Master of Science

In

Electrical and Electronic Engineering

Design a Grid Connected Hybrid Power System for Power Quality Improvement

Mohammad Nurul Absar

Department of Electrical and Electronic Engineering

Islamic University of Technology (IUT)

Board Bazar, Gazipur-1704, Bangladesh.

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CERTIFICATE OF APPROVAL

This thesis titled "**Design a Grid Connected Hybrid Power System for Power Quality Improvement**" submitted by Mohammad Nurul Absar, St. No. 152609 of Academic Year 2015-2016 has been found as satisfactory and accepted as partial fulfilment of the requirement for the Degree of MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING on 24 July, 2020.

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It is hereby declared that this thesis report or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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Dedicated to

My Beloved Parents

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LIST OF ABBREVIATIONS

PV	Photovoltaic
DC	direct current
O&M	Operation & Maintenance
RES	Renewable energy system
SVC	Static VAR Compensator
FACTS	Flexible Alternating Current Transmission System
NPC	Net Present Cost
COE	Cost of energy
CO_2	Carbon-di-oxide
HOMER	Hybrid Optimization of Multiple Electric Renewable
ETAP	Electrical Transient Analyzer Program
BMD	Bangladesh Meteorological Department
NASA	National Aeronautics and Space Administration
BP	British Petroleum
BPDB	Bangladesh Power Development Board
BPC	Bangladesh Petroleum Corporation
SREDA	Sustainable and Renewable Energy Development Authority
IRENA	International Renewable Energy Agency
RRRC	Refugee Relief and Reprobation Commission
UNHCR	United Nations High Commissioner for Refugees
IEA	International Energy Agency

LIST OF SYMBOLS

α:	Firing angle
σ:	Conduction angle
Y:	Bus admittance
δ:	Radians

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ABSTRACT

With the increasing of population and industrial revolution rapidly, has growing the demand of electricity in Bangladesh. The main source of electricity generation is natural gas and fossil fuel which contributes almost 90% of the total generation which is treated for the environment. The Government of Bangladesh has set up a plan to generate approximately 4190 MW of the country's total electricity from renewable source within 2030. But grid connection of renewable energy generation is a difficult because of it randomness of sources, non-linear characteristics etc. So power quality and reliability is important concern for design a renewable system. For solving the very basic light energy crisis, especially in rural, isolated and the coastal community of Bangladesh, it was proposed to design a hybrid renewable energy based grid connected power system. For design, optimization of the proposed system, Teknaf Rohingya Refugees camp have chosen because of nowadays refugee crisis has become very acute in Bangladesh. The Refugees camp is mainly the backward site in Bangladesh where there is no electricity available in those camp areas where renewable energy sources are mostly common. The system is designed using renewable energy (solar and wind) for refugee camp that will fulfill the basic electricity demand which upgrade the Refugees community. HOMER software used for power generation and optimization analysis and ETAP software used for power quality analysis of design system. The simulated results shown that hybrid renewable energy systems are the most economical and had fulfilled basic electricity demand of Refugees camp. Moreover, 1.5 MW solar wind grid connected hybrid system is designed where 62% electricity are renewable fraction and remaining is consumed from grid. This system met an average 5.4 MW load per day at a cost rate of $0.12/kWh. This is a reliable and stable arrangement, because the lack of electricity at the time of the peak load is filled in from the grid and during off-peak hours the additional power from the renewable energy source supplied to grid by improving the power quality using Static VAR compensator Device. On an average bus voltage improves 1.2% and branch losses reduce 0.94% and enhance power transfer capability from 314.7 kW to 317.7 kW. It is a vital energy solution for refugee camps which locate in rural areas.

CHAPTER 1

1. INTRODUCTION

1.1. Introduction

The World's Population reached 7.6 billion as of mid-2017 according to the World Population Prospects: 2017 Revision. This continues to grow, albeit more slowly than in the recent past. It is projected to increase by slightly more than one billion people over the next 13 years, reaching 8.6 billion in 2030, and to increase further to 9.8 billion in 2050 and 11.2 billion by 2100 that's shown in below Table 1.1 [1]. Many problem relate with the growth of world's population such as faster consumption of natural resources (fossil fuels) than the rate of regeneration, fresh water and food, environment pollution, increase the Refugees, deterioration in living conditions etc. Nowadays refugee crisis is the most usual problem in the world. Due to political and spiritual reasons, the crisis is increasing day by day.

Table 1.1 Population of the world and regions 2017, 2030, 2050 and 2100, according to the medium-variant projection.

Region	**Population (millions)**			
Year	2017	2030	2050	2100
World	7550	8551	9772	11184
Africa	1256	1704	2528	4468
Asia	4504	4947	5257	4780
Europe	742	739	716	653
Latin America and the Caribbean	646	718	780	712
Northern America	361	395	435	499
Oceania	41	48	57	72

At the end of 2017, according to United Nations High Commissioner for Refugees (UNHCR) report the world's refugee population are 25.4 million that is increased by 10 percent from previous year [2]. Bangladesh is one of those countries who has confronted this problem since last few decade. For the last 3-4 years, this refugee crisis has become very acute in Bangladesh due to the contradictory activities of the Rakhine state. Approximately 200,000 to 500,000 Rohingya refugees have been fleeing to Bangladesh in the last few decades, where 33,131 Rohingya refugees have been registered in two refugee camps at Ukhia and Teknaf where most of them are women and child [3].

According to the International Energy Agency (IEA) - By 2040, the global energy consumption will increase by 37% and it is expected that there will be rise in the world electricity demand by 80% over the period 2012–2040. Moreover, it is estimated that 90% of the primary energy consumption will be supplied by fossil fuel until 2020.This concerning scenario resulted from rapidly diminishing resources is highlighted by International Energy Agency which forecasted the exhaustion of fossil fuel in about 100 years [3]. According to British Petroleum statistical review of the world energy report 2019, the range of exhaustion is estimated to be 50–132 years that's shown in Table 1.2 [4].

Table 1.2 Global reserves and availability of major fossil energy resources.

Category item	Oil	Natural gas	Coal
Total reserve (end of 2018)	1729.7 thousand billion barrels	196.9 trillion cubic meters	1054782 million tonnes
Production in 2018	244.1 thousand million tonnes	6951.8 trillion cubic feet	3916.8 million tonnes of oil equivalent
Remaining years for exhaustion of fossil fuel	50	50.9	132

Global warming, the raising temperature around the world due to greenhouse-gas emissions. When mine coal and extract oil from the Earth's crust, then burn these fossil fuels for transportation, heating, cooking, electricity, and manufacturing, we are effectively moving carbon more rapidly into the atmosphere than is being removed naturally through the sedimentation of carbon, ultimately causing atmospheric carbon dioxide concentrations to increase. From 1981–2014, CO_2 emission has been increased from 19 billion tonnes to 34.7 billion tonnes and is expected to further increase by 85% within 2030 [5]. In 2018 Global Primary energy consumption grew in 2.9% that result to grow carbon dioxide emission 2%, the faster growth for seven years [4]. According to BP (British Petroleum) statistic report 2019, Coal is the dominant fuel for power generation, accounting for 38% and Gas is the second most used fuel with share of 23.2%. The share of oil and nuclear has declined substantially over the same period. But Renewable share is upward last 10 years, at present 9.3% share of green energy that is significant variation in the penetration of renewables (figure 1.1). Renewable energy sources such as wind, solar, ocean, biomass and geothermal power do not cause any significant environmental pollution or substantial health risks. Renewable energy in power generation increased by 14% in 2018 and china accounted for 45% of global growth. Wind energy contributed more too renewable generation than solar. 1270 TWh power generation from wind, 564.5 TWh from solar source and 625.8 TWh comes from other renewable energy source that is shown in figure 1.2. Wind has accounted for around 50% of renewables generation in the last few years. Solar has constantly increased its share and now represents 24%.

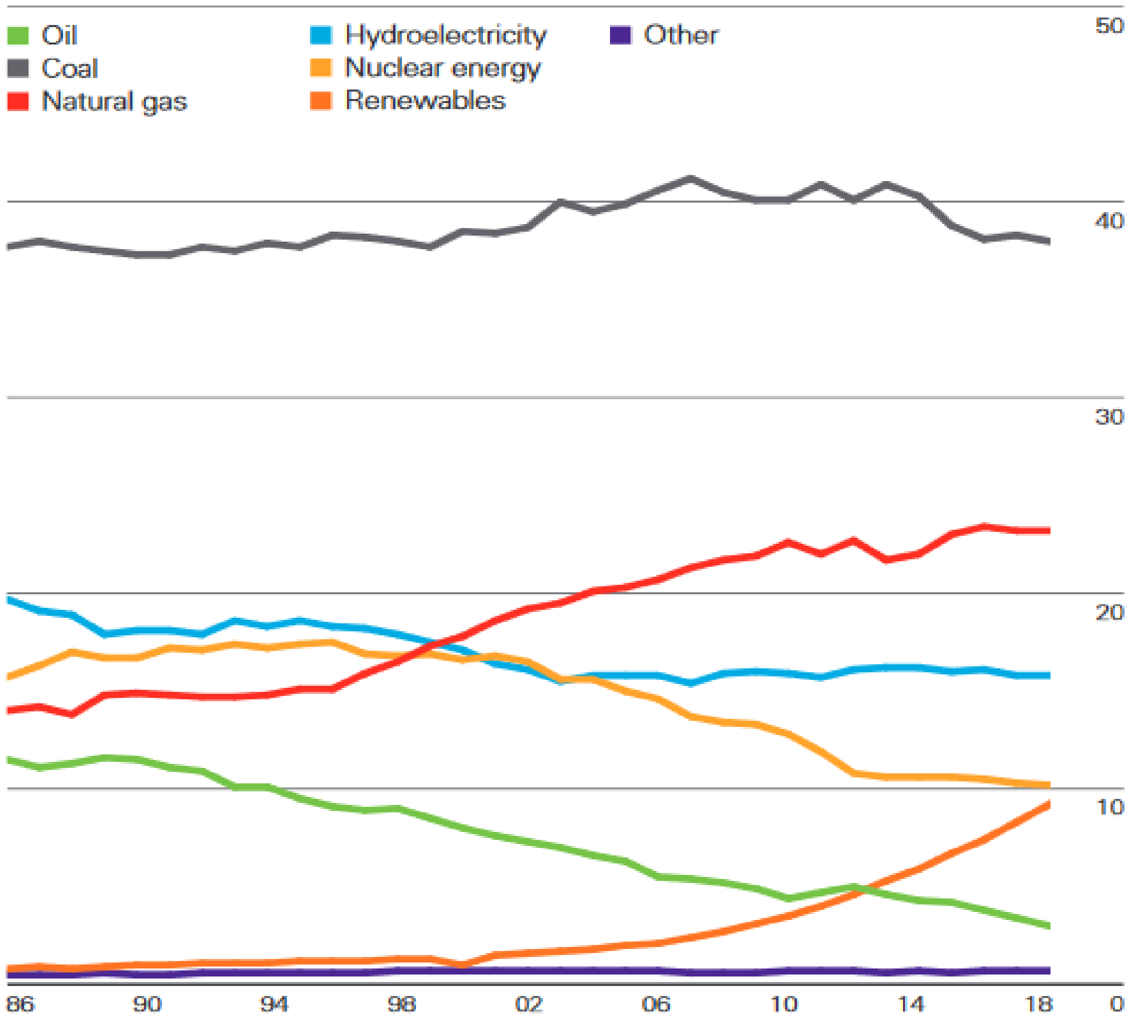

Figure 1.1 Share of global electricity generation by fuel [4].

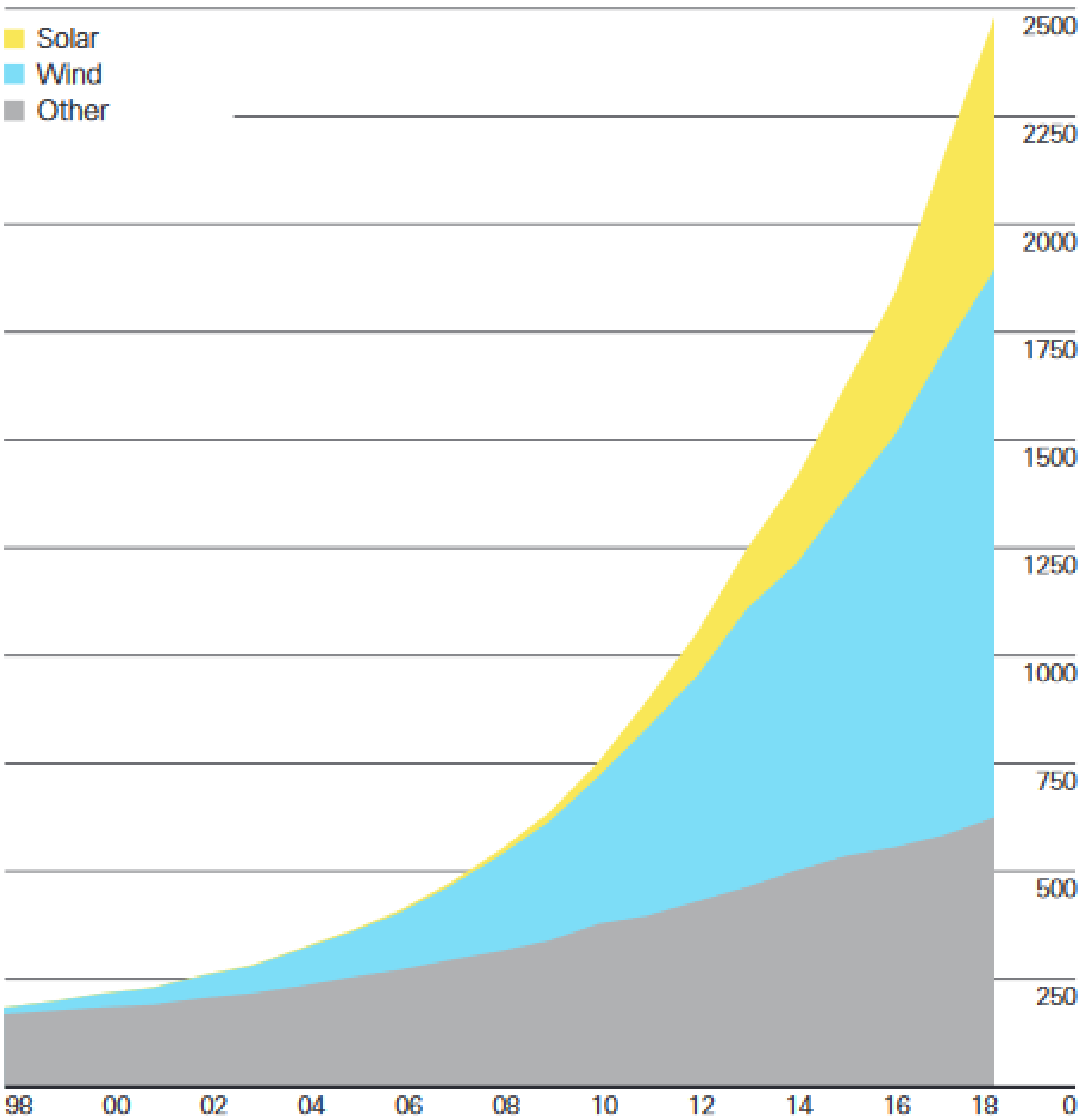

Figure 1.1 Renewables generation by sources [4].

However, the adoption of the renewable energy is still low due to high technological costs and the associated power system issues. The effectiveness of Flexible Alternating Current Transmission System (FACTS) devices in problems that are related to the power systems has been tremendous. Although, there are still relatively limited works on incorporating FACTS devices into renewable energy plants. It has been discovered that FACTS plays an equally effective role in improving the power system quality of green energy plants especially in wind and solar plants. The rate of penetration of green energy could be accelerated if applications of FACTS devices in renewable energy plants were to be more widely adopted [6].

1.2. Background and Present State of the Problem

Bangladesh is one of the developing countries with a population of 162.7 million in the world. At present population growth rate is 1.38% [7]. Beside this population growth, Recently Bangladesh facing another problem with the native country Myanmar on Rohingya refugees issue. In recent years, more than 500,000 Rohingya fled from Myanmar (Burma) to Bangladesh where 33,131 registered Rohingya refugees are living in two registered camps in Cox's Bazar, and up to 80,000 additional refugees are housed in nearby makeshift camps [8]. In 2014, Government of Bangladesh (GOB) announced its national policy for managing the Myanmar refugees, which is comprised of five elements: (i) preparation of a list of unregistered refugees; (ii) provision of temporary basic humanitarian relief; (iii) strengthening of border management; (iv) Diplomatic initiatives with the government of Myanmar; and (v) increasing national level coordination [9]. However, socioeconomic conditions of the host communities in Cox's Bazar, one of Bangladesh's poorest districts, has further complicated finding a durable solution for the Rohingyas in the area. Whether living in camp or non-camp areas, the Rohingya refugees have been subject to miserable living conditions marked by inadequate access to basic needs, exposure to violence, restricted movement, local hostility, and various forms of discrimination. Most refugees depend on energy resources for everyday use that pose risks to their security, safety and well-being. It's really difficult for a developing country like Bangladesh to maintain those problems in longer time and facilities of energy among the Refugees Camps.

The production status of energy in Bangladesh has not been matched to the power requirements of various categories of consumers. For the year FY (Fiscal Year) 17-18, the total grid based installed electricity generation capacity stood at 15,953 MW (excluding captive) of which the highest generation was 10,958 MW. To generate this electricity the share of gas, hydro, coal, imported and oil based energy were 63%, 2%, 3%, 8% and 24% respectively (figure 1.3). It's clear that the main source of electricity generation is natural gas and fossil fuel which contributes almost 90% of the total generation [10]. Natural gas and heavy fuel oil are the prime movers for internal supply of energy of the country. The natural gas plays an important role in the growth of the national economy, as a major internal source of energy.

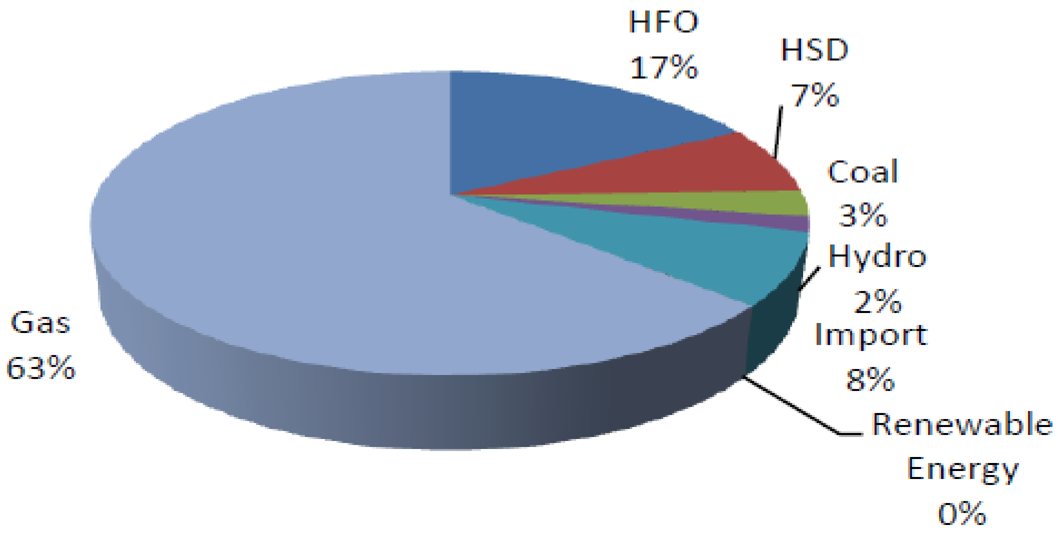

Figure 1.2 Energy generation (national) by fuel type [10].

According to the finance division, Bangladesh has 27.81 trillion cubic feet (TCF) of proven gas reserve as of 2018, in which 15.7 TCF gas already been recovered. The reserve of natural gas in Bangladesh would last up to 2027, possibly up to 2030 [11], if the consumption of gas for electricity generation continues at a present rate.

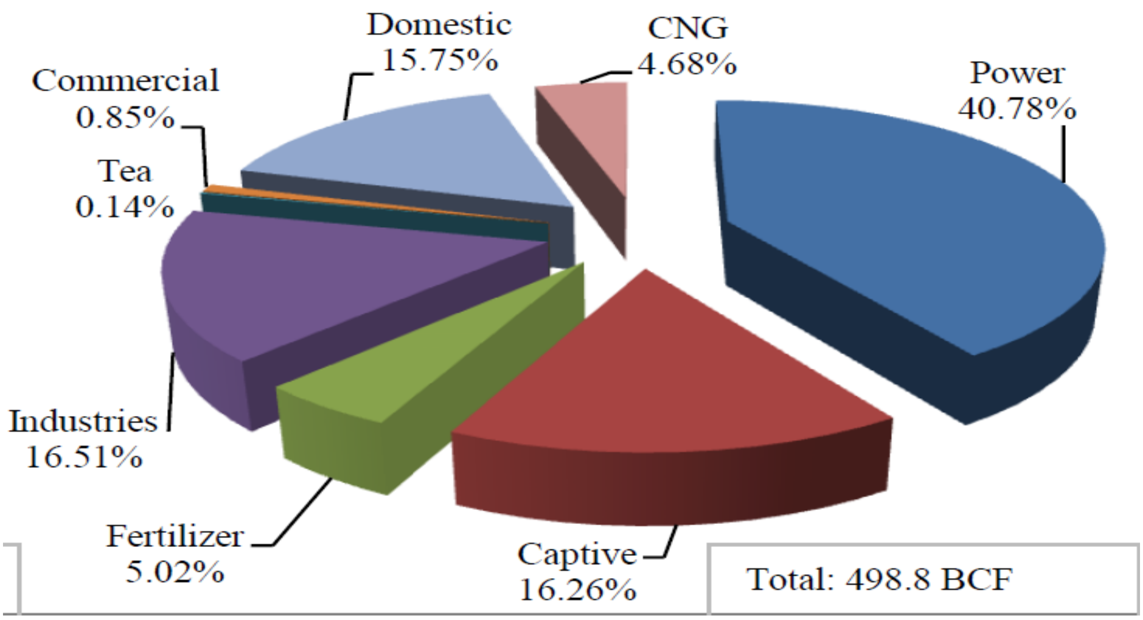

Figure 1.3 Sectoral use of natural gas in Bangladesh [11].

The main sectors utilizing gas energy are the power and industrial sectors, which account for 40.78% and 16.51% of total usage, respectively. The remaining energy is supplied to the captive (16.26%), fertilizer sectors (5.02%), the domestic sector (15.75%) and others (5.67%) shown in figure 1.4. However, supply of natural gas in household sector is being hindered by poor gas transmission and network distribution. The entire gas output is about 2180 million cubic feet per day (mmcfd) against its requirement of 2500 mmcfd. However, the actual demand will be higher when the awaiting industries and housing units will get a connection with the gas line [11]. Figure 1.5 shown the sectoral use of petroleum fuel in Bangladesh. According to the Bangladesh Petroleum Corporation (BPC), transportation sector is the largest consumer of petroleum fuel with 45% of total consumption. The fuel consumptions for other sectors are agriculture 21%, power (19%) and domestic (9%).

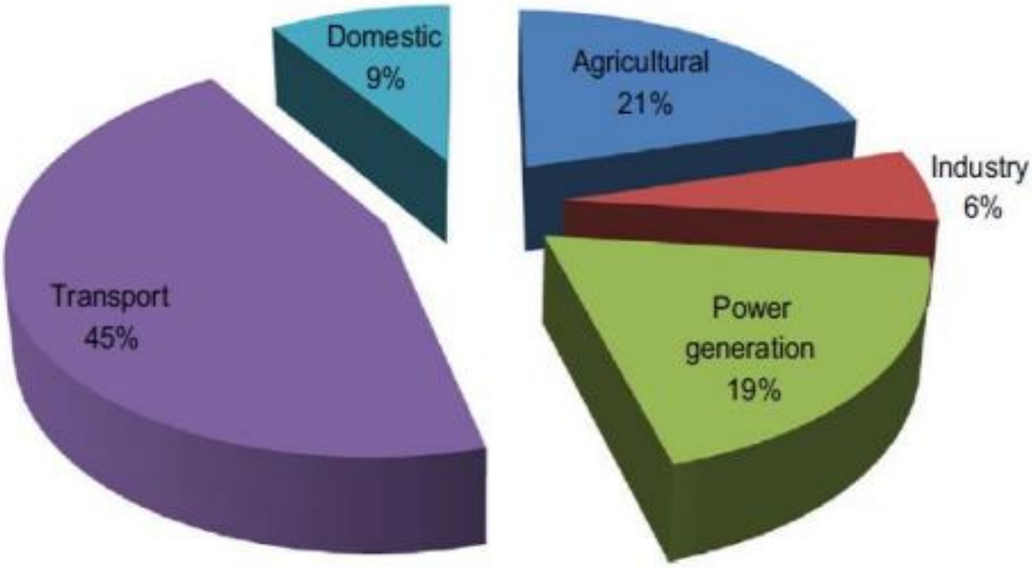

Figure 1.4 Sectoral use of petroleum fuel in Bangladesh [11].

Nevertheless, the regime of Bangladesh has recently under-taken the Quick Rental Power Plant (QRPP) projects based on oil-dependent power plants. Rental power is a system that has been pioneered and encouraged by the regime as an immediate measure to manage with the critical shortfall of power. With the exclusion of various plants whose contract run for a comparatively long term of 15 years, most of the contracts are short term ones of three to five years in which the per unit price of power inevitably becomes expensive as the rental power producer tries to take in the depreciation of the plant within such short times. Thus, the QRPP was failing to achieve expected results due to the following reasons: The quick rental power initiative was adopted without requiring feasibility study and financial analysis. Government's budgetary control was failing to anticipate impacts on price increase in liquid fuel to international market. Bangladesh Power Development Board (BPDB) was obligated to purchase the rental power produced at such high cost, and to sell the power at the regulated bulk tariff with no effective means to avoid the loss creating in the dealing operation. Therefore, all the power plants have miserably failed to begin production, According to the financial division [11], Bangladesh Petroleum Corporation (BPC) incurs a loss of about take 10.00 billion in 2011–2012. Thus, the lack of proper energy management contributed to the huge amount of financial loss to the national exchequer. Instead of qualifying developers through competitive bidding novice developers, mostly first timers were allowed to setup the power plants. Many of them failed to set up plants within time or even within several extended periods. Most of the developers brought fuel inefficient second-hand equipment's and machinery which generated a good deal less than the rated capacity of power. Thus, the feeling of Quick Rental Plants is not only causing a huge amount of financial loss to the national exchequer but also increasing the suffering of the citizen of the country. Therefore, it should have had a financial model and risk analysis carried out before jumping unguarded to contingency power plant actions. The government should have concentrated more on advancing the implementation of large base load power plants and act more positively on replacing old fuel inefficient power plants with new modern plants.

Despite using oil as a fuel for power generation, the country has considered using coal as substitutes for liquid based fuel due to declining production in recent years. The government of Bangladesh has planned to build more coal-fired plants, as substantial amounts of coal reserves have been discovered in the northwestern part of the country. The entire quantity of coal reserve is calculated at 1.756 billion, in which the major estimated deposit from Jamalgonj (in the Joypurhat district), Baropukuria (in the Dinajpur district) and Khalashpir (in the Rangpur district). The calculated rate of coal extraction from Baropukuria is 1.0 million tonnes/year, in which 70% will be practiced in a 250 MW coal-fired power plant [10,11]. Some rules have been made to increase the percentage of coal in the future vitality, particularly for electricity generation uses. However, the main obstacle of Bangladesh is the lack of a policy framework and financial mechanisms.

Renewable is the best alternative of fossil fuel that can reproduce without depletion in the course of time. Although the greenhouse gas emission is not a primary concern for a low economy country like Bangladesh, incorporation of renewable energy is obvious because of rapidly reducing natural resources. That's why Bangladesh Govt. establish sustainable and Renewable energy development authority in 2014 and set up a plan to generate 5% electricity from renewable sources within 2015 and 10% within 2020 but able to generate 3.5 % within 2015 [3]. As of June, 2019 total renewable generation capacity of Bangladesh is 586.04 MW where total power generation capacity is 21011.53 MW and the percentage of renewable share is 2.79% (Including the off grid system) [12].

Table 1.3 Installed renewable energy technologies in Bangladesh.

Technology	Off-grid	On-grid	Total
Biogas to electricity	0.63 MW		0.63 MW
Biomass to electricity	0.40 MW		0.40 MW
Hydro	-	230 MW	230 MW
Solar PV	295.74 MW	56.27 MW	352.11 MW
Wind	2.00 MW	0.90 MW	2.9 MW
Total	**298.77 MW**	**287.27 MW**	**586.04 MW**

As per Sustainable and Renewable Energy Development Authority (SREDA) aim of yearly generation capacity of renewable energy shown in below Table 1.4, they have extensive work is being undertake. In the FY 2018-2019, only 92.32 Million taka budget approve from the govt. for the SREDA. It is difficult for developing Renewable energy and achieve the target with this budget [12].

Table 1.4 Target of yearly generation from renewable energy

Year	Solar (MW)	Wind (MW)	Hydro (MW)	Biomass (MW)	Biogas (MW)	Other (MW)	Grand Total (MW)
Till 2018	350	2.9	230	0	1.08	0	583.98
2019	84	0	0	0	1	0	85
2020	100	38	0	0	2	0	140
2021	120	80	0	15	3	0	218
2022	150	120	0	15	4	0	289
2023	165	170	0	15	4	0	354
2024	165	170	0	15	4	0	354
2025	165	170	0	15	4	2	356
2026	165	170	0	15	4	4	358
2027	165	170	0	15	4	6	360
2028	165	170	0	15	4	8	362
2029	165	170	0	15	5	10	365
2030	165	170	0	15	5	10	365
Grand Total	2124	1600.9	230	150	45.08	40	4189.98

Grid integration is one of the major difficulties for renewable energies sources because of randomness of nature, non-linear characteristics etc. [13, 14]. Designing a power system is essential to ensure stability and reliability. Many power electronics device introduced to improve the power quality. The possible solution of a hybrid system for grid integration and improve the power quality is the power electronics device like FACTS, MPPT etc. [6, 15]. Facts devices like SVC, STATECOM, TCSC etc. plays an important role for improving the power quality in power system [16-20].

Energy, especially electricity is one of the most important pre-requirements for sustainable growth. Bangladesh is not an exception. Even with huge prospects for developments, the land has been crawling and has deprived of desired developments because of insufficient electricity supply in late times. Bangladesh depends mostly on mono fuel in power generation (i.e., about 63% of power is created from natural gas and the remaining comes from other authors, such as liquid fuel, coal and hydropower). Between 2001 and 2019, during 19 years period 14,956 MW power was added to the national grid, fed that the capacity for electricity generation was 4,005 MW in 2001 and extended to 18,961 MW in 2019. Force generation is a priority for the present regime. The Bangladesh Power Development Board (BPDB) has made a generation expansion plan to add about 24,000 MW by 2021 and approximately 40,000 MW by 2030 [21].

1.3. Objectives

The main objectives of this research are-

I. Design and analysis of a grid connected hybrid power system utilizing available renewable resources for Rohingya Refugee's camp that's locate in rural area.

II. To improve the voltage profile and enhance the power transmission of Grid connected hybrid power system using FACTS device.

1.4. Scope of Work

Rohingya Refugees camp is located in one of rural and backward regions in Teknaf, Bangladesh which is totally deprive from the mainstream, however, belongs to Chittagong Division [22]. It is situated at a rural or hill track area of Bangladesh being in 22' 52' north latitude and 92' 18" east longitude. As per provision of temporary basic humanitarian, Energy is one of the basic needs of refugee that improved safety, security, productivity and health in refugee settlements. Compared to energy production, Refugees energy demand is difficult to meet due to the high demand for electricity in the country. Current energy practices in refugee settlements are often inefficient, polluting, unsafe for the users and damaging to the surrounding environment. UNHCR and its partners rely highly on diesel generators to provide refugee settlements with electricity for common everyday needs, such as lighting, as well as to operate the infrastructure and services in the settlements. UNHCR spends more than USD 35 million annually on diesel fuel to produce electricity, including funds given to partners for the same purpose [9]. Now, International Renewable Energy Agency (IRENA) and other development partners are supporting UNHCR in addressing the issue of efficient, clean, affordable and reliable energy supply in few Refugees camp settlements.

These Studies proposed that a hybrid renewable energy based grid connected system using solar and wind energy which helps to meet the energy requirement in Rohingya refugee's camp in Teknaf or anywhere in Bangladesh and grid connection will help to accomplish the total requirement. FACTS device used for increases the Power quality of voltage level during the change of renewable sources.

To perform the work initially the data analysis is carried out to obtain the Rohingya refugees camp details and available resources within that area. System design is adopted to find out a cost-effective, reliable and environment friendly. To check the voltage stability against large disturbances of renewable resources power flow analysis is carried out.

1.5. Organization of the Thesis

The thesis is constructed as follows. Chapter 1 states the background of world's energy scenario and Bangladesh present power generation, status of energy source, current problem. It also specifies the present state of this work. Chapter 2 is composed of several analytical techniques which are adopted in this work. Chapter 3 presents details about the design procedure and also provides the modelling system in ETAP and HOMER. Simulation result is presented in Chapter 4. Chapter 5 concludes the present work with some future scope of present work. Appendix A contains list of publication from the present work. Appendix B contains the meteorological data format.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

Bangladesh is one of those regions where there is power crisis everywhere, mainly in rural area and this electricity demand is increasing day by day. To overcome this situation, government has taken few steps for solving the energy crisis by setup different type power station. There are many strategies for case study and a power system design. In this chapter the analytical techniques are stated in brief those are used in this work. The work begins with a study area and analysis of different types of data associated with this research. After that discussed of design techniques and theoretical analyzes that are relevant to this study. Finally, the use of the iterative technique and power flow analysis is reviewed to determine the power quality of the proposed system.

2.2. Study of Areas

Within the current problem of Bangladesh, Energy and Rohingya refugees is one the major concern issue. Bangladesh power generation mainly depend on fossil fuel where almost 90% electricity comes from nature gas and oil. According to Bangladesh Economic Report, Bangladesh's proven natural gas will be depleted within 7-10 years if current consumption of gas continues [10]. That will cause a breakdown of power failure after few years later because of 57.37 percent power plant based nature gas and the power generation almost 68.49 percent from that resources. It’s very essential for a growing nation like Bangladesh, to develop rural areas beside the urban area simultaneously because almost 72% People living in the rural area. In the age of information technology, it's quite difficult to develop rural community without electricity. But Bangladesh located in a geographical position where 42,154 sq.km are coastal zone (figure 2.1), including 710 km of exposed coastline. It spans 19 districts with a population 31.8 million that will be projected to grow 56.6 million by 2050 [23]. Two registered Rohingya refugees camp are situated in coastal area at Teknaf upazila under Cox's bazar district where around 33,131 registered refugees living. Overall, the living conditions of Rohingya refugees inside the overcrowded camps remain dismal. Mental health is poor, proper hygiene conditions are lacking, and physical/sexual abuse is high. Natural resource like wind, solar, tidal etc. are more available in the coastal areas compared to urban areas. It will be possible to generate electricity using sources of this nature, which creates the possibility of developing refugee communities. At present International Renewable Energy Agency (IRENA) is helping the UN Refugee Agency, UNHCR, address the need for efficient, clean, affordable and reliable energy in humanitarian community. Now humanitarian community dependent on expensive, polluting diesel generators. IRENA case studied on four refugees settlements at Iraq and Ethiopia where they find out the requirement of electricity for refugees and already they has contributed to UNHCR’s for sustainable energy.

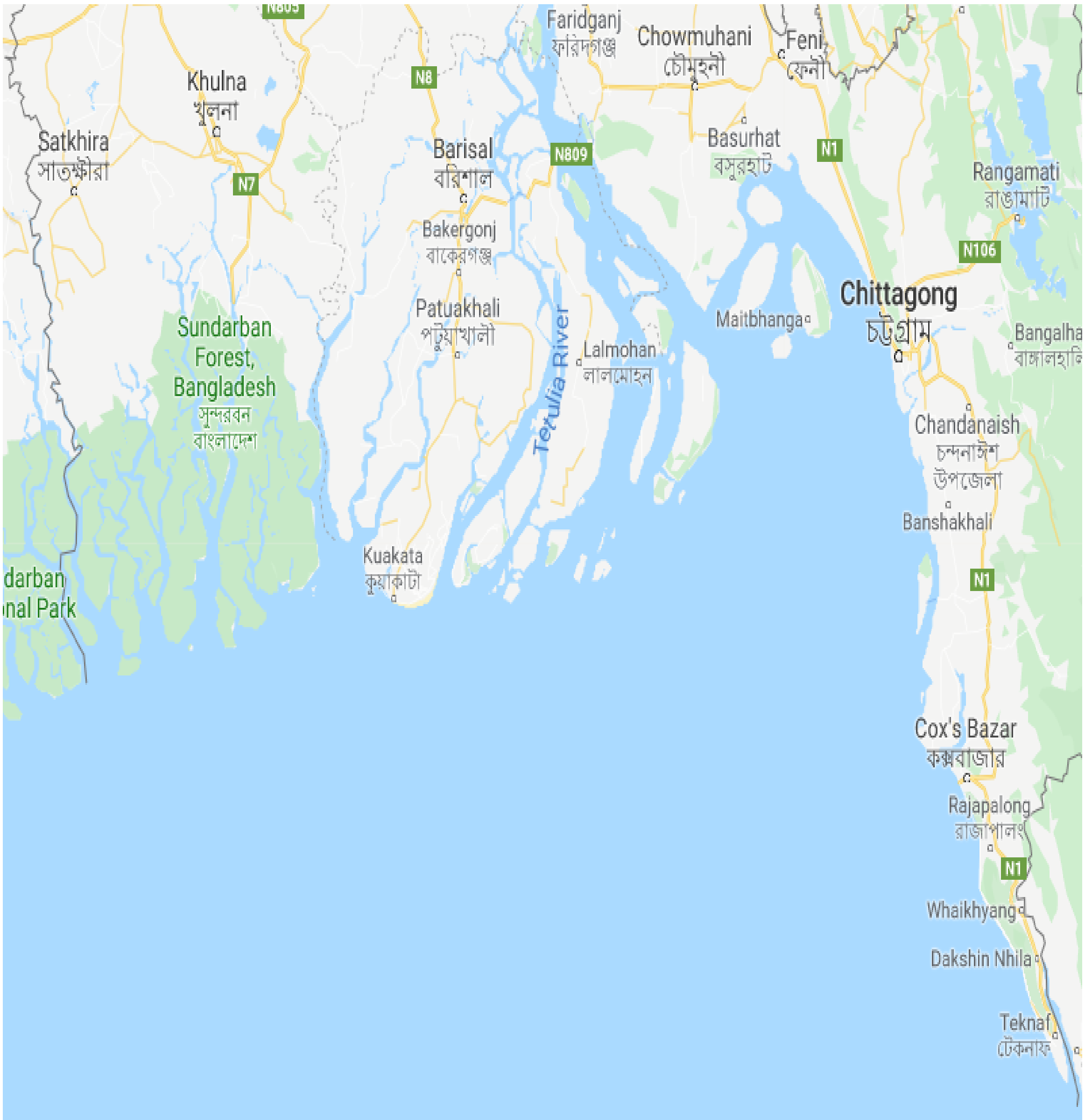

Figure 2.1 Bangladesh coastal zone

2.3. Data Collection Methods

Energy source selection is an important condition for designing a sustainable system or green system. Renewable sources are the best option for producing clean power generation because renewable sources like solar, water, wind and biomass will not finish and not limited. There is no fuel cost for renewable sources and does not produce any pollution which is harmful for the environment. In the first step, after a systematic literature review, Rohingya refugee's camp is considered that is located the coastal zone of Bangladesh. This Rohingya refugees Camp's focused on due to the miserable living conditions marked by inadequate access to basic needs, exposure to violence, restricted movement, local hostility, and various forms of discrimination. The information about the Rohingya refugees camps were identified from UNCHR data and a systematic literature review [8]. To design a power system it is very important to identify the available natural resources. To identify the available natural resources in coastal region in Teknaf upazila under Chittagong division, collecting various types of data likes wind speeds, solar radiations from different institutions like Bangladesh Meteorological Department (BMD), National Aeronautics and Space Administration (NASA) to the analysis of the required system. Therefore, finding an effective system for the coastal Refugees community.

2.4. Schematic Layout for System Design in Homer Software

The Grid connected PV-Wind hybrid power system is proposed for analyzing the feasibility and stability. The schematic layout for design in Homer software of this study is shown in figure 2.2 under to meet the electricity demand in the rural area of Rohingya refugee's camp, Teknaf. Simulation, optimization and sensitivity are elements of HOMER to model the system and analyze the result. During the simulation process, the power system components need to be determined and data needs to be input to meet the electricity load. This process can decide the lifecycle cost of system according to the installing and operating and maintenance cost of different components. In the operating process, after calculation, all the available alternatives will be shown.

The final choice should be based on costs of investment, fuels and maintenance and operation and environment impact. In the sensitivity analysis process, the parameters for components can be adjusted to determine the feasibility of configuration and the differences for the system.

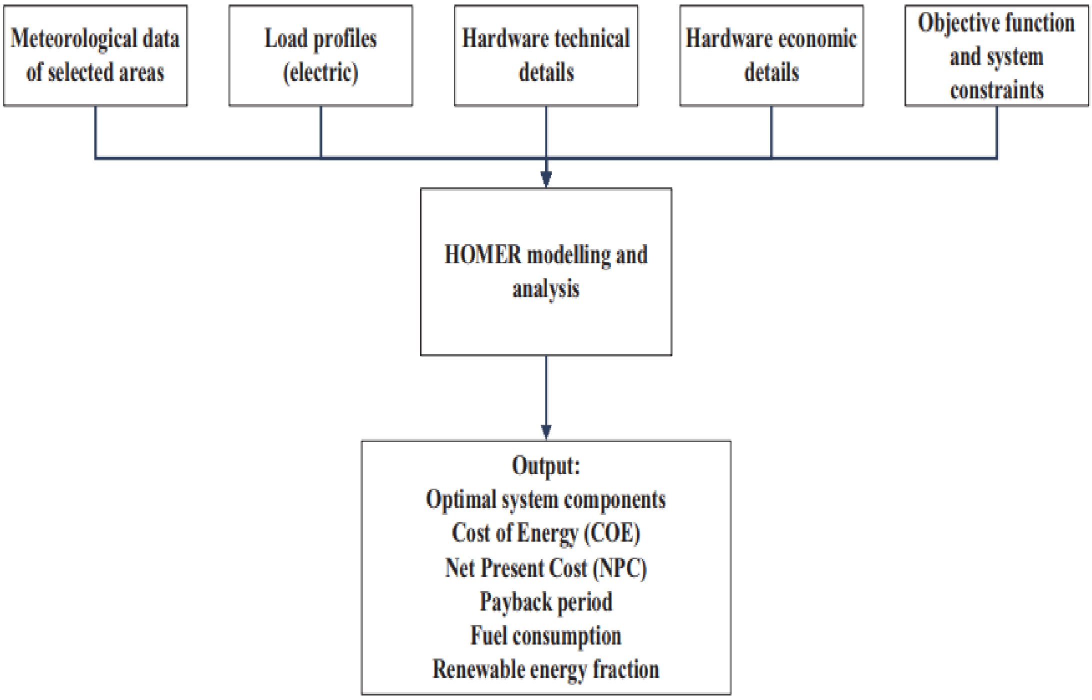

Figure 2.2 Flow chart of the framework of Homer software

2.5. Cost Optimization Model

HOMER simulates the system by making energy balance calculation for every hour in a year and comparing the hourly electric demand to the system hourly electric supply. It can calculate the energy flows for each system component and decide how the system works to meet the electric demand. Additionally, it will simulate all the feasible alternatives according to the cost of installing and operating the system, fuels and interest rate.

After simulation, HOMER shows the top ranked system configurations according to the Net Present Cost (NPC), and also shows the sizes and quantities of the components, the total capital cost and Levelized Cost of Energy (COE).

NPC is the main economic output in HOMER that's means the deviation between the total cost of the system and the total revenue. The total cost of the system includes the capital cost, replacement cost and the operation and maintenance cost of the system, fuel costs and emissions penalties. Revenues include salvage value and grid sales revenue. It is calculated according to the expression below: [24-25].

The total net present cost (NPC) is:

$$C_{NPC} = \frac{C_{Ann,tot}}{CRF_{(i,R_{proj})}} \tag{2.1}$$

Where $C_{Ann,\,tot}$ is the total annualized cost (USD/year), CRF is capital recovery factor, i = annual interest rate (6.3%), R_{proj} is project life time (20 years). To calculate the present value of annual cash flows firstly determined the capital recovery factor.

The equation for the capital recovery factor (CRE) is:

$$CRF = \frac{i(i+1)N}{(i+1)N} - 1 \tag{2.2}$$

Where, i is the real interest rate (%) and N is the number of years.

COE is the average cost per kWh of useful electrical energy produced by the system. It plays an important role when considering about the system, but HOMER ranks the result according to NPC instead of COE is because NPC is a more trustworthy number. It is hard to isolate and calculate the cost of electricity or the amount of electricity demand and actually supplied when the system serves both electric and thermal loads. COE is calculated according to the expression below: [26-27]

$$CEO = \frac{C_{ann,tot}}{EAC + E_{grid\ sale}} \tag{2.3}$$

Where $C_{ann,\,tot}$, EAC and $E_{grid\ sale}$ are the total annualized cost of the system (USD/year), the AC primary load (kWh/year) and the total grid sales (kWh/year).

2.6. Theoretical Analysis

In this proposed system some focus points are renewable generation sources (solar and wind), Load, FACTs device. The details are discussed in the following subsections:-

2.6.1. Solar PV System

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the bandgap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation.

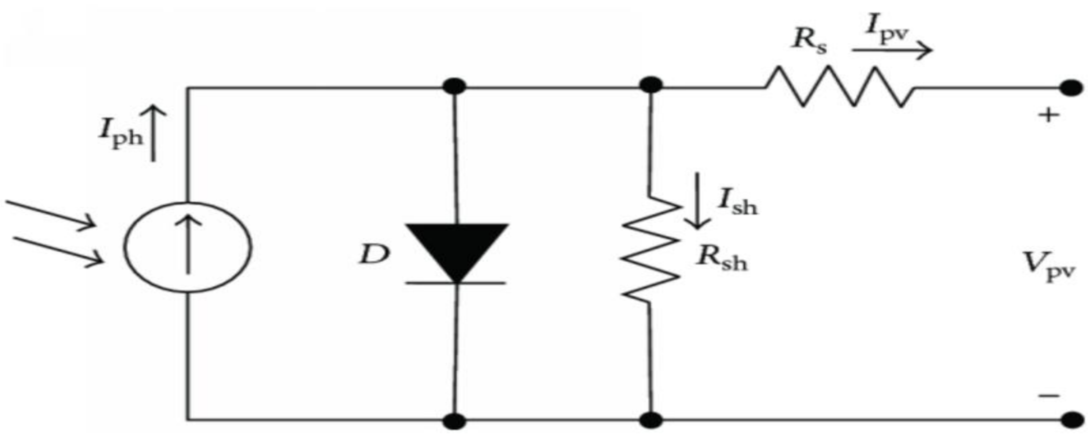

Figure 2.3 The equivalent circuit of the solar cell

In this equivalent circuit, a current source (I_{ph}), a diode, a series resistor (R_s) and a parallel resistor (R_{sh}) are included. The relevant equations are given below [28].

$$I_{Sh} = \frac{v + IR_s}{R_{Sh}} \tag{2.4}$$

$$I_{ph} = [I_{SC} + KI * (T - R_{Sh})] * \frac{I_r}{I_{ref}} \tag{2.5}$$

$$I_{rs} = \frac{I_{sc}}{\exp\left(q * \frac{V_{OC}}{A * k * T_{ref}}\right) - 1} \tag{2.6}$$

$$I_s = I_{rs} * \left(\frac{T}{T_{ref}}\right)^3 * exp\left(q * \left(\frac{E_g}{A}\right) * k * \frac{T_{ref} - 1}{T}\right) \tag{2.7}$$

$$I_d = I_s * \frac{\exp(V + IR_s)}{A * V_t * N_s} \tag{2.8}$$

$$I = (I_{ph} * N_p) - ((I_d * N_p) - (I_{sh} * N_p)) \tag{2.9}$$

$$V = A * V_t * N_s * ln\left[\frac{I_{ph}*N_p - I - I_{sh}*N_P}{I_s} * N_p + 1\right] - 1 * R_s \qquad (2.10)$$

Where,

I_{sh} is the shunt current.

I_{ph} is the photocurrent.

I_{rs} is the reverse saturation current at the T_{ref}

I_s is the reverse saturation current.

I_d is the diode current.

I is the load current.

V is the load voltage.

T_{ref} is the reference temperature.

q is one electron charge.

I_{rref} is reference irradiance.

KI is the short circuit current temperature coefficient.

E_g is the bandgap energy.

I_{sc} is the short circuit current.

V_{oc} is the open circuit voltage.

I_r is the actual irradiance.

A is the ideality factor.

N_p is the number of cells connected in parallel.

N_s is the number of cells connected in series.

T is the actual temperature.

2.6.2. Wind Energy System

The following table shows the definition of various variables used in this model [29]:

E = Kinetic Energy (J)

ρ = Density (kg/m^3)

m = Mass (kg)

A = Swept Area (m^2)

v = Wind Speed (m/s)

C_p = Power Coefficient

P = Power (W)

r = Radius (m)

$\frac{dt}{dm}$= Mass flow rate (kg/s)

x = distance (m)

$\frac{dt}{dE}$= Energy Flow Rate (J/s)

t = time (s)

Under constant acceleration, the kinetic energy of an object having mass m and velocity v is equal to the work done W in displacing that object from rest to a distance s under a force F, i.e.:

$$E = W = Fs \quad (2.11)$$

According to Newton's Law, we have:

$$F = ma \quad (2.12)$$

Hence,

$$E = mas \quad (2.13)$$

Using the third equation of motion:

$$V^2 = u^2 + 2as \quad (2.14)$$

We get,

$$a = \frac{V^2 - u^2}{2s} \quad (2.15)$$

Since the initial velocity of the object is zero, i.e. u = 0,

We get,

$$a = \frac{V^2}{2s} \quad (2.16)$$

Substituting it in equation, we get that the kinetic energy of a mass in motions is:

$$E = \frac{1}{2} * m * v^2 \quad (2.17)$$

$$P = \frac{1}{3} * p * A * V^3 \quad (2.18)$$

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the Betz Limit or Betz' Law. The theoretical maximum power 58 efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "power coefficient".

$$C_{pmax} = 0.59 \quad (2.19)$$

Also, wind turbines cannot operate at this maximum limit. The C_p value is unique to each turbine type and is a function of wind speed that the turbine is operating. Once we incorporate various engineering requirements of a wind turbine strength and durability in particular, the real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. By the time we take into account the other factors in a complete wind turbine system - e.g. the gearbox, bearings, generator and so on. Only 10-30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation and the extractable power from the wind is given by:

$$P_{avil} = \frac{1}{2} * \rho * A * V^3 * C_p \tag{2.20}$$

The swept area of the turbine can be calculated from the length of the turbine blades using the equation for the area of a circle:

$$A = \pi r^2 \tag{2.21}$$

Where, the radius is equal to the blade length.

2.6.3. Load

Constant PQ (Real and Reactive) load has been considered in this work. The power factor is very important issue, in BPS the power factor varies from 0.85 to 0.95 [30]. Power factor at the load buses has been chosen 0.95, lagging in this work.

2.6.4. Static VAR Compensator (SVC) and Control Scheme

Shortage of reactive power causes voltage sag which ultimately leads the system to voltage instability. Shortage of reactive power provides reduced level of voltage and on the other hand surplus reactive power causes the loss of transmission line. To provide the controlled reactive power in the system the shunt FACTS device like SVC can be used. It provides the reactive power in controlled manner which in turns increases the system capacity of power transmission as well as the stability. [31] The structure of SVC consists of a fixed shunt A.C capacitor and a thyristor controlled reactor connected in parallel. The module can be connected directly across the line or through a step down transformer. Figure 2.4 represents the basic construction of a SVC.

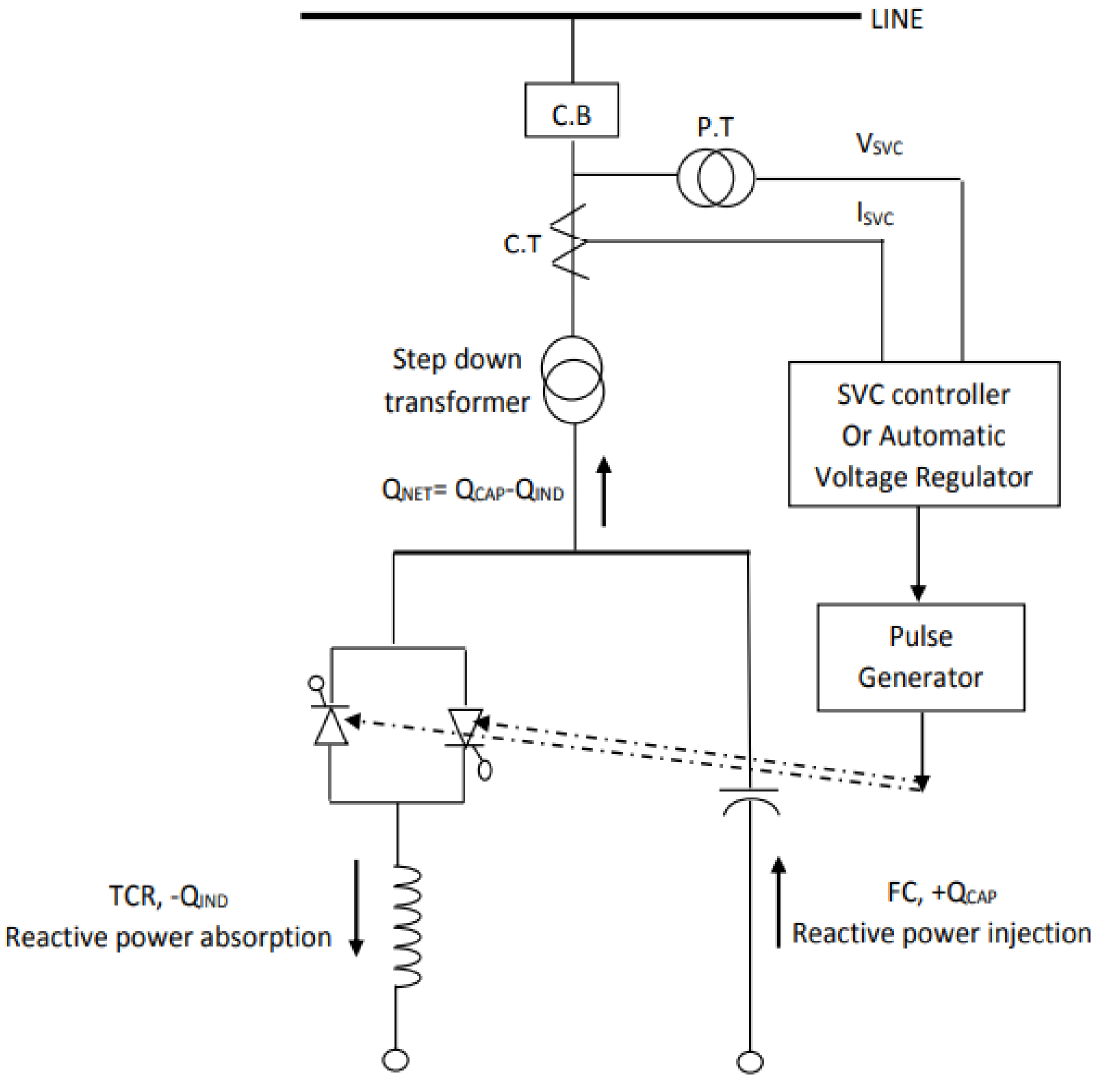

Figure 2.4 Basic construction of SVC [32]

SVC is basically a controlled shunt susceptance device which can provide or inject reactive power or can absorb reactive power when necessary. The control objective of the SVC is to maintain a desired voltage level in the system. From figure 2.4, $+Q_{cap}$ is a fixed capacitance value, when the system voltage reduces below the set point the SVC operates till this fixed value. Q_{net}, is controlled by the magnitude of $-Q_{ind}$ reactive power absorbed by the Thyristor Controlled Reactor (TCR) this is because some situation may arise when surplus of reactive power can exist in the system. Firing angle of anti-parallel thyristor can produce variable reactance [32]. The figure 2.5 shows the current waveform for various values of delay angle or firing angle (α).

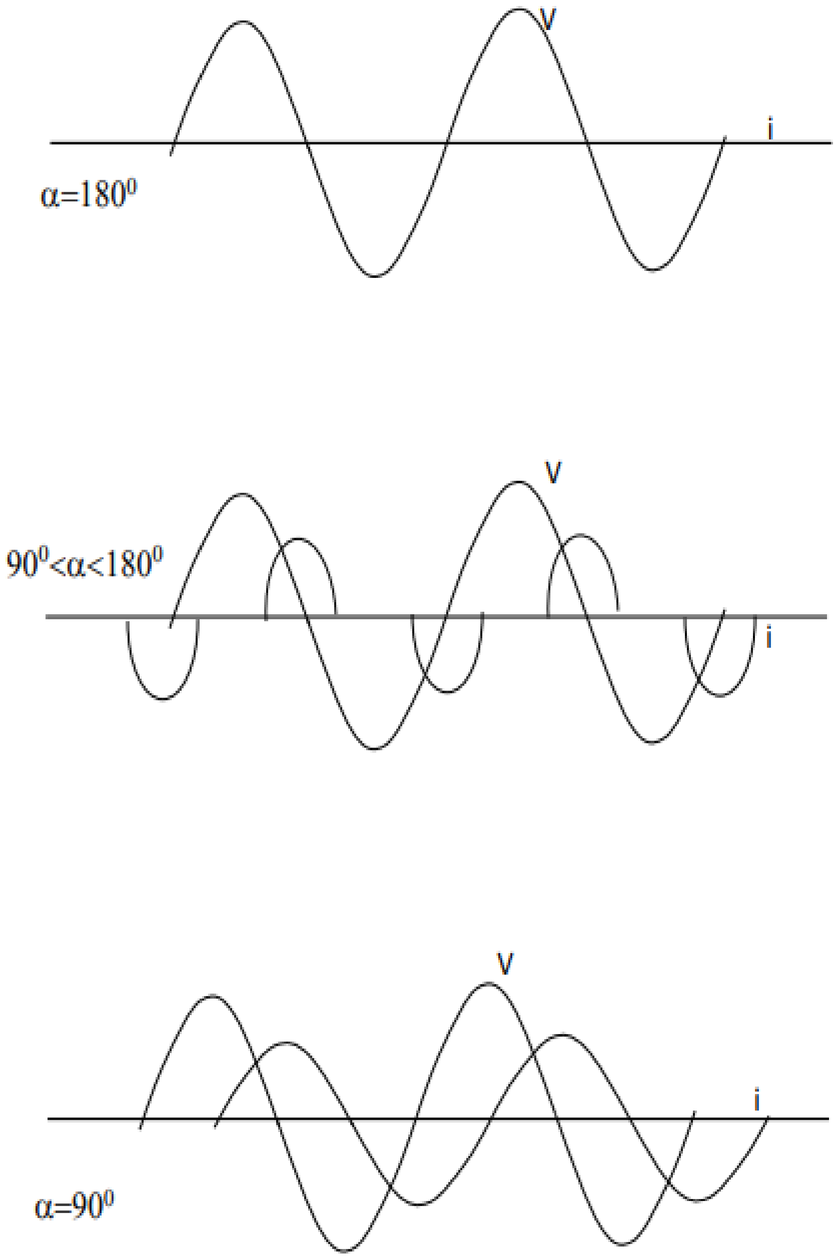

Figure 2.5 Variable inductance at variable firing angle of thyristor [32].

The voltage across the inductor can be used to get the current waveform through the inductor using the following equation.

$$L * i = \int v \, dt \tag{2.22}$$

The instantaneous current is given by,

$$i=\sqrt{2}\frac{V}{X_L}(\cos\alpha-\cos\omega t);\ \alpha<\omega t<\alpha+\sigma \tag{2.23}$$

$= 0;\ \alpha+\sigma < \omega t < \alpha+\pi$

Where, V is the rms voltage applied, $X_L=\omega L$ is the fundamental frequency reactance of the reactor. ω is the radian frequency of the voltage and σ is the angle for which a thyristor conducts. The current is non-sinusoidal (except α =90°) and contains odd harmonics which are functions of the conduction angle σ. The fundamental component of the TCR current, I_1 is obtained by Fourier analysis.

$$I_1 = B_{TCR}(\sigma)V;\ B_{TCR} = (\sigma - \sin\sigma)/\pi X_L \qquad (2.24)$$

Where, $B_{TCR}(\sigma)$ represents an adjustable fundamental-frequency susceptance.

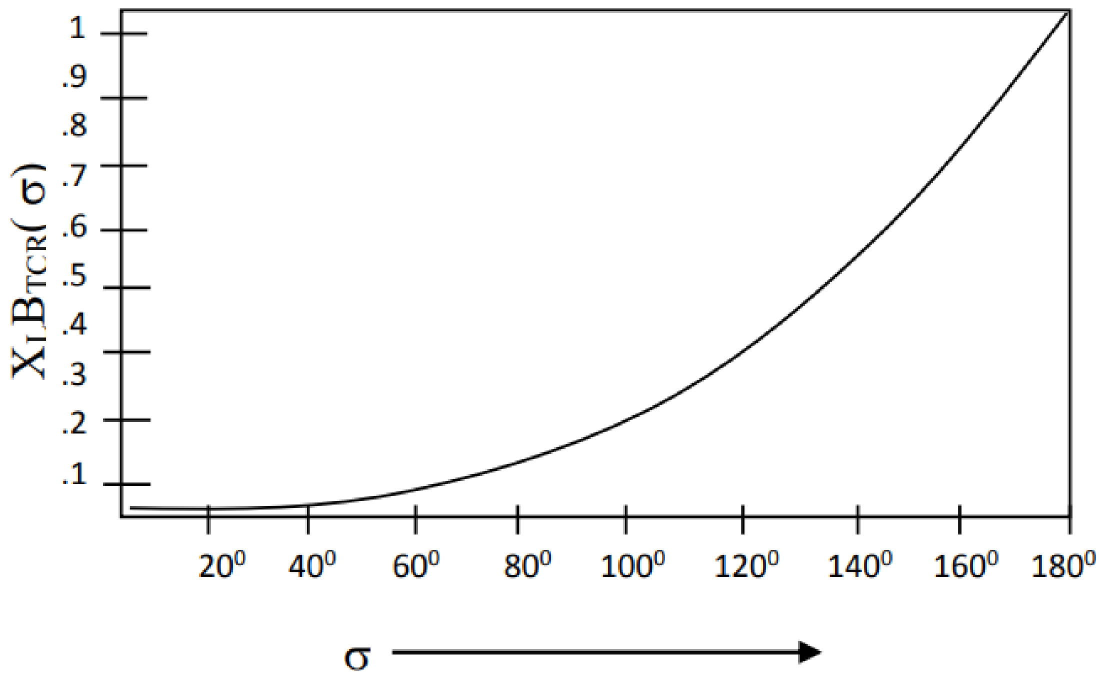

Figure 2.6 Conduction angle Vs Normalized susceptance [32]

The characteristics curve of SVC is given by the figure 2.7. The curve can be decomposed to three modes. They are capacitive, normal and inductive mode.

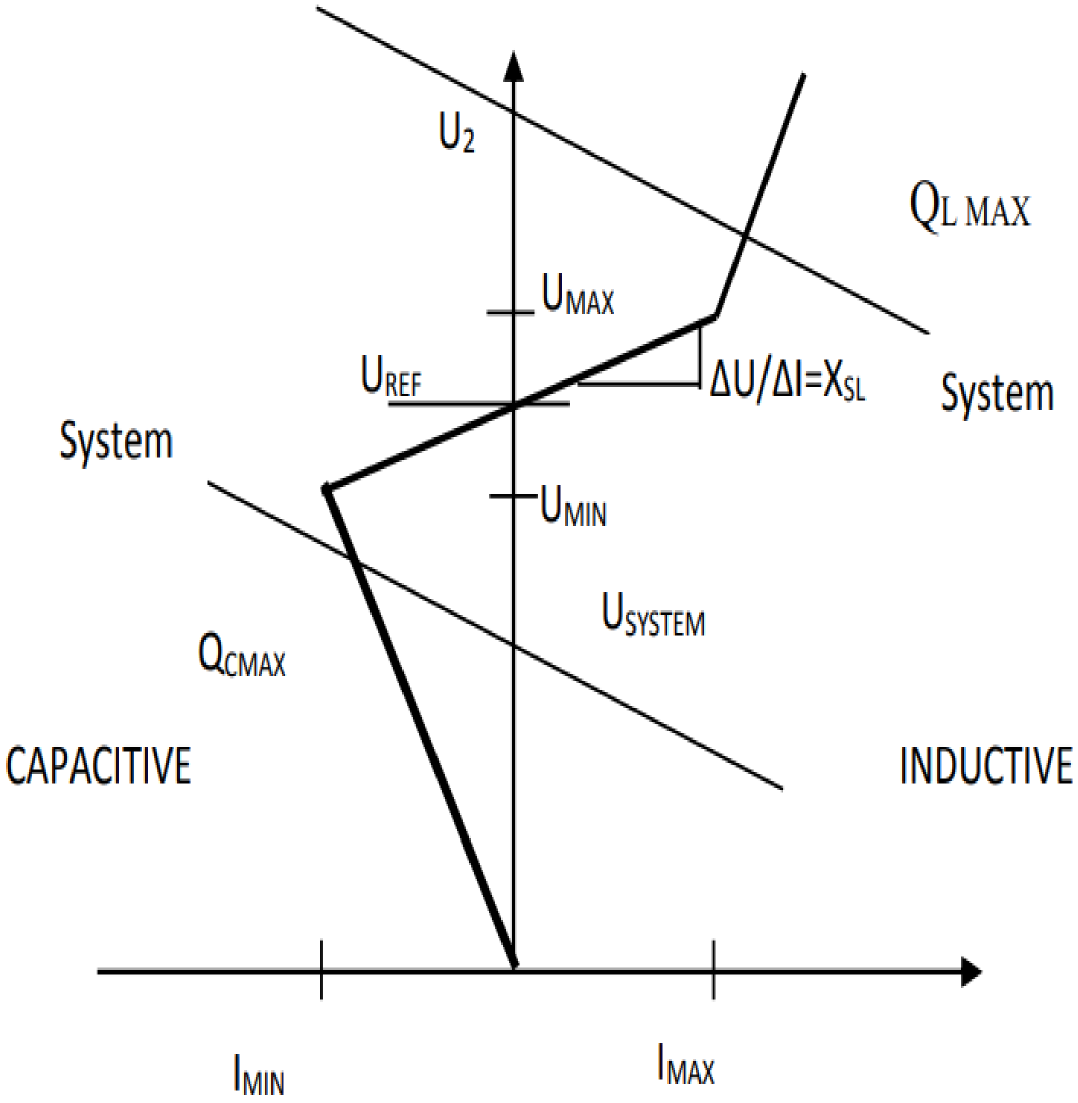

Figure 2.7 Characteristics curve of SVC [32]

Capacitive mode ($U_2 \leq U_{MIN}$):

$$I_2 = B_{CAP} * U_1 \; with \; B_{CAP} = -B_{CO} \; and \; B_{CO} = Q_{CMAX}/U_{2n^2}$$

Inductive mode ($U_2 \geq U_{MIN}$):

$$I_2 = B_{IND} * U_1 \; with \; B_{IND} = B_{lO} - B_{CO} \; and \; B_{lO} = (Q_{CMAX} + Q_{lMAX})/U_{2n^2}$$

Linear control range, Normal mode ($U_{MIN} \leq U_2 \geq U_{MIN}$):

$$I_2 = \frac{U_2 - U_{REF}}{X_{Sl}}; \; X_{Sl} \neq 0$$

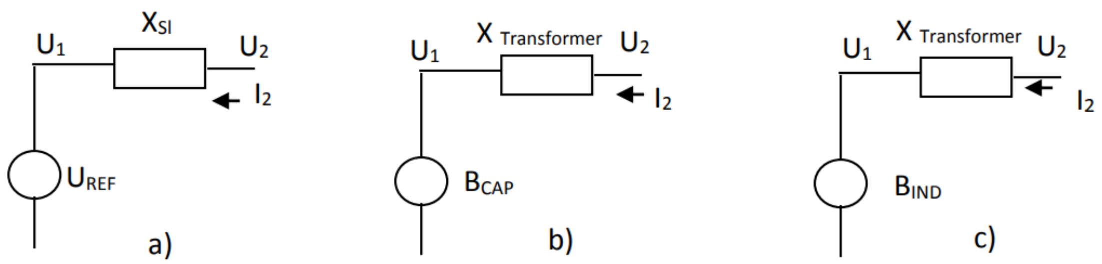

Figure 2.8 a) Normal Mode b) Capacitive Mode c) Inductive Mode

In figure 2.9 a SVC controller is shown [33]. The SVC controller provide fast compensation to provide transient and dynamic stability.

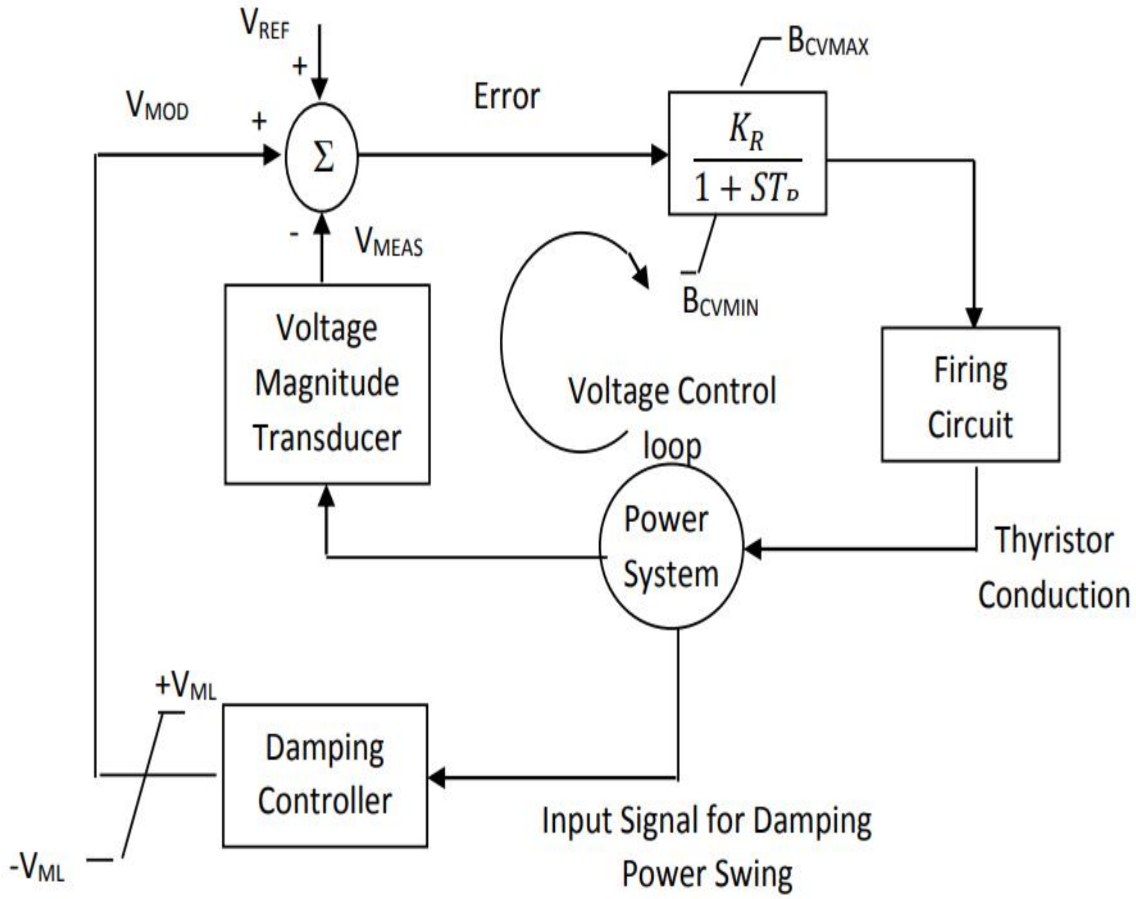

Figure 2.9 Control strategy of SVC [33]

The control strategy may be divided into two loop. Steady state susceptance modulation is given by voltage control loop. This loop consists of voltage regulator, firing circuit and a voltage magnitude transducer. Reference voltage and the measured voltage produce the error voltage which is passed through a voltage regulator to produce the desired susceptance level. To have the desired susceptance the controller uses a gate pulse to control the thyristor firing in a manner that the desired value is achieved and error becomes zero. To modulate the reactance in an instant manner the damping controller is used [33]. It senses the large disturbance in the power system and produces the modulated reactance to support the voltage level at the disturbance periods. When the damping control loop is used the V_{MOD} is added with the reference voltage level V_{REF}. Figure 3.19 shows a damping controller used for fast voltage modulation. The controller uses lead-lag compensator to produces desired phase compensation. It can use one or more lead-lag blocks. The final output is passed through a first order lag to produce the modulation signal.

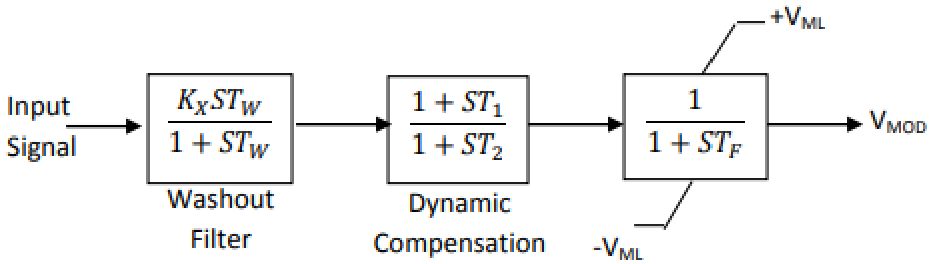

Figure 2.10 Damper control strategy of SVC [33]

2.7. Load Flow Analysis

In a power system, power flows from generating station to the load through different branches of the inter connected network. The flow of active and reactive power is known as load flow or power flow. The main information obtained from the load flow or power flow analysis comprises of real and reactive power flow in the system, transmission angle, voltage magnitude, line current and phase of voltage. The power flow equations are non-linear and are usually solved by iterative techniques using numerical methods (Holomorphic method, Abstract algebra method are also used in small scale). Numerical methods provide only approximate solution. The most commonly used iterative methods are the Gauss-Seidel, the Newton-Raphson and Fast Decoupled method [34]. The numerical analysis involving the solution of algebraic simultaneous equations forms the basis for solution of the performance equations in computer aided electrical power system analyses e.g. for load flow analysis [35]. The first step in performing load flow analysis is to form the Y-bus admittance using the transmission line and transformer input data. The nodal equation for a power system network using Y bus can be written as follows:

$$I_{BUS} = Y_{BUS}V_{BUS} \tag{2.25}$$

The nodal equation can be written in a generalized form for an n bus system:

$$I_i = \sum_{j-1}^{n} Y_{ij}V_j \, ; i = 1,2,3, \dots . n \tag{2.26}$$

The complex power delivered to bus i is

$$P_i + jQ_i = V_i I_i^* \tag{2.27}$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.28}$$

Eliminating Ii from equation (2.26) and (2.28) gives

$$\frac{P_i - jQ_i}{V_i^*} = \sum_{j-1}^{n} Y_{ij}V_j \tag{2.29}$$

Therefore, the voltage at any bus i where Pi and Qi are specified is given as

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{j=1, j\neq k}^{n} Y_{ij}V_j\right] \tag{2.30}$$

The equation (2.30) uses iterative techniques to solve load flow problems. Hence, it is necessary to review the general forms of the various solution methods; Gauss-Seidel, Newton Raphson and Fast decoupled load flow. Among these methods only Newton Raphson Method is discussed below.

2.7.1. Newton Raphson Method

It is an iterative method which approximates a set of non-linear simultaneous equations to a set of linear simultaneous equations using Taylor's series expansion. It is the most popular iterative method used for the load flow because its convergence characteristics are relatively more powerful compared to other alternative processes and the reliability of Newton-Raphson approach is comparatively good.

Equation (2.26) is expressed in a polar form, in which j includes bus i

$$I_i = \sum |Y_{ij}||V_j| \angle \theta_{ij}+\delta_j \tag{2.31}$$

The real and reactive power at bus i is

$P_i - jQ_i = V_i * I_i$ (2.32)

The real and imaginary parts are separated:

$P_i=\sum|Y_{ij}||V_i||V_j| \cos(\theta_{ij}-\delta_i+\delta_j)$ (2.33)

$Q_i= -\sum|Y_{ij}||V_i||V_j| \sin(\theta_{ij}-\delta_i+\delta_j)$ (2.34)

The above Equation (2.33) and (2.34) constitute a set of non-linear algebraic equations in terms of |V| in per unit and δ in radians. Equation (2.33) and (2.34) are expanded in Taylor's series about the initial estimate and neglecting all higher order terms, the following set of linear equations are obtained.

$$\begin{bmatrix}
\frac{\partial P_2}{\partial \delta_2} & \frac{\partial P_2}{\partial \delta_3} & \frac{\partial P_2}{\partial \delta_4} & \frac{\partial P_2}{\partial \delta_5} & |V_2|\frac{\partial P_2}{\partial |V_2|} & |V_3|\frac{\partial P_2}{\partial |V_3|} & \frac{\partial P_2}{\partial t} \\
\frac{\partial P_3}{\partial \delta_2} & \frac{\partial P_3}{\partial \delta_3} & \frac{\partial P_3}{\partial \delta_4} & \frac{\partial P_3}{\partial \delta_5} & |V_2|\frac{\partial P_3}{\partial |V_2|} & |V_3|\frac{\partial P_3}{\partial |V_3|} & \frac{\partial P_3}{\partial t} \\
\frac{\partial P_4}{\partial \delta_2} & \frac{\partial P_4}{\partial \delta_3} & \frac{\partial P_4}{\partial \delta_4} & \frac{\partial P_4}{\partial \delta_5} & |V_2|\frac{\partial P_4}{\partial |V_2|} & |V_3|\frac{\partial P_4}{\partial |V_3|} & \frac{\partial P_4}{\partial t} \\
\frac{\partial P_5}{\partial \delta_2} & \frac{\partial P_5}{\partial \delta_3} & \frac{\partial P_5}{\partial \delta_4} & \frac{\partial P_5}{\partial \delta_5} & |V_2|\frac{\partial P_5}{\partial |V_2|} & |V_3|\frac{\partial P_5}{\partial |V_3|} & \frac{\partial P_5}{\partial t} \\
\frac{\partial Q_2}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_3} & \frac{\partial Q_2}{\partial \delta_4} & \frac{\partial Q_2}{\partial \delta_5} & |V_2|\frac{\partial Q_2}{\partial |V_2|} & |V_3|\frac{\partial Q_2}{\partial |V_3|} & \frac{\partial Q_2}{\partial t} \\
\frac{\partial Q_3}{\partial \delta_2} & \frac{\partial Q_3}{\partial \delta_3} & \frac{\partial Q_3}{\partial \delta_4} & \frac{\partial Q_3}{\partial \delta_5} & |V_2|\frac{\partial Q_3}{\partial |V_2|} & |V_3|\frac{\partial Q_3}{\partial |V_3|} & \frac{\partial Q_3}{\partial t} \\
\frac{\partial Q_5}{\partial \delta_2} & \frac{\partial Q_5}{\partial \delta_3} & \frac{\partial Q_5}{\partial \delta_4} & \frac{\partial Q_5}{\partial \delta_5} & |V_2|\frac{\partial Q_5}{\partial |V_2|} & |V_3|\frac{\partial Q_5}{\partial |V_3|} & \frac{\partial Q_5}{\partial t}
\end{bmatrix}
\begin{bmatrix} \Delta\delta_2 \\ \Delta\delta_3 \\ \Delta\delta_4 \\ \Delta\delta_5 \\ \frac{\Delta|V_2|}{|V_2|} \\ \frac{\Delta|V_3|}{|V_3|} \\ t \end{bmatrix}
=
\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ \Delta P_4 \\ \Delta P_5 \\ \Delta Q_2 \\ \Delta Q_3 \\ \Delta Q_5 \end{bmatrix}$$

The element of the Jacobian matrix are obtained after partial derivatives of Equations (2.33) and (2.34) are expressed which gives linearized relationship between small changes in voltage magnitude and voltage angle. The equation can be written in matrix form as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (2.35)$$

J_1, J_2, J_3, J_4 are the elements of the Jacobian matrix. The difference between the schedule and calculated values known as power residuals for the terms ΔP_{ik} and ΔQ_{ik} are represented as:

$$\Delta P_{ik} = P_{isch} - P_{ik} \quad (2.36)$$

$$\Delta Q_{ik} = Q_{isch} - Q_{ik} \quad (2.37)$$

The new transmission angle and bus voltage are

$$\delta^{(k+1)} = \delta_i^k + \Delta\delta_i^k \tag{2.38}$$

$$\left|V^{(k+1)}\right| = \left|V_i^k\right| + \Delta\left|V_i^k\right| \tag{2.39}$$

2.8. Simulation Tools

In this work HOMER (Hybrid Optimization of Multiple Electric Renewable) and ETAP simulation software has been used. HOMER is frequently used most popular software tool for hybrid energy systems. It was developed by National Renewable Energy Laboratory in the United States [36]. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations. It provides the results as a list of feasible configurations sorted by net present cost in a wide variety of tables and graphs and help compare configurations and evaluate them on their economic and technical merit. In this thesis, Homer software is used to design a solar wind grid connected hybrid system for Rohingya Refugees camps. The specifications of PV panel, wind turbine, inverter and grid properties are to be modified for remodeling.

ETAP (Electrical Transient Analyzer Program) has great simulation modules for power system analysis, real-time simulations, monitoring, optimized control, intelligent load shedding, energy management, cost analysis, and load management. It is the most wide-ranging analysis software that is designed especially to design and apply tests of power systems. This software developed by Operation Technology Inc. [37-38]. ETAP software is used in this research for power flow analysis and monitoring the different power quality of design system.

2.9. Why ETAP software has been used besides HOMER?

ETAP is most popular power quality analysis software that is used widely around the world not only for research but also used practically in industry for power system monitoring purpose. In this study this software is attached for power quality analysis as there is no option to power quality analysis in HOMER software. HOMER software is used only for system optimization and cost analysis purpose. Power quality is one of the most important issue for designed a grid connected renewable hybrid power system. After optimization and cost analysis in HOMER software, the proposed system is designed in the ETAP software using the necessary equipment's to monitor the effects of power system parameters on changes in renewable sources or changes in renewable power generation through load flow analysis.

2.10. Summary

The chapter has discussed numerous analysis technique to check the feasibility and stability of system. The selected method has been validated for the proposed system to demonstrate system performance. Renewable resources, project location and economic point is most important for the analysis of feasibility in any renewable based power system. Load flow study helps to determine the parameters like voltage, current, power flow, power losses etc. of the power system.

CHAPTER 3

3. METHODOLOGY

3.1. Introduction

Energy access in any country or region is fundamental and significant beginning for social and economic development. A country like Bangladesh where energy generation is not enough to the proportion of the demand. Due to high population growth in Bangladesh, the demand for electrical power increases and a number of people are living in energy shortage despite continue positive efforts experienced for electrification across all over the Bangladesh. This Chapter highlights the modeling of proposed grid connected hybrid energy system consists of two renewable energy sources (solar and wind). The proposed system design based on Rohingya refugees camp where 19,311 registered refugees live in so that improve the safety, security, productivity and health in Rohingya refugee settlements, need to full fill the basic energy demand. The details of the proposed modeling system is stated for the study of power quality monitoring, feasibility and economic analysis.

3.2. Proposed Small Scale Grid Connected Hybrid System

The proposed green system is design for coastal region in Bangladesh to meet very basic electricity demand of Rohingya refugees and the system is proposed for 20 years.

3.2.1. Proposed Hybrid Power System Model

The proposed grid connected hybrid power generation system consists of renewable sources like solar, wind, grid and electrical loads. Figure 3.1 presents the proposed system block diagram. For reliable this system, grid is connected so that excess power supply to local grid and during the peak hour when solar or wind is absent the power demand backup by Grid. To enhance the power transfer capability and voltage stability of bus, reduce the loss of transmission line FACTs device is used in this system. Moreover, the system briefly discussed in section 3.3 and 3.4.

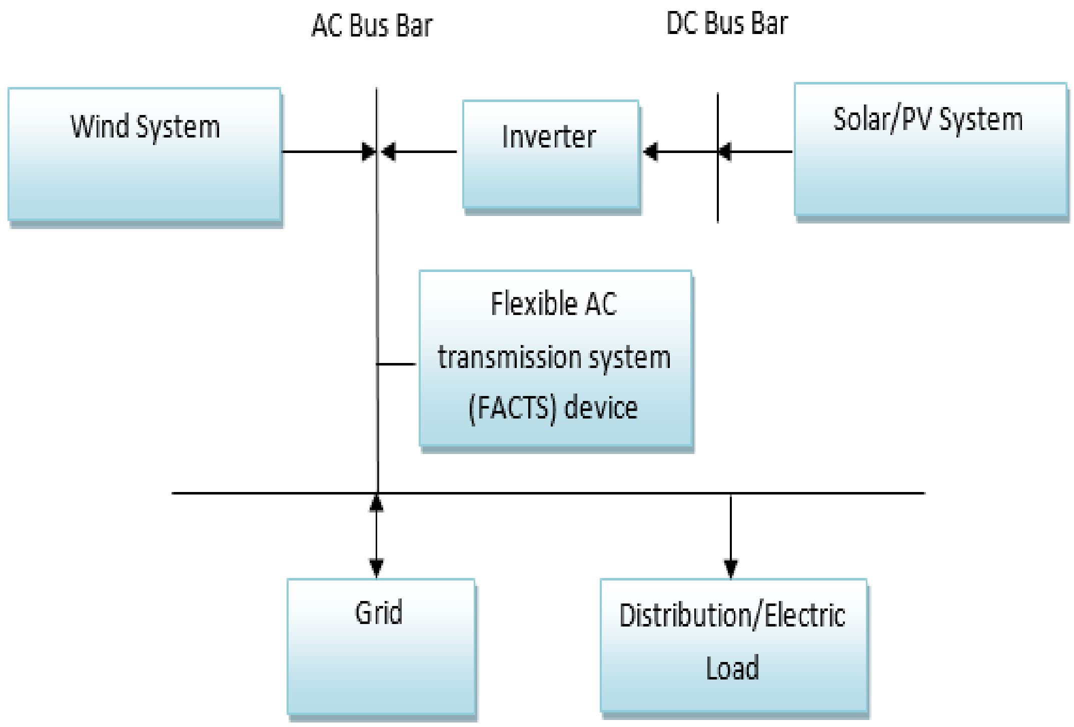

Figure 3.1 Proposed hybrid system for Rohingya Refugees

3.2.2. Site Selection

Teknaf is one of rural and backward regions in Bangladesh which is totally deprive from the mainstream, however, belongs to Chittagong Division under Cox's bazar District [39]. Cox's bazar is one of the coastal region in Bangladesh. It is situated at a rural or hill track area of Bangladesh being in 22' 52' north latitude and 92' 18" east longitude. For design and investigation, Teknaf Nayapara Rohingya camp has chosen which shown in figure 3.2. The areas has chosen because of the required sources are abundant in this area and full fill energy demand of Rohingya refugees.

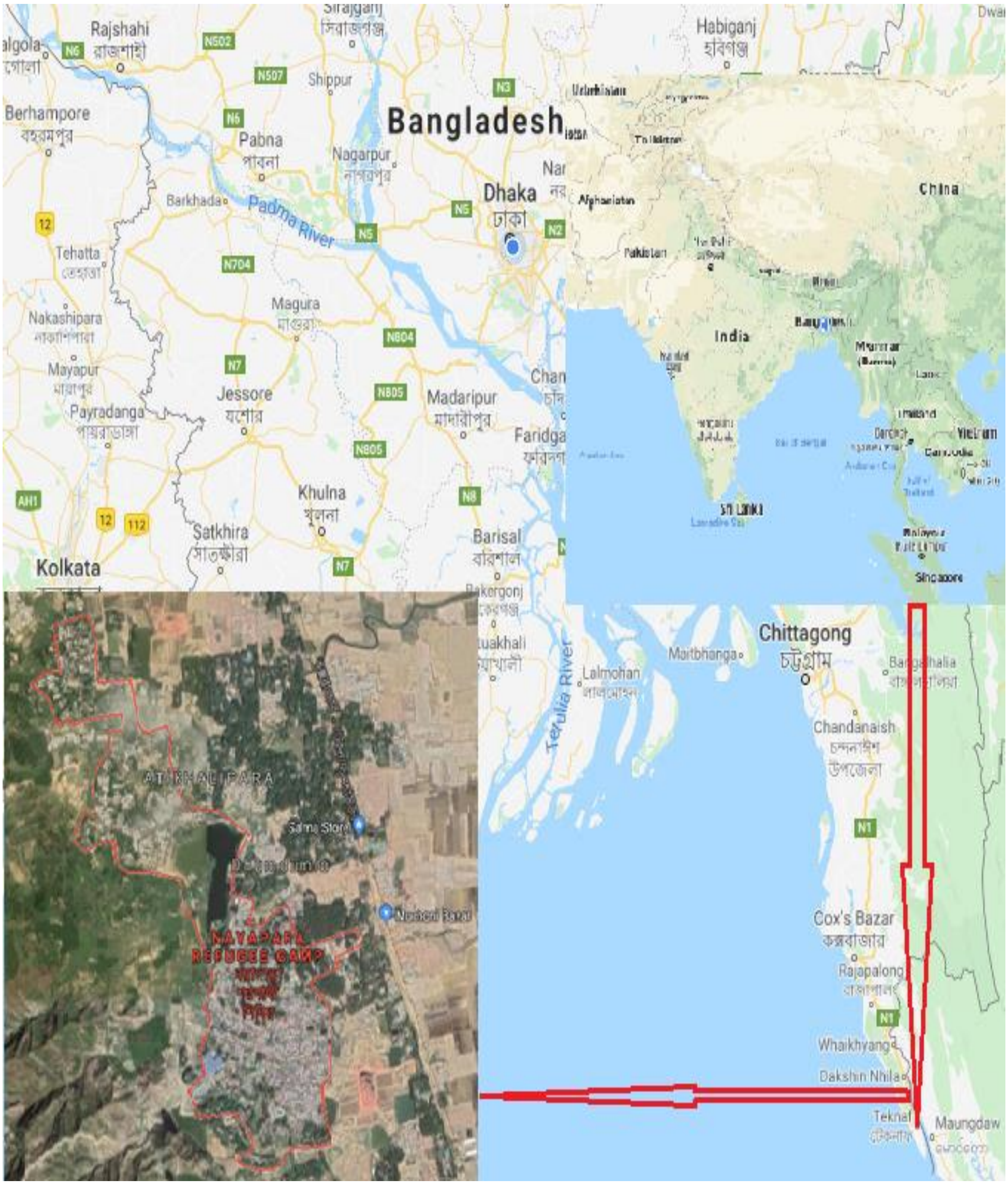

Figure 3.2 Geographical location of the proposed system

3.2.3. Proposed Load Demand Profile

According to the E-voucher system for the Food Assistance of the Refugee Relief and Reprobation Commission (RRRC), 3732 families have been registered in Teknaf Nayapara Refugee Camp [8]. Total registered refugees details is given in below Table 3.1.

Table 3.1 Registered Rohingya Refugee camp data

Details	Quantity
Refugee camps	2
Camp Population (registered)	33,131
Kutupalong camp, Ukhiya	13,820
Nayapara camp, Teknaf	19,311
Food support through food card (E-voucher system)	
Kutupalong (no. of families)	2627
Nayapara (no. of families)	3732

In order to provide electricity facility, an 80-watt ceiling fan, two compact fluorescent lamps (CFL) energy bulbs of 30 watts and other 10 watt load considered for each household where total connected load is 560 kWh shown in Table 3.2. According to the estimation, average daily electricity demand is 5.4 MWh. Figure 3.3 shows the average hourly load profile/day in January at which there is 560 kWh peak demand during 17.00 to 23.00hour in summer season. Figure 3.4 also represents the monthly average load requirement of the project place, which shows that compared to the summer (Mar to Oct) the load is relatively low at the winter (Nov to Feb).

Table 3.2 Total connected load with rating

Types of Load	Power(W)	Quantity Per Family	Number of family	Total Connected Load (kWh)
Lamp	60W	2	3732	224
Fan	80W	1	3732	299
Other	10W	1	3732	37
				560

The Rohingya refugee community's electricity demand for different periods is calculated as a percentage of the total connected load. In table 3.3 shown the details of power demand at different hours. The lamps load are same during whole year and Maximum lamp load needs only at night (Time 17.00-24.00) because sunlight is available at day time but fan load varies at time to time and also depends on weather, during winter no need of fan. At winter season just consider a minimum percentage of fan load and other load assume as a flat all the time.

Table 3.3 Power demand estimation at different time in summer and winter

Types of Load	Operating Hours	Percentage on Total Power demand in Summer	Percentage on Total Power demand in winter
Lamp	00.00-06.00	5%	5%
	06.00-17.00	10%	10%
	17.00-22.00	80%	80%
	22.00-23.00	70%	70%
	23.00-24.00	50%	50%
Fan	00.00-06.00	90%	2%
	06.00-11.00	40%	2%
	11.00-16.00	50%	10%
	16.00-17.00	50%	5%
	17.00-18.00	50%	2%
	18.00-24.00	80%	2%
Other	00.00-24.00	80%	80%

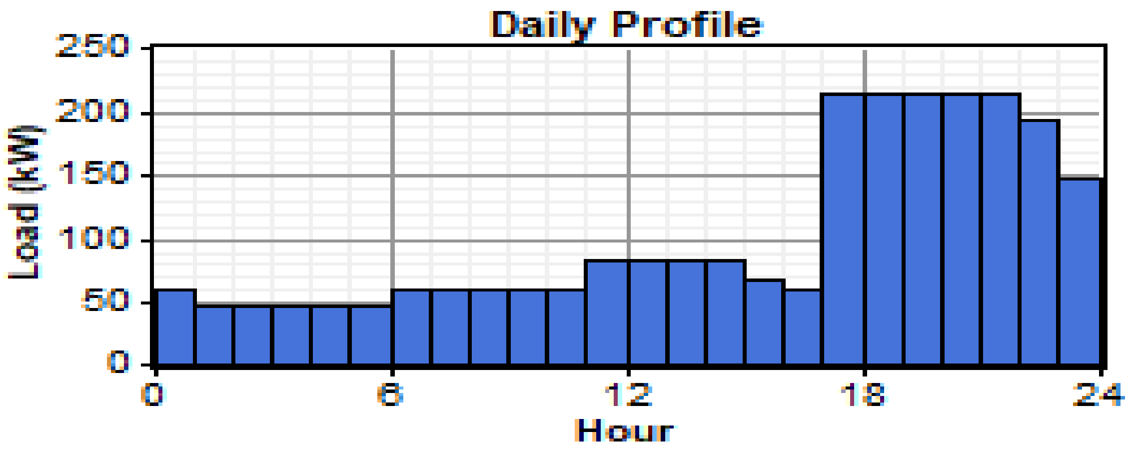

Figure 3.3 Average hourly load demand/day of January

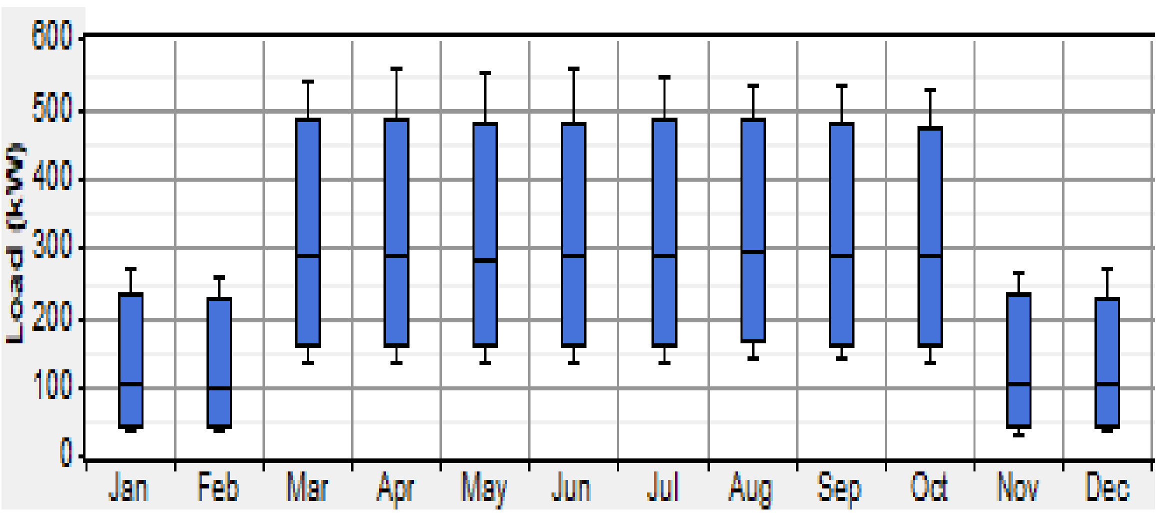

Figure 3.4 Monthly average load profile

3.3. Resources Assessment

At this moment, Bangladesh is trying to overcome the electricity crisis. The generation is not enough sufficient and day-by-day the electricity demand is increasing. So renewable source is the best possible option for fulfil the requirement of electricity demand. HOMER Software used to carry out for the design and economic optimization of Grid connected hybrid power system configuration for fulfil the required electricity of Rohingya Refugees demand. Energy derived from the sun, which reached the surface of the Earth, may be utilized and exploited for electricity generation. The Solar Photovoltaic system, the most promising of all the prevailing technologies, has considerable potential in different countries is regarded as an effective and evolving option to produce electricity. This form of energy is considered to be one of the most popular, viable and efficient renewable energy systems because of its abundant availability compared with other renewable sources (i.e., wind, hydropower, biomass, biogas and wave). High modularity, no demand for additional resources (e.g., water and fuel), immovable portions and low maintenance cost have led to the growing popularity of PV energy. One of the most important terms to establish renewable power plant is cost.

3.3.1. Solar Resource

The sunlight in Teknaf is sufficient for solar power plants expanding on account of the location. The average solar irradiation in this country is considerable high. In order to get final result in HOMER, the solar resources data is one of the important input data. In this part, the latitude and longitude of the selected location and the amount of solar radiation available to the photovoltaic (PV) array throughout the year are necessary to calculate the output of the PV array each hour of the year. Considering at the location is on latitude of 20.52°N, longitude of 92.18°E, and the monthly average solar radiation can be taken from Surface meteorology and Solar Energy-NASA. It is ranges from 3.15 kWh/m^2 /day and 6.29 kWh/m^2 /day, and the annual average solar radiation is 4.758kWh/m^2 /day [40]. Also compare this data with BMD after that calculating this data by using sunshine hours and temperature based equation because direct solar radiation data can’t record by BMD. The comparison result is shown in table 3.4 and figure 3.5. For estimation of solar radiation, different models is used based on sunshine hours and Temperature data after that compare the calculating result with NASA surface meteorology and SSE that’s represent in figure 3.5 [41].

Table 3.4 Solar radiation data

Month	Clearness Index	NASA Solar Radiation (kWh/m^2 /d)	BMD Solar Radiation (kWh/m^2 /d)	Average Temp (^{0}C)
January	0.635	4.732	4.67	20.5
February	0.636	5.508	5.32	22.9
March	0.620	6.098	5.94	25.8
April	0.581	6.292	6.11	28.4
May	0.520	5.592	5.69	29.2
June	0.384	3.864	4.24	28.2
July	0.310	3.156	3.39	27.5
August	0.333	3.900	3.53	27.7
September	0.450	4.446	4.43	28.2
October	0.549	4.600	4.77	27.8
November	0.635	4.676	4.80	25.3
December	0.614	4.230	4.31	22.1
Average	0.522	4.758	4.76	26.1

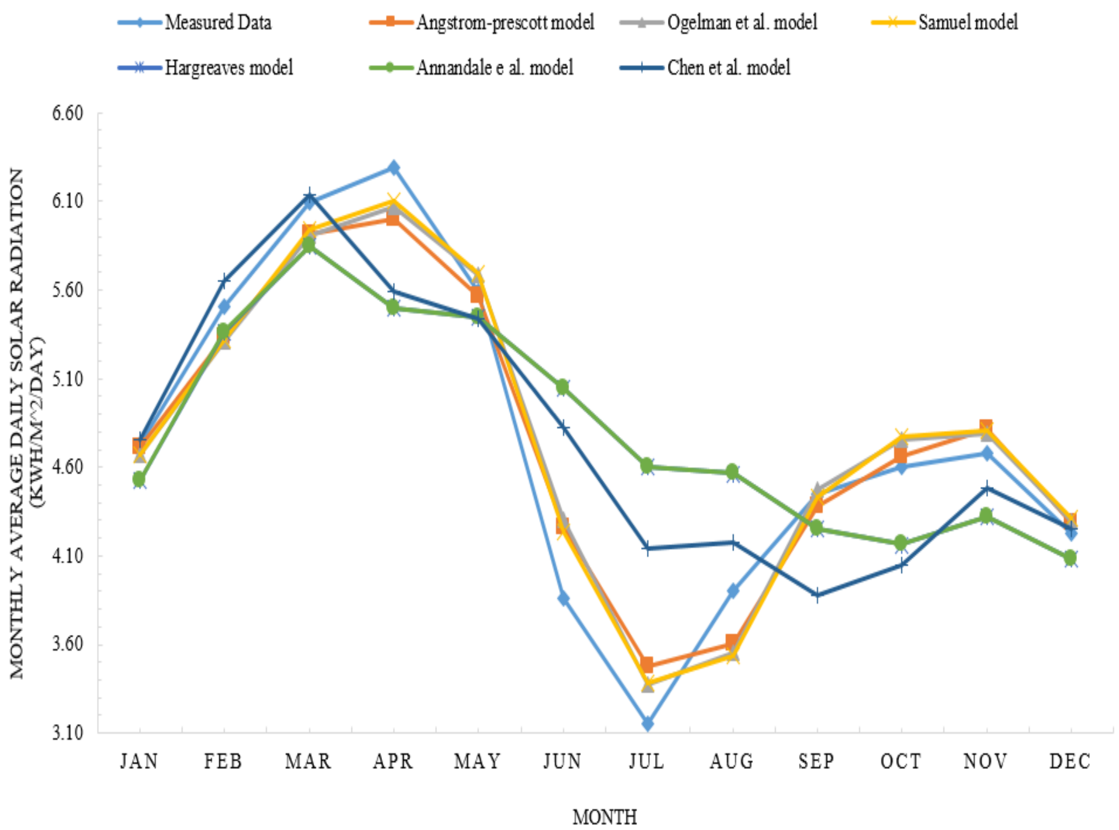

Figure 3.5 Comparison between NASA surface meteorology measured data and calculated values of monthly average daily solar radiation for Teknaf, Sunshine hour based and Temperature-based models

Homer displays the monthly average radiation and clearness index in the solar resource table and graph. The clearness index is an indicator of the clearness of the atmosphere and ranges from 0 and 1.Theoretically, the higher clearness index means the weather condition is sunnier. [42, 43] In this study, the average clearness index in Teknaf is around 0.522 and most counties are between 0.25 and 0.75.

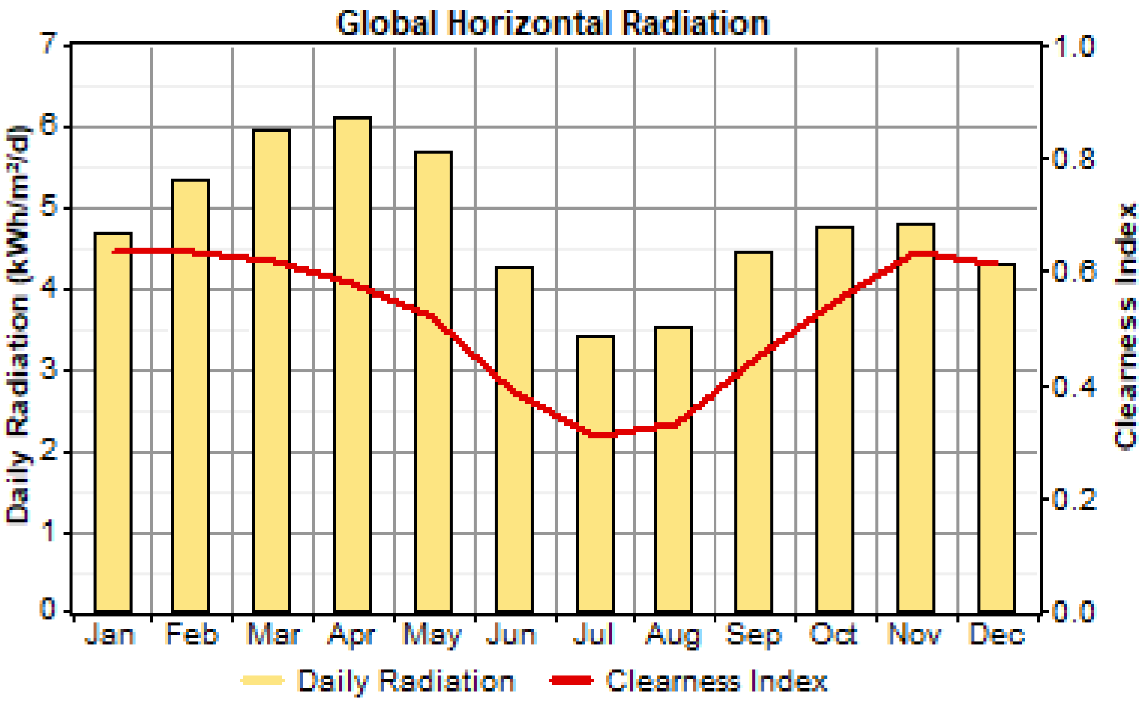

Figure 3.6 Monthly solar radiation

3.3.2. Wind Resource

On a global scale, wind power has experienced a rapid growth rate. In 2011, the total installed capacity reached approximately 240 GW and new installed capacity was around 40 GW compares with 2010. [44] Most wind farms focus on offshore wind energy since the higher wind speed in coastal area. The working principle for wind turbine to produce electricity is to convert the kinetic energy into mechanical or electric energy when the wind blows through.

Monthly average wind speed at 50m above the surface of earth of Teknaf, Bangladesh can be found from Surface Meteorology and Solar Energy-NASA and is used as wind resource input data in HOMER. The slowest wind speed and the highest wind speed are 2.66 m/s and 4.74 m/s and the annual average wind speed is about 3.40 m/s. Also collecting the data from BMD that shows average wind speed data in Teknaf is 3.79 m/s a little bit high compare with NASA Data [45]. Wind energy system will be economical when available speed will be 5 m/s. So, wind system less feasible in Teknaf area but solar energy is feasible in Teknaf areas which radiation is 4.75 kWh/m^2 /day for NASA and 4.76 kWh/m^2 /day for BMD. Resources data is the major requirement for design, analysis and investigation of the system. Entering all the parameters according to the software requirements will be find out the effective system for the consumer.

Table 3.5 Wind speed data

Month	NASA Wind Speed (m/s)	BMD- Teknaf Wind Speed (m/s)
January	3.67	2.78
February	3.28	3.50
March	3.01	4.06
April	2.96	3.65
May	3.25	6.89
June	4.37	5.09
July	4.74	6.02
August	3.98	3.70
September	3.10	2.57
October	2.66	2.88
November	2.84	2.37
December	2.97	1.95
Average	3.40	3.79

In order to calculate the wind energy yield of the wind turbine, the probability density distribution of the wind speed must been figured out. Because the wind power is unsteady, there is a two-parameter Weibull distribution which is often used to characterize wind regimes in HOMER. The graph below shows a typical distribution of wind speeds (figure 3.6).

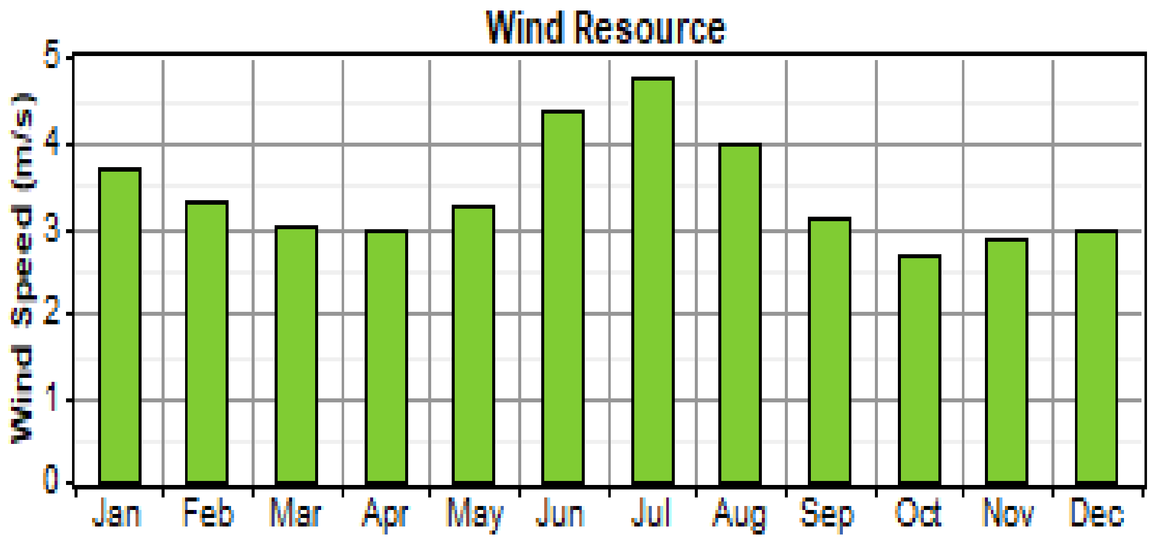

Figure 3.7 Monthly average wind speed

3.3.3. Components Assessment

According to the availability of the sources, the following configurations are simulated and finding a system which is suitable for Rohingya refugees communities. There are various factor depends which include economic parameter, initial cost, cost of energy, location, availability of resources, transportation, etc. Therefore, this system are analyzed by HOMER software. Figure 3.7 shows the configuration of this hybrid power system. The PV-Wind grid connected hybrid power system consists of PV arrays, wind turbines, grid and inverters. AC electricity is generated from wind turbine that can be used directly. But the PV arrays generate DC electricity that needs to be converted to AC electricity in the converter. The economic data inputs in HOMER software includes the capital costs, maintenance costs and replacement costs of system components are provided in Table 3.6. The project life of this study is 20 years and the annual real interest rate is 6.91%.

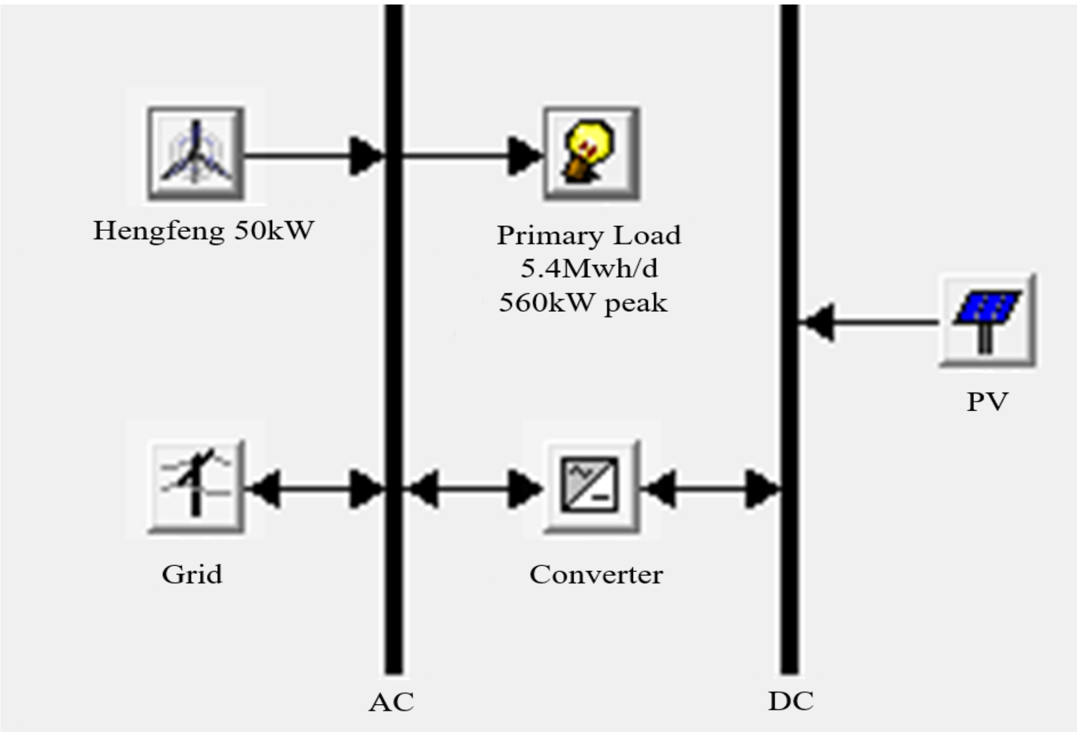

Figure 3.8 Diagram of the proposed system

Table 3.6 Technical input data for system design

Hengfeng 50 kW Wind turbine	
Maximum hub height	18m
Rated power	50 kW
Life time	20 years
Rated wind speed	12m/s
Initial cost	2634 US$/kW
Replacement cost	1317 US$/kW
O & M cost	26 US$/kW/year
PV panel	
Derating factor (%)	80%
Life time	20 years
Initial cost	700 US$/kW
Replacement cost	0 US$/kW
O & M cost	7 US$/kW/year
Converter	
Efficiency	95.9%
Initial cost	70 US$/kW
Replacement cost	60 US$/kW
O & M cost	7 US$/kW/year

3.3.3.1. Wind Turbine

The working principle for wind turbine is to convert the kinetic energy into mechanical or electric energy. For the wind turbine, cut-in (start-up) speed, normal speed and cut-out (maximum) speed are usually used to describe the turbine working processes. When the wind speed reaches the normal speed, the wind turbine will generate a steady power which does not change with the wind speed increase. The blade length and rotor diameter can influence the turbine rotor swept area, and therefore decide the wind power output. In the thesis, the 50 kW wind turbine made by Hengfeng a china company will be used to build the hybrid renewable power system, the relationship between wind speed and power output of the turbine is as table 3.7 [46].

Table 3.7 Relationship between wind speed and power output of Hengfeng 50kW wind turbine

Wind speed(m/s)	Power Output (kW)
0.00	0.000
3.00	2.500
4.00	4.000
5.00	7.000
6.00	16.00
7.00	24.00
8.00	33.00
9.00	40.00
10.0	50.00
11.0	57.00
12.0	60.00
13.0	55.00
14.0	50.00
15.0	50.00
16.0	50.00
17.0	50.00
18.0	50.00
19.0	50.00
20.0	50.00
24.0	50.00

Based on the above data, the Hengfeng 50 kW wind turbine characteristic curve is shown in the Figure 3.8.

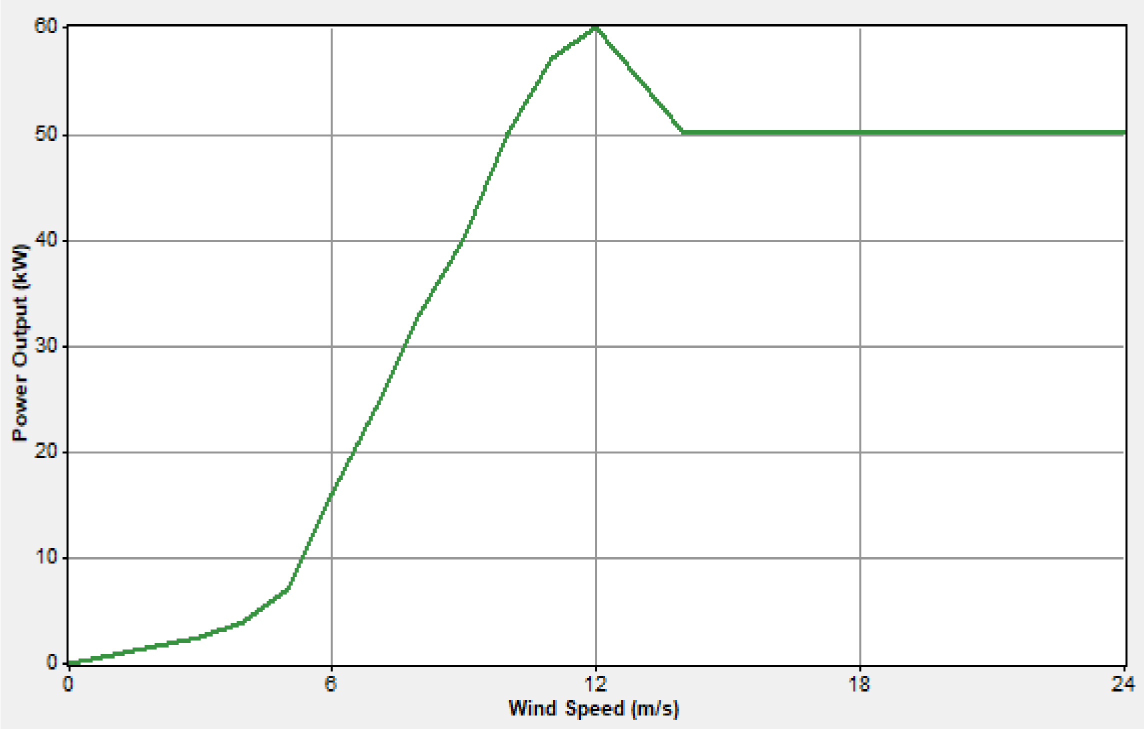

Figure 3.9 Hengfeng 50 kW wind turbine characteristic curve

The power curve represents varies between turbine power outputs and wind speeds. For 50 kW Hengfeng wind turbine, the rated output power is 50 kW. The cut-in speed for this turbine is smaller than 3 m/s that mean the turbine starts rotating and producing power at this minimum wind speed and keeps increasing rapidly with the wind speed increase. Until the speed creeps up to 14 m/s, the wind turbine is able to produce electric power at its maximum which is 50 kW. Considering of the safety and stability, all the wind turbines have maximum wind speeds to protect turbine structure. If the wind speed is increased up to the cut-out speed, the wind turbine will be shut down to prevent the damage to the rotor. For hengfeng 50 kW, the cut out speed is 24 m/s. When the wind speed reaches or higher than this critical point, it will stop working to prevent from the damage.

The capital cost of each hengfeng 50 kW wind turbine is 131,700 dollars, the operating and maintenance cost is 1,315 dollars per year, the lifetime is 20 years. The quantity of turbines that will be considered is from 0 to 10. The cost curve of wind turbines is shown in the figure 3.9.

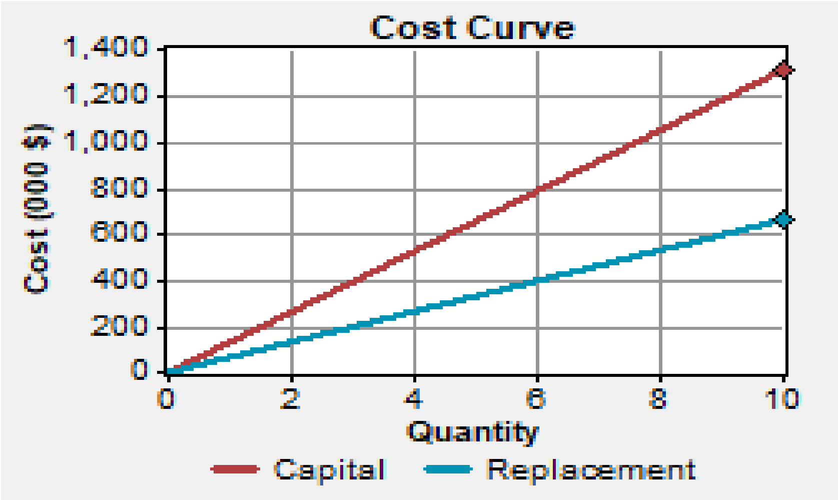

Figure 3.10 Wind turbine capacity in relation to cost

3.3.3.2. PV Array

In this paper, PV panel with a 20 years life time is selected. The working principle for PV panels is to absorb the sunlight and convert solar energy into direct current (DC) and then convert into alternating current (AC) to meet the electricity demand. After PV panels collect sunlight, the electricity flows between PV cells and the DC electricity is generated. The DC electricity will go through the electricity converter to be transformed.

In this thesis, equation 3.1 is used to calculate the output of the PV array:

$$P_{PV} = Y_{PV} f_{Pv} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) [1 + \propto_p (T_c - T_{c,STC})] \quad (3.1)$$

Where: Y_{PV} is the rated capacity of the PV array, meaning its power output under standard test conditions (kW)

f_{Pv} is the PV derating factor [%]. In this thesis, f_{Pv} is set 80%. GT is the solar radiation incident on the PV array in the current time step (kW/m^2). $\bar{G}_{T,STC}$, is the incident radiation at standard test conditions (kW/m^2). In this thesis, $\bar{G}_{T,STC}$, is 1000, $\propto_p$ is the temperature coefficient of power (%/°C), T_c the PV cell temperature in the current time step (°C), $T_{c,STC}$ is the PV cell temperature under standard test conditions (25°C).

The capital cost of PV is 700 dollars per kW, the operating and maintenance cost is 7 dollar/year, the lifetime is 20 years. The size of PV that will be considered is 0 kW, 1000 kW. The cost curve of PV can be draw as figure 3.10 [47].

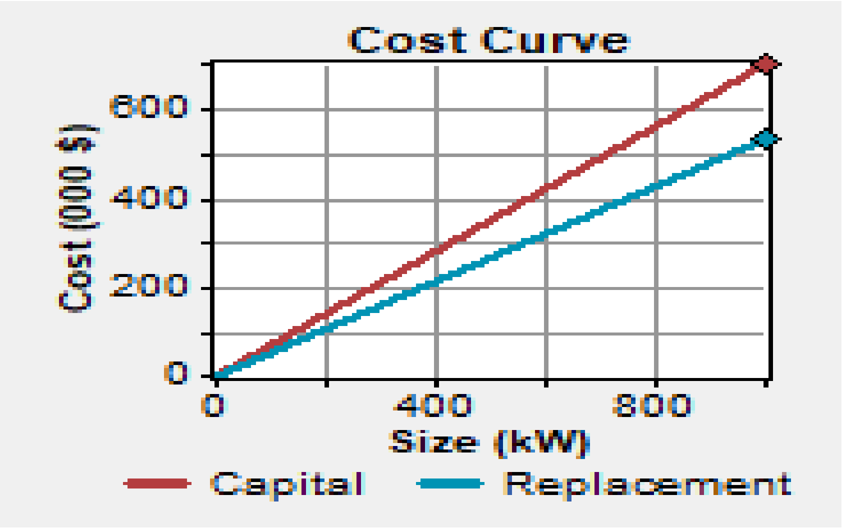

Figure 3.11 PV capacity in relation to cost

3.3.3.3. Converter

A converter (inverter) is used to convert the electricity between AC voltage and DC voltage. In this thesis, the efficiency of inverter is set 95.9%, the efficiency of rectifier is set 85%, and lifetime is 5 years. The capital cost of converter is 70 dollars per kW, the operating and maintenance cost is 7 dollars per kW per year. The size of converter that will be considered is 1000 kW. As the above data, the capital cost of convert curve is shown as the figure 3.11 [48].

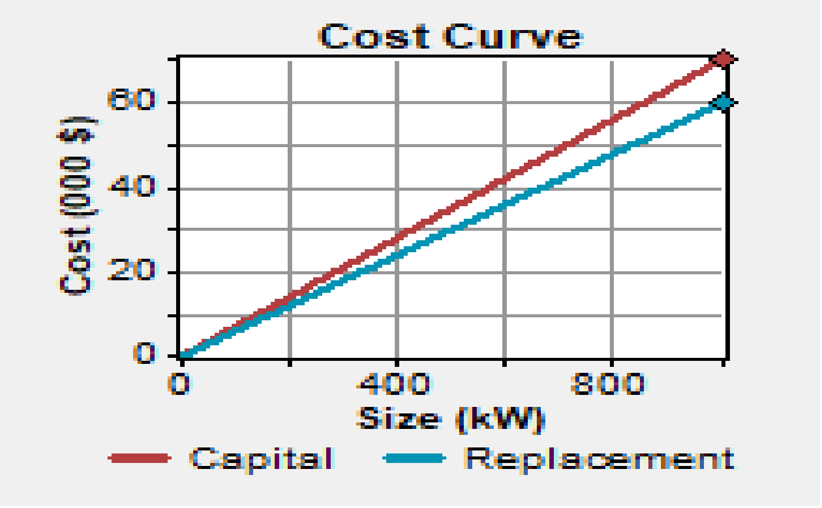

Figure 3.12 Converter capacity in relation to cost

3.4. System Optimization

In the optimization section, HOMER displays the feasible systems with their configurations under the search space defined by the user, sorted by the minimum cost micro grid depending on the total net present cost after the simulation finds out the system configuration of an economical system. HOMER defines the optimal system configuration, which is that configuration with the minimum total net present cost and meeting the require demand and helps to fulfill the crisis [36].

3.5. Proposed Hybrid System Design in ETAP Software for Power Quality Study

In this project, the combination of the solar PV panel and wind turbine are used for designing a grid connected hybrid renewable energy system. Using this renewable energy sources a single line diagram is designed in ETAP software to analyze power quality of above proposed system. ETAP software performs load flow analysis by observing power quality like bus voltage, current flow, power flow and branch power factor. It is a very powerful software that can analyses the load flow for loop or radial electrical systems. Furthermore, ETAP software is designed to be able to perform different types of load flow analysis based on the custom choices and purposes of the specific case.

The purpose of load flow analysis in ETAP is to build an extensive idea about the behavior of the power system under different supply and load conditions. It helps electrical power systems planners to design and test the performance of their systems prior to their installation and during their real time operation. It is also used to detect and forecast possible faults or power flow problems to propose the suitable solutions. The load flow Study is capable to define and adjust the parameters of the system for each case separately. ETAP has multiple choices to define the display options based on the user’s needs and requirements from load flow analysis. Load flow analysis in ETAP is based mainly on numerical solutions of systems of differential equations.

3.5.1. Single Line Diagram of Grid Connected Hybrid System

This proposed system is mainly focused to improve the voltage profile, enhance the active power transfer capability and reduce the losses of branch in the network. Renewable sources are varied with the nature that's effect on the system voltage. Also now a days maximum consumers load are inductive, so that the inductive loads are absorb the reactive power from the distribution system therefore the voltage becomes reduced. To improve the voltage means inject the reactive power in the network. Due to reactive power reduce in the system transmission loss increases and the system becomes inefficient. FACTS device is great innovation for improving the power quality. Therefore to include a facts device named Static VAR compensator (SVC) in the network system. Proposed system is shown in below figure 3.13.

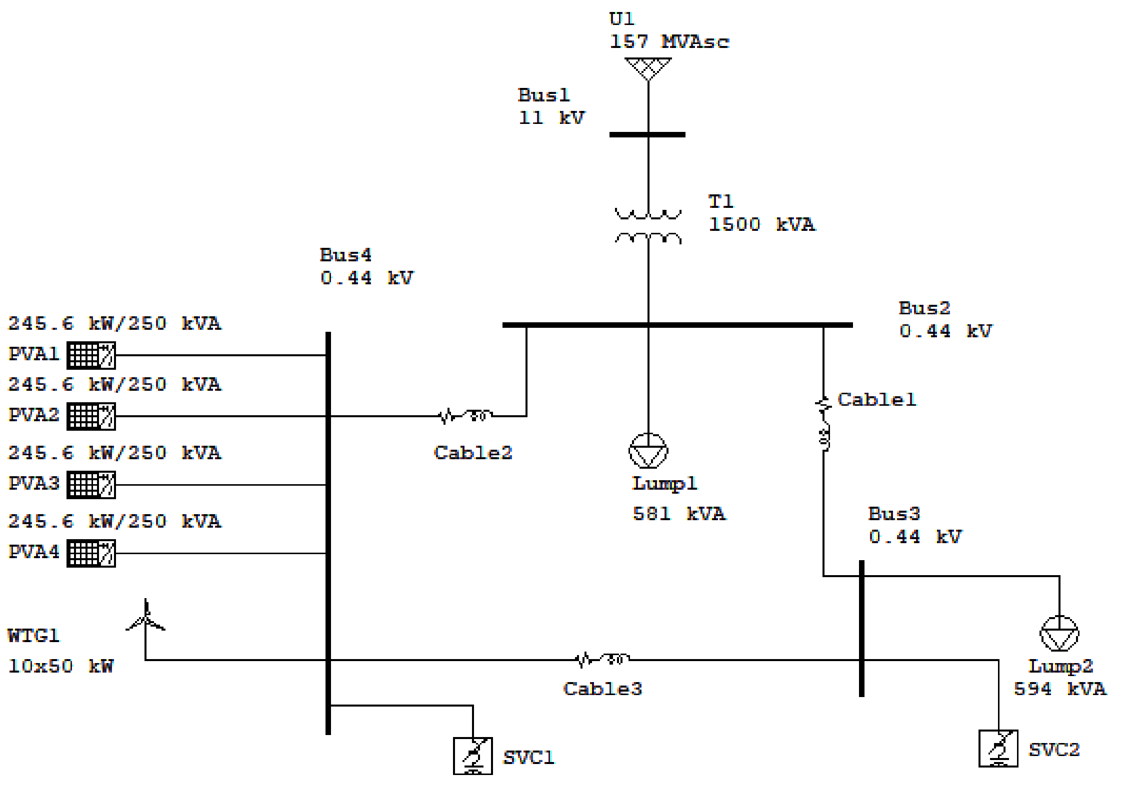

Figure 3.13 Single line diagram of proposed grid connected hybrid system using ETAP

In this Grid connected hybrid system, a single line diagram drawn of 11/.440 kV distribution system with 4 Buses as of above figure 3.13. It consists of four PV array rating of 245.6 kW with 250 kVA inverter and 10 no of 50kW wind turbine are used in voltage control Bus 4 and Utility or Power grid is used as slack or swing bus 1 and two lamp load in connected in load bus 2 & 3. Also a distribution transformer used having rating of 1.5 MVA. The two SVCs (rating of 2 VAR inductive and 3 VAR capacitive) device is placed in optimal location where voltage fluctuation is more. Design parameters are provide in table 3.8.

Table 3.8 System parameter connected at each bus

Equipment	Quantity	Rating	Bus Number
Transformer	1	1500KVA; 11/.44 KV	1 & 2
PV Array 1	1	245.6KW; 0.44 KV	4
PV Array 2	1		4
PV Array 3	1		4
PV Array 4	1		4
Wind Turbine	10	50KW; 0.44 KV	4
SVC1	1	2 VAR inductive and 3 VAR capacitive	4
SVC2	1		3
Lump1	1	581 KVA; 0.44KV	2
Lump2	1	594 KVA; 0.44KV	3
Cable 1	1	Type: Al; Length: 2 km; Size: 750 AWG/Kcmil; Voltage: 0.6KV; 3 phase	2 & 3
Cable 2	1		2 & 4
Cable 3	1	Type: Al; Length: .5 km; Size: 750 AWG/Kcmil; Voltage: 0.6KV; 3 phase	4 & 3

According to the availability of the sources, the following configurations are simulated and finding the power quality of proposed system. Table 3.9 represent the case 1 to 7 based on availability or resources under considering study 1 and 2. Generation sources is active marked by √, Source is down marked by X.

The main purpose of study 1 is when two renewable sources are completely out of service or one source is out of service and the other is in service, what happens to the system?

In Study 2, two renewable sources are in service, but the output is changing due to the variation of nature, Monitor what's happening to the system?

Table 3.9 Case study depend on renewable source status because of natural variation

	WTG	PV Array	Power Grid	Details
Study:1				When one or both sources is down
Case 1	√	√	√	All the source are working
Case 2	X	√	√	Wind turbine are out of service and PV array and grid supply the Power
Case 3	√	X	√	In this case PV array is down
Case 4	X	X	√	Only grid fulfil the load requirement
Study:2				RE generation output varies.
Case 5	Output 40%	Output 90%	√	In this case considering as peak supply from the renewable sources
Case 6	Output 20%	Output 35%	√	When wind speed is reasonable and weather is gloomy
Case 7	Output 5%	Output 20%	√	Minimum output consider from Renewable sources

3.6. Summary

The countries like Bangladesh, where a large coastal region is located and the summer season is formed for 8 months, when the average solar radiation is 4.5 kW / m^2 / day, the wind speed is relatively low but it is intermittent if one source is missing. The chapter has discussed the design procedure of a grid connected hybrid system using renewable resources for Rohingya refugees. After evaluating renewable sources in remote areas, it is necessary to come straight forward to design a renewable base hybrid system, which is possible to adopt the above idea, where energy sharing can be shared among the locals. Then design proposed system in ETAP software for load flow study that's helps to determine the parameters like voltage, current, power flow, power losses etc. of the renewable based power system. The simulation result are discussed in the chapter 4.

CHAPTER 4

4. RESULT AND DISCUSSION

4.1. Introduction

A grid connected solar wind hybrid system is taken as a case study for running the simulation and to perform as a power solution for Nayapara Rohingya refugee's camp. First of all the system is design in Homer software where system optimization and cost analysis is carried out. After that Power flow analysis is carried by using ETAP software to analysis the power system quality. The Power flow process is done twice considering several case with and without FACTs devices.

4.2. Hybrid System Analysis

After simulation, HOMER shows the top ranked system configurations according to NPC. Figure 4.1 below summarized top ranked system configurations obtained from the simulation results-

PV (kW)	50KW	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
			560	$ 0	108,230	$ 1,154,660	0.055	0.00
1000		1000	560	$ 770,000	61,996	$ 1,431,404	0.068	0.49
	10		560	$ 1,317,000	89,902	$ 2,276,123	0.108	0.27
1000	10	1000	560	$ 2,087,000	48,603	$ 2,605,521	0.123	0.62

Figure 4.1 Categorized optimization table

4.2.1. Grid Connected PV-Wind Hybrid Power System Solutions

Table 4.1 shows part of options that meet the electric requirement, they are ranked by the NPC. From the results, grid system is lowest NPC and COE but electricity production can't meet as per consumer demand in Bangladesh also there is no renewable fraction. The second lowest system is 1000 kW solar with grid connection, the problem is during the night time there is no solar output and also the storage system is not very much efficient due to power conversion. The third lowest system is 500 kW wind turbine with grid connection, but the renewable fraction is only 27%. So the last option grid connected PV 1000 kW, wind turbine 10×50 kW has a little bit higher NPC and COE compare to other existing configuration but it is the best hybrid power system schemes due to 62% energy share by renewable sources. For convenience, name this option "scheme GCPWS" in this thesis.

Table 4.1 System configurations of top power systems

PV (kW)	Wind Turbine (50kW)	Converter (kW)	Grid	Total NPC($)	COE ($/kwh)	Renewable Fraction
-	-	-	560	2,605521	0.055	0%
1000	-	1000	560	1431404	0.068	49%
-	10	-	560	2276123	0.108	27%
1000	10	1000	560	2,605521	0.123	62%

Table 4.2 shows the production proportion calculated by the simulator. The proportion of renewable power is 62%, which means this system can reduce the pollutant emissions immensely.

Table 4.2 Summary of yearly electricity supply to fulfill the requirement

Production	kWh/Year	Percentage (%)
PV array	1407888	44
Wind Turbine	594144	18
Grid Purchases	1233558	38
Total Energy	3235589	100
Total Renewable Fraction		62

The monthly average electric production of scheme GCPWS is shown as the Figure 4.2. From the plot, the complementarity of solar and wind is obvious in different months. In the summer (JUN to AUG), the wind power is contribute much energy rather than other months, the solar power is relatively small. In the winter, the situation is the inverse.

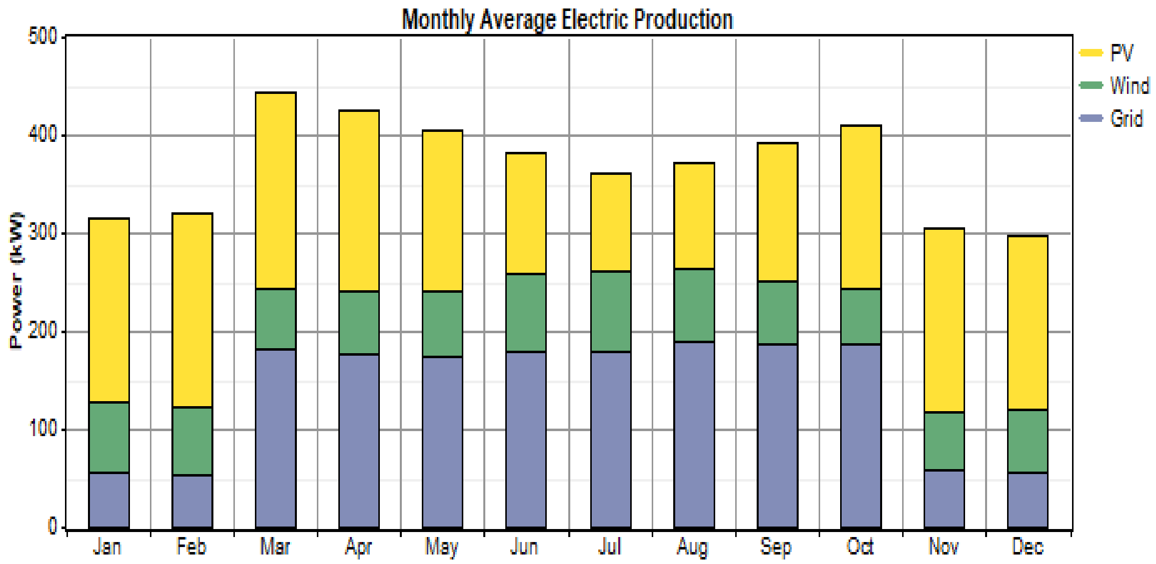

Figure 4.2 Monthly electricity production from hybrid system

Table 4.3 shows the power supply quality of scheme GCPWS, which is calculated by the simulator. The unmet electric load and capacity shortage proportion are less than 0.01%, which means the power supply quality is really good. But excess electricity proportion is as high as 4.46% because of the instability of solar and wind.

Table 4.3 Yearly electricity consumption and renewable contribution percentage

Consumption	**kWh/year**	**Percentage (%)**
AC primary Load	1981949	65
Grid Sales	1057622	35
Excess electricity	144170	4.46

Table 4.4 shows the cost summary of scheme GCPWS. The computed results consider the discount factor. From the cost summary, the capital cost of grid connected PV and wind hybrid system is much more than other system, which is the reason why renewable power generation system has a high cost.

Table 4.4 Cost analysis of the System

Component	Capital($)	Replacement($)	Operation and Maintenance ($)	Total Net Present Cost
PV	700000	0	74680	774680
Wind Turbine	1317000	0	140291	1457291
Grid	0	0	133129	133129
Converter	70000	95741	74680	240421
System	2087000	95741	422779	2605520

Based on the above data, Figure 4.3 shows the cost summary plot with components wise, figure 4.4 shows the cost summary plot with the types wise.

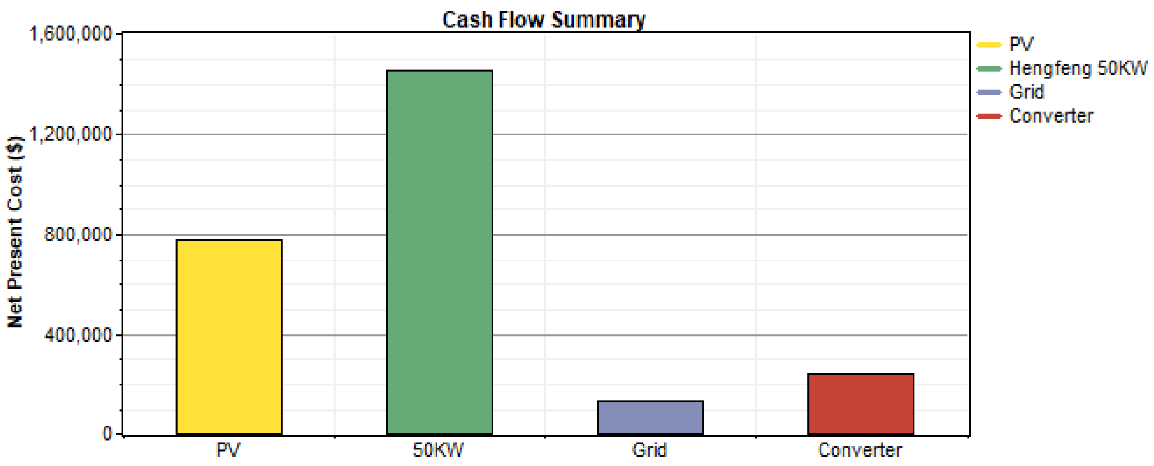

Figure 4.3 Component wise cost analysis

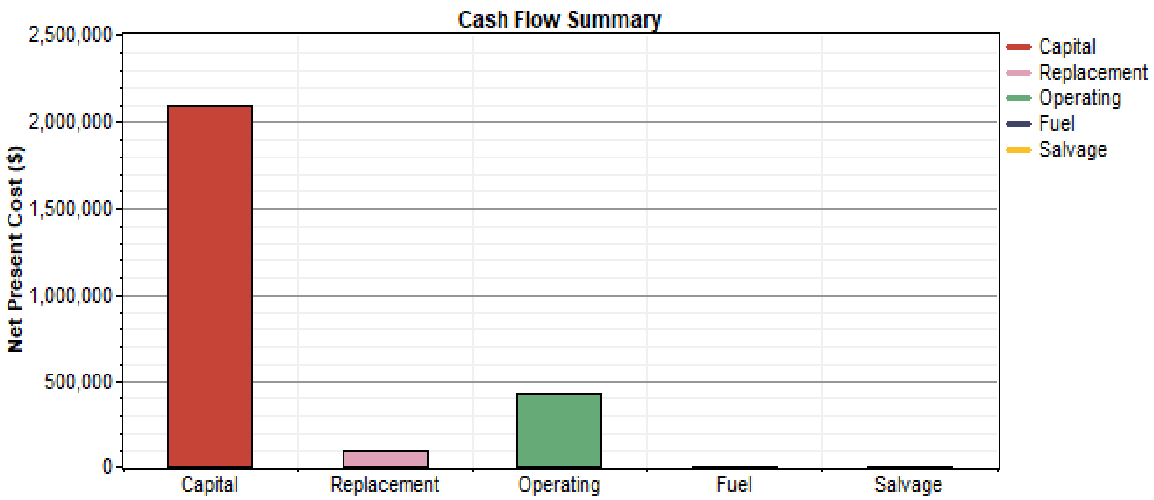

Figure 4.4 Types wise cost summary

4.2.2. The Simulation of the Optimal Hybrid Energy System

Based on the load analysis, solar and wind resource data analysis, and system components analysis in chapter three, put these data in the HOMER software, it outputs the simulation results of the grid connected hybrid power system that constitutes of 1000 kW PV, 10×50 kW wind turbine and 1000kW Converter.

4.2.2.1. PV Operation Simulation

In the works, solar energy fulfill the 44% of total electricity demand of the system. The electricity production from the solar energy is 3857 kWh/day and the cost of electricity from solar is $0.051/kWh that represents in table 4.5 and figure 4.6 shown the electricity production curves from solar system.

Table 4.5 Solar power output

Panel capacity	$1000kW_p$
Average Electricity	3857 kWh/day
Capacity factor	16.1%
Total Electricity	1,407,888 kWh/year
Total operation Hours	4365/year
Levelized cost	$0.051/kWh

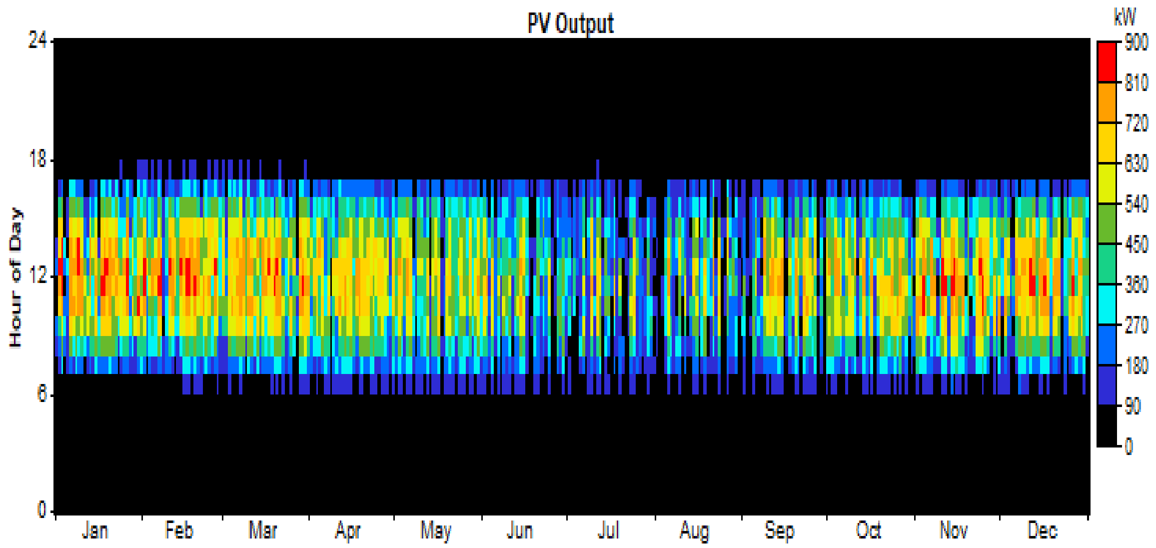

Figure 4.5 Electricity production from PV energy

4.2.2.2. Wind Turbine Operation Simulation

Wind energy fulfil the 18% of total electricity demand of the proposed system. The average electricity production from the wind energy system is 67.8 kW and the cost of electricity from wind energy is $0.23/kWh that presents in table 4.6 and figure 4.7 shown the electricity production curves from the wind turbine.

Table 4.6 Wind power output

Turbine rated capacity	500 kW
Mean Electricity	67.8 kW
Capacity factor	13.6%
Total Electricity	594,144 kWh/year
Total operation Hours	8519/year
Levelized cost	$0.23/kWh

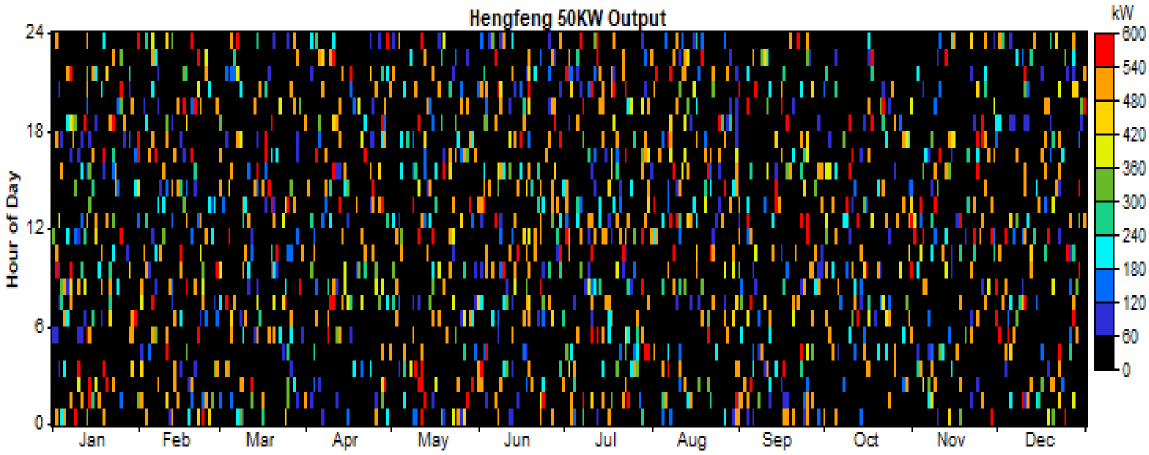

Figure 4.6 Electricity production from wind energy

4.2.2.3. Grid Operation

Grid connection makes this proposed system more reliable as it gives backups during peak hours and also works in case of renewable power generation failures or any abnormalities. Annually total energy purchased from the grid is 1,233,558 kWh and 1,057,622 kWh energy sold to grid. So, net energy has purchased 175,935 kWh which costs 9,325 dollar. Table 4.7 show the month wise grid operation details and figure 4.8 represents the time series plot of grid operation.

Table 4.7 Details of monthly energy purchased and sold from grid

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	42,387	128,605	-86,218	269	-4,570	159
Feb	36,238	120,489	-84,251	258	-4,465	152
Mar	134,532	95,907	38,625	533	2,047	314
Apr	128,203	86,832	41,371	554	2,193	327
May	130,406	80,506	49,900	549	2,645	324
Jun	128,808	59,300	69,508	560	3,684	330
Jul	132,919	50,161	82,759	544	4,386	321
Aug	141,175	52,984	88,191	534	4,674	315
Sep	134,469	65,882	68,587	523	3,635	309
Oct	139,089	79,410	59,680	515	3,163	304
Nov	42,544	118,403	-75,859	254	-4,021	150
Dec	42,787	119,144	-76,357	254	-4,047	150
Annual	1,233,558	1,057,622	175,935	560	9,325	3,154

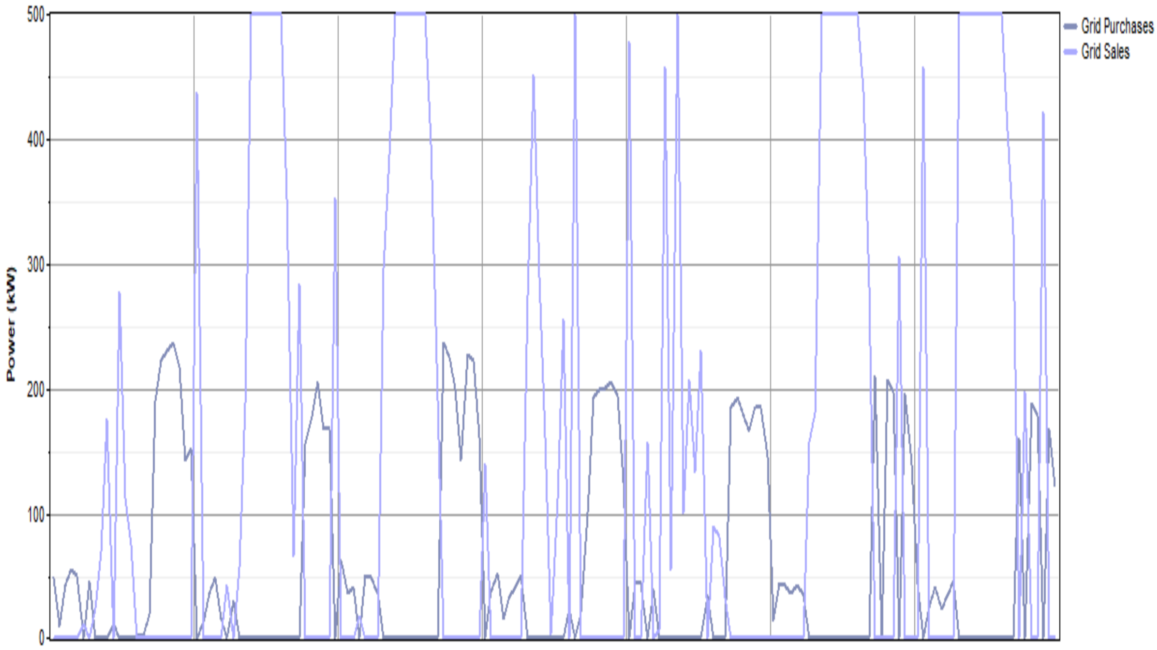

Figure 4.7 Time series plot of grid operation

4.2.2.4. System Operation Simulation Time Series Plot

Due to the limited space, this thesis displays the system operation simulation time series plot of first week in each month. The following plot is for the first week of January.

The black line is AC load consumption, the yellow line is PV array power, dark blue line is grid purchases, light blue represent the grid sales and the green line is wind turbine power.

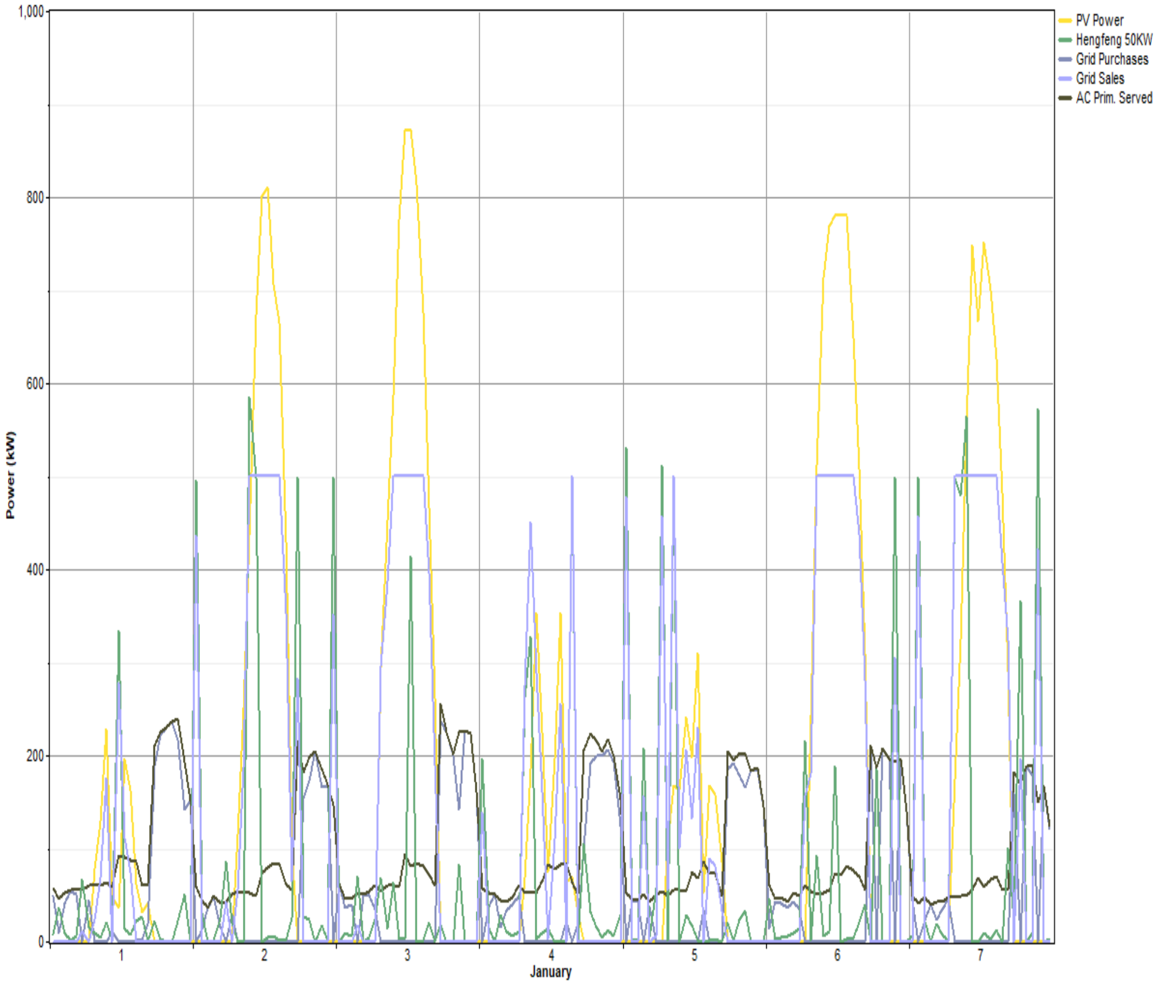

Figure 4.8 System operation simulation time series plot

4.3. Economic Analysis

HOMER calculates and shows the total cost and income of this hybrid power system. From a purely economic perspective, the total net present cost of this project means all the costs that it incurs over its lifetime minus the present value of all the revenue that it earns over its lifetime. The cost details of selected main scenarios are shown as below:

Table 4.8 Overall system summary

Net Presents Cost (NPC)	\$2,605,521
Levelized Cost of Electricity (LCOE)	\$0.123/kWh
Renewable Fraction	62%

At presents, to establish the proposed renewable energy system, the initial cost the system is quite high which is around \$2097000, after 20 years the total cost of the system will be around \$26055221 that shown in table 4.8 and 4.4 also figure 4.8 and 4.9. The cost of electricity of the system is \$0.123/kWh which is batter then conventional fossil fuel plant like diesel also better than quick rental oil based power plant in Bangladesh [36]. The payback period can be calculated using equation 4.1. Payback period means that the number of years required recovering the cost of the investment and cost benefit analysis of our system. [50].

$$\text{Payback Period}=\frac{NPC}{(P_{PV/year}+P_{WT/year})*C_{Unit}}\ Years \qquad (4.1)$$

Where, $P_{PV/year}$ is the total power generation from PV array per year, $P_{WT/year}$ is the total power generation from wind turbine per year and C_{Unit} is the cost of per unit energy.

Here considering 1 kWh=15.25 Taka that is 0.179 \$/kWh (1 dollar =85 Taka).

$$\text{So, Payback Period in years}=\frac{2{,}605{,}521}{(1{,}407{,}888\ +594{,}144)*0.179}=7.27\approx 7.50\ years$$

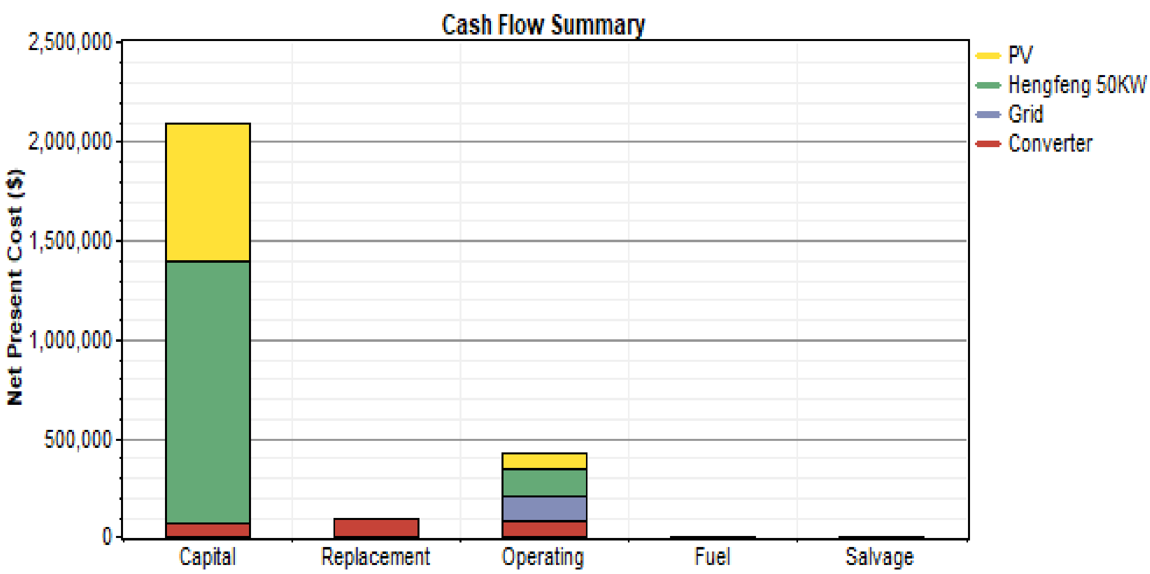

Figure 4.9 Categories wise cash flow

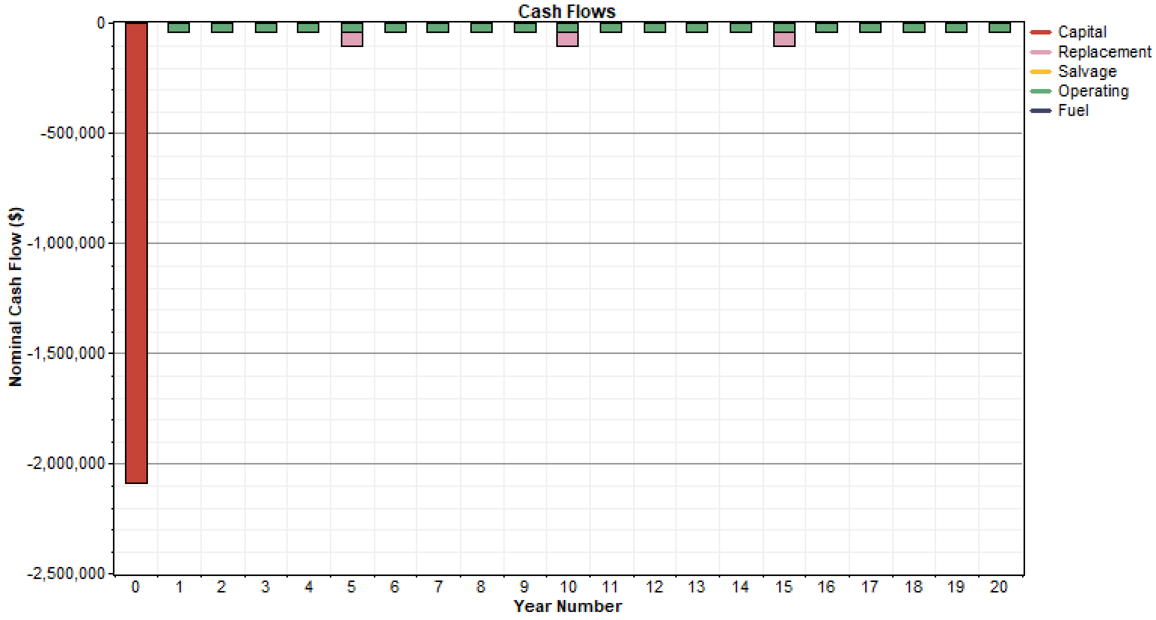

Figure 4.10 Yearly cash flow summary

4.4. Environment Effects

The aim of this project is to provide electricity for Rohingya Refugees from renewable energies. The reason of replacing fossil fuels with environment friendly and sustainable fuels is because it can potentially reduce the CO_2 emissions. According to the CO_2 baseline database [51] prepared by the Department of Environment, Government of People's Republic of Bangladesh, the weighted average grid emission factor (GEF) for power plants is 0.67 tonnes of CO_2 per MWh of energy generated. On the other hand, renewable energies can be seen as nearly emission free. Therefore, by replacing fossil fuels with renewable energies in electrification, a large amount of CO_2 emission can be avoided. In this project, by multiplying grid emission factor and the electricity production of each energy resources, the potentially emission reductions could be found using equation 4.2.

$$CO_2(Emission) = \frac{Electricity\ production\ per\ year\ (KWh)*0.67}{1000}(t/MWh) \quad (4.2)$$

Table 4.9 below shows the results of CO_2 avoided by those two renewable resources where 1341.36 tonnes CO_2 emission reduce per year of this proposed system.

Table 4.9 CO_2 emission reduction

Sources	Electricity production (kWh)	Emission reduction (Tonnes)
PV	1407888 kWh/year	943.28 Tonnes/year
Wind	594144 kWh/year	398.07 Tonnes/year
Total	2002032 kWh/year	1341.36 Tonnes/year

As per calculation of HOMER software, this system emitted 111.20 tonnes Carbon dioxide per year, .48 Tonnes Sulfur dioxide per year and Nitrogen oxides releases .23 Tonnes per year because of 38% energy supply from the grid.

4.5. Power Quality Analysis

The grid connected PV-Wind hybrid system is design by using ETAP software for Load flow analysis in chapter 3. Power quality like voltage stability, power factor, reliability is important for a renewable power plant. From this simulation, the observation of voltage regulation, power loss in the transmission and current flow of the system without Facts device and using Facts device.

4.5.1. Load Flow Analysis

Seven cases were considered for under the two study observations, which are shown in figure 4.10-4.23 and table 4.10-4.16 by performing the simulation.

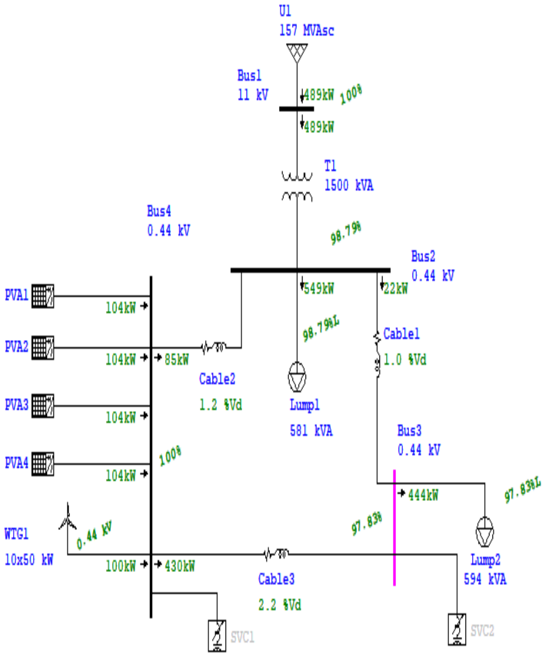

Figure 4.11 Load flow analysis of case-1 when SVC inactive

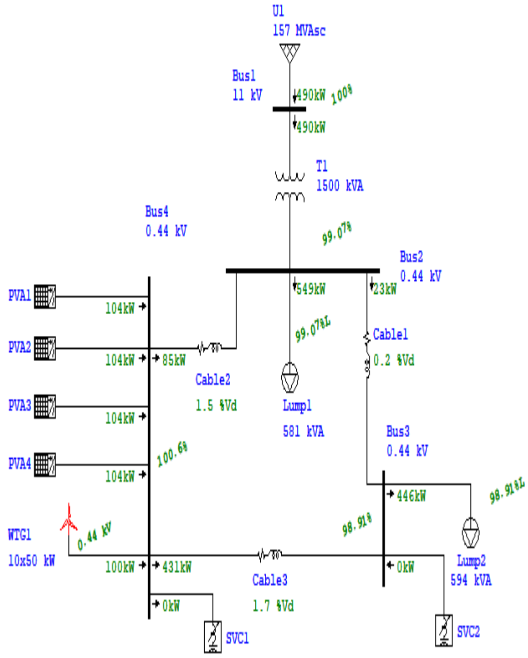

Figure 4.12 Load flow analysis of case-1 when SVC active

Table 4.10 Case-1: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	With SVC			Without SVC	With SVC	Without SVC	With SVC
Bus 1	100.0	100.0	Bus 1	Bus 2	489.0	490.0	1.21	0.93
Bus 2	98.8	99.1	Bus 2	Bus 3	22.4	22.6	0.96	0.16
Bus 3	97.8	98.9	Bus 4	Bus 2	85.4	84.6	1.21	1.53
Bus 4	100.0	100.6	Bus 4	Bus 3	430.0	431.0	2.17	1.69
AVG	99.2	99.6			256.7	257.0	1.39	1.08

(For Case 1) When wind turbine and PV array are active, the parameters of average bus voltage, average active power flow and average voltage drop are 99.2%, 256.7 kW and 1.39 % respectively. After the use of SVC, the average bus voltage improves at 99.6%, the average active power increases from 256.7 kW to 257.0 kW, and the average branch voltage drop is reduced by 0.31 units.

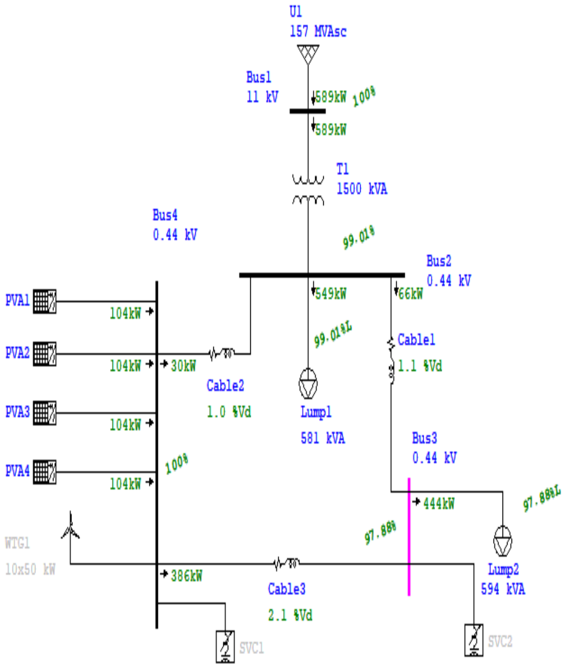

Figure 4.13 Load flow analysis of case-2 when SVC inactive

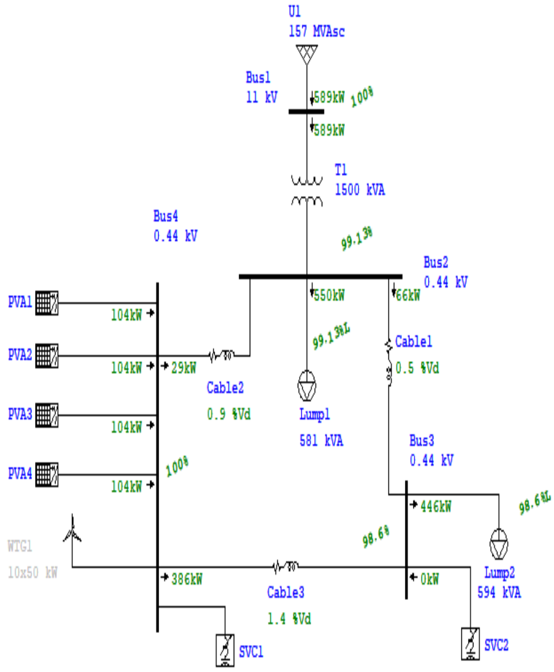

Figure 4.14 Load flow analysis of case-2 when SVC active

Table 4.11 Case-2: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	With SVC			Without SVC	With SVC	Without SVC	With SVC
Bus 1	100.0	100.0	Bus 1	Bus 2	589.0	589.0	0.99	0.87
Bus 2	99.0	99.1	Bus 2	Bus 3	66.1	66.4	1.13	0.53
Bus 3	97.9	98.6	Bus 4	Bus 2	29.6	29.5	0.99	0.87
Bus 4	100.0	100.0	Bus 4	Bus 3	386.0	386.0	2.12	1.40
AVG	99.2	99.4			267.7	267.7	1.31	0.92

(For Case 2) When PV array is active and wind turbine is inactive, the parameters of average bus voltage, average active power flow and average voltage drop are 99.2%, 267.7 kW and 1.31 % respectively. After the use of SVC, the average bus voltage improves at 99.4%, the average active power remaining same and the average branch voltage drop is reduced by 0.39 units.

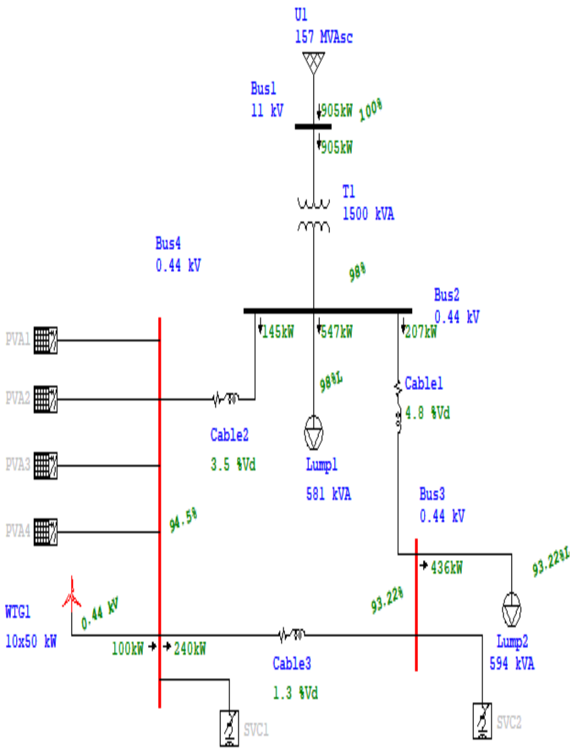

Figure 4.15 Load flow analysis of case-3 when SVC inactive

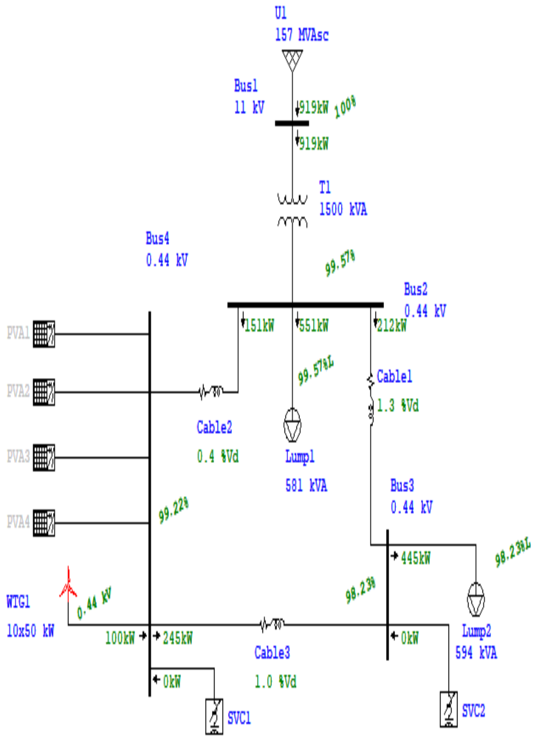

Figure 4.16 Load flow analysis of case-3 when SVC active

Table 4.12 Case-3: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	With SVC			Without SVC	With SVC	Without SVC	With SVC
Bus 1	100.0	100.0	Bus 1	Bus 2	905.0	919.0	2.00	0.43
Bus 2	98.0	99.6	Bus 2	Bus 3	207.0	212.0	4.78	1.34
Bus 3	93.2	98.2	Bus 4	Bus 2	145.0	151.0	3.50	0.35
Bus 4	94.5	99.2	Bus 4	Bus 3	240.0	245.0	1.28	0.99
AVG	96.4	99.3			374.3	381.8	2.89	0.78

(For Case 3) When wind turbine is active and PV array is inactive, the parameters of average bus voltage, average active power flow and average voltage drop are 96.4%, 374.3 kW and 2.89 % respectively. After the use of SVC, the average bus voltage improves at 99.3%, the average active power increases from 374.3 kW to 381.8 kW, and the average branch voltage drop is reduced by 2.11 units.

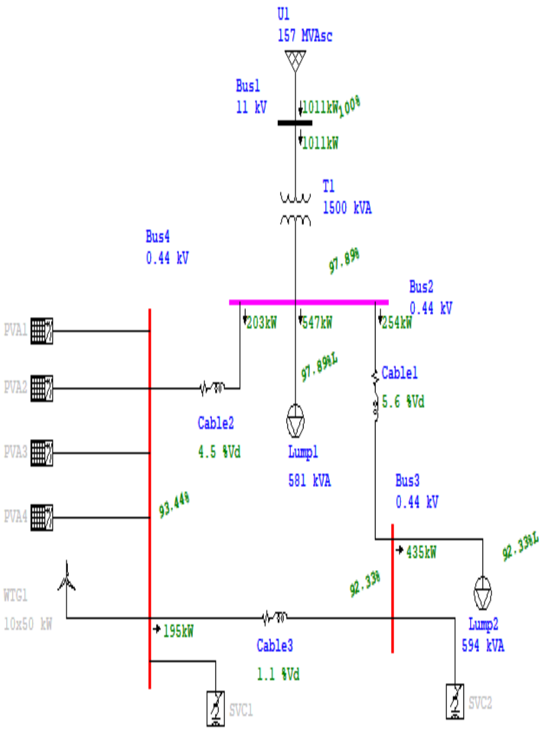

Figure 4.17 Load flow analysis of case-4 when SVC inactive

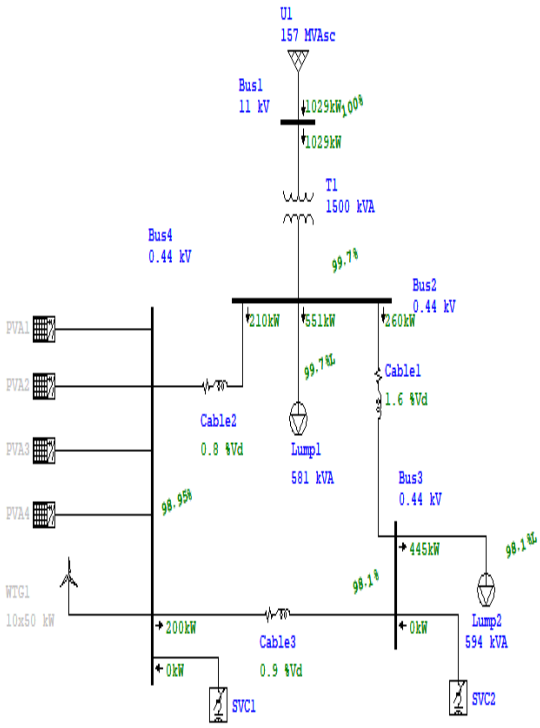

Figure 4.18 Load flow analysis of case-4 when SVC active

Table 4.13 Case-4: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	With SVC			Without SVC	With SVC	Without SVC	With SVC
Bus 1	100.0	100.0	Bus 1	Bus 2	1011.0	1029.0	2.11	0.30
Bus 2	97.9	99.7	Bus 2	Bus 3	254.0	260.0	5.56	1.61
Bus 3	92.3	98.1	Bus 4	Bus 2	203.0	210.0	4.46	0.75
Bus 4	93.4	99.0	Bus 4	Bus 3	195.0	200.0	1.11	0.86
AVG	95.9	99.2			415.8	424.8	3.31	0.88

(For Case 4) When wind turbine and PV array are inactive, the parameters of average bus voltage, average active power flow and average voltage drop are 95.9%, 415.8 kW and 3.31 % respectively. After the use of SVC, the average bus voltage improves at 99.2%, the average active power increases from 415.8 kW to 424.8 kW, and the average branch voltage drop is reduced by 2.43 units.

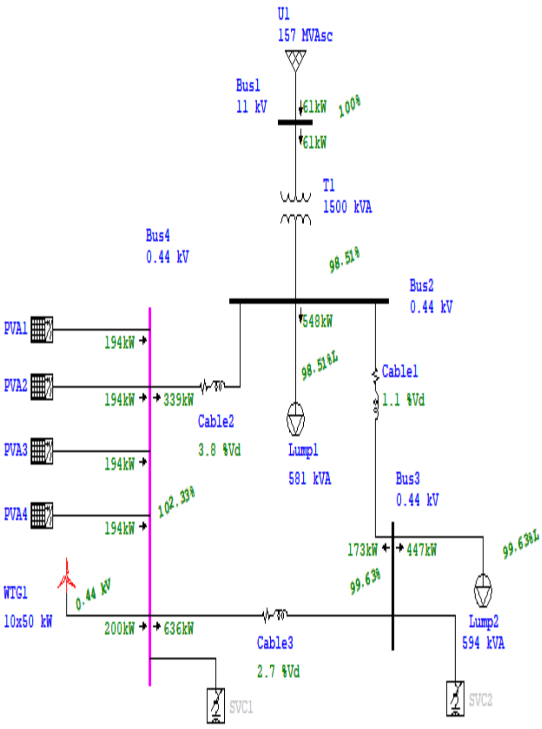

Figure 4.19 Load flow analysis of case-5 when SVC inactive

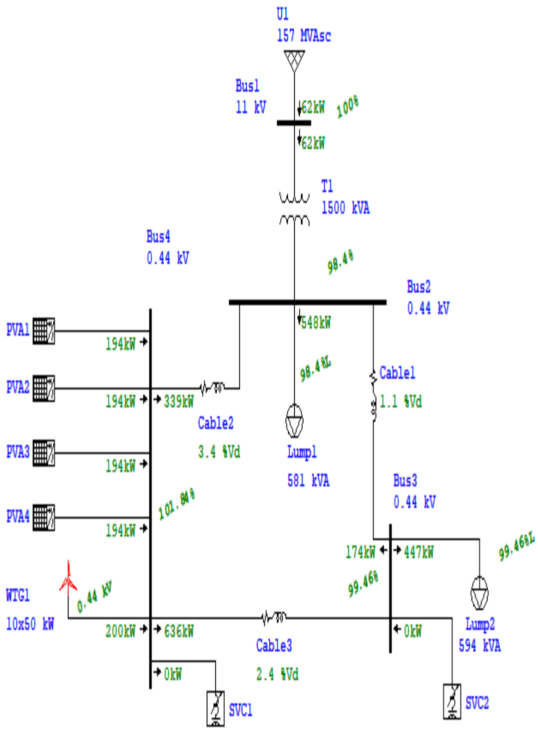

Figure 4.20 Load flow analysis of case-5 when SVC active

Table 4.14 Case-5: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	With SVC			Without SVC	With SVC	Without SVC	With SVC
Bus 1	100.0	100.0	Bus 1	Bus 2	61.1	61.6	1.49	1.60
Bus 2	98.5	98.4	Bus 2	Bus 3	173.0	174.0	1.12	1.06
Bus 3	99.6	99.5	Bus 4	Bus 2	339.0	339.0	3.82	3.44
Bus 4	102.3	101.8	Bus 4	Bus 3	636.0	636.0	2.70	2.38
AVG	100.1	99.9			302.3	302.7	2.28	2.12

(For Case 5) When wind and PV array are active but the output of wind turbine is 40% and PV array output is 90%, at that time the parameters of average bus voltage, average active power flow and average branch voltage drop are 100.1%, 302.3 kW and 2.28% respectively. After the use of SVC, the average bus voltage decreases a little bit, the average active power increases slightly, and the average branch voltage drop is reduced by 0.16 units.

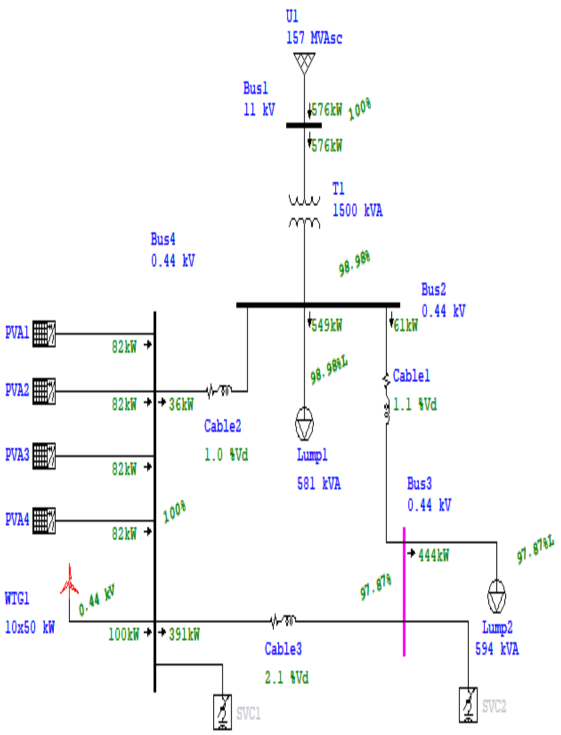

Figure 4.21 Load flow analysis of case-6 when SVC inactive

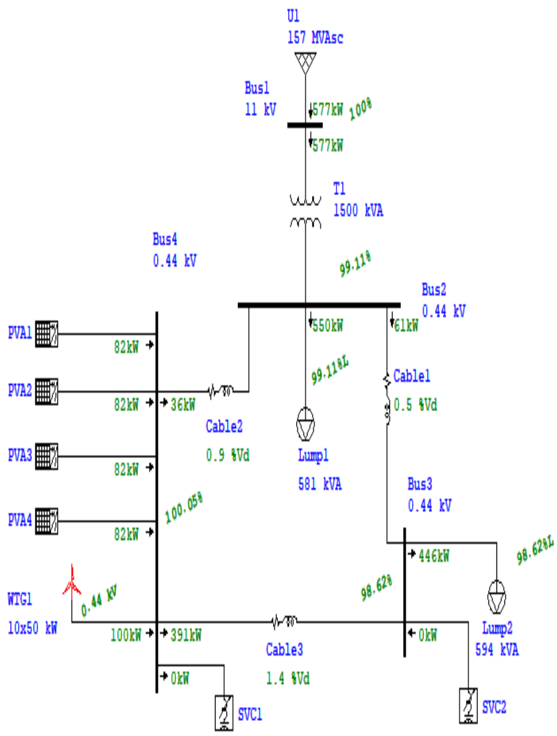

Figure 4.22 Load flow analysis of case-6 when SVC active

Table 4.15 Case-6: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	**With SVC**			**Without SVC**	**With SVC**	**Without SVC**	**With SVC**
Bus 1	100.0	100.0	Bus 1	Bus 2	576.0	577.0	1.02	0.89
Bus 2	99.0	99.1	Bus 2	Bus 3	60.7	61.0	1.11	0.49
Bus 3	97.9	98.6	Bus 4	Bus 2	36.5	36.2	1.02	0.94
Bus 4	100.0	100.1	Bus 4	Bus 3	391.0	391.0	2.13	1.43
AVG	99.2	99.4			266.0	266.3	1.32	0.94

(For Case 6) When wind and PV array are active but the output of wind turbine decreases at 20% and PV array output is 35%, at that time the parameters of average bus voltage, average active power flow and average branch voltage drop are 99.2%, 266.0 kW and 1.32% respectively. After the use of SVC, the average bus voltage and the average active power increases slightly, and the average branch voltage drop is reduced by 0.38 units.

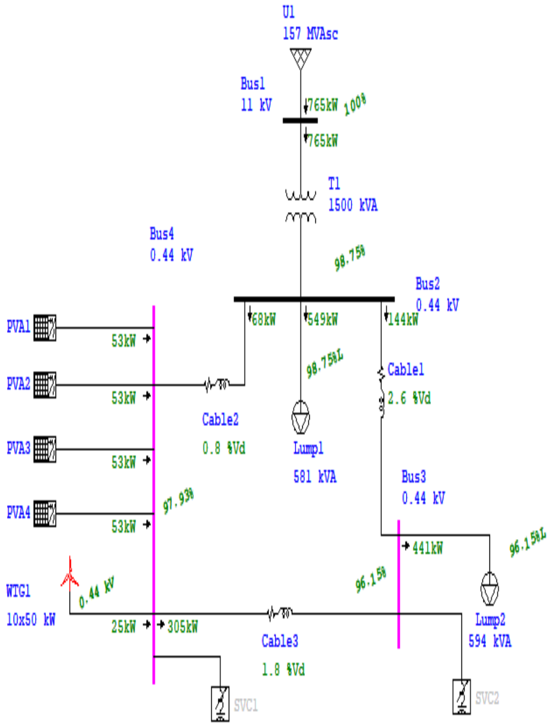

Figure 4.23 Load flow analysis of case-7 when SVC inactive

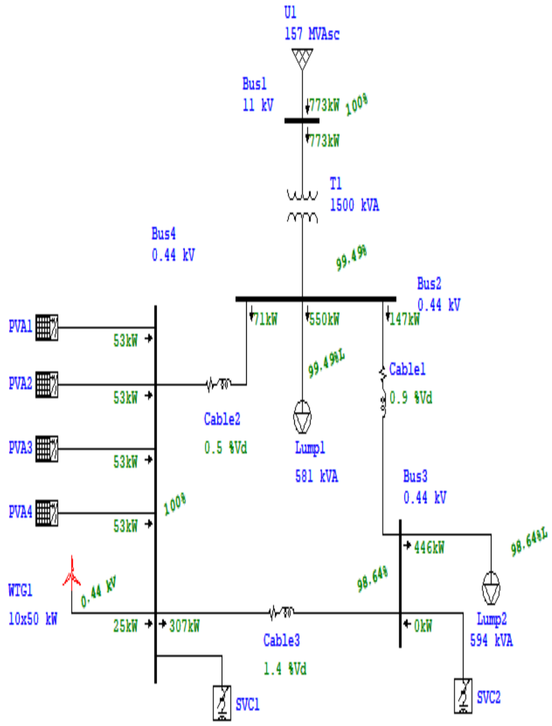

Figure 4.24 Load flow analysis of case-7 when SVC active

Table 4.16 Case-7: Comparative result of load flow analysis without SVC and with SVC

Bus No	Voltage Profile (%)		From Bus	To Bus	Active Power (kW)		Voltage Drop (%)	
	Without SVC	With SVC			Without SVC	With SVC	Without SVC	With SVC
Bus 1	100.0	100.0	Bus 1	Bus 2	765.0	773.0	1.25	0.51
Bus 2	98.8	99.5	Bus 2	Bus 3	144.0	147.0	2.60	0.85
Bus 3	96.2	98.6	Bus 4	Bus 2	67.9	68.9	0.82	0.51
Bus 4	97.9	100.0	Bus 4	Bus 3	305.0	307.0	1.78	1.36
AVG	98.2	99.5			320.5	324.0	1.61	0.81

(For Case 7) When wind and PV arrays are active but wind turbine and PV arrays output is further reduced to 5% and 20% respectively, then the parameters of average bus voltage, average active power flow and average voltage drop are 98.2%, 320.5 kW and 1.61% respectively. After the use of SVC, the average bus voltage improves at 99.5%, the average active power increases from 320.5 kW to 324.0 kW, and the average branch voltage drop is reduced by 0.80 units.

4.5.2. Performance Analysis of SVC

The demands of lower power losses, faster response to system parameter change, and higher stability of system have stimulated the development of the Flexible AC Transmission systems (FACTS). FACTS has become the technology of choice in voltage control, reactive/active power flow control, transient and steady-state stabilization that improves the operation and functionality of existing power transmission and distribution system. To improve the voltage profile and reduce the transmission losses Static VAR compensator is used in this proposed system.

Summary of case studies 1 & 2 without SVC are given in below table 4.17. Generation sources is active marked by √, Source is down marked by X.

Table 4.17 Summary of case studies without SVC

	Wind Turbine	PV Array	Grid	Analysis
Study-1				Effect on system will have when one or both sources is down completely.
Case-1	√	√	√	The Load bus is under voltage.
Case-2	X	√	√	The result in this case is almost the same as case-1.
Case-3	√	X	√	Bus 3 & 4 are under voltage and losses increases in the branch.
Case-4	X	X	√	Whole network is suffering from low voltage.
Study-2				Effect on system will have when power generation sources output varies.
Case-5	Output 40%	Output 90%	√	The bus near wind turbine is overvoltage.
Case-6	Output 20%	Output 35%	√	Same as case-2
Case-7	Output 5%	Output 20%	√	Bus 3 & 4 are under voltage.

After the used of Static VAR compensator the above effects on system is improved that is shown in table 4.18 to 4.20.

The obtained value of bus voltage, without SVC and with SVC shown in below table 4.18 where the average voltage increases from 98.3% to 99.5% that is 1.2% improves. Also average active power transfer capability increases from 314.7 to 317.7 and branch losses decreases by 0.94% after using of SVC. Details are given in below table 4.19 and 4.20.

Table 4.18 Average voltage profile (%) of each case

Case	Without SVC	With SVCs	Voltage Improve
Case 1	99.2	99.6	0.5
Case 2	99.2	99.4	0.2
Case 3	96.4	99.3	2.8
Case 4	95.9	99.2	3.3
Case 5	100.1	99.9	-0.2
Case 6	99.2	99.4	0.2
Case 7	98.2	99.5	1.3
Average of all case result	98.3	99.5	1.2

Table 4.19 Average active power (kW) transfer capability of all cases

Case	Without SVC	With SVCs	Enhancement of Power Transfer
Case 1	256.7	257.0	0.4
Case 2	267.7	267.7	0.0
Case 3	374.3	381.8	7.5
Case 4	415.8	424.8	9.0
Case 5	302.3	302.7	0.4
Case 6	266.0	266.3	0.3
Case 7	320.5	324.0	3.5
Average of all case result	314.7	317.7	3.0

Table 4.20 Average branch losses (%) of all cases

Case	Without SVC	With SVCs	Reduce of Voltage drop
Case 1	1.39	1.08	0.31
Case 2	1.31	0.92	0.39
Case 3	2.89	0.78	2.11
Case 4	3.31	0.88	2.43
Case 5	2.28	2.12	0.16
Case 6	1.32	0.94	0.38
Case 7	1.61	0.81	0.81
Average of all case result	2.02	1.07	0.94

From the above table its concluded that Case 3 and 4 shows the best power quality improvement result while PV array is out of service or both the renewable generation are down.

4.6. Summary

This research work is a role model to provide a reliable electricity facility to meet demands and improve the Rohingya refuges society located in remote and coastal areas in Teknaf Bangladesh. A cost effective simulation has been performed to find the optimum configuration for a renewable power system by utilizing HOMER software. It is shown that the grid connected hybrid power system can provide electricity supplies with better performance, both economically and environmentally viable, compared to the other alternative systems. Load flow simulation has been performed to bring the better power quality by utilizing ETAP software. There are a number of issues that should be taken into consideration while designing RES systems these are: present power demand in Bangladesh, renewable power generation status, the availability of renewable energy resources, Power quality and stability of RES, the initial cost of the project, including the cost of each component required, the life time of the project, the interest rate subsidies, etc. A techno-economic comparison between different scenarios can be carried out to study the feasibility of the project. Thus, the proposed system is an efficient power solution not only for Rohingya refugees but also all remote and rural regions in Bangladesh, which will help to fulfil the power demand in Bangladesh.

CHAPTER 5

5. CONCLUSION

5.1. Conclusion

In this research, a cost effective grid connected photovoltaic energy and wind energy based hybrid system for Rohingya communities in Bangladesh has been executed upon optimization in HOMER Software. The primary objective of this project is to bring out an effective scheme for living up to the refugee community’s basic electricity demand. It had been clearly distinguished that most of refugees regions are mainly backward regions and won’t access their basic human right. In this work, the cost of electricity of the system was found $0.123/kWh (or 10.46 BDT taka per kWh), which is really comfortable compared to the quick rental fossil fuel based electricity generation system that was around $0.32/kWh or 27.2 BDT taka per kWh in Bangladesh according to the Bangladesh power development board annual reports [49]. The scheme will help to meet the fundamental demands of the refugees camp or deprive communities and taking away the gap between urban and deprive communities simultaneously. Also recommendation this electricity solution can be implemented in Kutupalong refugee camp located in Ukhia, Cox’s Bazar, Bangladesh. To increase the power quality of proposed grid connected hybrid system, Static VAR compensator is used. Static VAR Compensators provides high performance steady state and voltage control compared with classical shunt compensation. It also used to improve the power transfer capability, reduce system losses by controlling the reactive power. Load flow analysis has been carried out for observing the behavior of power quality like voltage profile, enhanced the power transfer, reduce the losses. The analysis is shown considering various cases based on source status and output variations. In order to vary the power generation source, the voltage profile of different buses changes, which causes additional loss, reducing power transfer capacity. With using of SVC, on an average voltage profile improves 1.12%, increases the power transfer capability from 314.7 kW to 317.7 kW and reduce the branch losses by 0.94% and this power quality improvement is remarkable during one or both the renewable generation is down. That's makes the proposed system efficient and reliable.

5.2. Future Works

In view of the major findings of this study, a few areas of further development and investigation are recommended, mainly:

- It is desired to implement the model of the system in physically beside the Rohingya Refugee camp and other similar refugee camp if convince the investors.
- A prototype model can be implemented in the lab.
- Another renewable sources like biomass, biogas, can be added to increases the capacity.
- In this work SVC is used to improve the voltage stability, enhance the power capacity and reduce the losses. Other FACTS device like UPFC, IPFC, and STATCOM can be deployed to increase the capacity and stability of the system.
- To test power systems with large number of buses in order to imitate them in more realistic way as practical power systems are more complex in nature.
- Other analyses such as harmonic, transient stability and power factor correction can also be completed and compared against standard results.
- Optimum location of FACTS devices can be another point of interest of this work.

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APPENDIX

A: List of Publication from this Research

Some part of the scientific results of this study is disseminated in the following channels:

1. M. N. Absar and M. F. Islam, "Performance analysis of monthly averages solar radiation estimation models for Teknaf, Bangladesh," *5th International Conference on Advances in Electrical Engineering (ICAEE)*, Dhaka, Bangladesh, pp. 218-222, 26-28 September 2019.

2. M. N. Absar and M. F. Islam, "A case study on efficient grid connected hybrid energy system for Rohingya Refugees," *5th International Conference on Advances in Electrical Engineering (ICAEE)*, Dhaka, Bangladesh, pp. 240-245, 26-28 September 2019.

B: Data

Meteorological and Solar Average Monthly & Annual Climatologists data collected from NASA for Teknaf.

PARAMETER	Description	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
DNR	Direct Normal Radiation	7.54	7.19	6.95	6.41	4.40	1.68	1.76	1.93	3.18	4.88	5.89	7.28	4.91
CLRSKY_NKT	Normalized Clear Sky Insolation Clearness Index (dimensionless)	0.64	0.64	0.62	0.61	0.59	0.58	0.61	0.61	0.61	0.63	0.64	0.65	-999
NKT	Normalized Insolation Clearness Index (dimensionless)	0.62	0.60	0.58	0.55	0.46	0.29	0.30	0.31	0.39	0.49	0.54	0.61	-999
DIFF_MAX	Maximum Diffuse Radiation On A Horizontal Surface (kW-hr/m^2/day)	1.10	1.60	1.86	2.10	2.44	-999	-999	-999	2.10	1.84	1.56	1.13	-999
DIFF_MIN	Minimum Diffuse Radiation On A Horizontal Surface (kW-hr/m^2/day)	0.79	1.05	1.45	1.80	2.13	2.46	2.45	2.35	2.06	1.53	0.90	0.82	1.65
DIFF	Diffuse Radiation On A Horizontal Surface (kW-hr/m^2/day)	0.99	1.28	1.62	1.98	2.40	2.29	2.31	2.25	2.13	1.72	1.31	0.95	1.77
KT	Insolation Clearness Index (dimensionless)	0.68	0.66	0.65	0.62	0.50	0.33	0.33	0.35	0.44	0.54	0.61	0.66	0.53
CLRSKY_SFC_SW_DWN	Clear Sky Insolation Incident on a Horizontal Surface (kW-hr/m^2/day)	5.24	5.93	6.54	7.10	7.02	7.03	7.27	7.11	6.57	6.09	5.35	5.00	6.35
ALLSKY_SFC_SW_DWN	All Sky Insolation Incident on a Horizontal Surface (kW-hr/m^2/day)	5.04	5.56	6.16	6.41	5.48	3.47	3.54	3.60	4.27	4.73	4.57	4.74	4.80

Inter annual (2013-2017) wind speed data collected from NASA.

PARAMETER	Wind Speed at 50M height						Wind Speed at 10M height					
YEAR	2013	2014	2015	2016	2017	AVG	2013	2014	2015	2016	2017	AVG
JAN	4.91	4.46	3.81	4.05	5	4.446	4.06	3.69	3.17	3.31	4.14	3.674
FEB	4.68	4.13	4.01	3.35	3.91	4.016	3.82	3.38	3.29	2.73	3.17	3.278
MAR	3.41	3.95	4.15	3.4	3.52	3.686	2.83	3.2	3.36	2.79	2.86	3.008
APR	3.64	3.22	3.3	4.07	3.82	3.61	3.03	2.67	2.71	3.31	3.07	2.958
MAY	5.29	3.74	3.75	3.97	3.3	4.01	4.23	3.07	3.05	3.21	2.69	3.25
JUN	5.35	4.98	5.84	5.06	6.16	5.478	4.28	3.99	4.67	4.03	4.89	4.372
JUL	6.32	5.91	6.13	5.63	5.93	5.984	5.01	4.67	4.81	4.49	4.71	4.738
AUG	5.13	5.27	4.97	4.85	4.84	5.012	4.09	4.19	3.91	3.86	3.87	3.984
SEP	3.76	4.22	3.94	3.69	3.59	3.84	3.04	3.41	3.16	2.98	2.89	3.096
OCT	3.25	2.77	3.24	3.39	3.56	3.242	2.67	2.3	2.65	2.77	2.89	2.656
NOV	3.85	3.35	3.32	3.4	3.13	3.41	3.21	2.78	2.77	2.81	2.62	2.838
DEC	3.44	3.69	3.81	3.42	3.4	3.552	2.87	3.08	3.17	2.87	2.84	2.966
ANN	4.42	4.14	4.19	4.03	4.18	4.192	3.6	3.37	3.4	3.27	3.39	3.406

Monthly average Sunshine hour’s data of Teknaf collected from BMD

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
2013	8.50	8.60	9.50	9.10	3.90	4.60	3.60	3.80	4.20	5.60	8.40	8.10	6.50
2014	9.10	8.60	9.10	8.60	8.50	4.80	4.10	2.50	5.20	8.20	9.00	8.60	7.20
2015	7.80	9.10	8.40	7.00	7.10	3.10	2.20	4.10	6.50	7.10	8.10	6.80	6.50
2016	7.00	7.30	7.90	7.80	7.80	5.70	2.30	2.80	5.80	6.60	8.20	7.90	6.50
2017	9.20	8.70	7.80	7.70	7.80	3.80	2.00	2.80	4.00	5.40	7.20	7.00	6.20

Monthly Average Dry-bulb Temperature in degree Celsius of Teknaf collected from BMD

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
2013	19.8	23.3	25.6	27.9	27.6	28.2	27.5	27.7	27.8	27.5	24.8	21.6
2014	20.3	21.9	25.7	28.9	30.1	28.7	28.0	27.3	27.9	27.9	24.8	21.3
2015	21.2	22.2	25.7	27.9	29.1	27.6	27.2	27.9	28.4	27.4	25.1	21.5
2016	19.8	23.9	26.7	29.4	29.4	28.2	27.3	27.5	28.3	28.0	24.7	23.1
2017	21.2	23.1	25.3	27.8	29.6	28.5	27.6	28.0	28.5	28.4	27.2	22.9

Monthly Prevailing Wind Speed in Knots and Direction of Teknaf collected from BMD:

Year	Jan.		Feb.		Mar.		Apr.		May		Jun.		Jul.		Aug.		Sep.		Oct.		Nov.		Dec.	
	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir
2013	2.5	NW	2.9	W	4.3	W	4.5	W	3.4	S	4.3	SSE	4.1	SSE	2.2	S	2.6	SSE	2.4	S	2.0	NW	3.7	NE
2014	4.9	NW	5.4	NW	5.6	NW	4.3	W	3.8	S	3.3	S	3.5	S	1.8	S	2.0	SSE	1.1	NE	2.0	NW	2.8	W
2015	3.2	W	4.2	NW	5.5	W	2.2	WSW	4.1	W	3.6	S	3.9	SE	2.4	S	4.1	SE	2.3	W	2.3	NW	2.4	NW
2016	3.1	N	3.5	W	4.5	W	3.8	W	4.0	SE	4.8	SE	3.5	S	5.0	SE	2.3	SE	3.7	SE	2.4	W	2.5	W
2017	4.1	NW	5.4	NW	4.7	W	3.0	W	3.3	W	4.3	S	3.1	S	4.5	S	2.3	SSE	1.7	E	2.3	N	2.7	WSW

Data collection cost:

গণপ্রজাতন্ত্রী বাংলাদেশ সরকার
প্রতিরক্ষা মন্ত্রণালয়
বাংলাদেশ আবহাওয়া অধিদপ্তর
জলবায়ু মহাশাখা
www.bmd.gov.bd

জরুরি
সীমিত

স্মারক নম্বর: ২৩.০৯.০০০০.০২৯.৪৩.০০৫.১৭.১৪৬১

তারিখ: ১৩ শ্রাবণ ১৪২৫
২৮ জুলাই ২০১৮

বিষয়: **Meteorological Data of Teknaf for 2013-2017.**
সূত্র: E-Mail Message dt. 27-07-2018.

This is to inform you that Bangladesh Meteorological Department is able to supply the following meteorological data as per your request:
Data Type: Meteorological Data
Time Period: 2013-2017
Data Type: Max Temperature, Min Temperature, Wind Speed & Direction, Sunshine Hour
Station: Teknaf
Basis of Data: Monthly Data

The cost for supplying the above mentioned data is as follows:
Fee = BDT 2,200.00 and VAT (15%) = 330.00, i.e. Total Cost = BDT 2,530.00
You can pay the total cost through online payment system by using your PIN. Necessary steps for supplying the above mentioned data by e-mail will be taken after receiving the confirmation of the payment.

Alternate method of payment is given below for your kind information:
1. Fee BDT 2,200.00 Code No. 1-1913-0000-2661 by treasury challan from any branch of Sonali Bank
2. VAT (15%) BDT 330.00 Code No. 1-1133-0035-0311 by treasury challan from any branch of Sonali Bank

Original copies of both treasury challan must be sent to Deputy Director, Climate Division, Bangladesh Meteorological Department, E-24 Agargaon, Dhaka-1207 by post/courier/person. Necessary steps for supplying the above mentioned data by e-mail will be taken after receiving the challans.

মোঃ আবদুর রহমান
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বাংলাদেশ আবহাওয়া অধিদপ্তর