Smart Hybrid Power Consumption System for Green Future Energy: Cost and Social Benefits Analysis

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A thesis

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CERTIFICATE OF APPROVAL

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DECLARATION

It is hereby declared that this work has been done by us and no portion of this work contained in this thesis has been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

The purpose of this thesis is to lead smart power grid system towards focusing on green future energy. The research world is always looking for mobility and different innovative work types for making human life more upgraded and easier. Due to coping with the ongoing modern world, the energy demand also increases dramatically over the years. Consequently, to meet that energy demand and bring sustainability over the grid system research world is diverting towards renewable energy more and sustainable energy. Various countries of the world have come forward in the age of smart grid and acknowledge its verity. Several are working on smart grid pilot project or taking persuasive of this concept for experimenting and research with the purpose of testing probabilities before on full scale advancement and change. To lessen carbon emission and energy security, government of various countries all over the world are already seeing possibilities like smart grid. Reviewing the scenario of smart grid system for all over the world, Asian region and for Bangladesh, the purpose of this thesis is to design a hybrid power system with PV and conventional power plant for leading the smart grid system towards focusing on green future energy. The further explanation is about the designed model by MATLAB Simulink approaching to smart grid development. In addition, the comprehensive analysis of power consumption for about 30 years, CO_2 emission calculation only for conventional power system, PV system implementation cost, CO_2 emission comparison with and without the proposed system, CO_2 reduction rate analysis and social benefit, consumer benefit for about 30 years after combining the PV system with conventional power system. Finally, the paper concludes with the suggestions of environment impact analysis as well as green future energy.

Keywords: Smart Grid, PV system, Conventional power system, Hybrid power system, CO_2 emission, CO_2 reduction, Power Consumption, Social benefit, Consumer benefit, Green future energy.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

BPDB	Bangladesh power development board
PSMP	Power System Master Plan
GDP	Gross domestic product
TSEL	Technical Solartech Energy Ltd
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
PV	Photovoltaic
IBM	International Business Machines
WIMAX	Worldwide Interoperability for Microwave Access
EEGI	European Electricity Grid Initiative
DRES	Distributed Renewable Energy Sources
RERs	Renewable Energy Resources
SG	Smart Grid
PJM	Pennsylvania, New Jersey, and Maryland
NDRC	National Development and Reform Commission
WAMS	Wide Area Monitoring System
T&D	Transmission and Distribution
PPS	Power Producer and Supplier
IPP	Independent Power Producer
DERs	Distributed Energy Resources
VPPs	Virtual Power Plants
V2G	Vehicle-2-Grid
ISGF	India Smart Grid Forum
HES	Head End System
MDMS	Meter Data Management System
REMC	Renewable Energy Management Center
LNG	Liquefied Natural Gas
AMI	Advanced Metering Infrastructure
SREDA	Sustainable and Renewable Energy Development Authority
SCADA	Supervisory Control and Data Acquisition
AFD	Agence Française de Développement
DPDC	Dhaka Power Distribution Company
MID	Measuring Instruments Directive

CHAPTER 01

INTRODUCTION

1.1 Introduction

Modern world is growing with a diversity, innovation, and transformation along with the massive energy demand. Basically, energy demand denotes regarding the electrical energy which is now one of the unavoidable part of our daily life. Moreover, it is really hard for modern world to run any single function and activity without electrical energy. However, the term electrical energy can be defined in various way which is related to power system. In a simple way, it is one of the generation systems which converts the mechanical energy into the electrical energy and transmit that into the consumer lever via transmission line or electrical system. Most likely for running the generation system we need to depend on the limited source natural resources such as coal, natural gas etc. As with the flow of modern world, the energy demand has already started to increase drastically. In the consequence the limit resource has also started to be running out and as it is a burning element that causes the CO_2 emission. Therefore, global warming, greenhouse effect and natural disaster these are now very common scenario in all over the world. Hence, it is high time to make the efficient and smart use of the energy to meet the increasing demand [1]-[4]. In one sense people are responsible for that because people are not careful about the environment. Honestly speaking still people are trying to cope-up with the modern world for that they can sacrifice the environment issue as well. In that context, Bangladesh is also not lagging behind. Many research articles and statistics are showing that, the major causes of greenhouse effect is the carbon dioxide emission from the power plant, industry etc [5]. As days go, energy demand increases day by day due to globalization. Electricity is the major source of power for most of the country's economic activities [4].

Along with the developed countries, the emerging countries are also signing-up the electrical energy progress on highest prioritized list. In the context, country like Bangladesh is also the most widely utilizing and emphasizing on electrical energy since 1971 after earning the independence from Pakistan in 1971. Bangladesh is also trying to adopt new power challenges. Hence, concern bodies are taking various initiative eliminating the energy crisis. The amount of energy served is the flow of energy brought onto the market, and the amount of energy demanded is the quantity of energy purchased for a specific period of time. It leads the whole energy system, manipulating the entire amount of energy consumed; the location of, and forms of fuel used in the energy supply system; and the features of the end use technologies that consume energy. In houses, energy is required to run appliances, for cooking and to make a house warm. Massive duty machines and generation chains are driven by the energy supplied to them by the national grid in farms and factories. To run transport systems likewise cars, trains, buses and boats use fuel or electricity.

1.2 Power generation capacity and CO_2 emission statistics

Bangladesh power sector is highly relying on fossil fuels, as natural gas and coal are the governing sources for power production in the country. About 62.9% of Bangladeshi produced electricity arrives from natural gas, while 5% comes from coal, 10% is from diesel, and 3% of heavy oil and 3.3% is of renewable sources. The country has a very inadequate energy retain, small quantity of oil, coal and numerable natural gas reserves. The country undergoes an inner energy struggle, as about 93% of the country's power generating thermal plants are gas-based, nevertheless the gas is also required for the industrial segment. Consequently, the country has to endlessly make some concessions between power generation and emerging the industrial sector [6]. Regardless of the fact that the Bangladeshi energy sector uses and covers different products; electricity, coal, natural gas, petroleum products, biomass and solar, so far, the strategy and decision makers are mostly pre-occupied with electricity. As of April 2022, the installed capacity of Bangladesh power development board (BPDB) Power Plants based on various fuels are as following (see **Table 1.1**) which has been published in the website of BPDB [7].

Table 1.1 Installed Capacity of BPDB Power Plants [7]

Fuel Type	Capacity (Unit) [MW]	Total (Unit) [%]
Coal	1768.00	7.93
Gas	11330.00	50.82
HFO	6238.00	27.98
HSD	1341.00	6.01
Hydro	230.00	1.03
Imported	1160.00	5.20
Solar	229.00	1.03
Total	**22296**	**100**

Along with progressive work, the Power System Master Plan (PSMP) -2010 has been designed energy demand forecast by anticipating GDP growth rate 7 %. As it is necessary it to cope up with the modern world the development of electricity is required to be enhanced to increase access and reach economic expansion. The anticipated economic progression rate would be about 7% p.a. Based upon this study the peak demand would be about 10,283 MW in FY2015, 17,304 MW in FY2020 and 25,199 MW in 2025. According to PSMP- 2010 Study work year-wise peak demand forecast is shown below in **Fig. 1.1** [8].

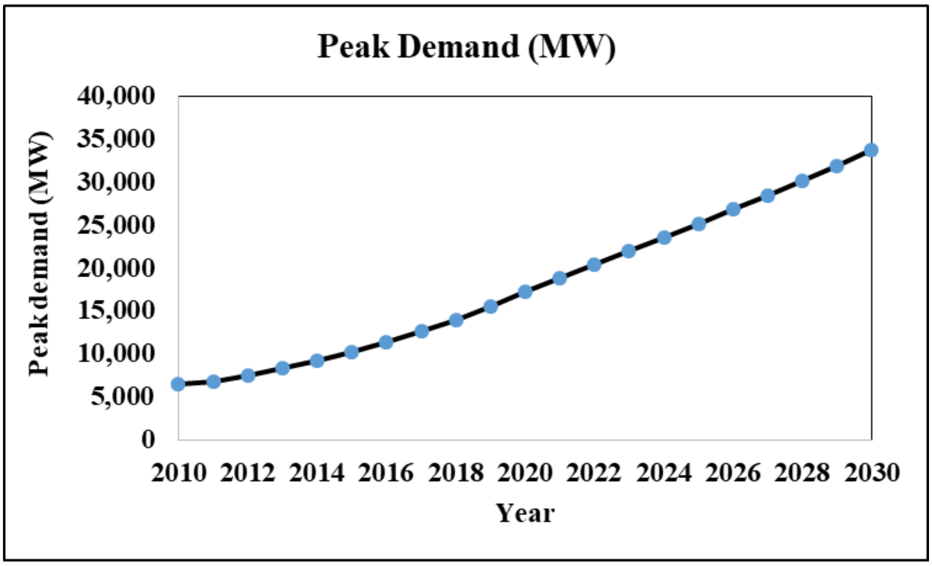

Fig. 1.1 Peak Demand forecast of Bangladesh according to Power System Master Plan (PSMP) – 2010 [8]

Basically, the modern world accelerations and developments are pushing every sector to think beyond the unseen boundary. As a counter action the research world is always looking for mobility and different innovative work types for making human life more upgraded and easier. Due to coping with the ongoing modern world, the energy demand also increases dramatically over the years [2]. Even in developing countries' share of the glob1al electricity demand jumps to 43% in 2030 from 27% in 2000 to [9]. Consequently, to meet that energy demand and bring sustainability over the grid system research world is diverting towards renewable energy more and sustainable energy. The mentioned field has been highly investigated in the research field for the last couple of decades [10]-[11]. Taking the modern world flow, the researchers are looking to develop a smart grid system for sustainable development of the energy system. According to some literature and organization, the term "Smart Grids" can be defined as "an electricity network that can intelligently fit in the actions of all users connected to it – generators, consumers and those that do both – for the purpose of confirming efficiently distribute sustainable, economical and secure electricity supply [12]. By 2021, the Bangladeshi government has set a vision of attaining 100% electricity access by integrating more solar PV and biomass sources, by way of the country is rich with these two particular ones. To produce electricity, the world is moving towards renewable energy rather than fossil fuel. By 2020, Bangladesh was also targeting to accomplish the goal of generating 10 percent electricity of national demand from renewable energy sources [13]. At present, less than 2 percent of our entire energy is delivered by renewable energy sources [14]. As such, within the upcoming three years, the country is undertaking few initiatives to set up some large scale solar power project [4]. Bangladesh government has also taken withstand initiative to run electricity to every rural household. Renewable energy, particularly solar will play the dynamic role to fulfil this determined goal. The country has the potential to produce a combined 3.6 GW of electricity from renewable energy sources consistent with the Bangladesh's Power Sector Master Plan 2016 (PSMP–2016). Additional research has expected that the potential from wind power alone stands at 20 GW. Bangladesh has 15 MW solar energy capacity through rustic households and 1.9 MW wind power in Feni and Kutubdia. The government of Bangladesh has accepted the structure by private developers of 19 on-grid solar parks, with would have cumulative production capacity of 1070 MW. A solar power plant having a power production capacity of 28 MW has just started its operation in Teknaf of Cox's Bazar. Accounting this, the power production capacity from renewable energy sources beats 5% of the country's total demand. Technical Solartech Energy Ltd (TSEL) has installed this power plant in Teknaf applying a total of 116 acres of land. The power plant is feeding 20MW to the national grid presently [15].

By 2020, Bangladesh has intended to generate 10% of entire power generation from renewable energy sources like solar energy, wind and waste. The country plans to raise its renewable energy share to 17% by 2041 under its Intended Nationally Determined Contribution (INDC) commitment to lessen the greenhouse gas emissions by 5% until 2030. In the energy sector the concern of the acceleration are dragging the entire world towards an alarming phase because large amount of CO_2 emission. This is really high time for all the nation to raise their hand and need to come into a solution to get-rid of from the course of CO_2 emission. In terms CO2 emission Bangladesh is also not lagging behind compare to other country. If we look at the some statistics it will be very easy to understand the scenario. As we know that coal and gas are the main source of the CO_2 emission. Unfortunately, our country has the most dependency on these fuel most which will be clearer if we see the published list of capacity of power generation based on the various types of fuel by BPDB (see **Table 1.2**) [16].

Table 1.2 Power generation capacity based various fuel type in Bangladesh [16]

Fuel Type	Capacity (Unit)	**Total Capacity (Unit)**
Coal	1768.00 MW	7.93%
Gas	11330.00 MW	50.82%
HFO	6238.00 MW	27.98%
HSD	1341.00 MW	6.01%
Hydro	230.00 MW	1.03%
Imported	1160.00 MW	5.20%
Solar	229.00 MW	1.03%
Total	22296 MW	100%

From the above statistics (**Table 1.2**), we can easily say that, maximum amount of power we consume comes from the natural gas based power plant. That means we are very much dependent on the conventional energy sources rather than renewable energy. Again, coal and gas based power plant emit carbon di-oxide at a concerning rate which is really harmful for our environment [17]. Moreover, if we look at **Fig. 1.2** and **Table 1.3** below we can easily come to the conclusion that, in Bangladesh maximum amount of CO_2 is emitted by power sector which is run by coal and gas and from **Fig. 1.3** the annual CO_2 emitted by natural gas fired power plant in Bangladesh has been depicted.

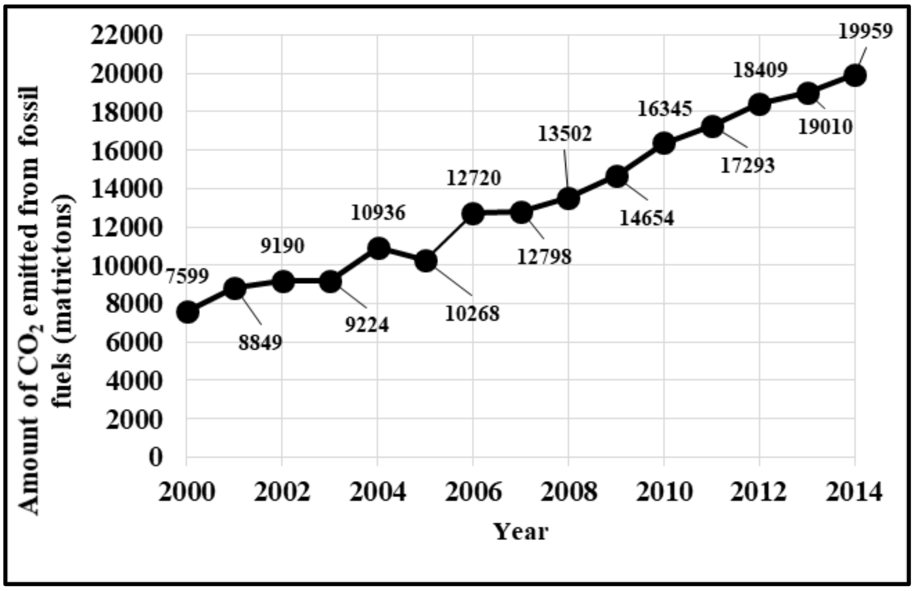

Fig. 1.2 Annual CO_2 emitted by fossil fuel-based power plant in Bangladesh [17]

Table 1.3 Top ten CO_2 emitting power plant list

Name of sector	Installation name	Estimated annual CO_2 emissions(kilotons)
Power	Ghorashal	4,731
Power	Barapukuria	2,075
Power	Ashuganj	1,502
Refinery	Eastern Refinery Ltd	983
Power	Haripur Barge	980
Power	Khulna	938
Power	Chittagong	914
Power	Haripur AES	653
Power	Shajibazar	631
Power	Shiddhirganj	631

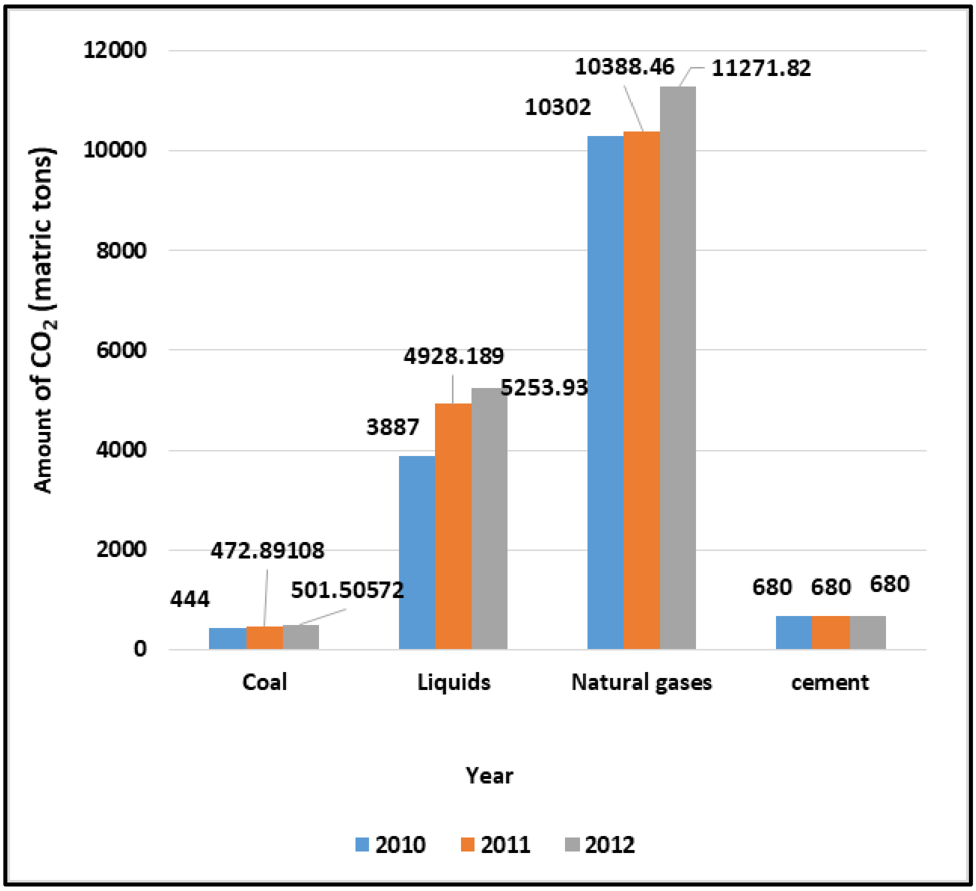

Fig. 1.3 Annual CO_2 emitted by Natural gas fired power plant in Bangladesh

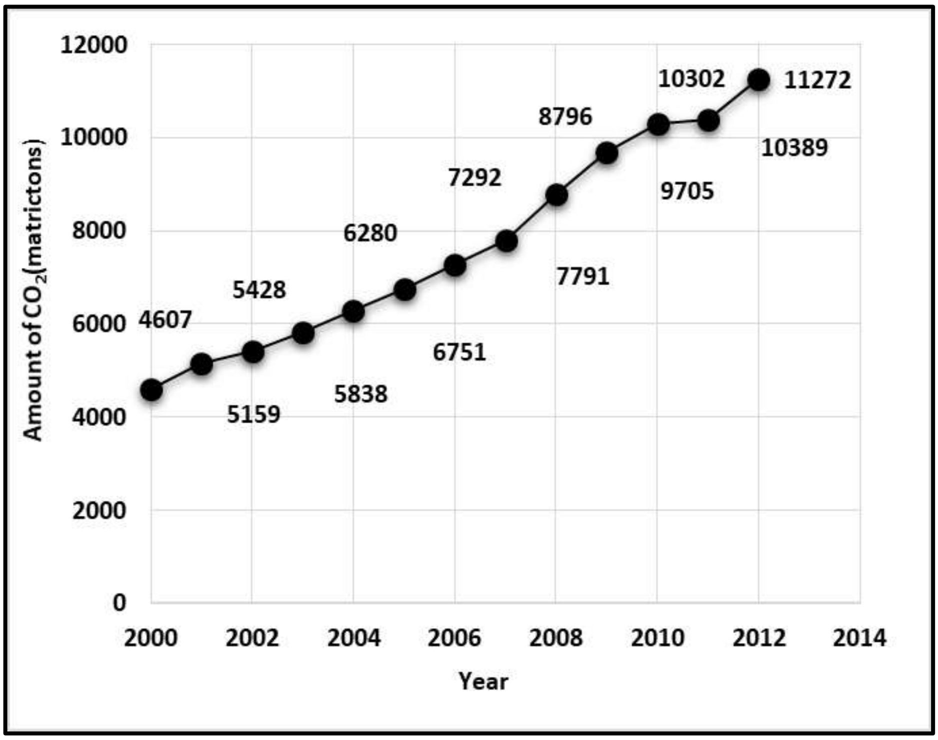

Fig. 1.4 CO_2 emission from different types of power sources and industries from 2010-2012

From above **Fig. 1.4**, we can see that the CO_2 emission is increasing per year. And the percentage of this CO_2 emission is increasing even further in the upcoming years with the addition of two 1320MW coal fired power plant one in Rampal [18] and another in Banshkhali [19]. It has predicted by experts that within the next 50 years almost 15 percent of Bangladesh will go underwater. In accordance with the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) published forthwith, the sea-level of the Bay of Bengal is growing per year at a rate of 1.5 mm. A permanent loss of up to 15600 square kilometers of land is projected, if the sea-level climbs by 45 cm. The increase in temperature is also caused by the rising CO_2 emission every year. Researchers at BUET have predicted that this temperature could increase to 3-5% by 2100 [17]. 250-550 million people will be in the danger of hunger if temperature rises by 3°C. Also, the growth, physiology, and chemistry of the plant life are likely to affect hugely by the growing CO_2 concentrations. It is projected that the GDP could be decreased by more than 3% if temperature rises by 2°C-3°C within 2100 and we could be seeing at a GDP reduction of 5-6% if temperature rises by 5°-6°C. Even the fishery sector which contributes 3-5% of the total gross domestic product (GDP) will suffer consequences.

As the oxygen level reduces with the rising temperature. The recent inclusion of the unstable weather pattern is also the consequence of this rising global CO_2 emission [17].

However, by putting the environment into highest priority list research must lead towards the smart grid power system. So that, we can prevent the situation of run out of fuel and pull down the CO_2 emission rate for the betterment of our future generation and future green modern world. We strongly believe with the introduction hybrid and smart control-based power system might help us to face the up-coming challenges.

1.3 Problem statement

As of now, it has been one of the enormous challenges for the research world to synchronize with the modern world demand specially energy production or generation. In some of the cases environment issues had left behind which now becoming a big thread for ourselves. Hence, it is high time to rethink about the environment with a combine way to prevent this threatening issue of CO_2 emission. At the same time developing countries should also raise their hand in this regard as well. Because in so many ways country like Bangladesh will be affected vastly due to the greenhouse effect which is due to the CO_2 emission. Yes, it will be more challenging for us to take steps quick, but we have react smartly to lead towards the smart green energy world. Here, by taking the concerning fact in this thesis working we have proposed a renewable energy system based smartly controlled power system for leading towards green modern world. The details of the proposed smart power grid system has been discussed in below section 1.4.

1.4 Objectives

The objectives of the proposed system are as following

1. Propose a hybrid power system combining both conventional power plant & PV system with the inclusion of light detection control system.
2. Cost calculation considering the consumer benefits.
3. Comparative cost calculation study of conventional & proposed system.
4. Environmental impact discussion & calculation via statistical report analysis.

1.5 Thesis outlines

1. Chapter 1 (Introduction) – Overall smart grid situation in developed and developing countries, power generation capacity and CO_2 emission statistics in Bangladesh, peak demands, installed capacity, CO_2 emitting power plant lists etc. and the problem statement, objectives have been briefly introduced.
2. Chapter 2 (Current Scenario of Smart Grid in All Over the World) – Where the scenario of smart grid in Australia, Canada, England, and United States of America have been elaborately discussed.
3. Chapter 3 (Scope of Smart Grid in Asia & Smart Grid Progression in Bangladesh) – Where the scenario of smart grid in China, Japan, India, and Bangladesh have been elaborately discussed, and progression of smart grid in Bangladesh has been discussed.
4. Chapter 4 (Methodology) – Methodology of our proposed hybrid power system with PV and conventional power plant has been discussed and the proposed simulation model has been designed in MATLAB Simulink.
5. Chapter 5 (Result and Discussion) – The simulation results, proposed system cost analysis, consumer and social benefits in terms of CO_2 reduction rate for 30 years after combining the PV system with the conventional power plant has been analyzed in detail.
6. Chapter 6 (Conclusion and Future Work) – Summation of entire research work and future work suggestion has been briefly discussed.

1.6 Summary

Power crisis is a major issue for such a developing country like Bangladesh. Due to their cheaper nature they tend to elect coal and natural gas fired power plants so that they can deliver as much power as possible to the population which also leads the country to environment pollution. But it is not possible to stop generating power from these existing sources just because of environmental issue as we must keep supplying power to our population. This is where smart control-based hybrid smart power system is needed as it has the capability to drive these existing plants. With the inclusion of smart control-based hybrid system the CO_2 emission can be decreased to a level and in addition, from that smart hybrid power system consumer can also contribute to the grid by supplying extra power and earn as well.

CHAPTER 2

CURRENT SCENARIO OF SMART GRID IN ALL OVER THE WORLD

2.1 Introduction

In terms smart grid and smart control system-based developments are on the speedy phase in all over the world to expose the new era. In that context, the national grid infrastructure of many countries is very moldy and comprises classical technologies in terms of power generation, transmission, and distribution [20]-[22]. In coalescence, the ability of controlling and monitoring of these systems are also not optimal. Contrariwise, in order to monitor and control the power system in both ways from power stations to end-users or vice-versa, smart grid technologies comprise sophisticated instruments [23]-[26]. There is an immeasurable increment in the demand of electrical energy due to the progression in technology which has not only become contravention for its generation but also its distribution. Meanwhile, this ascending demand is raising the complications of power grids by increasing necessities for greater reliability, efficiency, security, and environmental and energy sustainability concerns that results in a power grid unto smartness which ultimately known as today's concept of "Smart Grid". The current form of electricity grid is unreliable where the grid has poor power quality, high transmission losses, inclined to brownouts and blackouts, supplying insufficient electricity, discouraging to inclusion of distributed energy sources. There is a scarcity of control in monitoring and real time in the conventional non-smart systems, which creates a challenging chance for smart grids to act as a real-time solution [27]-[31]. Because of the growing demand for technology changes, electricity, emersion commutation and policies, smart grid is spreading globally. Hence, to keep up the economy and promote business performance, some form of electricity is required [32]. Smart Grid is a system that includes intelligent electricity distribution devices, two-way communications, automated metering, advanced sensors, and specialized computer systems to enlarge customer awareness and choice, reliability performance, motivate greater proficiency decisions of the customer and of the utility provider [20]. This system will simplify greater infiltration of distributed generation comprising renewable sources, plug in electric hybrid vehicles, micro-grids, and other technologies that may be enabled by the central functionality [33]-[35].

2.2 Conception of Smart Grid

The smart grid concept started originating with the start of distribution system of electrical networks. Heretofore, different requisites were essential such as control, monitor, prices and services of transmission and distribution of electrical power. Generally, Smart Grid execution is attached with the installation of smart meter. The most vital and elementary requirement which is still under consideration even with latest development is reliability and competency of energy transmission and distribution via electric power grid. Nonetheless, the latest promotional studies show that grid and network systems are not limited to transmission and distribution but perform a vital role in tidy and sustainable energy production to minimize greenhouse gas and carbon footprint. Technically, the traditional grids with some latest and automated properties which make them more feasible and sustainable is the main concept of smart grid. In mint condition, the concept of smart grid could store, communicate, or even decide following to the circumstances whereas the traditional grids were only used to transmit and distribute the electric power. Consequently, in accordance to Strategic Deployment Document for Europe’s Electricity Networks of future, a Smart Grid is an intellectual network of electricity that accomplish the actions of all the stakeholders that are producers, customers and one who does both with the aim of serving electricity with proficiency, sustainability, economically and safely [27]-[31].

2.3 Concernment of Smart Grid

Smart Grid research has a long history with the beginning of its first concept implementation in 1997. For better production of electric power and feasible way for transmission and distribution of this power, smart grid technology has a way for a solution. On account of its versatility, it can be more easily installed and needed less space as likened to traditional grids. Concept of Smart Grid design is intended for the ability of grid observation, create controllability of assets, and improve performance and specially the economic aspects of operations, surety of power system, maintenance, and planning. For this reason, we also can take into account that smart grid technology can be used to micro-grid level which ultimately connect to all other micro-grids to form a broad network of Smart Grid. In US, while producing electricity the country has 40% of the carbon dioxide emitting share in it whereas only 20% of the all carbon dioxide is been emitted by transportation. This is all caused by the high demand increase of electricity. Smart Grids are being considering as a key role to aim this problem by distributing electric power in an effective way and eventually lessen greenhouse gasses and pollutants such as NOx and SOx. It will also assist the consumer to forecast its demand and the best economical use of energy. Moreover, the effective utilization of power sources with minimum illegal usage and minimum loss is also handled in smart grid technology [27]-[31].

2.4 Investment in Smart Grid

Various countries of the world have come forward in the age of smart grid and acknowledge its verity. Several are working on smart grid pilot project or taking persuasive of this concept for experimenting and research with the purpose of testing probabilities before implementation on full scale advancement and change. To lessen carbon emission and energy security, government of various countries such as United States, Australia, China, South Korea, Britain and Japan are already seeing possibilities like smart grid [27].

2.4.1 Investment for smart grid in Australia

Since 2009 Australian government was keen in Smart Grid when a call for tender was conferred for smart grid. Government was devoted to invest about $100 million at first and was more inquisitive to nurture awareness in consumer about energy consumption and formation of distributed demand and production management system. Five separate sites in New South Wales were selected for smart grid formation and Energy Australia was selected for this motive with collection of IBM, GE Energy and Grid Net. The impression was to form a WIMAX-based smart grid that has ability of automatic substation, able to put up electric vehicles and also encouraging 50,000 smart meters' connections. For testing network fault recognition, segregation and restoration, power quality observing and automatic distribution of electric power via distribution management system another project was established. Australian government is also giving motivations for inspiring and financing in smart grid. Demand management, energy sanctuary and energy efficacy are the top precedence of Australian government [27]-[29]. At the same time Australian government has been focusing on the renewable energy sector since last decades with a decent encouragement. That is reflected on the statistical data as well [36]. Australia-wide large-scale target of renewable energy is depicted on **Fig. 2.1**.

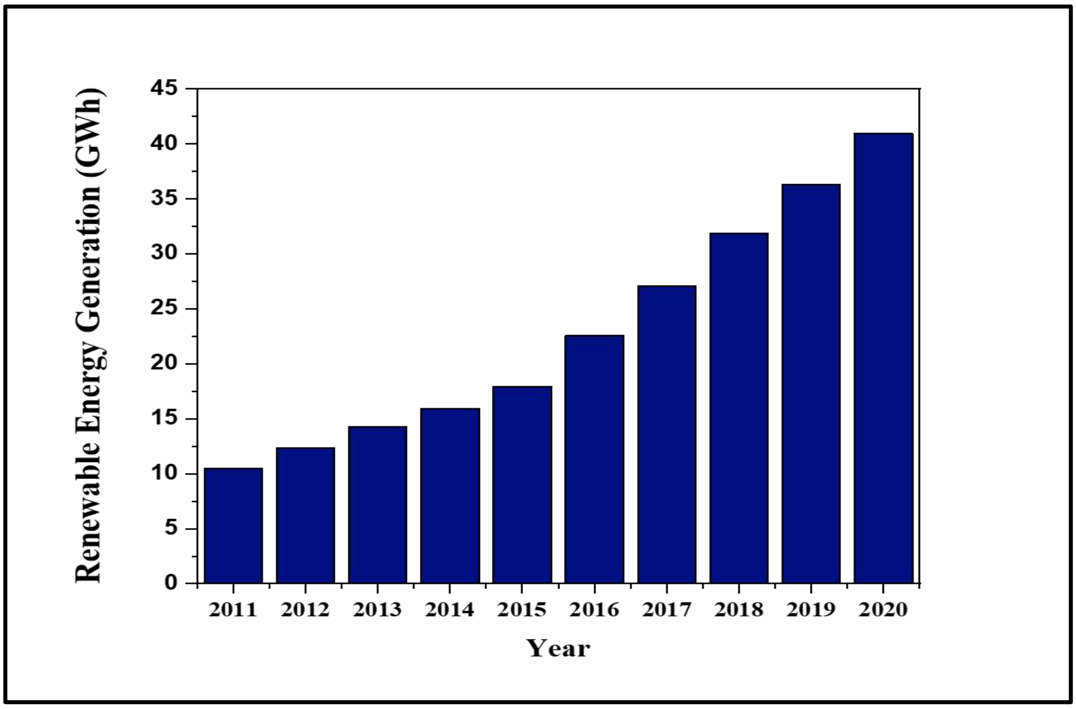

Fig. 2.1 Australia-wide large-scale target of renewable energy [36]

Compare to the other nation development this progressive are really impressive and inspirational. In terms of power production, imported, exported and dependence on the US have been reflected on the **Table 2.1**. From the **Table 2.1**, it is very much clear that from 2015 to 201 their market size has enlarged from 330 to 381. At the same time, their exchange was 0.77 in the fiscal year of 2018. Moreover, another thing is very much noticeable that Australia has a great dependency on imported power from US because during the year 2015 to 2018 it has been increased by 34.2% (see **Table 2.1**). As they have these sorts of dependency therefore, they now diverting towards renewable energy and smart grid system to increase the efficiency and reliability of the system [27]-[31].

Table 2.1 Power sector scenario of Australia during FY2015-FY2018

Content	2015	2016	2017	2018 (Estimated)
Total Local Production	55	57	59.4	69
Total Exports	5	5.3	5.5	6.2
Total Imports	250.0	263.3	273.9	316.2
Imports from the US	100	105.32	132	152
Total Market Size	330	347	364	381
Exchange Rates	0.74	0.77	0.77	0.77

2.4.2 Investment for smart grid in Canada

Government of Canada made the installation of smart meters obligatory for business and households in Ontario by 2010 through legislature Energy Conservation Responsibility Act 2006. In the same year, government also financed $32 million in a research of smart grid project of problems allied of handling renewable energy. Centralized government also took altered persuasive like unpolluted energy fund and eco-energy innovation persuasive. Presently, separate pilot projects in zone of Quebec and Ontario are going on. An association with the name Smart Grid Canada was designed which comprises academia and all stakeholders consist of, for the advancement and awareness campaign of Smart Grid. They were answerable to enable research and arrange various policies connected to smart grid. There are various units such as National Energy Board, National Smart Grid Technology, Natural Resource Canada and Standard task force which are being encouraged by government. Standard task force and National Smart Grid Technology was designed for the enlargement of all the aspects related to Smart Grid and also harmonize and include regional governments for the provision and expansion of smart grid [27]-[30].

2.4.3 Investment for smart grid in England

In the case of producing energy from photovoltaic, United Kingdom is one of the largest producers. A number of technologies like photovoltaic, electric vehicles, smart meters and heat pump were added with the distribution system to lower carbon emersion by Low Carbon

London institution. World’s first cryogenic energy storage solution was executed as a preliminary project in Reading, UK. Likewise, a fruitful trail of 9000 smart meters for homes and business was completed by Commission on Energy Regulation in Ireland [27]. The expansion of electricity Smart Meter is taking place with the aim of quickening the conversion from the conventional electrical grid to the new smart grid in different countries all around the world. In point of fact, numerous forthcoming changes by virtue of the Smart Grid approach highly rely on the availability of data from Smart Meters, either for deficiency or control. **Table 2.1** shows the expected diffusion rate of electricity Smart Meters by 2020 in countries from the European Union. Likewise, in America and Asia the deployments are taken place [37]-[39].

Table 2.1 Expected smart electricity meters deployment in the EU by 2020

Country	Expected Diffusion rate by 2020 (%)
Austria	95
Denmark	100
Estonia	100
Finland	100
France	95
Germany	23
Greece	80
Ireland	100
Italy	99
Latvia	23
Luxembourg	95
Malta	100
Netherlands	100
Poland	80
Romania	80
Slovakia	23
Spain	100
Sweden	100
United Kingdom	100

Meanwhile, the smart meters expanded follows with the requisitions of Measuring Instruments Directive (MID), but not inevitably with the most recent standards and suggestions. It is an inquisitive question to answer if certain meters could favorably meet the trials described by the new documents or if they could be progressed with new power definitions (via firmware update) [37]-[39].

2.4.4 Investment for smart grid in United States of America

Since early 20th century US seem to be a rising county for the smart grid advancement. An investment of $100 million per year for five years from 2008 for emerging and enlarging smart grid capabilities was set by a central policy which was established as Energy Independence and Security Act of 2007. Pursuant to this Act of 2007, National Institute of Standard and Technology will be answerable to superintendence the progression and renovation of grid and form an intermediation to access its advantages. It will also build standards to uphold the upliftment of smart grid. A fresh act was constructed as American Recovery and Reinvestment Act of 2009 which funded $11 billion for a smart grid preliminary project in 2009. This was the consequent of the legislatures and vow of US government that they exhibited smart grid projects and connected twenty-two utilities in five separate regions. A fully metering system with consumer web portal and automatic notice features was established by Houston’s smart grid. For the automation of power distribution network, smart Texas also extends a large number of smart meters. The U.S smart grid network management system market value forecast from the year 2010 to 2020 is shown in the following **Fig. 2.2**, where it is noticeable that in 2010, the market value was below 200$, whereas in 2020 it arises to 100$ up [27]-[28]. An early developer in the progression of the electric grid, the U.S. grid is showing symbols of aging and, in some instances, is in need of replacement [32].

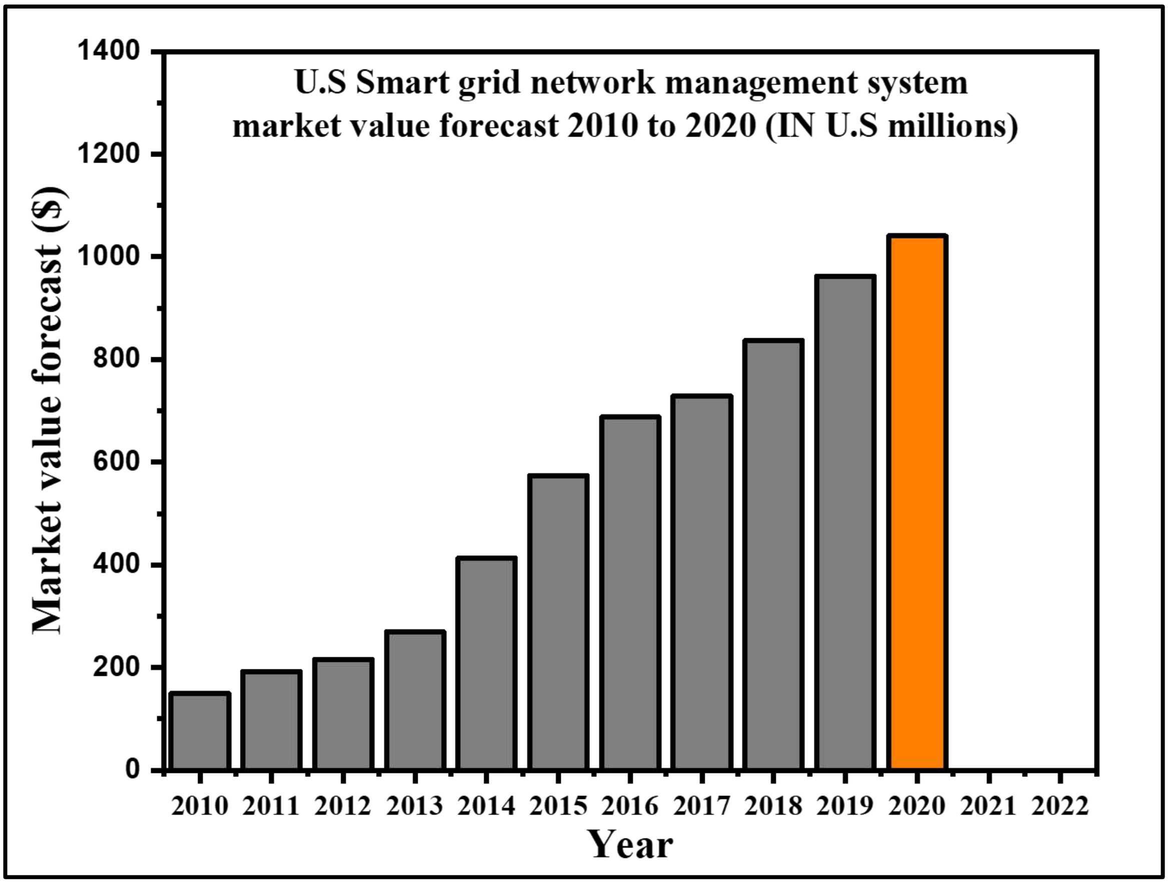

Fig. 2.2 U.S Smart Grid network management system market value forecast 2010 to 2020 (In U.S Millions)

In terms of the connected smart grid devices there is massive change in the U.S. market. Because in the early stage of 2010 the connected smart grid device less than 50millions. However, in the early phase of 2020, the connected smart grid device value has reached to around 330 million. In the following **Fig. 2.3**, the market forecast from the year 2010 to 2020 of the cumulative total smart grid connected devices in U.S is shown.

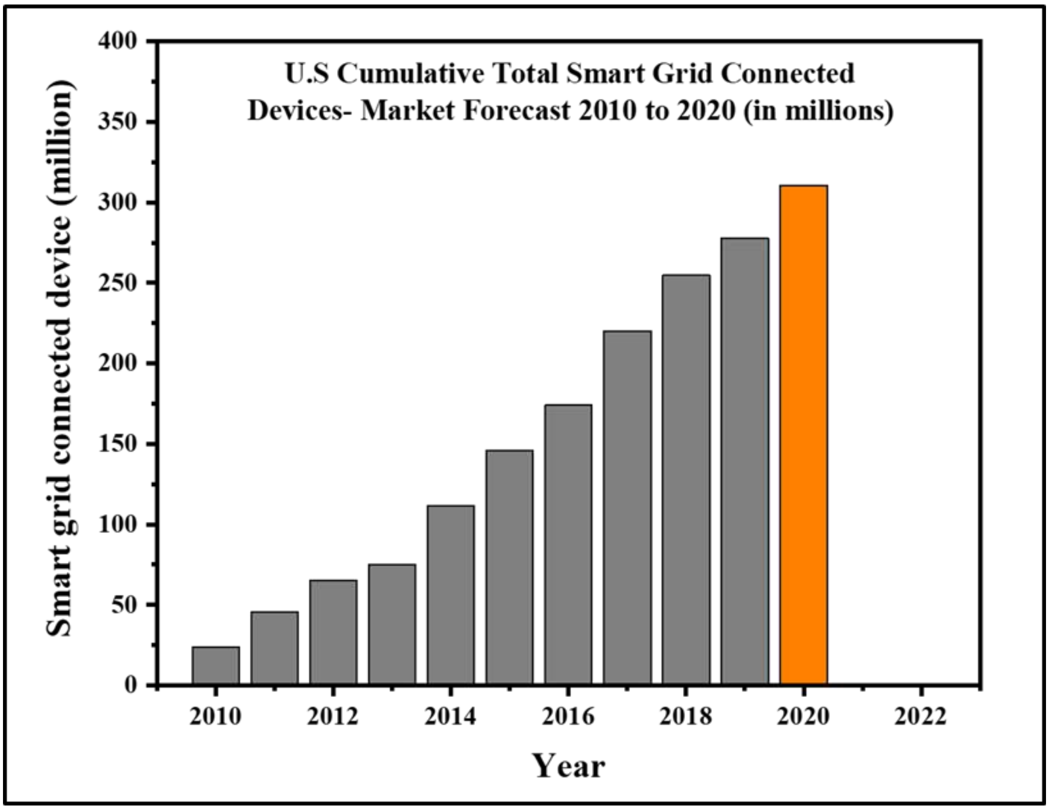

Fig. 2.3 U.S Cumulative total smart grid connected devices – market forecast 2010 to 2020 (in Millions)

2.5 Future Research in Smart Grid

For the advancement of smart grids a lot of research is going on. A heap of potential is still procurable for future research for various parts in different regions of smart grid. This comprise in area of forecasting, communication, power flow optimization, demand and energy management system, micro-grid integration, conformance of standards for interoperability, scalability, economical factors, data encryption and mainly automation of production, transmission and distribution [27]. United State is projected to hold 18.3% of the distribution transformer market value by 2022. The distributed transformer market is predicted to reach $2.6 billion in the upcoming 3 years. Rising policy and research is making the smart grid global [32]. In 2020, The Edison Electric Institute predicted investments in the US distribution system at more than $41.8 billion. The Institute for Electric Innovation reported that by the end of 2020, 107 million smart meters are expected to have been installed in the US. Further 115 million smart meter propagations are planned by the end of 2021 [40]. The report says that as the role of the distribution grid remains to raise and to grow, smart meters stay the vital building block [40].

Canada's Minister of Natural Resources, the Honorable Jim Carr, has declared a $100-million call for tenders to invest smarter grid systems. Smart grids are a key enabler for greenhouse gas remission by thriving the holding capacity of renewable energy, rising elasticity and progressing energy competency and conservation. These systems will form a base for the upcoming generation of advanced technologies and systems, supporting more consumer-owned energy production and service preferences and leading to entirely innovative applications [39]. If the UK has to meet its world-leading promises to hold climate change by 2050 then smart energy systems will be essential. To cope up with the growing demand for electricity, UK will need a system which ensures the supply of clean energy from renewable sources even when the sun is not shining or the wind is not blowing as fossil fuels are phased out [42].

CHAPTER 3

SCOPE OF SMART GRID IN ASIA AND SMART GRID PROGRESSION IN BANGLADESH

3.1 Introduction

The Smart Grid is observed as a fundamentally transformative, worldwide obligatory for assisting the earth cope with its energy and environmental contraventions. Environmental stewardship, detonating growth of global energy demand, rising emphasis on electrified transportation, aged infrastructures and empowerment of customers are some of the major drivers that are requiring this transformation [2]. The extremely rising power requisition around the world is putting extra loads on grids with the development in technologies. The subsisting grids do not afford the interface with Distributed Renewable Energy Sources (DRES) and also cannot carry that load. The energy shortfall cannot be overcome only by adding new lines and substations. To meet the ever increasing demands of electricity, a major conversion in electricity infrastructure is required. Transforming current power management system to a smart self-acting system is relevant to acquire a growing amount of renewable energy production [43].

In evolving economies with large spread population, consistent supply of energy is a good indicator of quality of life. Bearing in mind of increasing world population by 2040, the demand for electricity is expected to rise by about 70%. This concern can be tackled by using the promising technologies which use renewable energy resources (RERs) that have been experimented and used worldwide. Hence the cost related to the transmission lines can be saved, these technologies can be easily installed locally with low funding. The methods of operation and controlling such energy systems are unlike from the traditional energy systems. Apropos of, the smart grids are emerging in electrical power systems to acquire both environmental and economic purposes while contributing to the reliability of power supply to the consumers. These SGs are made up of millions of pieces and parts, such as computers, control, power lines and many real time communication apparatus. The smart grid (SG) technology is going through developments and its operation is under research in several cases [44]. In supplying mix of enlarged values ranging from higher security, reliability, demand optimization, power quality, lower cost of delivery and energy efficiency many countries and electricity markets are looking at smart grid as innovative solution. In fact, smart grid is an electricity network that can intelligently join in the actions of all users connected to its generators and consumers. Its radical capabilities are demand optimization, delivery efficiency, and renewable energy optimization will lead to lower carbon footmark and overall lower energy cost and funding in energy related infrastructure [45].

In every country, electric power industry is an elementary facility, and its improvement is thoroughly related to national construction. The research of electricity market formulation has been on increase in every country. So far the United States is alarmed, in 1990s PJM electricity market formed a good market competition atmosphere and shortened electricity prices to a great extent as they started to accomplish market oriented reforms [46]. Nordic electricity market is the foremost transnational electricity market having relatively perfect operation mechanism. Nevertheless, in the transformations of electricity markets there were also some problems in many regions. The illogical electricity modifications led to many large-scale blackouts in developing countries like India and Bulgaria. The employment of market-oriented transformations and the formation of reliable electricity markets require to go through a series of procedures. The aim of electricity market reform is to introduce competition, break monopoly, increase proficiency of electric power companies and reduce expense. Its principle is to constantly fine-tune the improvement way of electricity markets consistent with the actual progression of power industry [46].

3.2 Scenario of China

Chinese government is more concentrated on the policies related to reservation, encouraging diverse progression, protecting environment and depending on domestic resources. For this reason, advancement in Smart Grid is one of the priorities of Chinese policy which comprise incrementing renewable energy mix, developing energy proficiency and lessening carbon emission. Chinese agency National Development and Reform Commission (NDRC) is assigned for the research and advancement in smart grid technologies as its one of the priorities in five year plan. In 2009, China also declared a framework for smart grid which was more transmission centric than other countries like US and Europe. In five-year plan China planned to construct a Wide Area Monitoring System (WAMS) and intended to implement phasor measurement units on all power generators above than 300 MW and substation above than 500 kV in 2011 [27].

China is a rising power in the global distribution transformer market with its strong economy, growing population, and the drive to become a world manufacturing hub and leader. It is rapidly becoming a powerhouse in the market as it capitalizes in its industrial industry and electricity. Nevertheless, China is facing hindrances as it has a tough time distributing the energy it produces, causing losses as the grid becomes crowded [32]. The smart grid development of China has been illustrated in **Fig. 3.1**. There are two motives why smart grids will be massive and potent in China. Foremost, smart grid technologies are the undertaking responses to China's growing pledge to green progression. Another is China has an exceptional structural strand which could authorize it to forward the improvement of the smart grid likewise the availability of the market to downcast apparatus cost, government ownership of the power transmission and distribution (T&D) sector as well as key role of the government in the economy to make this feasible [47].

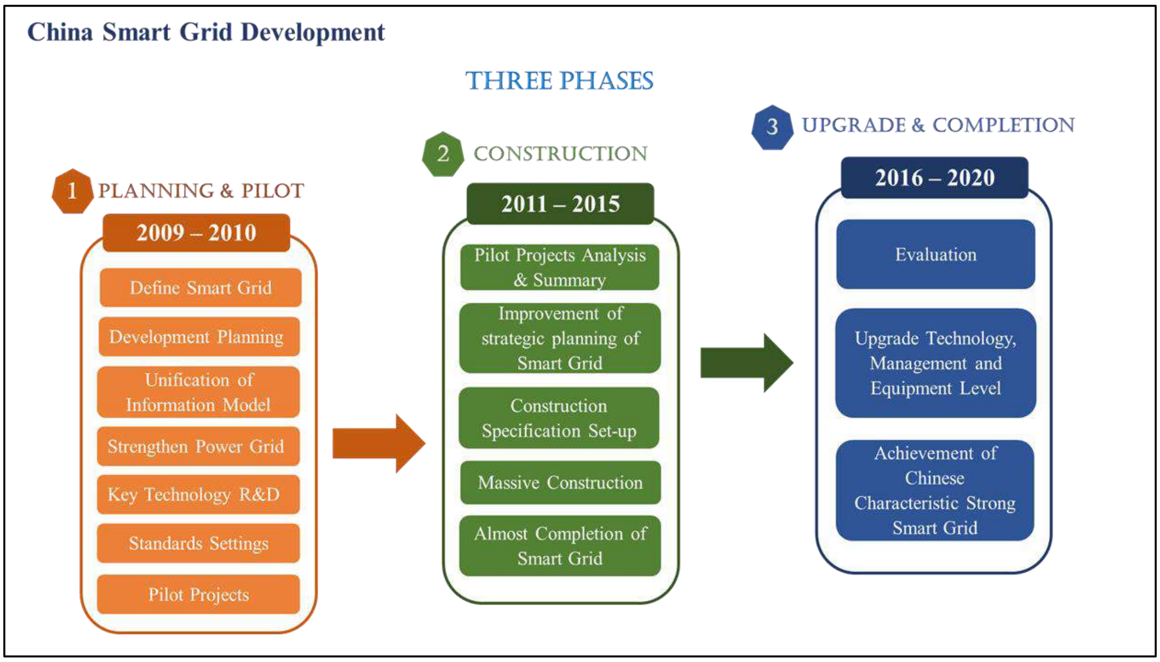

Fig. 3.1 China Smart Grid Development

3.3 Scenario of Japan

As an Asian country adjoining China, the way of Japan's electricity market reform is alike China's. Founded on the present situation of China's electricity market reform, the proposal of Japan's innovative electricity market regulation and mechanism system are scrutinized to be responsible for essential reference for the upcoming direction of China's electricity market production that can assist China's market reform out of its dilemma [46]. It can be found with the help of the research on electricity markets in foreign countries that there are many equivalences between the restructuring process of Japan's electricity market and that of China's electricity market. Presently, the reform progression of Japan's electricity market has come into the fifth round. It is hoped that Japan will progress new electricity market mechanism bit by bit around 2020 [46]. Japan' power grid is settled of 10 electricity companies. After Okinawa Electric Power Company controls independently, the other nine electricity companies are associated to the power grid of other electricity companies in surrounding fields. From most several countries, the east and west power grids in Japan have various frequencies. The frequency of the eastern power grid is 50Hz whereas the western power grid is 60Hz. The western and eastern power grids are linked by back-to-back converter stations. Nonetheless, the interconnection between the western and the eastern power grid leads to only 1.2 million kilowatts of mutual backing capacity that makes the coordination ability of the whole network insufficient in Japan in the face of main disasters and not able to dispatch in time [46].

Japan's electricity market is a representative local monopoly market. It fundamentally forms a general electric power company in every state while each power company controls the power supply in its jurisdiction. Japan resists them to be determined in Power Producer and Supplier (PPS), Independent Power Producer (IPP), General Electric Power Company as well as wholesale power companies for power suppliers. Amidst, General Electric Power Company mentions to 10 vertical integrated power companies in Japan which run provincial power generation, transmission, distribution, and sales. They own transmission and distribution networks and all power requisites to be supplied through the transmission and distribution networks [46].

It is essential to further activate the electricity market to acquire the reliable power supply as well as fair competition in the electricity market. Consequently, Japan schemes to promote the improvement of the power system by the market mechanism. Meanwhile, as shown in **Fig.3.2**, Japan aims to form new electricity market mechanisms likewise the capacity market, the base-load market, non-fossil value trading market and allocation of cross regional power tie-lines to improve the liquidity of the electricity market [46] and details have been discussed and illustrated in **Fig.3.2**.

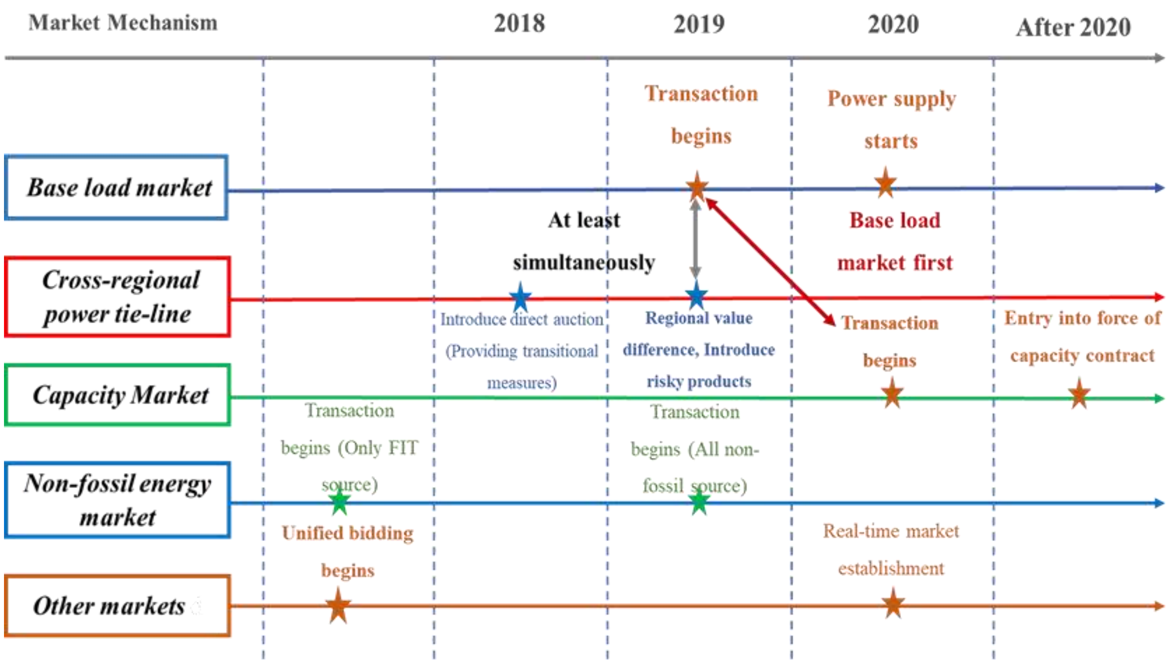

Fig. 3.2 Japanese electricity market introduction time

3.4 Scenario of India

India is one of the fleeting thriving economies in the world and smart grid is present electrical power system for providing reliable, economical, distribution, transmission and generation, reliable, secure and efficient energy consumption [48]. In different directions several new significant challenges are facing power generation and distribute system for leading to wide inquiry efforts to enlarge use of renewable and sustainable sources. In that case it is basically necessitating a willful program of distribution of energy systematically implementing the energy requisite for various zones. Hereafter energy system and power vitally rely on embedded and often a protective system of optimization, communication sensors and control. The smart grid is expectable to reform current power grid by permitting two-way communication to enhance proficiency, sustainability and reliability of consumption, generation, transmission, and distribution of electrical power. Through 70% of pilots claims had experienced 9% reliability progression in the survey of 200 projects in 2013 of smart grid [48]. The fact of smart meter setting up in smart grid scheme in India is shown in **Fig. 3.3** Smart Metering communications simplifies controlling, monitoring and measurement of consumer info and control via smart meters placed at consumer home. It aids bidirectional flow of data between consumer and utility control center via communication mode. Smart meter has two-way communication amenities to initiate smart grid. It also allows time of usage and ultimate peak pricing rate metering for demand response [48].

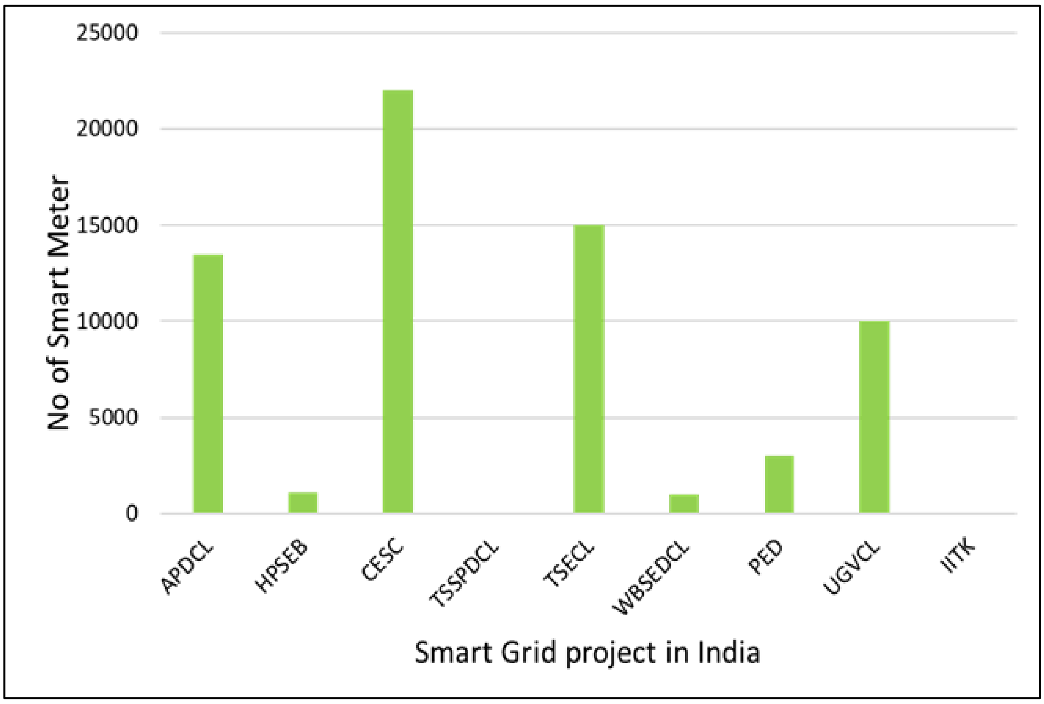

Fig. 3.3 Smart Meter Installation in smart grid projects in India

India is growing several smart grid initiatives likewise “Smart Grid Vision and Roadmap for India”, “National Smart Grid Mission”, “Nehru National Solar Mission” etc. with the aim of raising reliability and performance of the grid as well as to support technical, economic and social improvement. The installation of RERs has developed at an annual rate of 25% in the last decade. An initiative has been taken by POWERGRID Corporation of India to progress a smart grid pilot project at Puducherry. The purpose of this project establishing the technology efficiency, policy publicity and regulatory framework for tariff design, deliver input for standardization and interoperability framework of various technologies, net metering, electric vehicle expansion with charging via renewables, etc.[44].

Hydro, thermal, nuclear resources are in India, but nowadays renewable power production offers better electrical power generation. **Fig. 3.4** symbolizes generation capacity in India by different generation resources. The installed renewable energy capacity of India from available resources likewise small hydro, wind energy and biomass solar in fig. shows utmost power generation through wind energy [48].

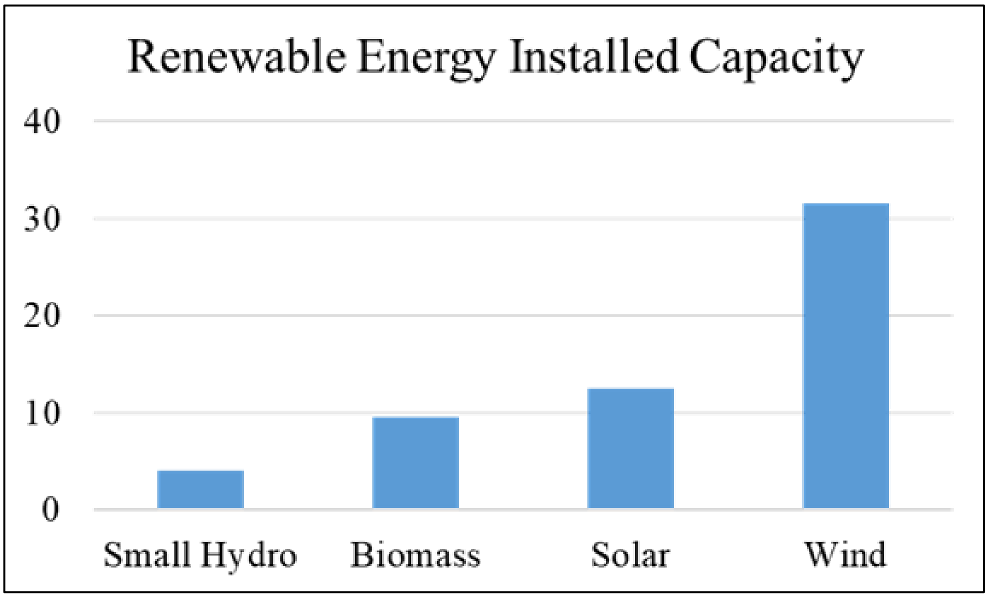

Fig. 3.4 Renewable Energy Installed Capacity

3.5 Reliability Problem in Smart Grid

Bulk Power System Reliability Risk, SG Uncertainty, Advanced System Optimization and Efficiency [48] which has been discussed in following **Table 3.1**.

Table 3.1 Reliability problems and facts in SG [48]

Sr. No.	Reliability Problems	Facts
1.	Bulk Power System Reliability Risk	➢ Cyber Security ➢ Increase Complexity ➢ Architectures
2.	Smart Grid Uncertainty	➢ Economic Growth ➢ Energy Markets ➢ Customer Trends
3.	Advanced System Optimization and Efficiency	➢ Stochastic Optimization ➢ Inter Control Area ➢ Enhancing System Performance

3.6 Future Aspect of Smart Grid in Asia

3.6.1 China

China plans to fund a lot in grid improvement to assist solving these issues. Meanwhile with its industrial base and rustic electrification purpose the country can reach $3.83 billion in 2022 [49]. It is hoped to double China's demand for electricity by the next decade and triple by 2035 as China has become the world's customer of electricity. To the thriving numbers of wind energy and solar energy, smart grid will be a significant approach. It has to figure out the way of carrying trillions of kWh of power to more than a billion consumers by means of distance being one of the tests [47]. There are a number of features exist in China for availing to its world smart grid impact. Southern Grid and State Grid had combined consumptions of $43 billion and the plan is anticipated to increase 15 to 20 annual rate over the upcoming 10 years. The hugeness of the expenses will be allowing China to implement the latest technology into its system [47]. The Chinese government will yield attempts to the advancement of smart grid over the next five years by the 12th in Five-Year Plan. In point of fact, the government has already been incrementing depositing into smart grid technology. This is in answer to the national demand that is prospective to double in upcoming 10 years. The intention is to lessen carbon density by 40 to 45 per cent by 2020 relative to 2005 by China's political leaders.

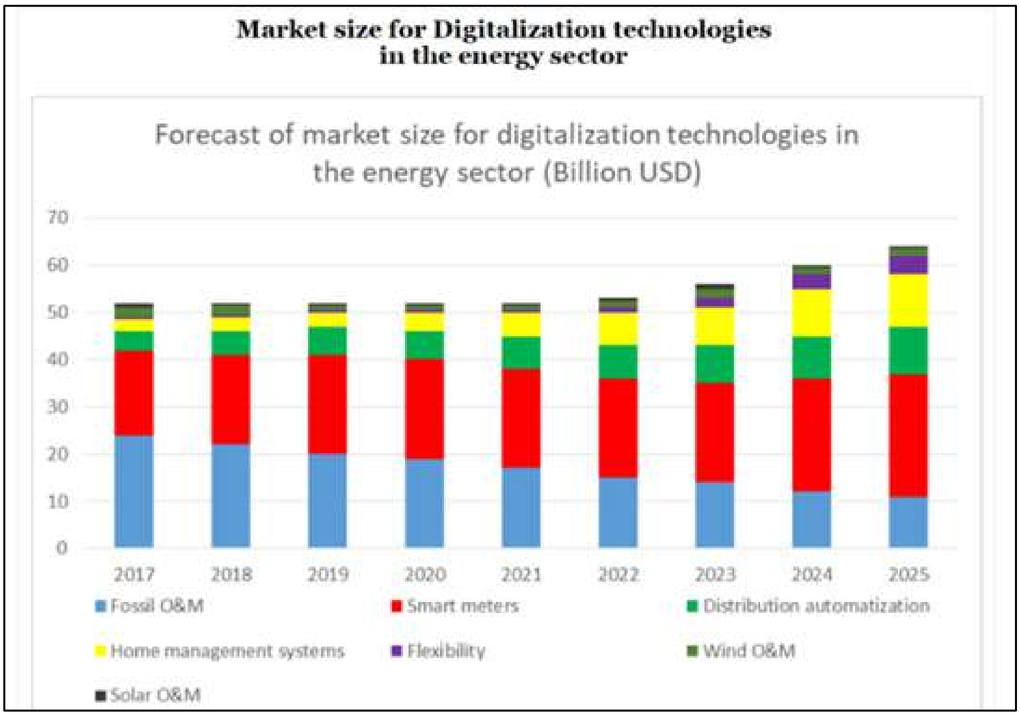

Fig. 3.5 Market size for digitalization technologies in the energy sector [47]

The government is also shoving for the usage of renewable energy source, cleaner, hopeful extensive transformation of the nation’s energy landscape. In **Fig. 3.5** market size for digitalization technologies in the energy sector has been depicted. The forecast shows that smart meter’s percentage is higher in 2025. At the same time from the **Fig. 3.6** it is very much clear that there is a sharp exponential increase for transmission upgrades. These are the indication of smart grid progression in China. These aspiring strategies of China have enticed top equipment makers, integrated solutions providers and communication device players around the world [47].

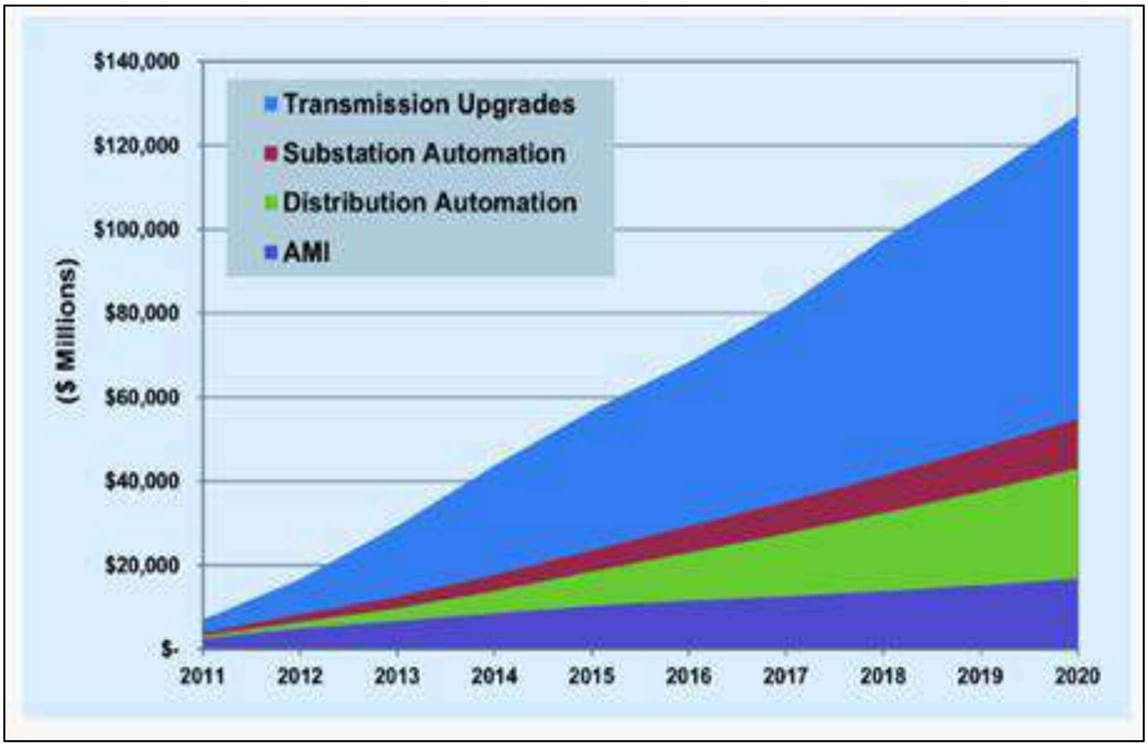

Fig. 3.6 Annual overall smart grid revenue of main smart grid technologies in China [50]

3.6.2 Japan

Japan’s electricity market was engrossed vertically by 10 general electric power companies and lacked market competition before 1995. Four times of conservative electricity modifications were carried out in 1995, 2000, 2005 and 2008 respectively driven by the impact of international trends and Japan's high electricity prices. The reforms concentrated on the liberalization of the production side and retail side (stage by-stage open users’ decision), however since it was relaxed to 50kV or above in 2005, the users’ choice was stagnated. Though the generation market was open to PPS, its market share is very inadequate, the power market is almost controlled by 10 general electric power companies. The Fukushima nuclear leakage headed to the scarcity of power supply, the constraint of cross-regional power support and the increasing price of electricity in 2011 [46]. Consequently, in 2013 Japan led the fifth electricity market transformation that was carried out in three stages (2015, 2016 and 2020). The aim of this round of reform is to guarantee the stable supply of electricity, limiting the rise of electricity prices, expanding the choice of power users and promoting the advancement of pertinent enterprises. The content and process of Japan's reforms are presented in **Fig. 3.7**.

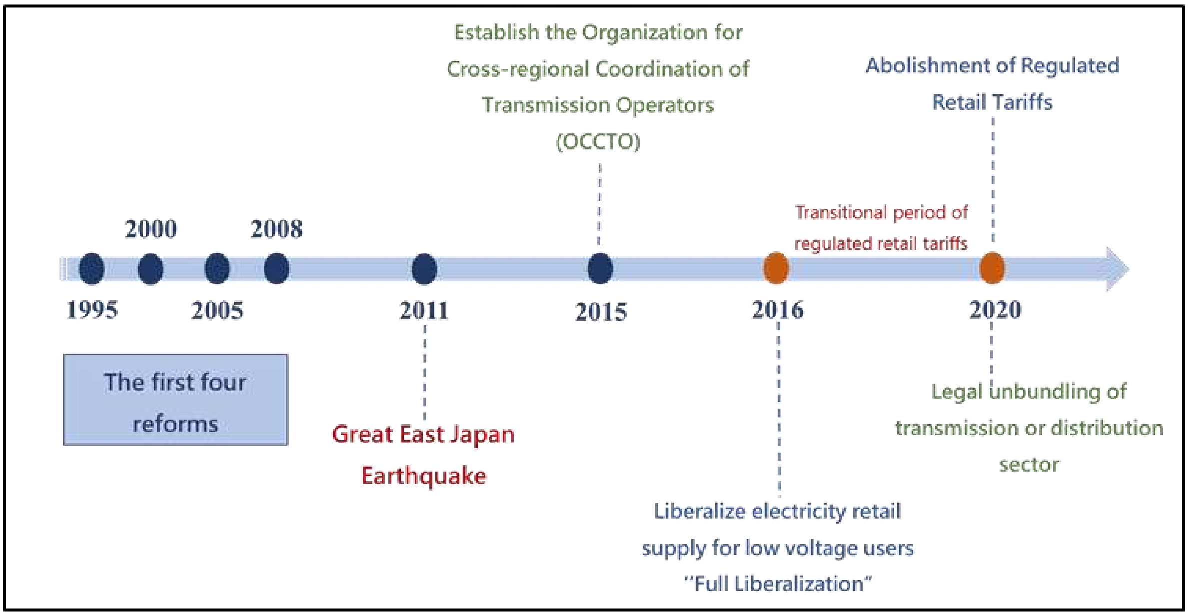

Fig. 3.7 Liberalization of Electricity market in Japan

On June 1, 2015, the Japanese government fixed the target of Japan's energy structure by 2030, as presented in **Fig. 3.8**. Japan will comprehensively increment the proportion of renewable energy in its upcoming energy structure as can be seen from the figure. Japan revised "Higher Energy Supply Structure Act" in 2016 which specifies that the proportion of non-fossil energy (nuclear energy, renewable energy) in the electricity sales of electricity sellers and annual electricity sales are more than 500 million kWh (see **Fig. 3.8**) and it should be more than 44% from 2030 [46].

It is hoped to extend 80 million smart meters by 2024 (see **Fig. 3.8**). The uplift of grid advancements and technologies in Japan are expected continuing bit by bit to aim a downfall in power demand from changing population demographics, cross-regional electricity trading and extension of distributed energy resources and integration of intermittent renewable power sources consistent with Fitch Solutions. Having strong government support, the deregulation and general falling costs, investor interests into smart grid technologies were observed to have risen noticeably in Japan with several large-scale projects succeeding. The country is hoping to have 80 million smart meters deployment by 2024 [51], which is very much understand from **Fig. 3.8** as well.

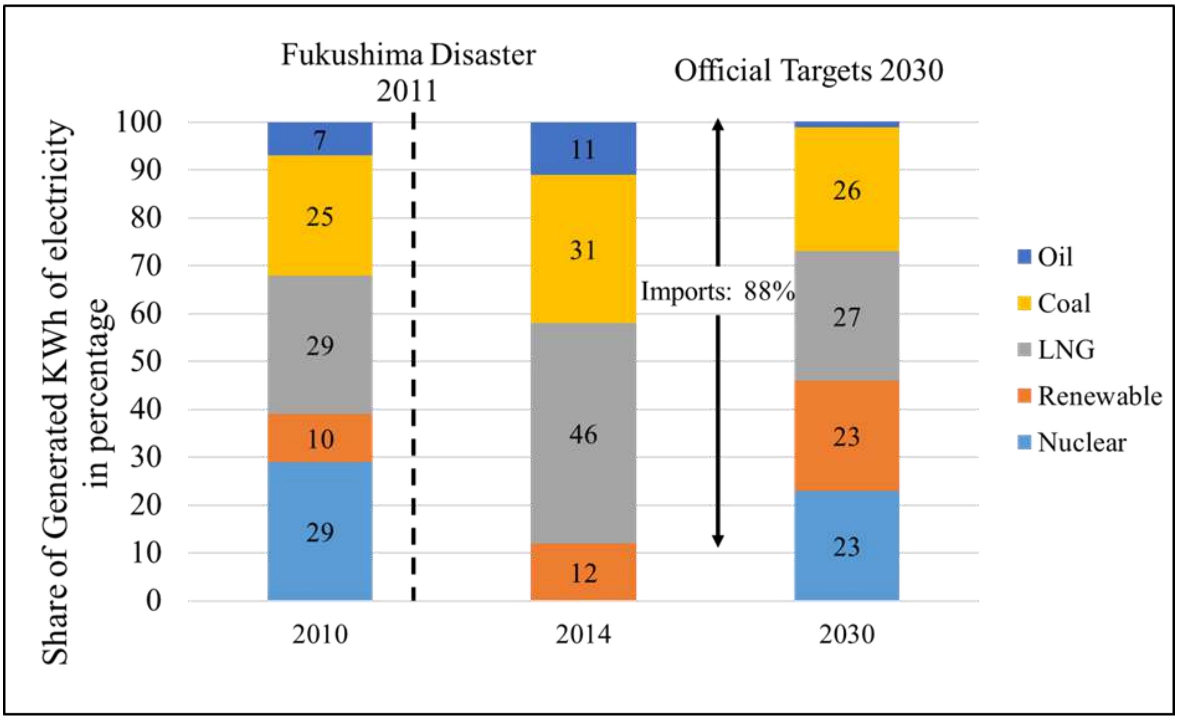

Fig. 3.8 Generation structure planning of Japan in 2030

These upgrades have taken essentially in the form of smart meter rollouts energy storage technologies and distributed energy resources (DERs), but then again also seen multiple pilot programs and advancements into other innovations likewise Virtual Power Plants (VPPs), Vehicle-2-Grid (V2G) and block chain technologies. These are prospective to encourage the intermittent nature of renewables as it expands power supply/demand management and energy efficacy [51].

3.6.3 India

Nearly every building in urban and semi-urban areas on earth will have broadband internet connectivity accompanied by India Smart Grid Forum (ISGF) by 2020. This can abolish the requisite of data concentrator units or gateways as it becomes promising to upload data from smart meters directly to internet and it can be downloaded at Head End System immediately. Furthermore, the Government of India intents to implement 250 million smart meters, replacing traditional meters, eyeing its technological benefits. Smart meters can be connected to a Wi-Fi network in the building or home or neighborhood which links the meter via broadband internet to send meter records. The Head End System (HES) and the Meter Data Management System (MDMS) can collect data by linking to internet. Data can be send to utility applications also as well as consumer's application on their smart phones abolishing the requisition for In-Home Displays. The Govt. of India was following a program, National Optical Fiber Network, for providing broadband connectivity to 250,000 villages. It was decided to spread to 600,000 villages under the Digital India program to provide universal broadband access to everyone. These structures will form a dedicated fiber backbone network for the Indian power system and may bring broadband access to utmost part of the country [52].

An extensive master plan for grid integration of large scale renewable capacity adding 12th -Five Year plan across India has been formulated in the "Green Energy Corridors" report which covers intra-state & inter-state transmission systems and alleviating measures for grid interconnection of variable & intermittent renewable energy likewise flexible generation, setting up of Renewable Energy Management Center (REMC), renewable forecasting, energy storage facility etc. The master plan also covers perspective idea for large scale renewable generation by 2030 and 2050 [53], which has been presented in **Fig. 3.9**.

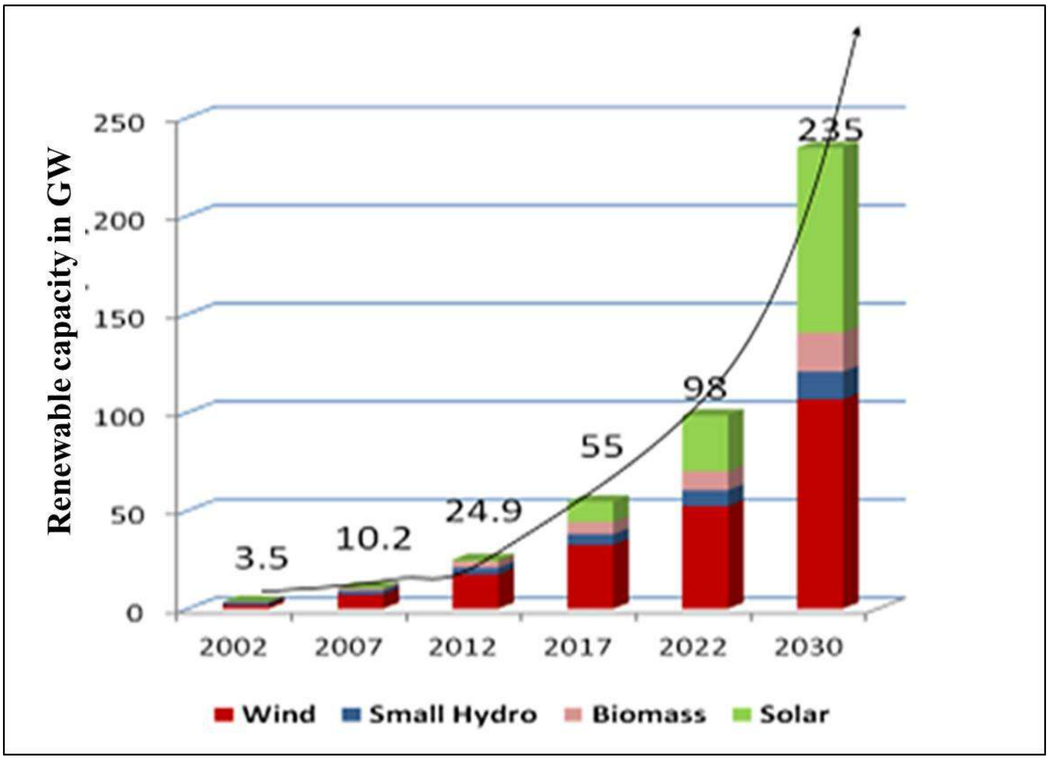

Fig. 3.9 Renewable generation growth trend in India [53]

3.7 Progression of Smart Grid in Bangladesh

3.7.1 Introduction

The research world is always looking for mobility and different innovative work types for making human life more upgraded and easier. Due to coping with the ongoing modern world, the energy demand also increases dramatically over the years [54]. A modern power grid is necessary which will be smarter on the basis of power generation, transmission and distribution to ensure a sustainable, reasonable and reliable supply of electricity. Smart grid implementation can be better means to progress greener digital Bangladesh. This modern technology ascertains feasible control of electric supply, demand using information technology and promises the potential use of environment friendly power generation [55]. Electricity supply through smart grid mechanism is achieving significance in many countries' priority lists. To guarantee a smooth transition to the smart grid, a detailed study on electricity forecasting is requisite. To make sure better management of production plants, supply grids and the transmission system, forecasting is obvious [54]-[56]. Current power industry faces an exceptional challenge with the constant rising cognition of energy and environment, the demand of safe and steady running grid, requirement of high quality and reliable supply along with forming a sustainable economy that assures progress of present and upcoming world inhabitants. Consequently, expanding smarter grid is being deliberated as a common goal for various countries in the entire world and they are looking forward to this modern intellectual grid system as the upcoming solution for the prevailing moldy power infrastructures. The aim is frequently focused on integrating several sources, energy monitoring and real-time controlling, interoperability, wide area communications systems and support of innovative services to customers [54]-[57].

However, the smart power grid is achieving very fast interest over the world, several nations have several status in energy sector, which makes their own contraventions and roadmap towards smart grid different. Current power distribution infrastructure is very complicated and unsuitable to the requisitions of the 21st century. In addition, because of its scheme and engineering is not that much proficient and skilled to handle such power demand with feature, Bangladesh power grid meets many challenges. In Bangladesh, up to 35% of the current electricity production capacity is not utilized properly; presenting a smarter grid this loss could be lessened [57]-[61]. Scarcity of automated analysis, poor visibility, slow response by reason of using mechanical switches, absence of situational awareness etc., have contributed for unskillful and poor power quality as well as service which occurring blackouts over the past

30 years. The greenhouse gas emergence has been a major threat over the last few years because of fossil fuel used in electricity production and transportation industries. Hence, a new and inventive power grid infrastructure is immediately needed to address these significant technological contraventions in Bangladesh. Having discerned to follow smart grid technology, all of its various characteristics should be taken into consideration [55]. Electricity is a prerequisite for economic enrichment. Overall consumption will be raised by 50% by 2030, if the present world energy consumption pattern stays [59]-[62]. These energy exchanges are more noticeable in a country undergoing an economic shift. The industrial sector commonly uses 45% to 50% of the total commercial energy in a developing country [62]. It comprises various operational and energy measures via smart appliances, smart meters and energy proficient resources [58]-[60]. Demand forecasting even in end-user level can be gained via the smart grid [56]. It will provide the essential information for better awareness of separate usage pattern and proficient pricing strategy also planning for growth [60]. Electricity production cost decrement and peak demand are two vital requisitions for smart grid. To reduce the peak demand for reducing generation cost, load scheduling is an effective way [58]-[60].

Power generated in various power plants all over Bangladesh is transmitted to the national grid via 230kV and 132kV transmission lines. In Bangladesh, at the end of 2018, the installed renewable power capacity was 579 MW, on-grid and off-grid installations comprised. In the year 2020, the total electricity generation was 25,000 MW. The government has given top importance to the improvement of the power sector in view of its significance in overall progress of the country and has set the aim of supplying electricity to all citizens by 2020 [58]-[60]. The problems in Bangladesh electric power sector comprise many moldy infrastructures, lags in completion of modern plants, high system losses, low plant proficiencies, unpredictable power supply, blackouts, electricity theft, land crisis, unproductive planning, overloading of system components, corruption, and scarcities of funds for power plant operation and maintenance etc. These leads to widespread load shedding causing severe interruption in all essential and economic activities.

3.7.2 Power Sector Overview

Electrical production capacity has raised from about 5 gigawatts in 2009 to around 21 gigawatts in 2019 and access to energy has extended to approximately 95% of the population. Nevertheless, the quality of electricity and reliability endure major issues. While keeping affordability, the progression of the supply and reliability of electricity as well as energy in general is vital to support the continued growth of industry and commerce in Bangladesh. The fuel mix of Bangladesh's power plants is deeply based on natural gas. The Government of Bangladesh plans to improve the use of imported liquefied natural gas (LNG) as well as to lessen the requirement on domestic natural gas. The Ministry of Power, Energy, and Mineral Resources Plans was reportedly reviewing plans since July 2020 to move Bangladesh's fuel mix towards coal comprising by producing approximately 50% of total electricity using coal-based power plants by 2030. The government is also bearing in mind to import electricity from adjacent countries and increasing the use of renewable resources, comprising solar and wind power [63].

90% of the population had penetration to electricity as stated by the Bangladesh Power Development Board in July 2018. In Bangladesh, an average of 77.9% of the population had penetration to electricity. Bangladesh's power sector is one of the rapid developing in South Asia. The progression in terms of capacity summation has been notable. It is growing from 5% to 28% from 2012 to 2018 consistent with the World Bank and the Bangladesh Power Development Board [63].

3.7.3 Demand Response

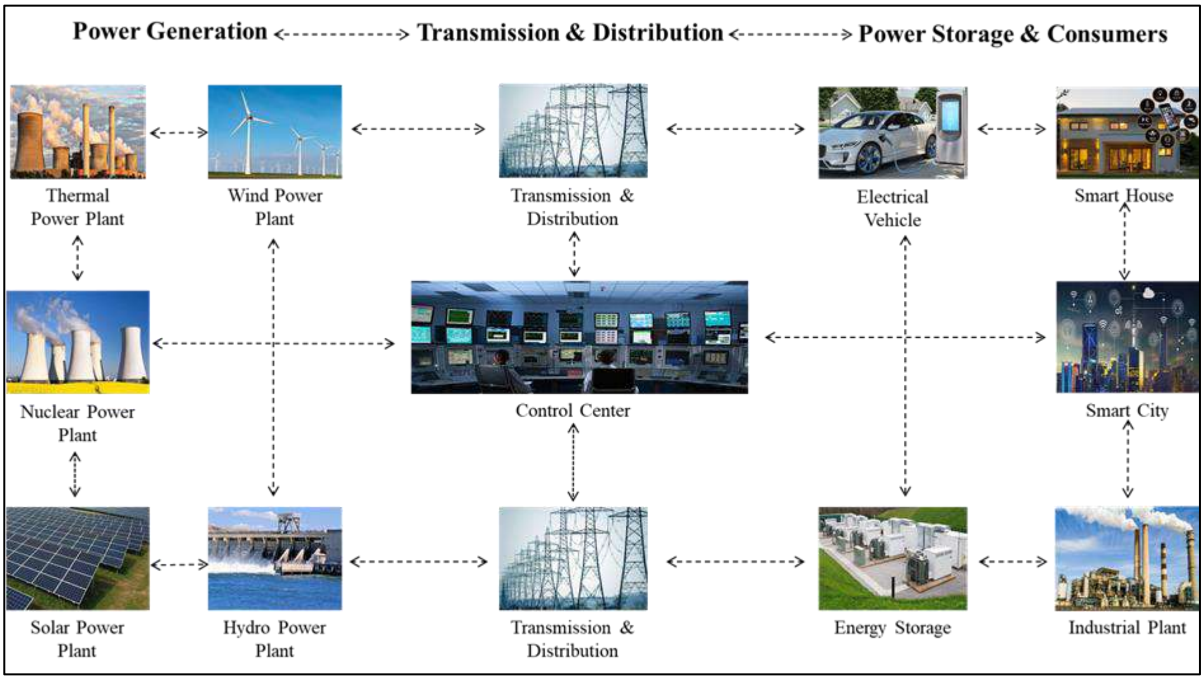

Fig. 3.10 General framework including Power Generation, Transmission & Distribution, and Power storage & Consumers for implementation of Smart Grid (SG) technology replacing a traditional grid system [60]

Demand response strengthens mostly on partial use of electricity when the system demand goes in peak and organizes the consumers to support them lessening the peak use with price indicators or time-based inducements. In the **Fig. 3.10**, the General framework including Power Generation, Transmission & Distribution, and Power storage & Consumers for implementation of Smart Grid (SG) technology replacing a traditional grid system [60] has been represented. This illustration shows the energy versatility and interconnection between the smart power system grids.

The solutions differ from simple advanced metering infrastructure (AMI) systems to completely automatic home systems. New smart gird will assist demand response consumptions and it will significantly minimize farmers cultivating expense when irrigating off peak hours as Bangladesh is an agricultural dependent country and its irrigation consumes massive amount electricity [54]-[60].

3.7.4 Integration of the Renewable Energy Sources

Another significant part of the smart grid system is integrating renewable energy with it. It is an essential part for rising the self-healing criteria in smart grid. Either the renewable source can be linked straight to the grid, or it could be linked to the home network precisely. The benefit of integrating renewable energy into the home network is they could feed the enduring energy back to the power grid if an exact home or a building can generate more energy beyond its energy demand [64]. In doing so, the consumers can also be monetarily benefited. Renewable energy sources mostly rely on natural resources and graphically represented in **Fig. 3.11**.

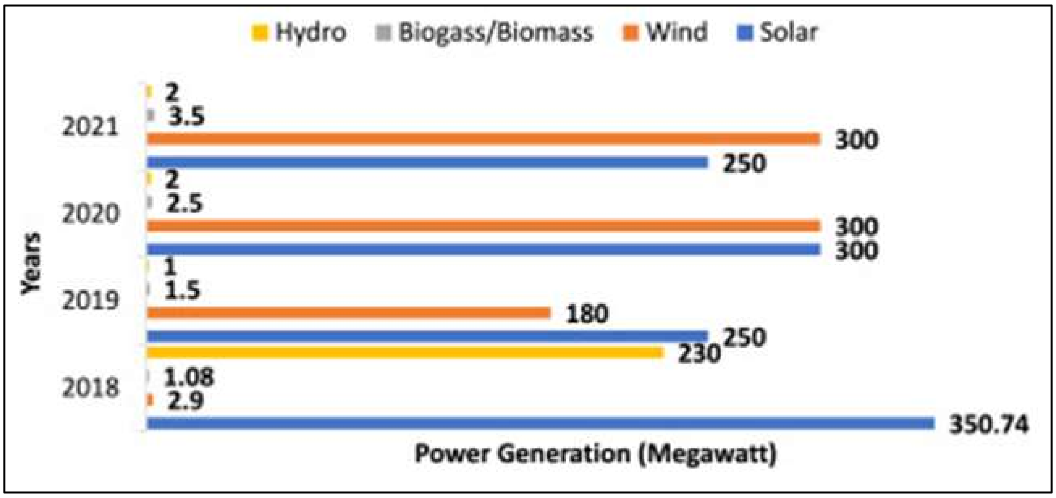

Fig. 3.11 Renewable energy source dependent power generation in megawatt [2018-2021]

The existing energy resources in Bangladesh are solar energy, wind, biomass, and hydropower. For propagating power from renewable sources, the government of Bangladesh has taken few projects. Sustainable and Renewable Energy Development Authority (SREDA) is the chief answerable department of Bangladesh to supervise these projects. SREDA has been planning to yield from renewable sources 10% till 2020, 15% till 2021 as well as 20% till 2030 of total electricity [54]-[60].

3.7.5 Prospects of Smart Grid in Bangladesh

Through a great pressure of daily improved power demand, currently the utilities are collecting many new generation facilities with little capacities to its power grid. It is for quick rent basis to deal with the current power shortage problem. But eventually, Bangladesh requires a power system reformation and a sustainable clarification to the problems. These reforms must be in a path that would fulfil the prospects of power plant in the 21st century. With the aim of reaching this aim, the Smart Grid is a definite choice for Bangladesh [60].

3.7.6 Proposed Adaptation for SG Implementation in Bangladesh

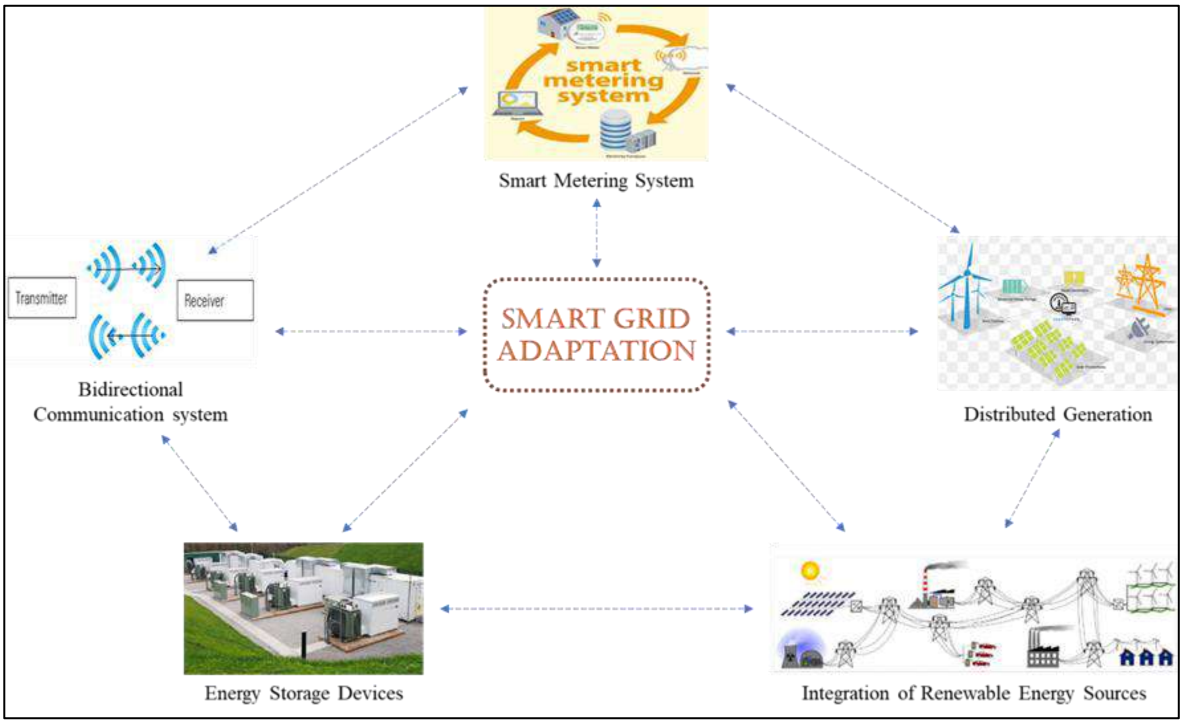

Fig. 3.12 Flow chart of the proposed adaptation of SG implementation in Bangladesh [60]

One of the most important concerns not only in the developed countries but also in the developing countries likewise Bangladesh is energy proficient power system. Henceforward sustainability is the first and foremost topic in a proficient energy system by lessening power losses likewise smart grid system. Moreover, in view of the economy in Bangladesh, transforming the full power sector into an energy efficient smart grid system will be time-consuming. Consequently, the next steps are planned here to adapt the SG system in Bangladesh. Likewise installing smart metering system, integrating all the power sections by using smart communication system, advancing automation in the grid system, founding some software application to integrate the SCADA and AMI system. **Fig. 3.12** explains the known significant factors influencing the effective implementation of SG [60].

3.7.7 Future Prospect and Necessity of Smart Grid for Bangladesh

In Bangladesh the demand for electricity is prominent to attain 40,000 megawatts (MW) by 2030. The Government of Bangladesh has plans to rise power production beyond predictable demand. It is to assist propel development in the export-oriented economy as well as meeting the requirements of a rising middle class by raising $70 billion in total funds in the sector over the upcoming 15 years. Electricity generation capacity has enlarged meaningfully over the last decade, in spite of insufficient thermal proficiency in a great number of moldy power plants, poor transmission and distribution infrastructure and a disparity between the types of energy required by current plants and the fuel mix existing. About half of total installed capacity is comprised via Private power generation units [63]. Bangladesh will require an expected 34,000 MW of power by 2030 to maintain its economic development of over 7%. Oil, coal, and gas are the nation's main source of fuel for generating electricity. To make sure the electricity production, it is necessary to assure major energy sources. Total electricity demand in Bangladesh will be nearly 20,000 MW in the year 2021 [63].

Smart grid systems assist to give quality electricity for everyone. They simplify the interchange of data between electricity providers and consumers as well as synthesize the flow of electricity in real time, by such means enabling more proficient management of the electricity network. This is the happening in Bangladesh, the 8th most overcrowded country in the world. 116 million of its 166 million people still live in rustic areas. The country’s current economic improvement has minimized the number of people living below the impoverished line additionally to creating advancements in infrastructure. As witnessed in the increasing rate of households linked to the electricity grid from 10% in 1994 is working towards gaining its aim of 96% connectivity by 2020.

Today, the smart grid in Bangladesh is in its childhood and simply contains propagating smart meters. Our project conveniences from around 100 million euros in investigating collection to a further 12 million euros from the European Union. With this project, AFD is fortifies its role as an active participant in the search for and the use of advanced digital solutions in distribution stations and in medium-voltage grids. Moving forward automation will come to expand performance of the grid permitting the electricity provider to optimize energy distribution without making it too bulky of an investment. The concept is to work with the current network, ensuring to control if as it refuges its dynamic limits to assure it doesn’t cause blackouts for the users. In this manner it becomes more stable, having no interruptions as well as having a greater volume of energy distributed.

It will hence remove the pollution caused by the diesel generators that are used as back-up by grid outages as the smart grid advances grid performance. A total of 1,141,000 people will be convenient from a noteworthy development in the quality of electricity service. The project also assists fighting climate change by restraining an accumulated 104,000 tons of CO_2 emergence per year. The smart grid solution is of vast operational value in total by not just comprising the project with Dhaka Power Distribution Company (DPDC). It makes it promising to perform maintenance upstream of failures as well as to optimize the use of tools (circuit breakers, power transformers etc.). This is made probable by real-time algorithms that endlessly analyze the hardware linked to the grid and in this way prolong its life. The digital occurrence at all levels of the network permit for better knowledge of the network and expectation of outage-related events. The smart grid provides us a more reliable and approachable grid.

CHAPTER 4

METHODOLOGY

4.1 Introduction

In the last couple of decades smart world seeking for smart solution and leading towards the renewable based reliable smart power grid system. In most of the research result and experiment comes into a certain conclusion that direct conversion into renewable is rising the reliability issue. As a consequence of that reliability wise hybrid smart grid system comes into the context. By taking current demand and research world flow our research work has also focused on the hybrid system power development process with the introduction of the smart control system.

4.2 Proposed Model Details and Working Principle

Reviewing the scenario of smart grid system for all over the world, Asian region and for Bangladesh, the purpose of this thesis is to design a hybrid power system combined with PV and conventional power plant to lead the smart grid system of Bangladesh towards focusing on the green future energy. By implementing this hybrid system, we can reduce global warming as it will help to lessen the CO_2 emissions and it will also help us to reduce the power consumption from conventional power plant rather than before. A light detection system as a smart controller can assist as a switching system to shift from PV to conventional power system at night and also can shift from conventional to PV system at daytime. We found out by reviewing some research papers that no such work like implementing this proposed hybrid system has been done in Bangladesh till now. So, the purpose of our research thesis is to implement the smart hybrid system combining both PV and conventional power system with a smart light dictions system. The proposed model image has been depicted in **Fig. 4.1**.

The proposed hybrid system model is to combine the conventional power plant system with the photovoltaic system to lessen carbon emission. As in Bangladesh, the power generation sector mostly depends on the conventional power plant likewise coal, oil, natural gas and so on, every year in Bangladesh, the CO_2 emission rates increases extensively only to generate the electricity. From the **Fig. 4.1**, it is noticeable that by cause of the emissions of CO_2, Bangladesh will eventually face the impact as picture in near future. Nevertheless, in this regard, electricity production from photovoltaic system can assist in lessening the CO_2 emission and present a green future energy to Bangladesh. This is why, photovoltaic system is introduced with the conventional power plant system in this proposed model.

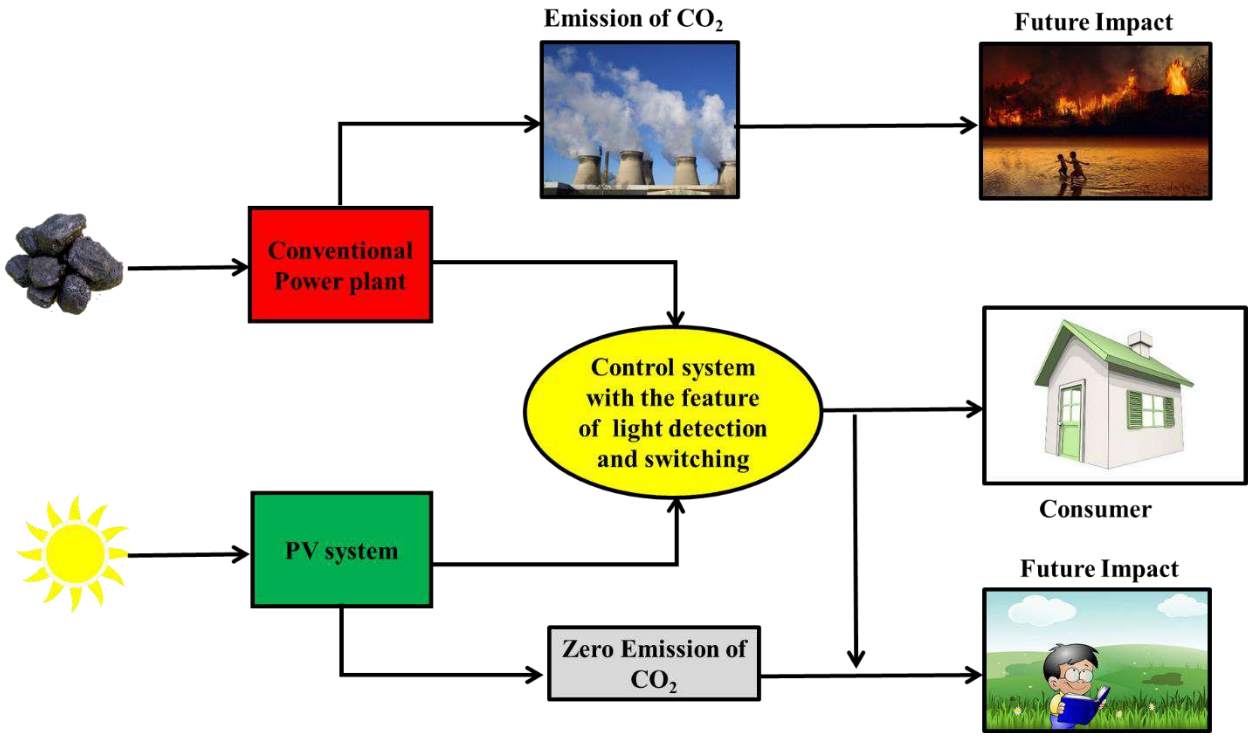

Fig. 4.1 Proposed hybrid system combining conventional power plant and PV system

However, simply if we summarize our proposed model comprise of the following items.

1. Photovoltaic system (PV)
2. Conventional power system
3. Smart control system
4. Consumer (Household and Industry)

4.2.1 PV System

A photovoltaic device or solar cell can be defined as an electrical device that converts light energy into electrical energy via the photovoltaic effect. Basically, a solar cell is a p-n junction diode. Solar cells are a form of photoelectric cell which has electrical characteristics – such as current, voltage, or resistance and those characteristics vary when exposed to light. To form the modules each solar cells can be combined and that is known as solar panels [64].

Advantages of Solar Cell [64].

- No pollution associated with it.
- It must last for a long time.
- No maintenance cost.

Disadvantages of Solar Cell [64].

- It has high cost of installation.
- It has low efficiency.
- During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

The solar module produces the DC power and to make it usable form for the household and grid, it has to convert into the AC power through inverter. In a simple way the working principle can be explained with the following **Fig. 4.2**. When the sun light strikes the solar module due to the movement of the carrier from valance band to conduction band the flow of electric current which is one directional (DC). Then by using the inverter it can be supplied to the grid and household [65].

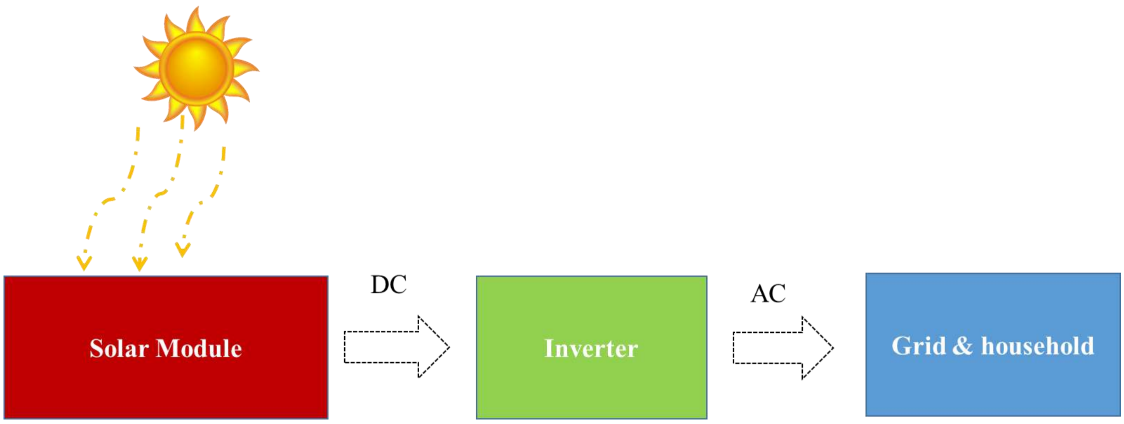

Fig. 4.2 PV module working condition image [65]

Entire world is now focusing on the solar cell. But as it has environment dependency, efficiency and stability concern therefore, it is little bit difficult to convert fully to PV system-based power system [65]-[69].

4.2.2. Conventional Power Plant

Conventional power plant is the common term applied to the generation of electrical energy from oil, coal or natural gas using the medium of steam. The generator is generally a synchronous machine with a small number of poles (two or four) which runs at high speeds (1500–3600 rpm). The overall proficiency of energy transformation from fuel to electrical is highly authorized by the poor efficacy of the turbine and condenser [70]. The distinctive overall efficiency ranges from 30% to 40%. The main characteristics of these conventional plants are virtually no limit on their size and their low capital expense per kilowatt installed as compared to other plants. Habitually, these plants are centrally controlled at national level, taking into concern their capacity and dynamic features, aiming to match the overall demand that frequently varies but follows a fairly expectable pattern. This match is essential intending to keep the frequency of supply constant. The national grid control center selects a number of generating units with sufficient capacities to meet a particular demand [70].

4.2.3. Smart Control System

In the proposed hybrid model the third element is the smart control system which will be an electronic device. This electronic device will be made of light intensity detection system. Based on the light intensity detection it will response or perform the switching of power input for the consumer. In that system the program will be set to a certain minimum intensity level. If the light intensity goes beyond it the input power line will be connected the PV module and if the intensity goes below the certain limit value it will be switches to the conventional power system. As a result of that power supply will be uninterrupted and at the same time the power consumption from the conventional power plant will be reduced. Hence, the emission of the CO_2 will be reduced which is one of the major goal of this research work.

4.2.4. Consumer

In the proposed model the final element is consumer. After the generation we have to transmit the power to the consumer level. The consumer can be classified into two types.

- Household
- Industry

In terms of household consumer of Bangladesh the standard 220 V and the frequency is 50 Hz [71]. Country wise it may vary because of the manufacturing condition such as 220 - 240 V range is for the UK, Europe, Australia and most of Asia and Africa. Again, the range of 100 V - 127 V is in the US, Canada and most South American countries [71]. On the other hand, in terms of industry consumer of Bangladesh the voltage level reach to 440V.

Hence, due to this, we will be going to have a control system with having the feature of light detection and switching. At the time of daylight, using the solar irradiation and temperature from sun, consumer can get the electricity. This time there would be zero CO_2 emissions because of using the PV system. At the time of evening, consumer can switch to the conventional power generation by using the control system and use the electricity. As this will be a hybrid system, so as a result, the total CO_2 emissions rate can be lessened to normal and beneficial rate every year which have been discussed in the result and discussion part in brief.

4.3. Designed Simulation model

In this section, the MATLAB simulated model has been discussed in detail and depicted in **Fig. 4.3**. As fig shows the proposed smart comprises with the three main section. In left top PV system (see **Fig. 4.3**). In left most bottom Conventional power plant (see **Fig. 4.3**) and in-between PV and conventional power plant the light irradiance dependence control system has been placed. Final in the right most side for checking the output of our designed model a scope has connected. However, in our modeling the irradiance value has been changed from 800 W/m^2 to 1700 W/m^2 to verify our model whether it is working or not.

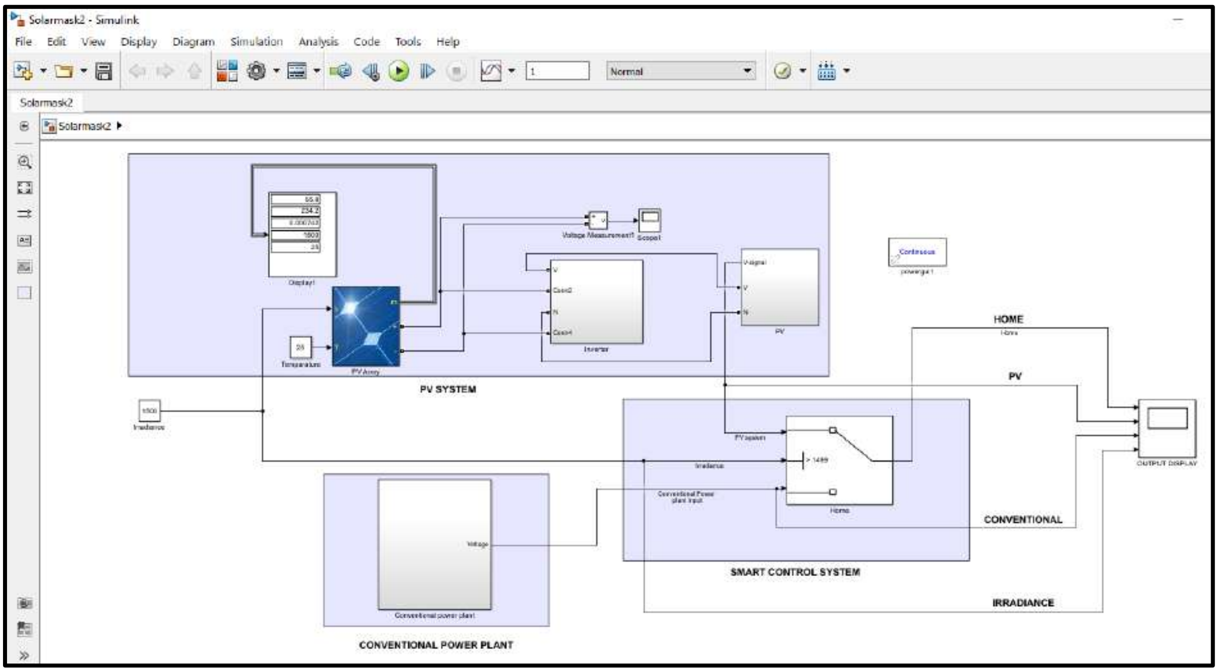

Fig. 4.3 Simulated MATLAB design of our proposed smart power grid system for household consumer

Here, in the control system the condition has been set as following.

1. If irradiance value >1499 W/m^2, the consumer will receive power from PV.
2. If irradiance value <1499 W/m^2, the consumer will receive power from Conventional.

In our model the PV system temperature was fixed to 25^o C and control system irradiance was fixed to 1500 W/m^2. However, based on the area and country irradiance value we can easily reset the condition value of our designed model. For different irradiance the designed model has been checked and output data collected, which is discussed in the RESULT AND DISCUSSION (CHAPTER 5) more briefly.

4.3.1. Design of PV System

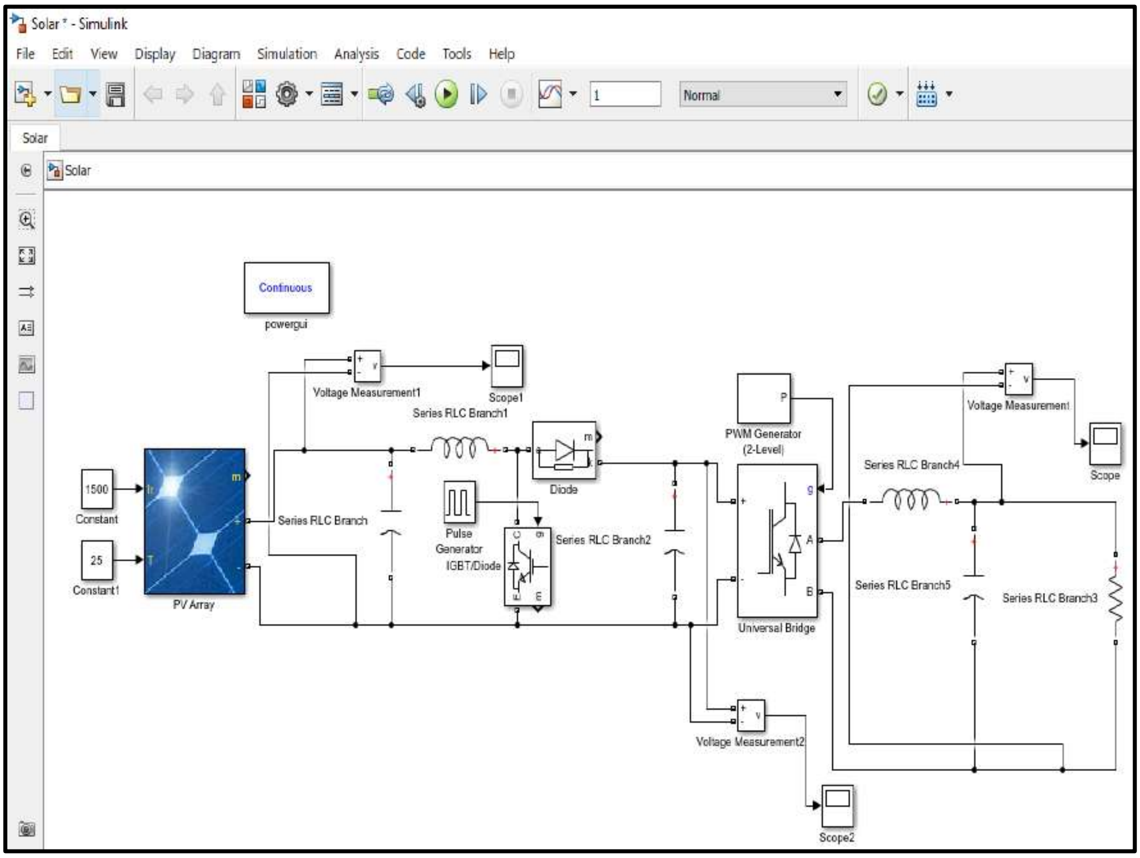

Fig. 4.4 Elaborated design of PV System in MATLAB

4.3.2. Design of Inverter

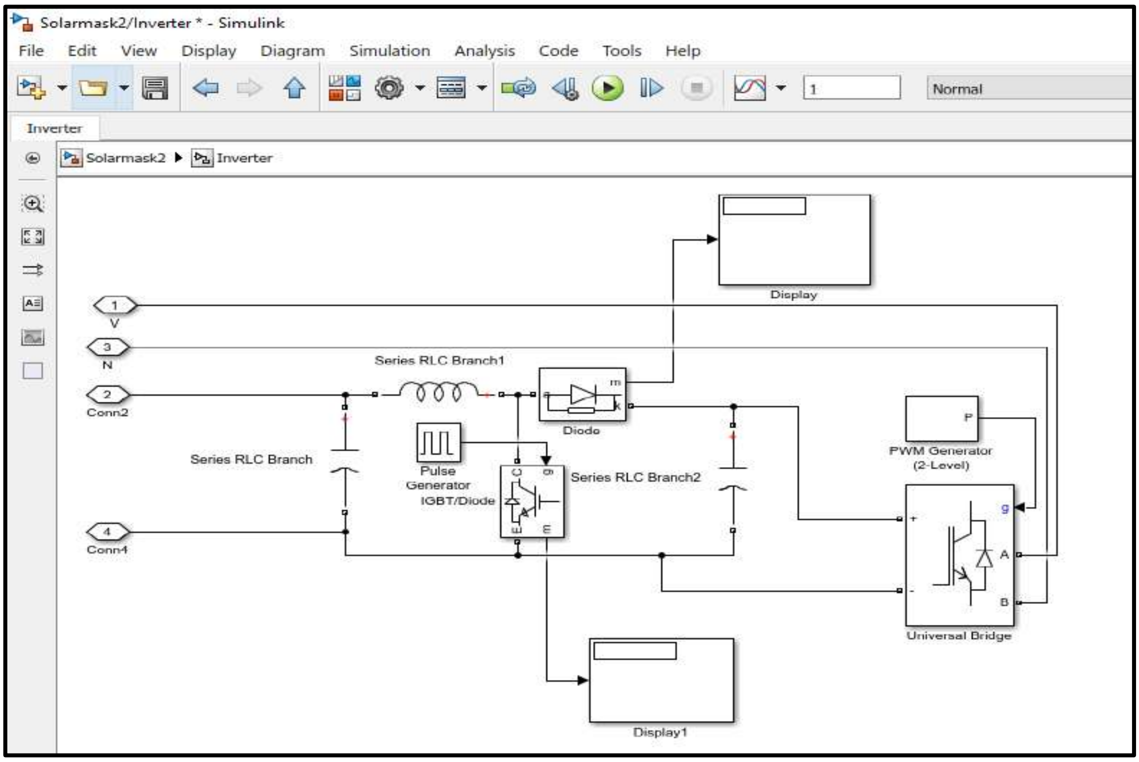

Fig. 4.5 Elaborated design of Inverter in MATLAB

4.3.3. Smart Control System

The following is the block diagram of smart control system. The given condition of solar irradiance in the control system is u>1499 W/m^2. The first input is connected from the PV signal and another one is connected from conventional power system signal. The output port of the controlled switch is connected with the scope from where we could get the output signals which would be matched with the given condition.

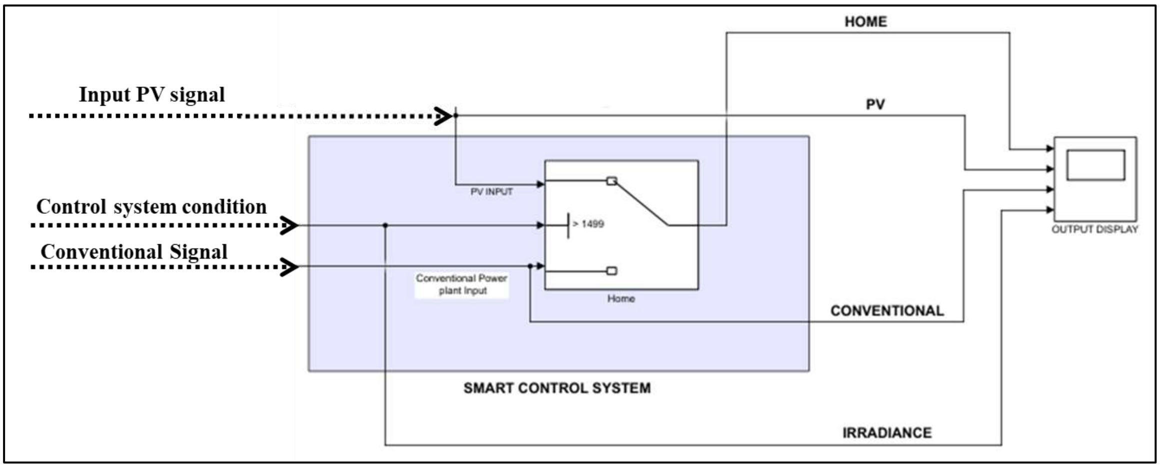

Fig. 4.6 Smart Control System Block

Likewise, if the condition goes with irradiance value below 1499 W/m^2, then from the scope result, we will get the conventional system signal supply to home system. If the condition goes with irradiance value greater than 1499 W/m^2, then from the scope result, we will get the PV system signal supply to home system. The irradiance value would be also shown in the scope getting the value from the control system condition port.

CHAPTER 5

RESULT AND DISCUSSION

5.1. Simulation result

In this chapter, the output scope result of the proposed and designed simulation model is described briefly. In the result section, (see **Fig. 5.1** to **Fig. 5.6**) the top sinusoidal voltage signal in red represents the home system, the second signal in blue represents the PV system and the third one in green represents the conventional power plant system and lastly the fourth one in pink represents the line of solar irradiance value which is given as the constant value in the designed control system. The system is working following the given condition to the system as u>1499 W/m^2. Whenever the solar irradiance value will be greater than 1499 W/m^2, then the signal should be gone through the PV system to home system and if the solar irradiance value is less than 1499 W/m^2, then the system will work as conventional power plant system. In this chapter along with the simulation result the energy demand for a standard house, hybrid power system implementation cost, impact on CO_2 emission have been discussed over the period of 30 years. Meanwhile, here the time has been selected for 30 years because as in our hybrid power system PV included and its warranty period is considered for 30 years.

5.2. Simulation output result at various irradiance value

In this section, the output result of the designed simulation model for different irradiance values are depicted and discussed briefly.

5.2.1. Irradiance value at 800 W/m^2

The output result for solar irradiance value at 800 W/m^2 is depicted in the following **Fig. 5.1**. If the irradiance value is at 800 W/m^2, then the signal should be gone through the conventional power plant system to home system by following the control system condition given as u> 1499 W/m^2. This is what is proven by the result output as the red (home) and green (conventional system) signals are matched because of solar irradiance value is below 1499 W/m^2.

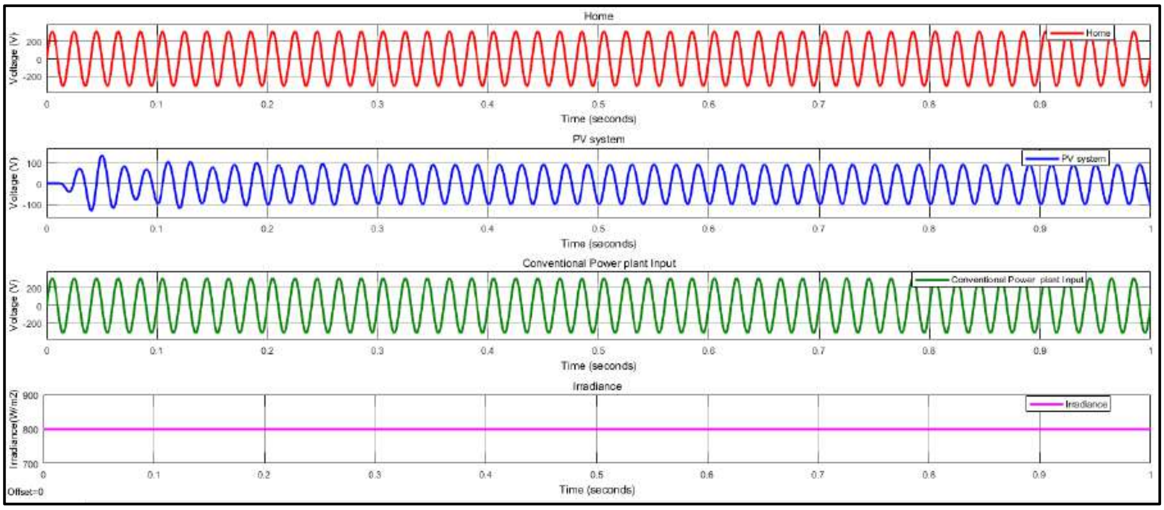

Fig. 5.1 Designed model output at 800 W/m^2

5.2.2. Irradiance value at 1000 W/m^2

The output result for solar irradiance value at 1000 W/m^2 is depicted in the following **Fig. 5.2**. If the irradiance value is at 1000 W/m^2, then the signal should be gone through the conventional power plant system to home system by following the control system condition given as u> 1499 W/m^2. This is what is proven by the result output as the red (home) and green (conventional system) signals are matched.

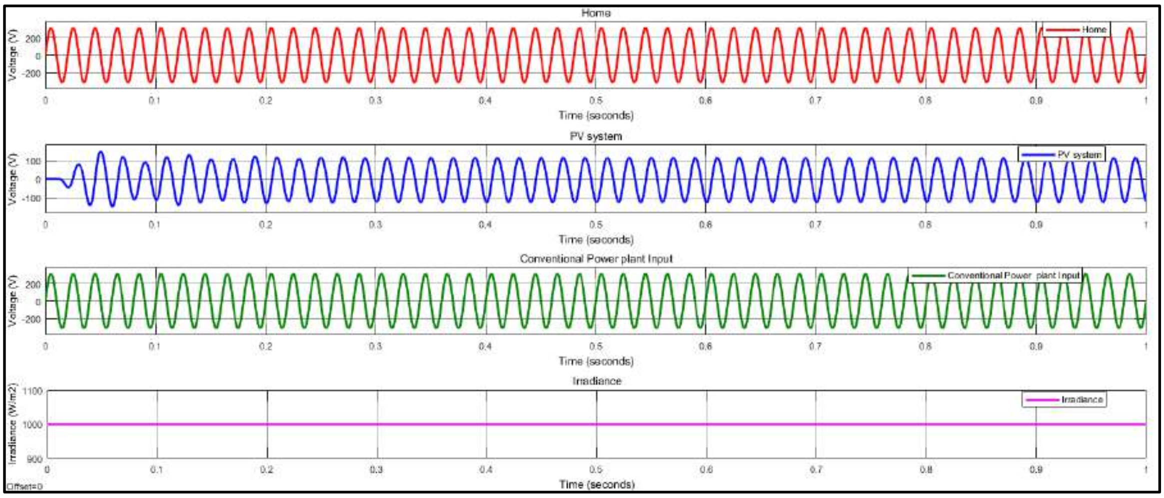

Fig. 5.2 Designed model output at 1000 W/m^2

5.2.3. Irradiance value at 1200 W/m²

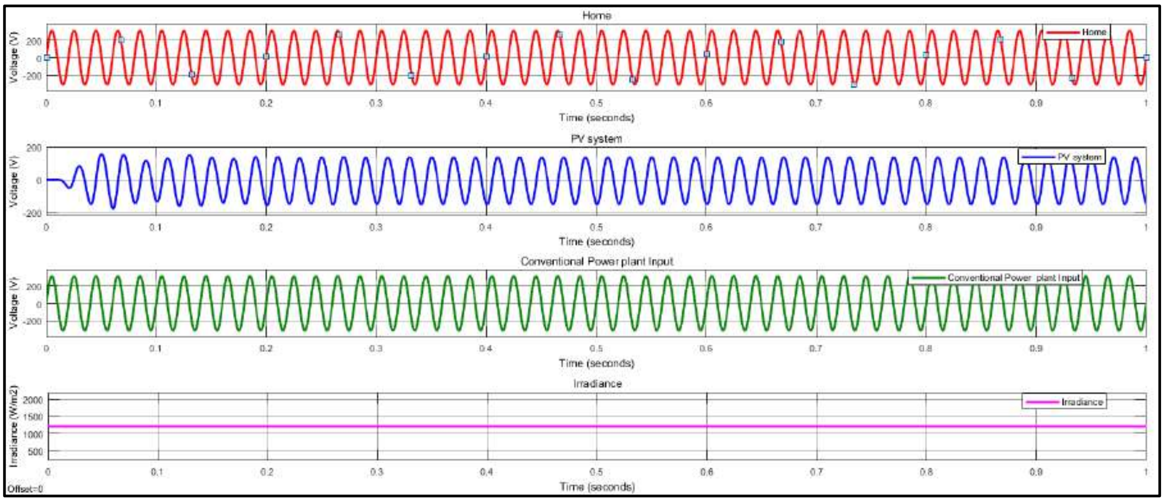

Fig. 5.3 Designed model output at 1200 W/m^2

The output result for solar irradiance value at 1200 W/m^2 is depicted in the following **Fig. 5.3**. If the irradiance value is at 1200 W/m^2, then the signal should be gone through the conventional power plant system to home system by following the control system condition given as u> 1499 W/m^2. This is what is proven by the result output as the red (home) and green (conventional system) signals are matched.

5.2.4. Irradiance value at 1400 W/m²

The output result for solar irradiance value at 1400 W/m^2 is depicted in the following **Fig. 5.4**. If the irradiance value is at 1400 W/m^2, then the signal should be gone through the conventional power plant system to home system by following the control system condition given as u> 1499 W/m^2. This is what is proven by the result output as the red (home) and green (conventional system) signals are matched.

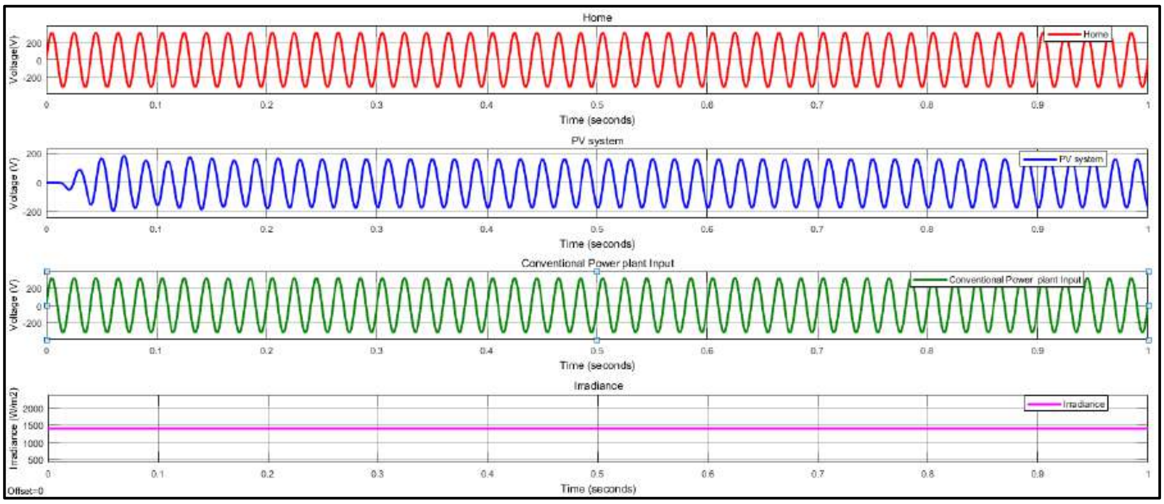

Fig. 5.4 Designed model output at 1400 W/m^2

5.2.5 Irradiance value at 1500 W/m^2

The output result for solar irradiance value at 1500 W/m^2 is depicted in the following **Fig. 5.5**. If the irradiance value is at 1500 W/m^2, then the signal should be gone through the PV system to home system by following the control system condition given as u> 1499 W/m^2. This is what is proven by the result output as the red (home) and blue (PV system) signals are matched because of irradiance value is greater than 1499 W/m^2.

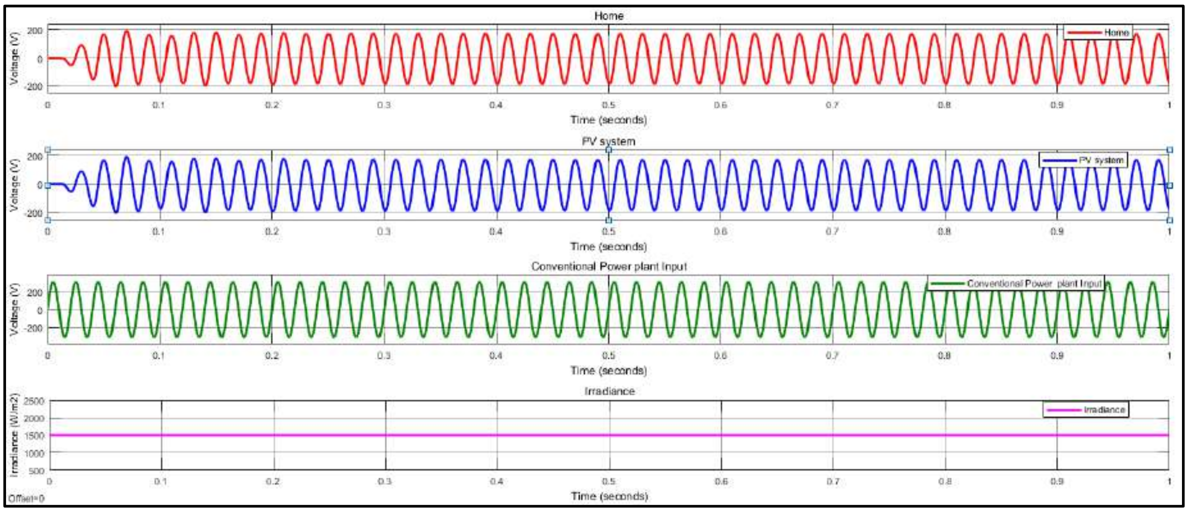

Fig. 5.5 Designed model output at 1500 W/m^2

5.2.6. Irradiance value at 1700 W/m²

The output result for solar irradiance value at 1700 W/m^2 is depicted in the following **Fig. 5.6**. If the irradiance value is at 1700 W/m^2, then the signal should be gone through the PV system to home system by following the control system condition given as u> 1499 W/m^2. This is what is proven by the result output as the red (home) and blue (PV system) signals are matched because of irradiance value is greater than 1499 W/m^2.

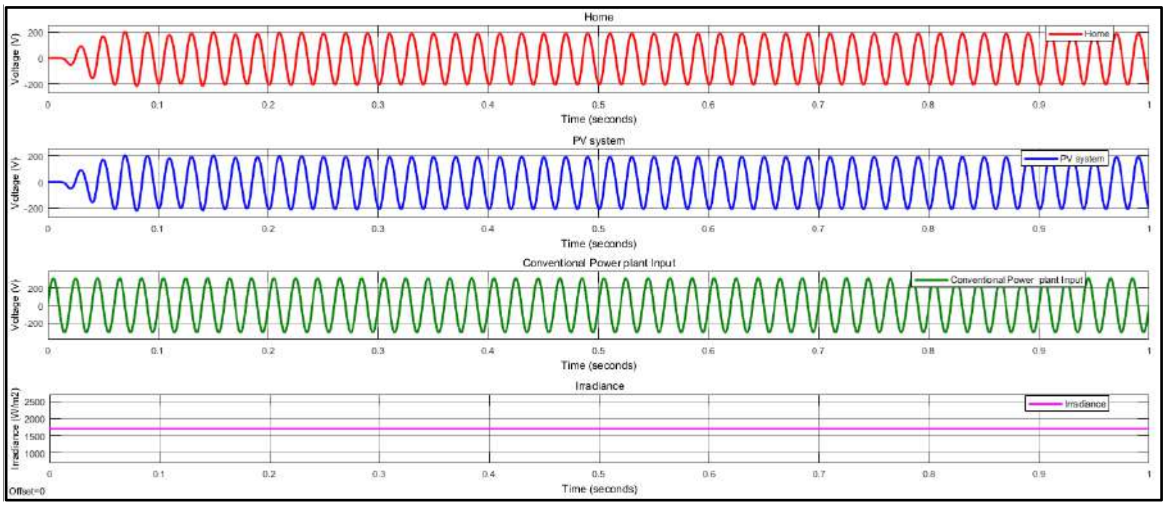

Fig. 5.6 Designed model output at 1700 W/m^2

5.3 Power demand of a household over the period of years

To show the benefit and cost analysis of the proposed hybrid system combining PV with conventional power system, we considered a typical apartment having an area of 120 m^2. The apartment has 3 bedrooms, 1 dining room, 1 drawing room, 1 kitchen and 3 bathrooms. Load calculation for an apartment is given below in **Table 5.1**.

Table 5.1 Energy demand per day for a standard apartment

SL	Appliance name	Appliance rating (watts)	Appliance number	Total power (watts)	Operating time (hour)	Total consumption (kWh/day)
01	Room Light	30	06	180	07	1.26
02	Kitchen light	26	01	26	05	0.13
03	Bathroom light	12	03	36	04	0.14
04	Fan	80	05	400	15	6
05	Television	100	01	100	06	0.6
06	Fridge	200	01	200	24	4.8
07	Washing Machine	500	01	500	01	0.5
08	Microwave	1000	01	1000	0.5	0.5
Total Energy consumption per day						13.93 kWh/day

Table 5.2 Power demand over the period of 1 year to 30 years

Year	Days	kWh	MWh
1	365	5084.45	05.08
5	1825	25422.25	25.42
10	3650	50844.50	50.84
20	7300	101689	101.68
30	10950	152533.5	152.53

Total energy consumption per day for the apartment is 13.93 kWh/day. So, the total power demand for the time period of 1 year to 30 years is shown in **TABLE 5.2**. If the apartment relies on the coal or conventional power plant only how much CO_2 emission might occurs over the time duration of 30 years have been depicted in **FIG. 5.7**. If we consider Ghorashal power plant which is coal based power plant and it emits 0.54 kilotons CO_2/hour [17]. The **FIG. 5.7** shows in one year we might get 4730.4 kilotons CO_2 emission. At the same time, if the power consumtion is continued from this sector till 30 years the amount emission will reach to 141912 kilotons, which is a huge amount and it will cost us with a huge pay. So many statistical report is showing that it will effect our GDP by decent mergine. As a developing country we cannot afford to let this happen. Hence, it is very high time to work on this and get rid of from the consequences.

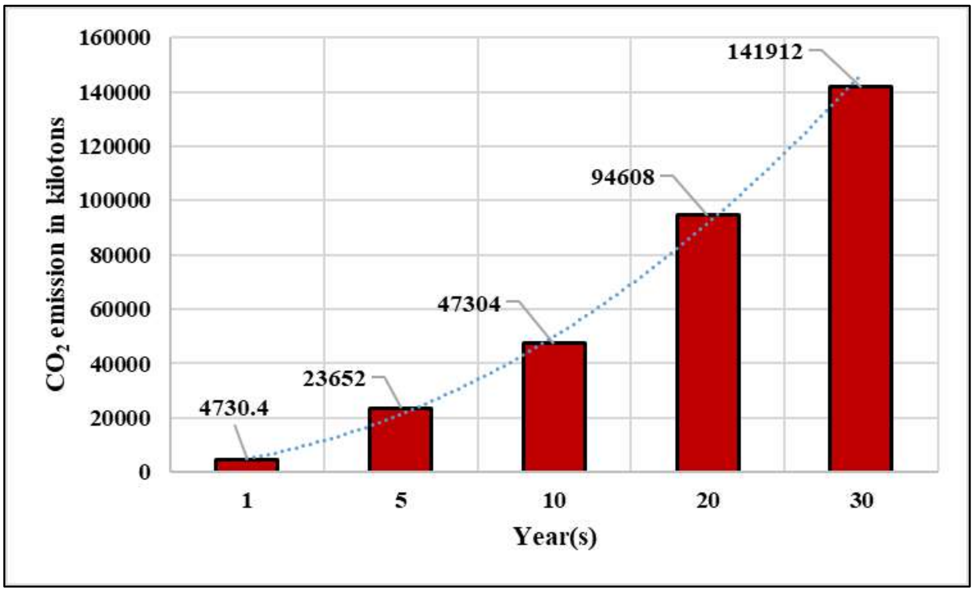

Fig. 5.7 Statistical comparison of CO_2 emission over the time period of 1 to 30 years

From the represented **Fig. 5.7**, it is very much clear that along with the power consumption from the conventional coal-based power plant over the period of 30 years, the CO_2 emission amount increases exponentially. To prevent the consequences, as in our thesis, a proposed model has been demonstrated and its implementation cost, social benefits, individual benefits have been analyzed in the following section.

5.4 In terms of various aspect proposed model cost analysis

5.4.1 Proposed model ratings calculation with the backup system

In the following **Table 5.3**, the total energy consumption from the proposed system is calculated for the same apartment. In the daytime, the operating hours for room light, kitchen light, bathroom light, fan, fridge and television are less than the night time.

Table 5.3 Total energy consumption from proposed system per day

SL	**Appliance name**	**Appliance rating (watts)**	**Appliance number**	**Total power (watts)**	**Operating duration (hour)**	**Total consumption (kWh/day)**
01	Room Light	30	02	60	2.5	0.15
02	Kitchen light	26	01	26	1.5	0.04
03	Bathroom light	12	03	36	1.5	0.05
04	Fan	80	04	320	06	1.92
05	Fridge	200	01	200	08	1.6
06	Television	100	01	100	02	0.2
	Total load in house			742		
	Total Energy needed to supply by alternative source per day					3.96 kWh/day

Total Energy needed to supply by alternative source per month = (3.96×30) kWh=118.5 kWh

Total Energy needed to supply by alternative source per year = (118.5×12) kWh = 1422 kWh

5.4.2 Inverter, battery, solar panel selection

5.4.2.1 Inverter selection

From **Table 5.3**, Power Requirements for household in watt = 742 W

DC Battery volt = 12V

DC current required = 742W/ 12V = 61.83 A = 62 A (approx.)

If an inverter operates with 100% proficiency, then the power requirement of the electrical items and power supplied by the inverter will be same. Hence, everyone knows that 100% or ideal conditions do not exist in real. Most inverters have the efficiency range from 60% to 80%. This efficiency is also called the power factor of an inverter and is simply the ratio of power required by the electrical appliances to the power supplied by an inverter. Power factor of most inverters ranges from 0.6 to 0.8. So, here the value of power factor or efficiency has been considered as 0.8.

Power of inverter (VA) = 742W/0.8 = 927.5 VA = 1000 VA inverter.

In the market, 1000 VA inverters are available. So, an inverter with 1000 VA will be the precise choice for home.

5.4.2.2 Battery size selection in Ah

PV systems usually use storage devices such as battery to store excess electricity which can help to run the cell for few hours in the inexistence of sunlight. Thus, storage device is also modeled so that the energy stored in battery can be used whenever the solar radiation is feeble or when the generation is not possible from solar cells likewise during rainy days, cloudy days. The battery can also be used as the source of energy during night time [72].

Battery is the mainstay of an inverter. The presentation and life of an inverter largely be contingent the battery quality. The battery capacity can decide the backup hours. It is expressed in unit of Ah (Ampere Hours). Batteries with the capability of 100 Ah, 150 Ah, 180 Ah etc. are readily available in the market.

Here the operating hours are less due to daytime (see **Table 5.3**). The total operating hours for the appliances are 21.5 hour. So, the let us assume the backup average hour as 21.5/6 hour = 3.6 hr. and total power consumption for the house we get 742W. So, we need a battery that can provide backup for 3.6 hours.

Battery capacity = Power requirement in watts * Back up hours / Battery Voltage (in volts)

Battery Capacity = (742 * 3.6) / 12 = 222.6 Ah

Therefore, two batteries with a capacity of 150 Ah*2 = 300 Ah will work for the system.

We would need 1000VA inverter and two batteries of individual capacity 150 Ah.

5.4.3 Solar System Implantation

5.4.3.1 Rating of solar panel

The best tilt angle of solar panel for the fixed system is equal to the latitude angle of the local place south faced in Bangladesh. Let the apartment is situated in Dhaka and annual insolation for Dhaka is found 4.7 kWh/m^2 [72]. Using the peak hour approach [73],

$$\text{Energy (kWh/year)} = P_{ac} \times \left(\frac{h}{day} @1\ sun\right) \times 365 days/year$$

$$P_{ac} = \frac{1422\ kWh/year}{4.7\ h/day \times 365 days/year} = 0.79\ \text{kW}$$

For the implementation of PV system, we need to get the Pdc which we can get from the following equation where conversion efficiency is taken as 0.75 [73]. Conversion efficiency includes inverter efficiency, dirty collectors, mismatched modules, and differences in ambient conditions.

$$P_{dc,STC} = \frac{P_{ac}}{Conversion\ efficiency} = \frac{0.79\ \text{kW}}{0.75} = 1.05\ \text{kW}$$

Here, STC denotes rated dc power output of an individual module under standard test conditions (STC)—that is, 1-sun, AM 1.5 and 25◦C cell temperature. To find the area of collector, we need to know the efficiency of the collector. The solar cell we have chosen has an efficiency of about 17.5%, [74], then

$$P_{dc} = 1kW/m^2\ insolation \times A(m^2) \times \eta$$

$$A = \frac{1.05\ \text{kW}}{1kW/m^2 \times \eta}$$

$$A = \frac{1.05\ \text{kW}}{1kW/m^2 \times 0.175} = 6\ m^2$$

We need 1.05 kW or 1050 W dc to deliver by the solar panel to selected system. So, if we choose PV module of 350 W of Energy System Company (ensysco) company, then we will need three panels to supply desired dc power. The area required for that 3 panel is 6 m^2, which matches with our calculated value. So, the implementation cost of the proposed system is calculated below in **Table 5.4**. The cost of these components could be dissimilar depending on its brand, place, quality, and quantity. At the same time, the currency price which has been included in the table might vary according to the date. Here included currency on the date of 10 June 2022. In the calculation, 1 dollar and 1 rupee are equivalent to 93.03 BDT and 1.21 BDT respectively.

Table 5.4 Proposed model implementation cost [75]-[81]

Component name	Quantity	Currency Conversion	Price of one (BDT)	Total Cost (BDT)
PV module (Yangtze Solar 350 W) [75]	3	US $0.22/w	7220	21,660
Battery (IBP 150) [76]	2	BDT	19,400	38,800
Cotek SP1000-212 Inverter [77]	1	US $359	33,660	33,660
Charge controller [78]	1	Rs. 1500	1800	1800
Control circuitry, Installation, Maintenance etc. [79]-[81]	-	BDT	10,000	10,000
Initial Implementation total cost				105,920

Now we can estimate that PV module will serve for around 30 years as it comes up with a warranty of 20 years. Battery and charge controller will last for 5 years, and each inverter will serve for around 10 years. Maintenance cost will be 10,000 BDT for every 10 years.

So, the total cost with solar system for 10 years,

$$= 38800 \times 2 + 33660 + 1800 \times 2 + 10000$$

$$= 77600 + 33660 + 3600 + 10000$$

$$= 1{,}24{,}860\ BDT.$$

So, total cost with solar system for 20 years,

$$= 38800 \times 4 + 33660 \times 2 + 1800 \times 4 + 20000$$

$$= 155200 + 67320 + 7200 + 20000$$

$$= 2{,}49{,}720 \text{ BDT.}$$

So, total cost with solar system for 30 years,

$$= 38800 \times 6 + 33660 \times 3 + 1800 \times 6 + 30000$$

$= 232800 + 100980 + 10800 + 30000$

$= 3{,}74{,}580$ BDT.

As the value of money changes over time so let's take the interest rate of BDT over the period of time is 5 percent [82]. So, we have calculated the total cost value of money for the time period based on net present value formula.

Present Value (P.V) = Future Value (F.V) / $(1+r)^n$

Where, r = interest rate = 5% = 0.05

Let, the future value is 1 BDT. So, the present value of the given future value for the time of,

10 years will be = 1/ $(1+0.05)^{10}$ = 0.61 BDT

20 years will be = 1/ $(1+0.05)^{20}$ = 0.37 BDT

30 years will be = 1/ $(1+0.05)^{30}$ = 0.23 BDT

The initial implemented cost we get is 105,920 BDT.

Total cost with solar system for 10 years = $1{,}24{,}860\ BDT$.

Total cost with solar system for 20 years = $2{,}49{,}720\ BDT$.

Total cost with solar system for 30 years = $3{,}74{,}580\ BDT$.

The present value, PV of the total cost value of the system for the time period would be,

For 10 years = 124860 * 0.61 BDT = 76165 BDT

For 20 years = 249720 * 0.37 BDT = 92400 BDT

For 30 years = 374580 * 0.23 BDT = 86154 BDT

In terms of 10 years, 20 years and 30 years, the current calculated value might vary with the addition of 76,165 BDT, 92,400 BDT and 86,154 BDT amount respectively.

5.5 Individual benefits

Here average we have chosen 12.1 hours to run our proposed system because the statistical result of sunlight duration in our country average is 12.1 hours (see **Table 5.5**)

Table 5.5 Average sunlight duration per month [83]

SL	Month	Average hours of daylight	Conventional
1	Jan	10:55	13:05
2	Feb	11:22	12:38
3	March	11:59	12:01
4	April	12:38	11:22
5	May	13:11	10:49
6	June	13:28	10:32
7	July	13:20	10:40
8	Aug	12:52	11:08
9	Sep	12:14	11:46
10	Oct	11:35	12:25
11	Nov	11:02	12:58
12	Dec	10:46	13:14
Average		12:06	11:53

Table 5.6 Comparative analysis of Power Consumption and cost of conventional Vs proposed hybrid for 10~30 years

Year	Days	Proposed system consumption for 12.1 hours	Conventional consumption for 11.9 hours	Cost per kWh [84]	Cost of Conventional consumption (BDT)	3.6 hours back up (BDT)	Cost of PV (BDT)
10	3650	25623	25221.5		141,593	184347	1,24,860
20	7300	51246	50443	5.614	283,187	368695	2,49,720
30	10950	76869	75664.5		424,780	553042	3,74,580

Power consumption cost for 12.1hr (12 hour 6 minutes) at the day time, if we consume it from PV system. At the same time if we consume it from conventional power plant for 11.9hr (11 hours 53 minutes), how much we need to pay that has been discussed and compared at **Table 5.6**.

5.6 Contribution to grid from proposed model with the individual benefits

If we look at **Table 5.5**, May, June, July are the month where we can get 1hr extra sunlight per day. At this extra one hour, the amount of power we will get that we can contribute to the grid. Furthermore, from the **Table 5.5**, November, December, and January are the months considered as winter in our country and during these months per 6 kWh for fan consumption (see **Table 5.1**) will be reduced which will be our extra power. This extra power we can contribute to the grid. For the above two mention condition how much power we can contribute, and income individual can get, that has been shown in the following **Table 5.7**.

Table 5.7 Consumer benefit and grid contribution for 1~ 30 years

Year (s)	During winter extra energy kwh	During additional sun light kwh	Total extra energy kwh	BDT if sell per unit 5 BDT Income	With 5% interest rate per year Income
1	540	94.5	634.5	3172.5	3332
5	2700	472.5	3172.5	15862.5	20240
10	5400	945	6345	31725	51650
20	10800	1890	12690	63450	167508
30	16200	2835	19035	95175	411156

5.7 Social Benefits

The following depicted **Fig. 5.8** of statistical comparison of CO_2 emission over years describes the future of social benefits with having the proposed system and benefits for green future environment of Bangladesh. Without the proposed PV system, the amount of CO_2 emission is 4730.4 kilotons per year whereas with PV system it can be reduced to the amount of 2345.49 kilotons. Same as for 5 years, the CO_2 emission without PV system is 23652 kilotons whereas with the inclusion of PV, it goes to the value of 11727.45 kilotons which is far reduced by 11924.55 kilotons in the comparison we might see. This is also true for upcoming 10 years till 30 years calculation represented from the **Fig 5.8**. The amount of CO_2

emission for 30 years will be 141912 kilotons without PV system which is a very huge amount so far. With the inclusion of PV system, the amount could be lessened to only 70354.7 kilotons which hints the emission will be very less in comparison with the amount of CO_2 emission without PV system. Though, here the calculation is showing the scenario of PV system for 12.1 hours. With the inclusion of PV system for 12.1 hours in our conventional system, the CO_2 emission reduces by 50.147% which is evidently a great percentage and hope for green future energy (see **Table 5.8**).

Table 5.8 CO_2 emission and reduction data with and without the proposed system over the period of 1~30 years

Year	Days	CO_2 emission without PV System (kilotons)	CO_2 emission with PV System (kilotons)	CO_2 Reduction (kilotons)
0	1	12.96	6.426	6.534
0	30	388.8	192.78	196.02
1	365	4730.4	2345.49	2384.91
5	1825	23652	11727.45	11924.55
10	3650	47304	23454.9	23849.1
20	7300	94608	46909.8	47698.2
30	10950	141912	70364.7	71547.3

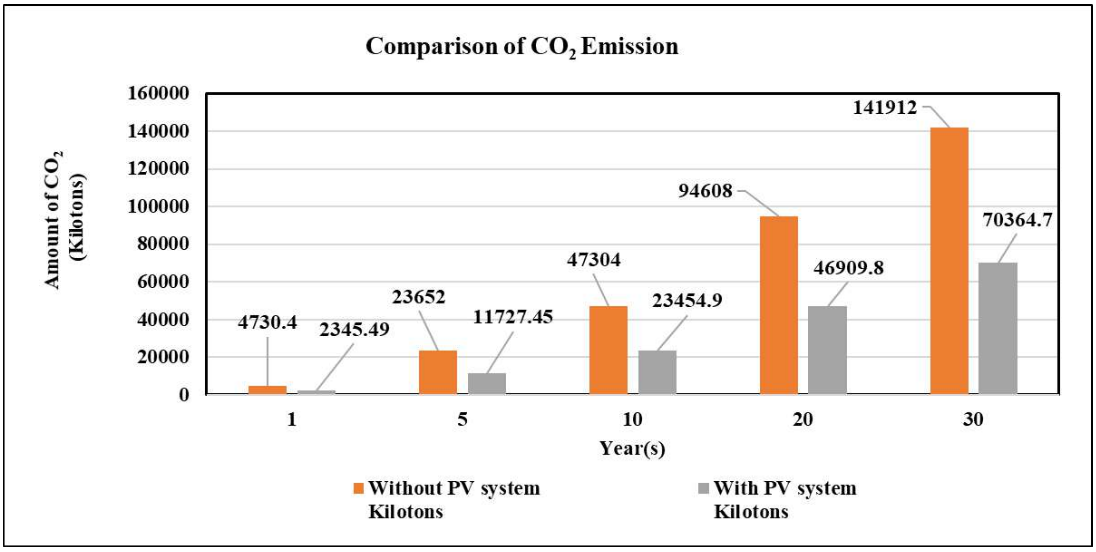

Fig. 5.8 Comparison of CO_2 emission in kilotons over the time period of 1~30 years with and without PV system

The statistical view by the comparison of CO_2 emission in kilotons over the time period of 1~30 years with and without PV system is depicted in **Fig. 5.8**.

Fig. 5.8 If we can lessen the amount of CO_2 emission with the inclusion of PV system along with the zero consumption from the conventional power plant in future, then the CO_2 emission could have been reduced to fully zero level. Evidently then we can easily predict how green could be our country without having the harmful effects of vast amount of CO_2 in everywhere. The following depicted **Fig. 5.9** shows the reduction rate of CO_2 with the inclusion of the proposed system in terms of time for 1 to 30 years. We might see, for 1 year the CO_2 emission reduced by 2384.91 kilotons inclusion with the PV system whereas it was 4730.4 kilotons without the proposed system. Apparently, till 30 years, CO_2 emission would be reduced by the amount of 71547.3 kilotons which could be a huge and harmful amount of 141912 kilotons without the inclusion of PV system. The **Fig. 5.9** evidently demonstrates the great reduction of CO_2 with the proposed system which would be a big hope to approach to green future energy.

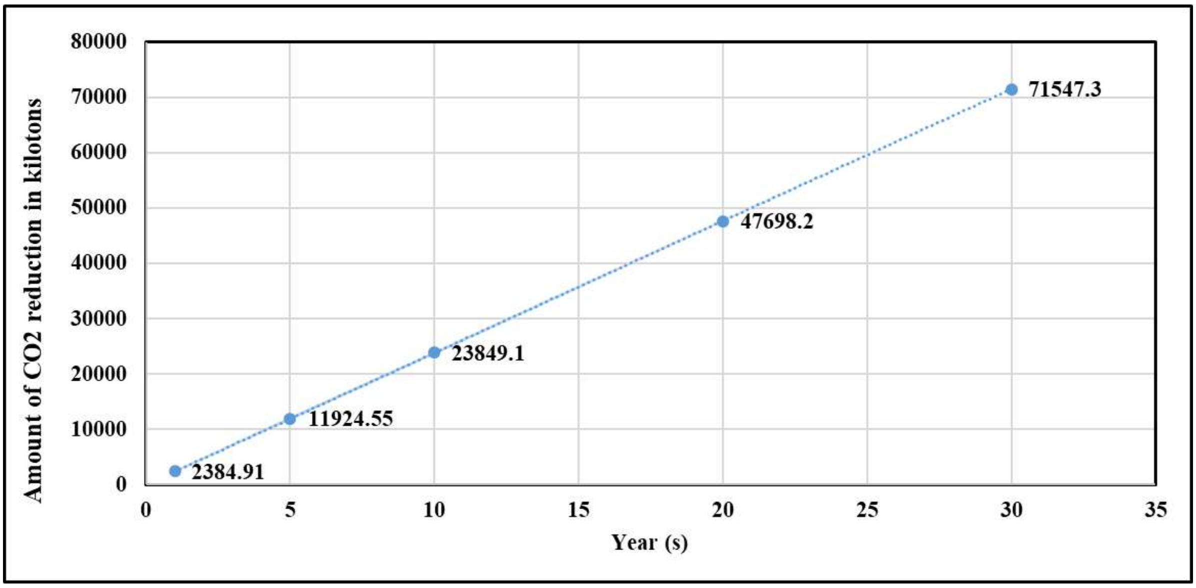

Fig. 5.9 CO_2 reduction rate over the time s of 1~30 years with the inclusion of proposed system

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

Our thesis flow has started with the demonstration of the green energy system contribution and situation along with the study of three regional distribution. In the first regional distribution study, we have discussed about the green energy situation and future aspect combining all over the world. Secondly, the scenario of the Asia in terms of smart grid progression has been discussed briefly. Meanwhile, finally in the third regional discussion, green energy progression in Bangladesh has been concisely discussed. Hence focusing on the lacking and so far not contributed areas, we have proposed light dependency switching control system based hybrid smart power system which has been demonstrated via MATLAB Simulink. In terms of light dependency, the developed MATLAB simulation model has been checked and validation output result has been depicted in the result and discussion section. In the cost analysis section, the proposed model implementation cost has been calculated which is around 105,920 BDT. At the same time, with the implementation of this proposed model, over the period of 30 years, the CO_2 emission possible to reduce by 50.147%. In the cost analysis section also showing that, the comparison between the conventional cost if we use the hybrid system for the average daylight hours of 12.1. With the backup, the conventional cost showing comparatively less than using it with only conventional system. Moreover, within a year there are several months where the generation power is more than the consumption power which has been verified with some statistical data. This surplus energy can be contributed to the grid (19,035 kWh) and this will help the consumer to earn from his own smart power consumption system and also the amount of money for 30 years is around 95,175 BDT.

In summary, we can say that our proposed light dependency smart control power system will not only lead the power system towards the green energy with the reduction of CO_2 but also help the consumer to earn money by supplying power to the grid.

6.2 Future research work suggestion

In this proposed topic of hybrid system, we have worked with the inclusion of PV system for 12.1 hours. In addition, the backup system is 3.6 hours. By analyzing the calculated result, we could not get the CO_2 emission at zero level. In future we have a plan to design more efficient smart power system which will not only bring the CO_2 emission to zero but also lead our future generation towards smart and secure lifestyle.

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