KfW Bankengruppe Development Bank), GPOBA (Global Partnership for Output-Based Aid), JICA (Japan International Cooperation Agency), USAID (United States Agency for International Development), ADB (Asian Development Bank), and DFID (Department for International Development)[54].

5.5 : Drawback Observation of Smart Grid Implementation

The core characteristics of smart grid include several benefits and potential insights in power dominion, revitalizing the realms' socio-economic strategies. In the other hand, widespread use of emerging technology creates weaknesses that, if not addressed, will lead to dangerous consequences such as long-term blackouts, economic collapse, cyber-attacks, and so on. The Table 5.4 below offers a quick overview of some of the smart grid's problems [55].

Table 5.4 Drawbacks of Smart Grid Technology

Serial No.	Technology	Challenges	Drawbacks
01.	Self-Healing Action	Security	Security of being exposed to internet threats (spam, worms, viruses, and so on) there is a concern for national security.
		Reliability	Device outages, complete blackouts, and failure during natural disasters are also possibilities.
02.	Renewable Energy Integration	Forecasting	Intermittent energy sources that are long-term and unpredictable, as well as power flow and dispatch that are unscheduled.
		Power Flow Optimization	Congestion on transmission lines and large investments.
		Power System Stability	Owing to the high degree of wind penetration, decoupling creates system stability problems and decreased inertia.
03.	Consumer Participation	Security	Malware, data eavesdropping, data theft, unauthorized power distribution, and smuggling.
		Privacy	Data sharing results in privacy infringement, identification spoofing, and eavesdropping, among other things.
		Consumer Awareness	Corruption, as well as systemic challenges such as security and privacy concerns.
04.	Power Quality	Detection of a Disturbance	Local grid faults, load centers, or outlets cause grid disruptions.
		Harmonics Suppression	During sags, dips, or voltage variations such as over-voltages, under-voltages, voltage flickers, and so on, the system may become unstable.
05.	Energy Storage System	Cost of Implementation	Highly cost of storage element such as Battery, MSES, SMES, UC etc.
		Intricacy	Networks and complex customary interface modules
		Lack of Adaptability	Specific network architectures differ, making adaptation difficult.
06.	Reliability	Grid Automation	For efficient security, control, and communication, a good data routing scheme with a stable and private network is required.
		Grid Reorganization	Grid complexity affects generation demand equilibrium and power system reliability.

The measurements, expense and advantage analysis of Smart Grid field projects were some important issues with these previously listed challenges as well. This include allowing a fair compare between baseline performance and intelligent grid efficiency, gathering correct data at appropriate frequency and position, assessing social benefits and monetization, using the required methods of inference and prediction, etc.

Different universities do extensive studies on this technology to address the multi-level problems. Power system and architecture engineers are qualified to consider and investigate system variables and to reconfigure the electricity grids more intelligently [56]. As a corner stone in the potential configuration of power grid networks, it was expected that the problems of the electricity market will be seen as a solid and feasible alternative.

5.6 : Technical Challenges Faced to Implement SGT in Bangladesh

Operate the grid properly and reliably; careful cooperation among power generation, transmission and distribution are needed. The following are some of the potential challenges that a medium-developing country like Bangladesh might face in developing a smart grid;

5.6.1 : Grid Infrastructure Inadequacies

Grid infrastructure in growing countries like Bangladesh is still emerging. The current grid network would be insufficient to meet future renewable energy and distributed generation needs, posing architecture, installation, service, and maintenance challenges. Aside from working on SG, current grid infrastructure challenges must also be addressed. Several electrical areas of Bangladesh are unevenly wired to the national grid in order to best evacuate massive wind turbines or solar parks, which would otherwise necessitate the construction of entire utilities. In this sense, it is encouraging to hear that the Government of Bangladesh, through its working arms Central Transmission Utilities and National Load Dispatch Centre, is taking all feasible and constructive steps to address Grid activity and connectivity issues.

5.6.2: Renewable Energy Integration

Renewable energy supplies must be expanded to half of overall generation power for better smart grid deployment, which would necessitate a substantial commitment and a high level of technological expertise. Forecasting and dependence, sustainability, grid connectivity needs, power flow optimization and stability problems, reactive power management, presence of power electronic devices, and other technological and commercial difficulties face renewable energy sources such as small hydro plants, solar PV, wind, biomass, and tidal energy based generation. The government and power companies have updated integrated grid connectivity codes in order to eliminate certain problems for the efficient and scalable application and incorporation of Renewable Energy into the traditional grid. This is described in detail in the following part.

5.6.3 : Energy Storage System

Renewables are used in both bulk and distributed power generation in Smart Grid technology. Since renewable energy generation is not uniform, i.e. intermittent and flexible, it may necessitate storage. Due to the erratic behavior of RE and to maintain the power network's endurance, it is desirable to incorporate energy storage technologies such as batteries, flywheel, and electric vehicles into the RE implementation in the future. When renewable energy options are available, this improves the efficiency and optimum consumption of those resources. Due to Bangladesh's rapid growth, we frequently face issues such as complexity and non-flexibility, architecture considerations, high capital cost, and a lack of technological awareness about Energy Storage Systems.

5.6.4 : Data Measurement System Drawbacks

Smart Grid infuses a massive number of meters, sensors, and controllers into the power network. Operators' capabilities are enhanced by data from these units and other outlets such as weather forecasts, surveillance cameras, and so on. A failure or disruption may be prevented until it occurs by effective data collection. This big data may also be used for device running, alarms, forecasting demand, generation, and price, among other things. The data obtained is very large in volume; for example, using a smart meter that allows reading every 15 minutes rather than once a month raises the data by almost 3000 times. The gathering and storing of large amounts of data from these instruments is difficult, and recovery and handling are often challenging. In Smart Grid, database administration is critical. Data processing, review, and report generation can be slowed by a large amount of data.

5.6.5 : Automation, Protection and Control Scheme

Automation allows for high-quality, reliable and consistent power in both the customer and service industries. Automation for customers means collecting hourly electricity price signals, while automation for utilities means automated islanding of distribution feeders with local dispersed energy supplies in the event of a power outage. Million-dollar investments and strong design skills are expected in developing countries like Bangladesh. Automation, security, and regulation would aid in the proper functioning of smart grid services. The Bangladeshi power grid faces a number of serious problems, including a complex delivery network, a shortage of suitable sensors and actuators, contact connection delays, system ageing, and so on.

5.6.6 : Participation of the Customers

Consumer interest is the most important factor in the creation of a smart grid. In the configuration, service, and connectivity of a smart grid, customers' equipment and behavior are taken into account. Consumers can better monitor smart appliances and devices in their homes and businesses using a bidirectional data connection. Despite the difficulties in customer engagement in smart grid deployments, such as the lack of a bidirectional connectivity data connection between customers and utilities, consumer protection, reliability of system continuity, consumer understanding of energy efficient smart appliances and energy storage, billing process complexity, and the high capital cost required for constructing smart buildings.

5.6.7 : Intelligent Electronic Equipment's (IEDs)

The electronic-based multipurpose meters used in current grids are known as Intelligent Electronic Devices (IEDs). IEDs collect data from sensors and power equipment and may send control commands, such as tripping circuit breakers if voltage, current, or frequency disturbances are detected, or raising or lowering voltage levels to sustain the desired level. It poses challenges in IEDs, such as the conversion from electromechanical to static metering, architecture standardization, quick data acquisitions, and management of advanced state-of-the-art transmission data wiring.

5.6.8 : Information and Communication Technology

Intelligent communications networks or the involvement of information and communication technologies with systems as a medium for grid instrumentation, monitoring and management of energy services from power generation to trading, and the transmission and delivery to retail, are central to the transformation of intelligent grids. We have a wide variety of networking systems for Smart Grid rollout, but each has its own set of limitations. One has reduced capacity, while the other runs over a short distance; the third has greater data loss, while the fourth has limited success in underground installations. Despite its many benefits, connectivity infrastructure for the Smart Grid also lacks a fail-safe approach. In a Smart Grid network, communication protocols are not clearly developed. In Bangladesh, wired and wireless communications are developed, such as Power Line Carrier Communication (PLCC), landline and other communications. The main problems of smart grids are assessing infrastructure stability, security and availability, data processing, storage, architectural design and surveillance systems, physical and cyber security, threat protection and access control.

5.6.9 : Cyber Security Distraction

Connecting the grid to the cyber network causes a number of infrastructure bugs and unfortunately we do not know about them. It is really important to recognize and remove these vulnerabilities before any security violation occurs. Access to data and other information is secure and timely; integrity requires protection against inappropriate format/modification and loss of information; confidentiality applies to preservation of Information against unauthorized access, including protection against unauthorized access. Cyber protection is a major operational issue, as a single breakdown threatens to lead to a catastrophe for grid companies and individuals. Well known cyber threats include hackers, malware, and so on. Any protection mechanism is not enough alone to address this challenge of grid logical disaster. Indeed, smart grid has a multi-layer configuration and requires a special protection problem for any layer. No silver bullet for cyber threats, but innovative strategies for combating sophisticated cyber threats still evolve are essential.

5.6.10 : Quality of Power

In Bangladesh, proper awareness of power quality issues and low-cost mitigation measures is needed. Variations and incidents are the two general groups in which power quality issues are categorized. Since power electronic based circuits are becoming an increasingly important feature of smart grids, the quality of power must be assessed. The main issues are the technological problems of power efficiency, such as the study of discharge of new devices attached to the smart grid and their allocation, calculation of power quality indices, decreased voltage assistance and a broad issue of voltage sag, weak transmission systems, a lack of market knowledge, and the high expense of mitigating methods.

5.6.11 : Reliability

Blackouts and brownouts are frequent in Bangladesh due to a shortage of usable capacity, which must be successfully reduced within a niche timeframe. System modernization, grid reconfiguration, diminishing human activity, high-speed fault locators and repair, and maintaining generation-demand equilibrium are all potential obstacles in achieving enhanced efficiency.

5.6.12 : Energy Market Mechanism

Market-based structures are needed to accommodate developments in retail power markets. In this way, market participants would be encouraged to support all stakeholders. In Bangladesh, manufacturers and service providers lack coordination. The challenges of the electricity industry are as follows: Financial accounting, open access to data, developing data and new industry exchange protocols, developing business modeling infrastructures.

5.6.13 : Power System Stability

On a global scale, the Smart Grid is expected to combine distributed generation (Renewables) and micro grids (MGs). The divided generation triggers two-way power flow. Renewable energies have different benefits from traditional and nuclear power, but high renewable energy penetration and MGs are concerned with reliability:

a. angular stability due to lower overall inertia of the mechanism
b. Stability of voltage because of lower support for power sharing.
c. The force oscillation of low-frequency.
d. Worsening of the Profile of SG transients during MG insulation.
e. Cannot be a backup for the scheme.

5.6.14 : Demand Side management (DMS)

The DSM is generally regarded as a reliable and realistic source of data. DSM refers to the planning, execution, and control of utility operations aimed at influencing consumer energy use in ways that result in desired improvements in the utility's load form. Smart metering, load research and dispatch, load management and scheduling, and program development for DSM are among the obstacles.

Since the current power grid has the above technological difficulties and problems, Bangladesh needs a smart grid to overcome it. As previously mentioned, numerous technological issues can arise when constructing a smart grid [57]. The solutions to these problems can be found by proper study programs involving the government and power provider authority, well designed ability testing facility. Furthermore, power plant engineers must now be better trained on the smart grid and its associated problems in order to address these technological issues.

5.7 : Introduction to Micro-grid and Hybrid-grid System

A “micro-grid” is a decentralized power grid that has autonomy, so it can separate from and work autonomously from the conventional grid. When the integration involves nuanced, end-to-end management strategies and customer incentives to participate, integrating renewable energy technologies into the traditional bulk production power infrastructure can be achieved by a smarter power grid.

Microgrid allows autonomous and automated self-healing operations by performing dynamic control over energy resources. The microgrid can run independently from the larger grid during routine operations, peak loads, or grid failures, isolating its internal properties and related loads without compromising the larger grid's integrity [58]. The sensing, tracking, and subsequent management of distributed energy supplies is a technological challenge for microgrid.

Microgrid would be used to perform advanced device control functions such as;

i. Introducing or eliminating additional energy services dynamically without modifying current elements,

ii. Automating request response, self-healing and autonomous

iii. Connecting to or isolating from the transmission grids seamlessly and
iv. Manage reactive and active power as load needs change.

Microgrids would continue to deal with legacy bulk power networks, as well as the data and network infrastructure that goes with them. A utility-run urban area grid, an industrial park, or rural energy-efficient cities are all examples of microgrid deployments. Microgrid controls become tools for larger bulk solar generators until they are operating at a local level on the distribution grid.

As opposed to single-source systems, hybrid energy systems incorporate two or more sources of energy generation, storage, or end-use technology, and they can have a slew of benefits. Hybrid energy technologies have been developed to produce power from a variety of sources, including solar panels and wind turbines, and now tap into sources like hydrogen, which is treated in a unique way and is available as a renewable energy source.

For independent applications hybrid power systems are difficult because of several factors such as the right mix, which decreases the initial investment in capital, maintains efficiency of power supply, reduces maintenance of system components, and so on.
In everyday life, energy networks play a significant role. While we use power and resources, it is smart that very few of us are interested in saving energy. Although we still want to reconcile it with financial factors, we believe like, in the light of social obligation, there is something more. At the same time we are faced with several challenges caused by fossil fuel emissions, which are rapidly diminishing. We are now at a time when the conservation of energy needs to be given particular consideration.

Hybrid energy solutions currently available on a commercial basis include [59];

- Biomass + Solar PV
- Wind + Solar PV
- Hydro + Solar PV
- Biodiesel + Wind
- Gas + Solar PV
- Coal + Solar PV

5.8 : Framework of Microgrid Agent Control System (MGAS)

Mentioned previously, modern and new control systems technologies would be essential to integrate renewable and variable energy. Integration of Distributed Energy Resources (DER) requires a controlling logic that tackles both the special features of the DER units and enables the control in a dynamically dispersed system to be coordinated. We have developed Microgrid Agent Control System (MGAS) for this purpose, as demonstrated in Figure 5.4 MGAS is a scalable platform to perform distributed control of the microgrid.

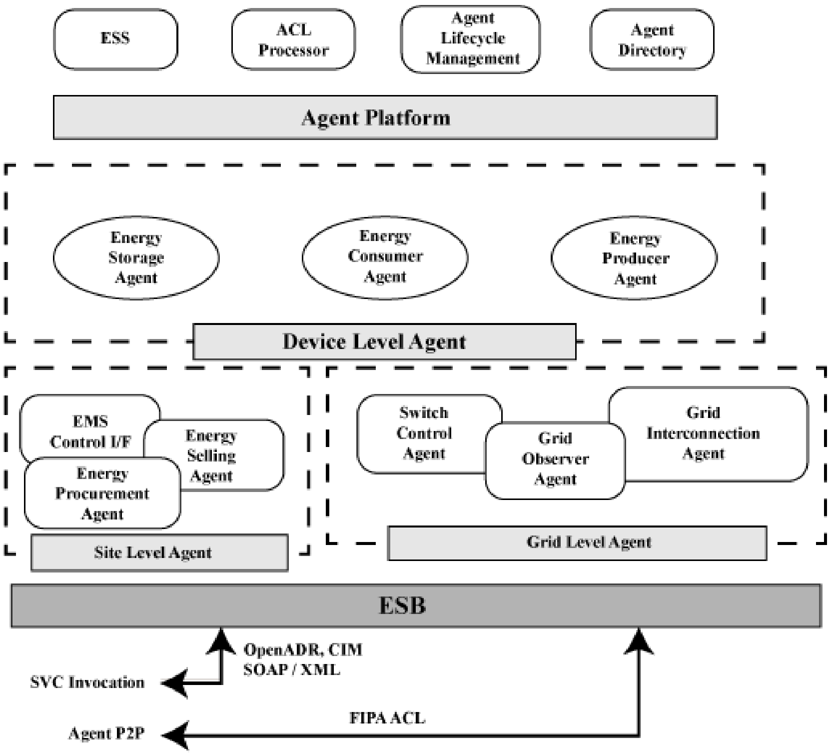


Figure 5.4 Schematic Diagram of Microgrid Agent Control System (MGAS)

MGAS services are made up of cooperative an agent that's comprise the control and automation of distributed energy resources as well as microgrid switching and self-healing. MGAS agents work together as a co-operative control mechanism to carry out distributed demand management, energy Storage, and energy production control protocols and services. For the sharing of information metadata, MGAS applies Open Automated Demand Response (OpenADR) for Demand Response (DR) signal control and IEEE 1547 for interconnection and Common Information Model (CIM) for International Electrotechnical Commission (IEC) Standards. FIPA (Foundation for Intelligent Physical Agents) conforming protocols for communication agents are also used in order to promote interoperability for agents based on standards [60].

MGAS's primary system purpose is to build an adaptive and intelligent control system that allows DER nodes to cooperate together and collaborate. Three main families have been identified in agent attitude: Grid-Level Agents, Site-Level Agents, and Device-Level Agents. A multitude of agent forms are sub-cast and applied from these three main sets of conduct [61]. Both sub-cast agents inherit the three main conducts and support traditional decision-making and accessibility frameworks.

5.9 : Framework of Hybrid Grid System

A mix of diverse energy sources limits the effect of renewable energy sources' time-limited energy potential. The energy of Solar Photovoltaics (SPV) is simply usable during the day, but any other solutions or other SPV energy must be stored during the night. It also has similar characteristics, but is mostly very unstable when it comes to wind energy. The time-diverging aspect of the opportunities for green energies makes incorporating energy storage and energy sources crucial. In completely autonomous mode, the renewable resources are un-sustained because of stability problems related to asymmetric activity and weather disruption. As in such situations, the power generator consists of two or more distributed generation devices such as wind-PVs, wind-diesels, etc. to supply a typical load [59]. The Hybrid Energy is considered a technology of this kind.

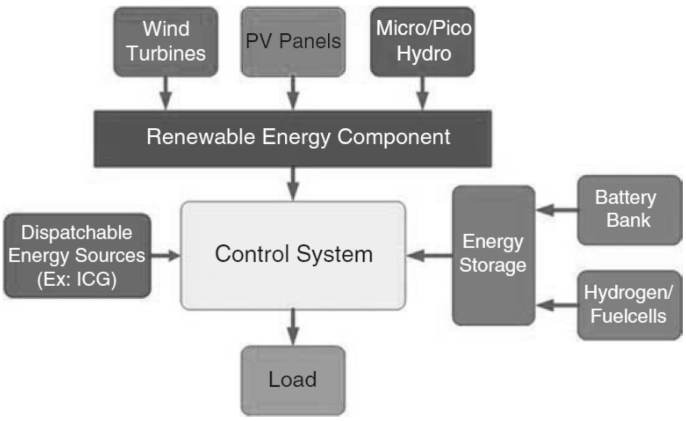


Figure 5.5 Illustration of a stand-alone hybrid energy system

In these conditions, optimum concepts of energy systems become critical. It is often a difficult phase in which a variety of technical and environmental considerations must be taken into account. It is a daunting challenge much of the time to model these energy systems. In the meantime it is necessary to consider the number of design parameters. This hampers the function of optimization and it is important to avoid traditional approaches.

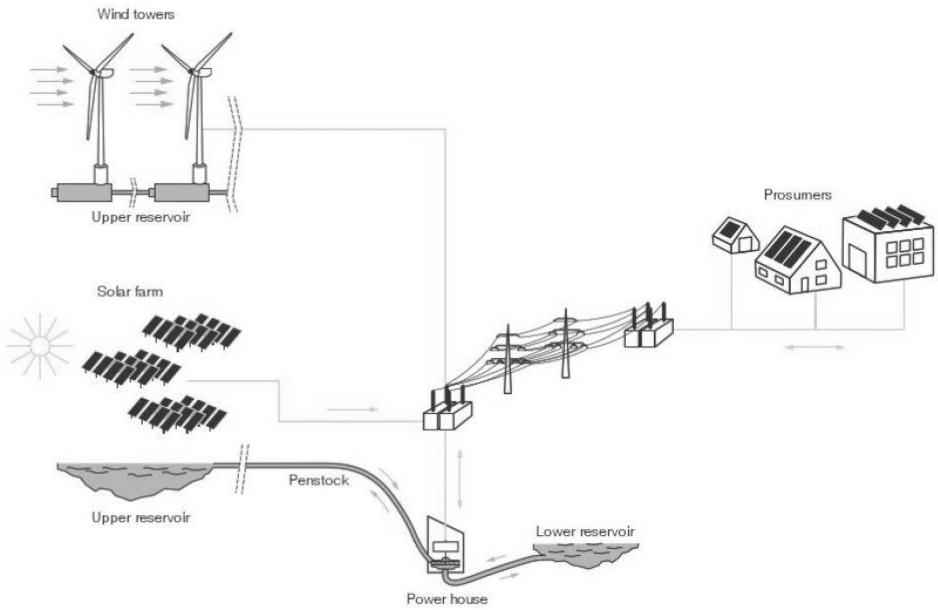


Figure 5.6 Graphical Representation of Hybrid Grid System

The hybrid integration of various resources and/or storage devices increases system stability while ensuring that all those techniques are combined into Micro grid, physically and economically viable. With smart technology, redundancy, distributed generation and storages, cogeneration or combination of heating and electricity, improved power profile, reduced costs, reduced carbo-hydraulic credits, intelligent appliance and load control systems etc., Smart Micro Grid can build perfect power system.

Following Figure 5.7 provides an understanding of the hybrid energy grid with multiple Alternative Energy Distributed Generation (AEDG) dividing the centralized and de-centralized DC and AC buses.

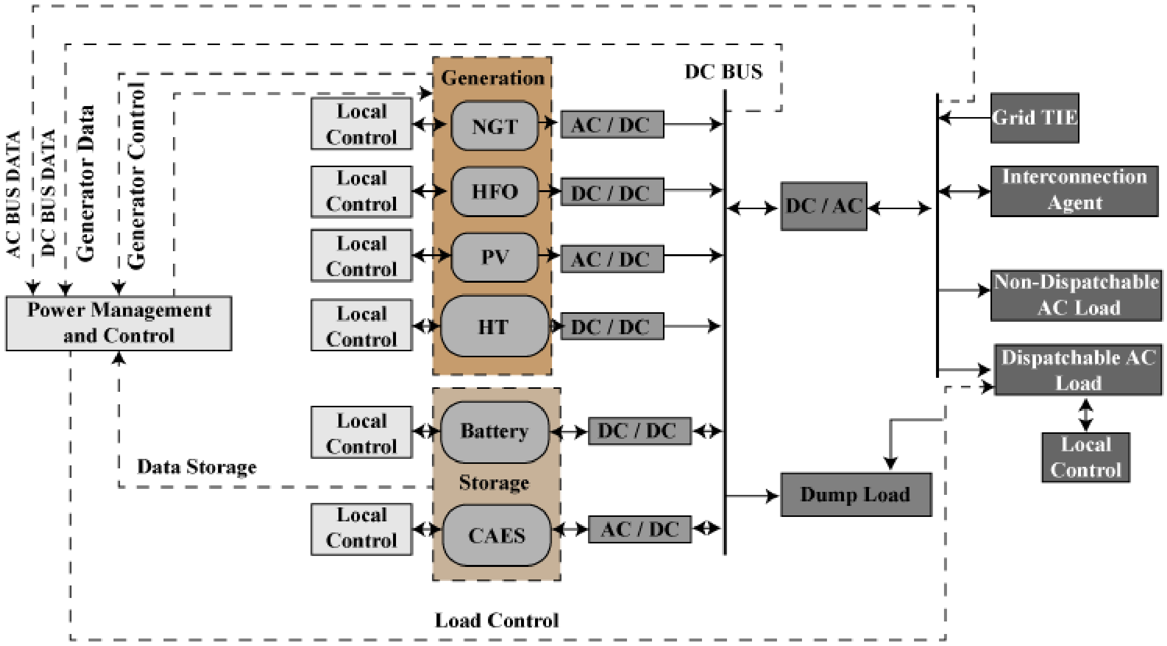


Figure 5.7 Block Diagram of Hybrid Energy System

5.10 : Energy Storage System

Due to its reliance on environmental conditions, renewable energies such as wind and PV intermittently occur in nature and thus need to be stored in surplus electricity to correspond to the grid energy demand curve. As discussed earlier, the Smart Grid model can be used to eliminate costly grid energy storage. Smart measurements can condition the demand curve (energy control on the demand side) by matching the current generation curve with a lower cost. By contrast, the Distribution Generation (DG) system can be used to store electricity and discharge energy into the network that comes out of RES power supply sources. This Distribution Generation (DG) system can provide power back to the grid.

For the coordinated and reliable operation of power grids, the advantages of energy storage have become significant. Stores guard against prediction errors, removing obstacles for linking renewables to a wide range of networks, shifting demand to peaks by storage of off-peak electricity, providing frequency controls, which can slow down costly grid upgrades and downtimes because of abrupt demand or other drop-off from sources connected to the national grid [62].

The follows are a few large energy storage systems that are favored for use in energy storage facilities, as well as an optimized study on how to operate them efficiently and reliably;

a. Battery Storage (BS)
b. Compressed Air Energy Storage (CAES)
c. Hydrogen Gas (H2) Storage
d. Pumped storage in Hydroelectric Plant
e. Vehicle-to-Grid (V2G) Storage
f. Flywheel (FW) Storage
g. Ultra-Capacitor (UC) Storage
h. Superconducting Magnet Energy Storage (SMES)
i. Molten Salt Energy Storage (MSES)
j. Cryogenic Energy Storage (CES)

The integration of sophisticated power electronics and the grid, known as an energy storage facility, plays a key role in both technological and financial benefits. The following advantages are summarized in the Table 5.5:

Table 5.5 Benefits of Smart Grid Technology

Technical Benefit	**Financial Benefit**
Voltage stability increase	Bulk Storage revenue increase
Non-variable Frequency Response Achieve	Increase distributive generation revenue
Transient Fault Decrease	Ancillary Services' revenue increased
Grid Angular Stability Increase	Transmission access revenue boost
Equal Load Dispatch	Reduced demand charges
Grid Reserve Increase	Financial Losses Due to Reliability Reduction
Power Quality Improvement	Increased revenue from Renewable Energy
Reliability of Power increase	Cost of Central distribution will decrease
Unbalanced load compensation Remove	Generation related power distribution cost reduce

CHAPTER 6

COST AND CURRENT STATISTICS ANALYSIS

6.1 Cost Analysis of typical Smart Grid Equipment

Bangladesh is now on the primary stage to implement of Smart Grid Technology. Few numbers of smart equipment's are implemented in all over the country. The power transmission system and distribution system of Bangladesh is so huge that, smart grid implementation is not possible at one stage in such a large system. Through small transformations can do smart grid implementation some benefits will be available as some costs will be reduced. So first of all it is better to implement smart grid in distribution sector.

Here is the cost analysis (including installation cost) of Transmission and Distribution side of Power Sector with apparatus [63-64]:

Table 6.1 Cost Analysis of a T&D system

Serial No.	**Particulars**	**Specifications**	**Unit (Nos.)**	**Price Per Unit (BDT)**
01.	Battery Energy Storage System (BESS)	250kW × 1hr	1	4,800,000
02.	3-phase Phasor Measurement Unit (PMU)	Up to 500 kV	1	2,000,000
03.	Smart Meter	Up to 10kW	1 × 100	800,000
04.	Intelligent Universal Transformer With PV Inverter	Bi-Directional	1	800,000
05.	Feeder Line Sensor	2kW-10kW and	1 × 3	432,000

		up to 5MW		
06.	Communication Gateways		1	280,000
07.	Smart Inverter	5kW-10kW	1	240,000
08.	Application Software - XNET		1	56,000
09.	Autonomous Load Controller	2kW-10kW and up to 2.5MW	1	24,000
10.	Advanced A/C Energy Saver	For 2T-10T Air Conditioner	1	16,000
11.	Power Factor (0.9 pf) Correction Equipment	2kW-10kW and up to 5MW	1	12,000
12.	PMU Analytics, Stations, Accessories		Lumpsum (1%)	100,000 (appx.)
Total				**9,560,000**

This calculation is for a 5km long T&D line. At first time, this equipment's are set up on T&D line. So, there will be an additional expenses occur.

Table 6.2 Transmission and Distribution Expenses analysis according to current statistics

Particulars		**Capital Saving (BDT/Year)**
Transmission (11kV/.4kV) cost for 10 ckt. km is (appox.)	=	50,000,000
Distribution (400V and 220V) cost for 10 km is (appox.)	=	150,000,000
Total T&D cost is (appox.)	=	200,000,000

$$\text{Increases of expenses for integrating Smart Grid Technology} = \frac{\text{Additional T\&D Expences}}{\text{Fixed T\&D Expenses}} \times 100\%$$

$$= \frac{9{,}560{,}000}{200{,}000{,}000} \times 100\%$$

$$= 4.78\%$$

By integrating smart grid technology on Transmission and Distribution sector there has been 4.78% additional expenses occur.

6.2 : Benefit Analysis After Installing Smart Grid Technology on Distribution Side

After installing smart grid technology Bangladesh will achieve some financial advantage in every year. Here is the some beneficial data after installing Smart Grid Technology in a unit of a Diesel Power Plant [65]:

Table 6.3 Capital Savings by Reducing Diesel Consumption

Reducing Diesel Consumption			
Formula	**Calculation**		**Capital Saving (BDT/Year)**
Electricity Savings (kW) × Plant use in Year (Hrs) × Fuel Use for Electricity Produce (L/kW) × Fuel Price per Liter (bdt/L)	250kW × 6000Hrs × 0.28 L/kW × 85tk/L	=	35,700,000

Table 6.4 Capital Savings by Avoidance of CO_2 Emissions Equipment's

Avoidance of CO_2 Emissions Equipment's			
Formula	**Calculation**		**Capital Saving (BDT/Year)**
Fuel Density (kg/L) × Plant use in Year (Hrs) × Installed capacity (kW) × Fuel Use for Electricity Produce (L/kW) × Capital use for Remove CO2 (bdt/ton)	0.85kg/L × 6000Hrs × 1000kW × 0.28L/kW × 2000tk/ton	=	2,856,000

Table 6.5 Capital Savings by Capacity/Headroom Improvement

Capacity/Headroom Improvement			
Formula	**Calculation**		**Capital Saving (BDT/Year)**
Plant Capacity (kW) × Capital Savings in Plant Planning (bdt/kW)	1000kW × 64,000/kW	=	64,000,000

Table 6.6 Capital Savings by Reduce Running Cost of Diesel Generator

Reduce Running Cost of Diesel Generator			
Formula	**Calculation**		**Capital Saving (BDT/Year)**
Capital Savings per Hour on Reserve Capacity (bdt/Hr/kW) × Electricity Savings (kW) × Plant use in Year (Hrs)	80tk/1hr/20kW × 250kW × 6000Hrs	=	6,000,000

Table 6.7 Capital Savings from Energy Saving for A/C energy Sever in Power Plant

Energy Saving for A/C energy Sever in Power Plant			
Formula	**Calculation**		**Capital Saving (BDT/Year)**
Average Energy Saving per Day (kWh) × Average Tariff of Electricity (bdt/kWh) × Days of Service (Day)	5000kWh × 8tk/kWh × 300Days	=	12,000,000

Table 6.8 Yearly Saving Analysis

Particulars		**Capital Saving (BDT/Year)**
Avoidance of CO_2 Emissions Equipment's	=	2,856,000
Capacity/Headroom Improvement	=	64,000,000
Reducing Diesel Consumption	=	35,700,000
Energy Saving for A/C energy Sever in Power Plant	=	12,000,000
Reduce Running Cost of Diesel Generator	=	6,000,000
Total Savings (in a year)	=	**120,556,000**

Total Annualized capital cost of a conventional diesel power plant (1MW) is = 1,960,000,000 bdt/year [66].

Annual savings for implementing Smart Grid technology = $\frac{\text{Total Savings per year}}{\text{Power Plant cost per year}} \times 100\%$

$$= \frac{120{,}556{,}000}{1{,}960{,}000{,}000} \times 100\%$$

$$= \mathbf{6.15\%}$$

By implementing smart grid technology with a conventional diesel power plant, there will be about **6.15%** higher capital saving achieved.

6.3 Net Savings Calculation

Generation side achieved around 6.15% more savings. But the transmission and distribution sector has additional expenses around 4.78%.

So, the overall efficiency achieve of total power system is around (6.15 - 4.78) % = 1.37%.

But, if more power plants are integrating with smart grid technology, it will be achieved more efficient system.

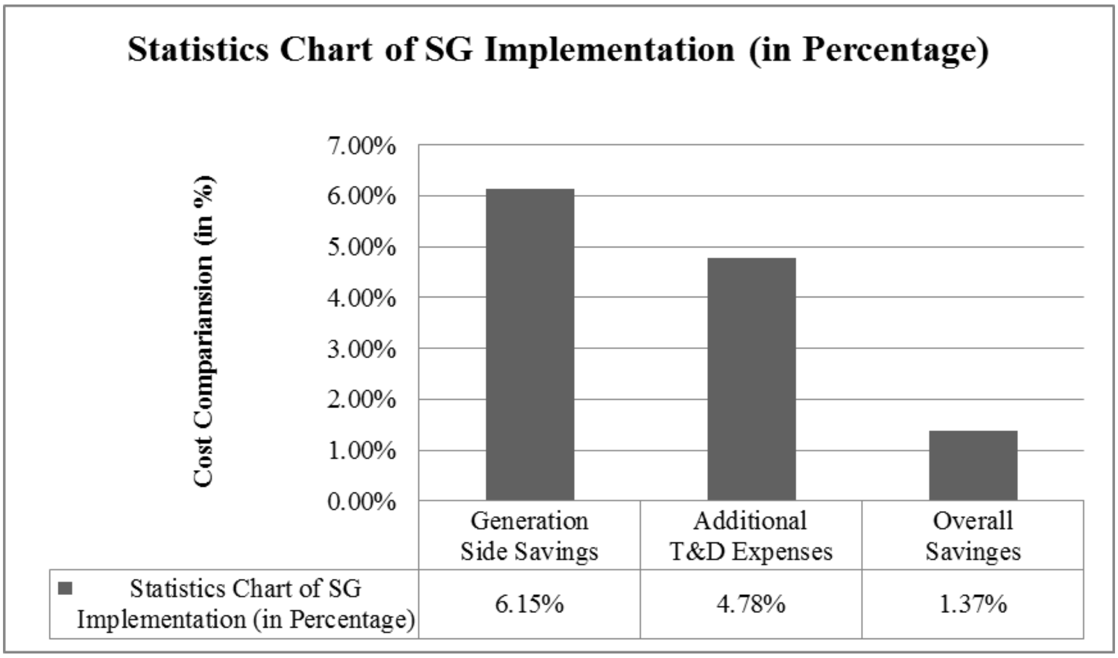


Figure 6.1 Percentage Chart of Smart Grid Technology Implementation

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 : Conclusion

There are many obstacles to implement Smart Grid Technology in Bangladesh Power Sector; such as lack of knowledge, equipment unavailability, initial investment and so on. But, if it is possible to install it in the context of Bangladesh, then the power sector can improve along with the consumer. The cost analysis shows that, initial Transmission and Distribution expenses rise due to implement of smart technology around 4.78%. But, when smart grid system will attached with generation sector, the savings of a conventional diesel power plant achieved around 6.15%. As a result, about 1.37 percent of capital is saved. After completing implementation; reliability and efficiency of the system will be increase in many times, since there is no financial expenses occur due to implementation of the transmission and distribution side. If it is possible to connect more power plants through smart grid technology, the efficiency of this system will be increase linearly. That can be a major point to implement of smart grid system by breaking the barriers of smart grid technology. This thesis also shows, by improving knowledge about smart technology power consumption availability of consumer also be improved. If microgrid technology can be merged with smart grid technology, both the prosumer and national grid systems reliability can increase.

Through this thesis the details of the implementation process of smart grid mainly highlighted which has been illustrated in view of the increased power demand of Bangladesh. Along the government of Bangladesh, numerous non-governmental power producing companies must step forward to replacing smart grid from traditional grid system. Smart grid technology creates the opportunity to the use of unusable green energy which is one of the considerations of this thesis and this thesis also focuses on green technology by promoting green energy.

7.2 : Recommendations for Future Work

According to this thesis, it's only discusses on smart grid system and some financial benefits in detail, but the rest of the smart technology and there consequences which should be similar to smart grid are not discussed.

Here are some future works recommendations which are related to smart grid technology:

- Connection of Micro-grid system with Smart Grid in case of Bangladesh power sector.
- Implementation of smart grid with non-conventional resources (e.g. wave energy, geothermal energy, tidal energy, sound energy etc.).
- Proper implementation and compatibility test of Smart Grid by analyzing Bangladesh Electricity Grid Code.
- Analyze the improvement process of Transmission and Distribution loss by implementing Smart Grid technology.
- Future Smart Grid challenges and their mitigation process.

REFERENCES

[1] http://datatopics.worldbank.org/world-development-indicators

[2] https://www.dhakatribune.com/bangladesh/2021/03/31/world-bank-bangladesh-can-expect-3-6-gdp-growth-in-2021

[3] https://www.bpdb.gov.bd/bpdb_new/index.php/site/new_annual_reports

[4] https://www.atlanticcouncil.org/in-depth-research-reports/issue-brief/transforming-the-power-sector-in-developing-countries-geopolitics-poverty-and-climate-change-in-bangladesh/, http://southasiajournal.net/prospect-of-a-saarc-power-grid/

[5] https://www.saarcenergy.org/wp-content/uploads/2019/05/SAARC-Energy-Outlook-2030-Final-Report-Draft.pdf

[6] https://en.wikipedia.org/wiki/Non-renewable_resource

[7] https://www.bpdb.gov.bd/bpdb_new/resourcefile/annualreports/annualreport_1605772936_AnnualReport2019-20.pdf

[8] https://idcol.org/home/about

[9] https://solar.huawei.com/apac/news/apac/2020/10/The-largest-solar-power-plant-in-Bangladesh-connected-to-the-grid-with-Huawei-PV-Solution#:~:text=October%2016%202020%20%2D%20Bangladesh's%20largest,grid%20since%20beginning%20of%20October

[10] https://ndre.sreda.gov.bd/index.php?id=11&i=&ag=&sg=&submit=Search

[11] http://sreda.gov.bd/site/notices/2ee87680-e210-481e-bf40-126ac67949a2/DRAFT---National-Solar-Energy-Roadmap-2021---2041 "National Solar Energy Roadmap (2020-41)" Page : 80, 82, 84

[12] http://www.sreda.gov.bd/site/page/0e65b027-0289-448c-aec7-2e58c83cfcc2/-

[13] A.Z.A. Saifullah, M. A.Karim and M. R. Karim "Wind Energy Potential in Bangladesh" *AJER Research Paper,* Vol. 5, No. 7, pp. 85-94, December 2016.

[14] M.N.Uddin, M.A.Rahman, M.Mofijur, J.Taweekun, K.Techato and M.G.Rasul "Renewable energy in Bangladesh: Status and Prospects" *2nd International Conference on Energy and Power*, Vol. 160, No. 02, pp. 655-661, February 2019.

[15] M.H. Ullah, T Hoque, and M. M. Hasib, "Current Status of Renewable Energy Sector in Bangladesh and a Proposed Grid Connected Hybrid Renewable Energy System" *International Journal of Advanced Renewable Energy Research,* Vol. 01, No. 11, pp.

618-627, January 2012.

[16] M.N.Uddin, M.A.Rahman, M.Mofijur, J.Taweekun, K.Techato and M.G.Rasul "Renewable energy in Bangladesh: Status and Prospects" *2nd International Conference on Energy and Power*, Vol. 160, No. 02, pp. 655-661, February 2019.

[17] M. M. Rahman, N. Nasrin, S. Chakraborty, M. A. Siddique, S. Bhowmik and R. Barua "Renewable Energy: The Future of Bangladesh" *International Journal of Engineering Research and Applications*, Vol. 07, No. 06, pp. 23-29, June 2017.

[18] M. A. H. Mondal and M. Denich "Assessment of renewable energy resources potential for electricity generation in Bangladesh" *Elsevier*, Vol. 14, No. 08, pp. 2401-2413, October 2010.

[19] https://www.dhakatribune.com/bangladesh/dhaka/2020/09/24/2-waste-to-energy-power-plants-in-dhaka-on-the-cards

[20] https://www.bpdb.gov.bd/bpdb_new/index.php/site/new_annual_reports

[21] https://www.bpdb.gov.bd/bpdb_new/index.php/site/power_generation_unit

[22] https://www.trade.gov/country-commercial-guides/bangladesh-power-and-energy

[23] https://reglobal.co/wp-content/uploads/2021/01/bangladesh-power-sector-an-appraisal-from-a-multi-dimensional-perspective.pdf

[24] https://www.bpdb.gov.bd/bpdb_new/resourcefile/annualreports/annualreport_1605772936_AnnualReport2019-20.pdf

[25] http://pgcb.gov.bd/site/page/05a258ae-2288-44d5-95c1-4e30b35eb7ec/-

[26] https://web.pgcb.gov.bd/report/2783/download

[27] http://pgcb.gov.bd/site/page/835ce844-2055-4730-b2a1-71f607063d0a/-

[28] https://www.desco.org.bd/uploads/attachments/annual_report_2020.pdf

[29] https://www.dpdc.org.bd/list/annualreport/DPDC_Annual_Report_2020.pdf

[30] http://www.reb.gov.bd/site/page/c08b56bd-c300-4d08-8ea2-c25eedffbfdb/-

[31] http://www.wzpdcl.org.bd/sites/default/files/files/wzpdcl.portal.gov.bd/annual_reports/147fa6b0_c186_4a3f_8634_e478945fdcc4/2020-06-29-15-58-360277a20257be6c999c1535d20b0909.pdf

[32] http://nesco.gov.bd/sites/default/files/files/nesco.portal.gov.bd/annual_reports/5db73b42_5b66_4f83_8666_549b57383753/2020-12-21-16-17-891254e0fc4d79038e03e39b1ab006fb.pdf

[33] S. J. Bossart and J. E. Bean "Metrics and benefits analysis and challenges for Smart

Grid field projects," *2011 IEEE conference EnergyTech*, pp. 1-5, 25-26 May 2011, Cleveland, OH, USA.

[34] P. K. Steimer "Enabled by high power electronics - Energy efficiency, renewables and smart grids" *The 2010 International Power Electronics Conference - ECCE ASIA*, pp. 11-15, 21-24 June 2010, Sapporo, Japan.

[35] J. W. Feltes, B. D. Gemmell and D. Retzmann "From Smart Grid to Super Grid: Solutions with HVDC and FACTS for grid access of renewable energy sources," *2011 IEEE Power and Energy Society General Meeting*, pp. 1-6, 24-28 July 2011, Detroit, MI, USA .

[36] W. Breuer, D. Povh, D. Retzmann, Ch. Urbanke and M. Wienhold "Propects of Smart Grid Technologies for Sustainable and Secure Power Supply" *20th World Energy Congress and Exhibition*, pp. 1-30, 11-15 November 2007, Rome, Italy.

[37] F. Li, W. Qiao, H. Sun, H. Wan, J. Wang, Y. Xia, Z. Xu and P.Zhang "Smart Transmission Grid: Vision and Framework" *IEEE Transactions on Smart Grid*, Vol. 01, No. 02, pp. 168-177, September 2010.

[38] X. Fang, S. Misra, G. Xue and D. Yang "Smart Grid - The New and Improved Power Grid: A Survey" *IEEE Communications Surveys & Tutorials*, Vol. 14, No. 04, pp. 944-980, December 2011.

[39] V. C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C Cecati and G. P. Hancke "Smart Grid Technologies: Communication Technologies and Standards" *IEEE Transactions on Industrial Informatics*, Vol. 07, No.04, pp. 529-539, November 2011.

[40] H. Sui, Y. Sun and W.J. Lee "A demand side management model based on advanced metering infrastructure" *2011 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*, pp. 1586-1589, 6-9 July 2011, Weihai, China.

[41] L. Zhou, F. Y. Xu and Y. N. Ma "Impact of smart metering on energy efficiency" *2010 International Conference on Machine Learning and Cybernetics (ICMLC)*, pp. 3213-3218, 11-14 July 2010, Qingdao, China.

[42] W. Funika, P. Pegiel, M. Bubak and J. Kitowski "Towards Role-Based Self-healing in Autonomous Monitoring Systems" *2010 International Conference on Complex, Intelligent and Software Intensive Systems (CISIS)*, pp. 1063-1068, 15-18 February

2010, Krakow, Poland.

[43] https://electricalacademia.com/electric-power/difference-traditional-power-grid-smart-grid/

[44] https://onlinelibrary.wiley.com/doi/full/10.1002/wcm.2258

[45] K. Zhu, J. Song, M.Chenine, and L. Nordström "Analysis of Phasor Data Latency in Wide Area Monitoring and Control Systems," *2010 IEEE International Conference on Communications Workshops (ICC)*, pp. 1001-1006, 23-27 May 2010, Cape Town, South Africa.

[46] http://en.wikipedia.org/wiki/SuperSmart_Grid

[47] R. Bedard, G. Hagerman, M. Previsic, O. Siddiqui, R. Thresher, and B. Ram "Project definition study - Offshore wave power feasibility demonstration project" *Electric Power Research Institute*, 22 September 2005, Palo Alto, CA.

[48] F. R. Pazheri, H. Khan and I. Ahamed, "Smart grid implementation across the globe: A survey" *2011 IEEE PES Innovative Smart Grid Technologies - India (ISGT India)*, pp. 1-5, 1-3 December 2011, Kollam, India.

[49] https://www.bpdb.gov.bd/bpdb_new/index.php/site/page/2cd8-9540-95fe-d2c3-23bc-fc84-3475-2c9d-3acc-a10a

[50] https://powerdivision.gov.bd/site/page/f68eb32d-cc0b-483e-b047-13eb81da6820/Power-System-Master-Plan-2016, PSMP-2016, Page-568, 581

[51] https://solar.sreda.gov.bd/nem/nemstatistics.php

[52] http://www.sreda.gov.bd/site/page/88e1e1db-f2df-4987-83ab-c327087c1545/-

[53] http://documents1.worldbank.org/curated/en/669331512390210193/pdf/ESM-%20aBangladeshCountryCaseStudy-PUBLIC.pdf

[54] https://idcol.org/home/solar_min

[55] F. B. Beidou, W. G Morsi, C. P. Diduch and L. Chang "Smart grid: Challenges, research directions and possible solutions" *2010 2nd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, pp. 670-673, 16-18 June 2010, Hefei, China.

[56] G. N. Jadhav and A. A. Dharme "Technical challenges for development of smart grid in India" *2012 International Conference on Advances in Engineering, Science and Management (ICAESM)*, pp. 784-788, 30-31 March 2012, Nagapattinam, India.

[57] R. Kappagantu and S. A. Daniel "Challenges and issues of smart grid implementation

: A case of Indian scenario" *Journal of Electrical Systems and Information Technology*, Vol. 05, No. 03, pp. 453-467, December 2018.

[58] T Mohn and R. Piasecki "A Smarter Grid Enables Communal Microgrids" *2011 IEEE Green Technologies Conference (IEEE-Green)*, pp.1-6, 14-15 April 2011, Baton Rouge, LA, USA.

[59] B. Zohuri "Hybrid Renewable Energy Systems" Springer, pp. 1-38, January 2018.

[60] “FIPA Structure on Agent Communication” [Online]. Available: http://www.fipa.org/specs/fipa00026/SC00026H

[61] S.S. Murthy “Micro-Grid Integration with Renewable Energy in Indian Perspective” [Online]. Available: http://www.xcdsystem.com/energyTech2012/pdfs/133.pdf

[62] A. Mohd, E. Ortjohann, A. Schmelter, N. Hamsic, and D. Morton "Challenges in integrating distributed Energy storage systems into future smart grid" *2008 IEEE International Symposium on Industrial Electronics*, pp. 1627-1632, June 30 2008-July 2 2008, Cambridge, UK.

[63] "Study on development of roadmap for implementation of smart grid concepts, practices and technologies in SAARC countries" Published on December 2018; Available on: https://www.saarcenergy.org/wp-content/uploads/2019/05/SEC-Smart-Grid-Study-2018-Draft.pdf

[64] "Estimating the Costs and Benefits of the Smart Grid" Published on March 2011; Available on: https://smartgrid.gov/files/documents/Estimating_Costs_Benefits_Smart_Grid_Preliminary_Estimate_In_201103.pdf

[65] "Principles of Power System by Rohit Mehta and V.K. Mehta"; Available on: https://www.amazon.com/Principles-Power-System-V-K-Mehta/dp/8121924960

[66] M. K. Vandani, A. M. Khoshkar, F. Joda and R. B. Boozarjomehry. "Exergic, economic and environmental impacts of natural gas and diesel in operation of combined cycle power plants" *Elsevier*, Vol. 109, No. 02, pp. 103-112, February 2016.