# Design and Analysis of Grid-Connected Hybrid Power Systems Based on Renewable Energy: Bangladesh Perspective

**By**

**(Md. Nurunnabi)**

A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Electrical and Electronic Engineering

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July 2016

# Declaration

This certifies that the thesis work entitled "Design and Analysis of Grid-Connected Hybrid Power Systems Based on Renewable Energy: Bangladesh Perspective" has been carried out by Md. Nurunnabi in the Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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**July, 2016** **Md. Nurunnabi**
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**Dedicated to My Parents**

# ABSTRACT

Current power generation scenarios all over the world are not climate friendly as the generation systems are mainly dependent on fossil fuels that produce greenhouse gas (GHG) which contributes to global warming. This thesis presents an economical expediency of grid-connected hybrid (PV/Wind turbine) power system model by investigating the potentials of the wind and solar energy. It also conducts a feasibility analysis to explore the potentialities of green energy at different locations namely Kuakata, Sitakunda, Magnamaghat, Dinajpur, Rangpur and Khulna in Bangladesh. Initially, a flowchart of the proposed hybrid power system model is developed and then a hybrid model is designed with varying the contributions of renewable resources for the considered coastal region and the northern part of Bangladesh using a software tool named Hybrid Optimization of Multiple Energy Resources (HOMER). The simulation results are calculated for finding the cost of energy (COE), net present cost (NPC), total annualize cost, annual real interest rate, capital recovery factor (CRF), fraction of renewable energy (RE) contribution and greenhouse gas emission in terms of tons/year from which an optimum combination of RE sources and fraction of different RE sources in the designed hybrid power plant are determined. Sensitivity variables, such as range of wind speed, solar radiation, PV panel price, wind turbine hub height, are defined as inputs during simulation. The optimization process is carried out repeatedly for the sensitivity variables and the results are refined accordingly. Also, a comparison is made between off-grid and grid connected models on the basis of COE and GHG emission. The simulation results show that the proposed grid-PV-wind hybrid power system model is most suitable, economical and eco-friendly for the considered regions in Bangladesh.

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# Nomenclature

| | | |
|---|---|---|
| A | Cross sectional area | ($m^2$) |
| ac | Alternating current | |
| CDF | Cumulative Density Function | |
| COE | Cost of energy | ($/kW) |
| $C_p$ | The power coefficient | |
| C | The Weibull scale factor | (m/s) |
| c | The chord (width) of the blade | (m) |
| $C_{fuel\ eff.}$ | The effective price of fuel | ($/L) |
| $C_{om\ gen.}$ | The O& M cost | ($/hr) |
| $C_{rep\ gen.}$ | The replacement cost | ($) |
| D | the rotor diameter | (m) |
| dc | Direct current | |
| DC | Duration Curve | |
| $f_{PV}$ | The PV derating factor | (%) |
| $G_{sc}$ | The solar constant =1367 | ($W/m^2$) |
| $G_{T\ STC}$ | The incident radiation at standard test conditions =1000 | ($W/m^2$) |
| HOMER | Hybrid Optimization of Multiple Energy Resources | |
| $h_1$ | The reference height | (m) |
| KE | The kinetic energy of a stream of air | (J) |
| k | The Weibull shape factor | |
| m | Mass of air parcel | (kg) |
| NPC | Net present cost | ($) |
| COE | Cost of energy | ($) |
| N | the rotational speed of the rotor | (RPM) |
| P | Power | (W) |
| PDF | Probability Density Function | |
| $P_{gen}$ | Output of the generator in this hour | (kW) |
| $P_{PV}$ | The power output of the PV array | (kW) |
| p | Air pressure | (Pa) |
| RF | Renewable fraction | |
| RE | Renewable energy | |

| | | |
|---|---|---|
| RPM | Revolution per minute | |
| $R_{gen}$ | The generator lifetime | (hr) |
| T | Temperature | ($^oK$) |
| $T_c$ | The PV cell temperature in the current time step | ($^oC$) |
| V | Wind speed (velocity) | (m/s) |
| $V_1$ | Reference speed | (m/s) |
| v | The volume of air parcel | ($m^3$) |
| $Y_{gen}$ | Rated capacity of generator | (kW) |
| $Y_{PV}$ | The rated capacity of PV array | (kW) |
| Z | Height above ground level for the desired speed | (m) |
| $Z_o$ | Roughness length in the current wind direction | (m) |
| $Z_1$ | Reference height | (m) |
| z | The number of the blades | |
| Z' | Elevation | (m) |
| $a_p$ | The temperature coefficient of power | (%/$^oC$) |
| s | The solidity of the turbine | |
| r | The density of air | ($kg/m^3$) |

# CHAPTER I

# Introduction

## 1.1 Background

Every sector of modern civilization is dependent on energy which comes from various energy sources such as nuclear energy and fossil fuel (coal, oil and natural gas). The combustion of fossil fuels emits a huge amount of greenhouse gasses (GHG) such as carbon dioxide, sulfur dioxide, nitrogen dioxide that harm the atmosphere and health of the population [1]. Therefore, there is a critical need for a robust and sustainable power generation system which is reliable and environment-friendly that overcomes various problems associated with the existing power system. Recently, hybrid power systems using renewable energy (RE) are becoming popular due to their potential benefits on the environment [2]. RE can play an important role in reducing global warming as well as the high cost of energy [3]. Bangladesh is responsible for a large amount of GHG emission. Moreover, the present reserve of fuel used for power generation would be depleted by a decade [4]. Therefore, an alternative way of energy generation in Bangladesh is very urgent. RE sources are considered as the best way to meet the energy demand as they are clean and environmental friendly [5].

In October 2015, the power demand of Bangladesh was about 12,000 MW [6] and it is increasing day by day. In Bangladesh, natural gas is used for about 62% energy generation and coal or other fossil fuel is used for about 31% energy generation. Currently, RE sources fulfill 15% to 20% of the world's energy demand. However, 16% of production is coming from the hydroelectric system and rest of the production comes from other renewable systems [2]. RE contributes around 3% of Bangladesh electricity generation, with 1.94% sourced from hydro-electricity, while rest of the renewables contributes about 1% [6]. Therefore, it is highly necessary to investigate the environmental policy of

Bangladesh to bring the higher percentage of RE sources into the energy mix to build a climate-friendly environment for the future.

Already 122.2 MW capacities of PV systems are installed throughout the country that's supply electricity over 2.9 million households. These solar PV systems are implemented and assisted by various NGOs and private organizations, IDCOL, REB, LGED and BPDB [7]. The availability of wind energy is mainly in coastal areas, especially in Bangladesh. Though coastal region of Bangladesh has high wind energy potential but only 2 MW capacity of the wind turbine are installed. One is a grid tied system that is situated at Feni and another is off grid system situated at Kutubdia. In Bangladesh, there is a limited source of hydro energy system except for Chittagong area. A 230 MW capacity hydropower plant is installed in Kaptai in 1960 [7].

## 1.2 Problem Description and Motivation

It is known that Bangladesh has a vast potential for RE sources such as the wind and solar. Although RE sources have several advantages, a solar or wind generator in a stand-alone system cannot supply the load continuously due to their intermittent nature. As load demands are always changing with time, the changes in solar or wind energy generation do not always match with the time distribution of load [8]. Therefore, there is a need of additional battery storage or other components for providing continuous power supply to the consumer. It has been investigated that a hybrid PV/Wind/battery system is a reliable source of electricity [9]. Since, due to the high cost of battery energy storage, a stand-alone system is very expensive [10, 11]. However, the issue related to the cost-benefit analysis of the grid connected and off grid mode hybrid power system has attracted much less attention in the literature. Moreover, what will be the best mixture of renewable energy sources to reduce cost and GHG emission is still an open question? Therefore, it is important to find a suitable combination of different RE sources to maximize the benefit which is the prime interest of this research.

**Research questions -** With the above factors in mind this thesis will address the following questions:

- How can weather conditions change the behavior of a hybrid system and to what extent?
- How important is the correct choice of renewable energy source (RES)-equipment according to the primary desirable electricity requirements that should be covered by the established system?
- Can a RES based grid connected hybrid system be feasible and under which circumstances or not?

This thesis focuses on answering the above questions regarding the involvement of RESs in everyday life. Moreover, this study could help by providing solutions to such problems as supplying electricity to remote and urban areas, which usually requires large investments and leads to power losses associated with transmission and distribution networks.

### 1.3 Objectives

Bangladesh is a developing country. With the increase of population, the energy demand also increased. Nowadays energy crisis is the vital problem in our country as there is only 59.60% (2015) of people having access to electricity [6]. On the other hand, the climate is an important issue for ecological balance situation. To find out a suitable solution for sustainable and climate-friendly power generation system, the objectives of this research are given below.

i) To investigate the potentialities of green energy at various locations in Bangladesh.

ii) To design a hybrid power system determining the best mixer of green energy to meet the load demand of a specific area and the exact hub height of wind turbine.

iii) To analyze the economic and environmental feasibility of the designed model in different modes of operation, e.g. grid connected and off grid mode.

iv) To quantify a number of GHG emissions from different system models.

## 1.4 Literature Review

Every sector of the current world are highly dependent on energy and about 80 % of the total energy comes from fossil fuels and nuclear energy which is responsible for global warming [1]. As hybrid renewable energy system has robust characteristics instead of conventional system, massive researches and studies have been carried out on it. The optimal design of the hybrid renewable system has been selected based on economic analysis namely cost of energy (COE), net present cost (NPC), and excess of energy and environmental impact that means greenhouse gas emission rate [12]. For remote residence, three different types of configuration have analyzed and a comparative result based on COE and $CO_2$ was shown that a hybrid PV-diesel-battery system was more cost effective than the other two models [13]. Other studies shown that the rural village of Iran is economically best suited for PV-diesel power generation system if they have no storage system [11]. A sensibility analysis has been done on the basis of fuel cost for hybrid PV-diesel system [14]. For identifying the optimum model of PV-diesel-battery system in the various climatic region, some model has been developed by using C-programming and HOMER software and results were shown on the basis of minimum NPC and $CO_2$ emission rates [15, 16]. Also, some author studied about the economic feasibility of PV-diesel-battery power generation systems. Research showed that the implement of PV-diesel-battery system instead of diesel system was more feasible and this study also revealed that COE is much lower than the other models. Also, a brief comparison has been carried out with various models namely PV hybrid system, stand-alone PV and some others by considering various component cost. A sensibility analysis also has been performed on the basis of PV panel price and diesel price and the result showed that minimum COE was found in PV hybrid system [17]. By using HOMER and LINGO software authors studied and analyzed off-grid configuration for electrifying seven villages in the Almora district of India. Four different types of model have been considered with integrating four RESs namely biomass, hydro, solar and wind energy sources and finally, the optimum result has been worked out [18]. A techno-economic analysis was conducted on the basis of various system configuration models and the experimental result showed that the hybrid PV-wind energy system gives the better system performance than the only PV and the only wind energy system. The author has also observed that the capacity of battery bank played an important role on system performance [19]. The author described wind energy-based power system model by analyzing the characteristics of wind turbine that means blade length, cut in speed, rated speed, and shutdown speed to investigate wind energy potential in Islamabad, Pakistan. It has been observed that due to insufficient of wind speed the designed models cannot work properly and it has been investigated that the designed model performed efficiently in Margalla hills because it has high wind speed range [20]. Therefore, it is important to analyze the potentiality of the RESs in different locations of Bangladesh. It requires details technical, economic and environmental analyses to find out the most appropriate model of the hybrid power system in Bangladesh.

### 1.5 Outline of the Thesis

This thesis is divided into six chapters.
The first chapter introduces the background of the hybrid power generation system, problem description, motivation, objectives of the study and literature review.

In chapter two, the basic theory related to the wind and solar energy technology and available renewable energy recourses in Bangladesh are presented. Besides, some basic theory of cost calculation has been described.

Chapter three covers the proposed methodology in brief for determination and evaluation of the output of this thesis. In this chapter, load data at different locations, solar radiation from the sunshine, duration curve, and wind energy potential are analyzed with a software tool. The way of finding an optimum model for the hybrid system is also described in this chapter.

Chapter four presents results of the thesis with their significance.

Chapter five describes a case study for feasibility analysis for KUET area by demonstrating various factors.

In chapter six conclusions are drawn and scope of the future studies are made.

# CHAPTER II

# Technology of Renewable Energy System (Wind and Solar)

## 2.1 Introduction

This chapter begins with the demonstration of the wind and solar power technology and described various factors that are associated with the renewable energy power conversion system. At present most of the RE of the world comes from wind energy and solar energy. The wind turbine is used for producing wind power from wind energy by capturing the kinetic energy of wind air mass. The wind turbine is placed on a tall tower to capture wind energy over the year [21]. The biggest energy source of the world is obviously the sun and all energies of the world come from the sun even energy in fossil fuels also.

## 2.2 Technology of Wind Power

The maiden wind energy-based power system was installed in the United Nation in 1890 [22]. After that the wind power technology becomes the most popular technology for power generation in the world. In 1973 wind power technology and other RE technology was increased in different countries of the world [22]. The huge number of research and illustration on the wind turbine technology was simulated. Some advantages of using modern wind turbines to generate power are

- Environmentally friendly
- Produce no pollution
- No traditional fuel required
- Requires relatively little maintenance
- Long lifetime (up to 30 years)

Some disadvantages of using wind turbines to generate power are

- Interference with radio/TV signals if located inappropriately
- The wind does not blow all the time at required speed
- High initial cost

Since the wind power technology has robust characteristics for utility scale power generation, a large wind firm implementation is becoming most familiar at present [23]. A typical wind power technology diagram is shown in Figure 2.1 below.

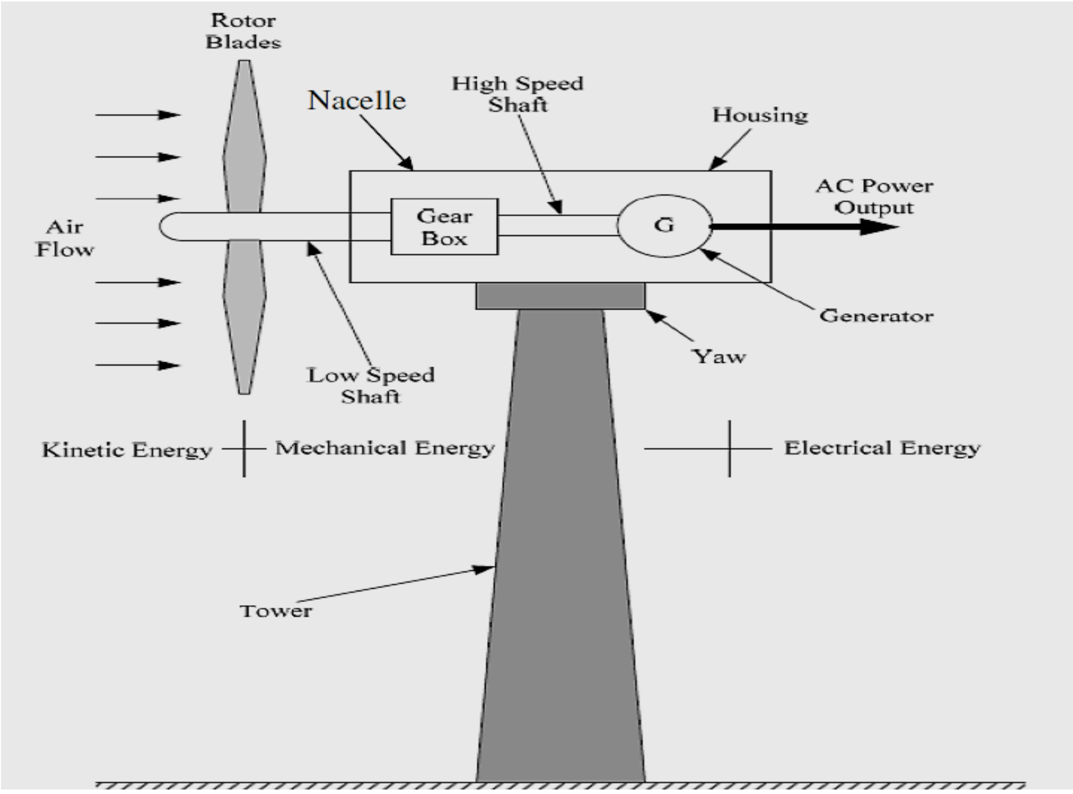



**Fig. 2.1:** A typical wind power technology diagram [24].

The key components of a present wind turbine are the tower, the yaw, the nacelle, the rotor, the generator and the gearbox. The main and important part of the wind turbine is the tower holds that keeps the turbine blade. For turning the wind turbine rotor blades in the direction of wind speed a yaw system is used. The gearbox is another part of wind turbine that is used for increasing the rotational speeds on the electrical generator side. Now a day's the gearless wind turbine has been implemented in various situations which is very easy and maintenance is so easy [24, 25]. By inserting modern control strategy and techniques, the efficiency of wind power generation system can be increased. Wind technologies for electricity production are the second most well-established form of “green” equipment. The capacity of wind turbine that means how much kinetic energy that can be captured by wind turbines and converted to electrical power depends on two factors one is the wind speed and another is the height of the wind turbine [26]. The energy stored in the wind potential can be expressed by Equation (2.1).

$$E_{kinetic} = \frac{1}{2} m v^2 \quad \text{..........} \quad (2.1)$$

where m represents the mass of the air in kg and v denotes the wind speed (m/sec).
Equation (2.1) is the energy stored from wind potential. By using the mass flow rate instead of the mass, wind power can be obtained through Equation (2.2). The critical parameter for the produced electric power through the blowing wind is the size of the blowing area, which is represented by the rotor swept area of the wind turbine.

$$p_{power} = \frac{1}{2} A \rho v^3 C_P \quad \text{..........} \quad (2.2)$$

where A denotes surface area of wind turbine in $m^2$ and v is the wind speed (m/s), ρ represents air density in $kg/m^3$ and $C_p$ is the power coefficient (practically 0.5).

Equation (2.2) calculates the mechanical power of a typical wind turbine. Moreover, it must be noted that in the case of horizontal axis turbines, approximately only 30-40% of the wind power in Equation (2.2) can be transformed into electrical energy because mechanical losses are occurred [26].

### 2.2.1 Classification of Wind Turbines

The wind turbine has been classified into several types. If the devices are designed for converting kinetic energy of the wind to mechanical energy it is called wind turbine. This mechanical energy can be used in different mode. Windmill machines use this type of energy directly but wind generator converts mechanical energy to electrical energy. Wind turbines are classified into two groups one is horizontal axis wind turbine (HAWT) and other is vertical axis wind turbine (VAWT) and this classification is made by considering the position of the rotor axis [27].

### 2.2.2 Horizontal Axis Wind Turbines (HAWTs)

If the axis of rotation of wind turbine is rotated directly in the horizontal direction to the ground and almost parallel to the wind flow direction it's called horizontal axis wind turbine that is shown in Figure 2.2. They can be operating in two different modes that are in front of the wind and behind the wind. At present approximately 90% of wind turbine that is installed around the world is horizontal axis and they have one, two, three or a large number of blades. Since three blades horizontal axis wind turbine have aerodynamic stability, three blades HAWTs are used for commercial purposes.

Fig. 2.2: HAWTs (horizontal axis wind turbines) [28].

### 2.2.3 Vertical Axis Wind Turbines (VAWTs)

In vertical axis, the wind turbine axis of rotation is kept vertical position to the ground level and almost vertical position to the wind direction. For better understanding, this types of the turbine are shown in Figure 2.3. VAWTs have some good characteristics that are it can operate in any direction and yaw mechanism are not used because yaw devices have a complex structure. It has very good aerodynamic characteristics and the manufacturing cost is also low. Most of the vital components that are generator and gearbox of the wind turbine of such system can be placed at ground level. Maintenance cost and procedure of

VAWTs is simple since it can be done at ground level [29]. Moreover, some extra guy wires are needed to support the tower structure which increases the complexity of the systems.

Fig. 2.3: Vertical axis wind turbines (VAWTs) [29].

### 2.2.4 Efficiency and Power Output of Wind Turbine

According to the German aerodynamicist Albert Betz [30], only 59% or less of the kinetic energy in the wind can be transformed to mechanical energy using a wind turbine. But practically, the efficiency of a wind turbine is found much lower than the Betz limit because it depends on various factors namely turbine rotor, generator, and transmission mechanism. The efficiency of turbine rotor is varied from 40% to 50% and 80% to 90% is varied for generator and gearbox [30]. It also depends on wind speed so it is not a constant term. The power curve is the alternative measurement system for wind turbine output characteristics instead of efficiency. This curve represents the turbine power output at various wind speeds and it is provided by the manufacturer company Northern Power and that is shown in Figure 2.4. From this power curve, it is found that output power is zero at point 0 to 2. After this values wind turbine will run in operation. The cut-off speed of these types of a wind turbine is 25 m/s that means when the wind flows at a speed of 25 m/s of over then turbine will automatically turn-off its operation.

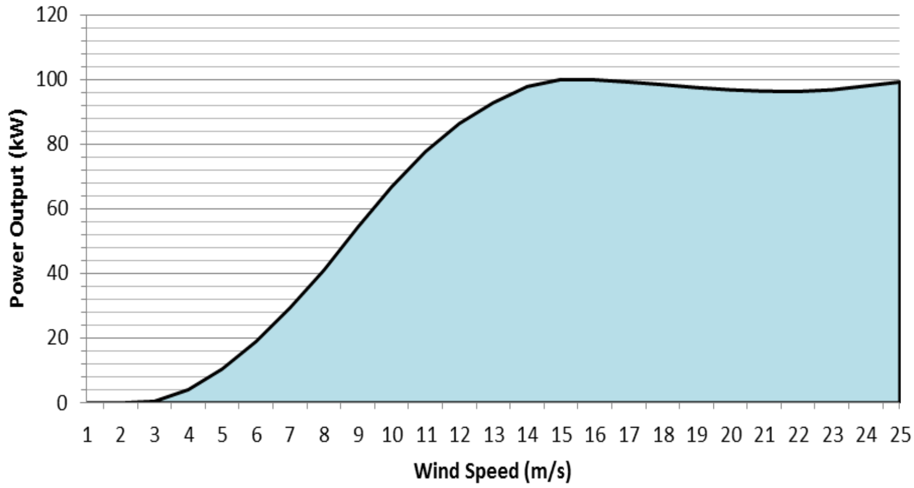



Fig: 2.4. Wind turbine power curve (Northern Power NPS100C-21,100 kW) [25].

### 2.2.5 Wind Speed Measurement

An anemometer is a wind speed measurement instrument. Several types of the anemometer are found and the cup type is most common which has a vane for detecting the wind direction and tree or more cups for wind speed measuring. The most important phenomenon is that the placement of speed measuring equipment and it should be set-up at enough height to avoid disturbance which is created by trees or other obstructions. If the anemometer height is kept at the same level of wind turbine then reading would be most useful [31]. If the height of the anemometer is lower than the wind turbine hub height it is essential to modify the collected data to hub height. This adjustment can be done by using two types of equation namely logarithmic law and power law. Equation (2.3) and (2.4) represents these two types law. The wind speed at desired height can be obtained by using the logarithmic law that is given as follows

$$V_2 = V_1 \times \frac{\ln\left(\frac{h_2}{Z_0}\right)}{\ln\left(\frac{h_1}{Z_0}\right)} \quad \text{.......} \quad (2.3)$$

where $V_2$ represents the wind speed at height $h_2$ (m/s), $V_1$ is the known wind speed at height $h_1$ (m/s), $h_2$ is the desired level where wind speed is needed (m), $Z_o$ is roughness length in the current wind direction (m) that is shown in Table 2.1, and $h_1$ is the anemometer height (m).

Table 2.1: Surface roughness lengths [32]

| Terrain Description | $Z_o$ (m) |
|---|---|
| Very smooth, ice or mud | 0.00001 |
| Calm open sea | 0.0002 |
| Blown sea | 0.0005 |
| Snow surface | 0.003 |
| Lawn grass | 0.008 |
| Rough pasture | 0.01 |
| Crops | 0.05 |
| Few trees | 0.10 |
| Many trees, few buildings | 0.25 |
| Forest and woodlands | 0.5 |

Figure 2.5 depicts the variation of wind speed with respect to height by using logarithmic function. This graph also shows that wind speed will be increased with increase the hub height.

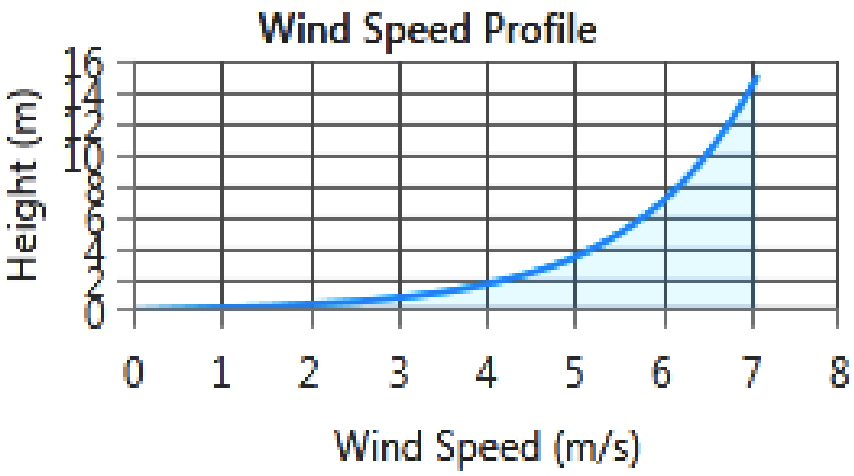



Figure 2.5: Wind speed variation with height [32].

The wind speed at the desired height can be measured by using power law and it can be given as follows [28, 30]:

$$V_2 = V_1 \left( \frac{h_2}{h_1} \right)^{\alpha} \quad (2.4)$$

here: $V_1$ is the known wind speed in m/s, $V_2$ is the wind speed at desired height (m/s), and $\boldsymbol{\alpha}$ is friction coefficient. The friction coefficient $\alpha$ of various terrains is given in Table 2.2.

Table 2.2: Friction coefficient α of various topographies [33, 30]

| Terrain type | Friction Coefficient α |
|---|---|
| Lake, Ocean, and smooth hard ground | 0.10 |
| Foot-high grass on level ground | 0.15 |
| Tall crops | 0.20 |
| Many trees area | 0.25 |
| Small town with some trees | 0.30 |
| City area with tall buildings | 0.40 |

### 2.2.6 Various Factors for Wind Speed Measurement

**Autocorrelation factor:** Wind speed time series data show autocorrelation, which is defined as the degree of dependence at the previous values. This factor is dependent on topography features. The range of autocorrelation factor is varied 0.9 to 0.97 for uniform topography and 0.7 to 0.8 for which area have complex surface and it also dependent on weibull value [34].

**Diurnal Pattern Strength:** It is a measure of how strong the wind speed depends on the time of day. The wind speed is affected by the availability of solar radiation; most sites indicate some diurnal pattern in wind speed.

**Hour of Peak Wind Speed:** Hour of peak wind speed is defined as it is the duration of the day in which the highest wind speed is recorded that means the average windiest time of the day. In this paper, the value of peak hour of 15 is obtained from HOMER.

## 2.3 Technology of Solar Energy

The sun is largest energy sources which release 174 trillion kWh of energy in every hour to the universe [35]. The high temperature is the main source of this energy. Some reports show the surface temperature of the sun is about 5527$^{o}$C and the internal temperature is about 2500 times higher than its surface temperature. This high temperature is produced by a reaction namely nuclear fusion reaction which transforms hydrogen to helium molecule and thus sun emits huge amounts of energy continuously [35]. By electromagnetic radiation, the solar energy is radiated to the earth and almost 33% of this energy is reflected back. About 66% of this is retransmitted to the universe and earth creates a constant energy. By using a photovoltaic array or using solar thermal systems electricity can be generated from solar energy [36]. Figure 2.6 shows the 17 MW power plants using a photovoltaic array at Gujrat, India that is completed in 2012 [37]. The history of photovoltaic technology is discussed in the next section.

Fig: 2.6: 17 MW Mithapur solar power plant, Gujarat in January 2012 (India) [37].

### 2.3.1 History of Photovoltaic Array

The photovoltaic array discovered by French physicist in 1839 and the main component of this array was to metal electrodes. After a long year of the invention period, the maiden report was published in 1877 and builds a selenium PV cell with efficiency less than 1% [38]. After that solar cell efficiency is increased day by day. In 1954, solar panel element was built with p-n junction and efficiency was improved to about 6% [38]. By integrating the p-n junction PV cell, a revolution had been done for solar power systems. Although the cost of production was as high as initially the solar panel was made by crystal silicon but the technology of solar power system has been improved quickly during last part of the twentieth century. The modern PV was used in United Nation for electrifying the earth-orbiting satellites [39]. As the price of PV system was very high, the use of PV array has been limited. It was used only in remote areas but after decreasing the cost of PV cell, the use of the solar system is increasing rapidly [20]. For aerospace technology, a special PV cell is used that is made of crystalline silicon, the efficiency of which is 24% and the efficiency varies 14% to 18% for industrial and domestic purposes. After all, at present, a multi-junction solar panel has been integrated which efficiency reached about 41% [38].

### 2.3.2 Basic Structure of Photovoltaic

Figure 2.6 shows the basic PV cell's structure. For demonstrating the PV cell's structure, first focus is on the surface area of PV cell. Both sides of the junction are covered by the metallic contacts for collecting electrical current that is produced by stimulated photons. Mesh of thin silver fibers are inserted in the top surface of the cell. Between silver conducting fibers some spacing is made for maximizing the electrical conductance and minimizing the blockage of the light [40]. The main elements of the solar panel are the cover glass that gives the mechanical protection, anti-reflection coating in front face that is used for absorbing maximum light energy by minimum reflection. The conducting-foil (solder) contact is displayed over the foot surface and also on one side of the top surface.

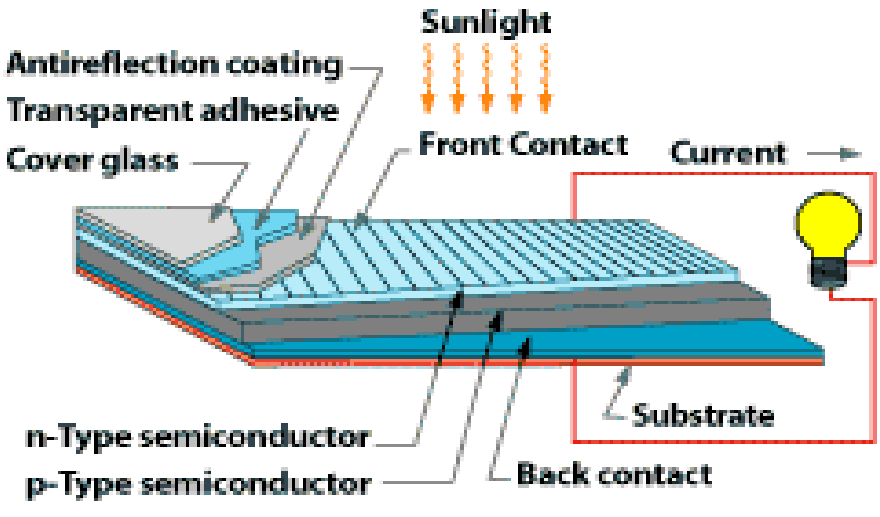



Fig: 2.7 Basic structure of a generic silicon PV cell [36].

### 2.3.3 Characteristics of PV Cells

The silicon is a common semiconductor material which is used for making the PV cells. The basic operating principle of PV cell is that when solar energy strikes on the PV panel, a proton is absorbed by silicon and creates free electron inside the semiconductor materials. Electric fields of PV cell act to force on free electron and that's why electron will flow in a definite direction. This phenomenon is called current and by placing some metal contact on top and bottom side of PV cell current is transferred for external uses. PV cells have several advantages and also have some drawback that is described below.

**Advantages**

- Environmentally friendly and pollution free (emission free)
- No use of fuels and water
- Requires minimum maintenance and low running cost
- Long lifetime, up to 30 years
- Modular or "custom made" energy, can be designed for any applications from watch to a multi-megawatt power plant
- No restriction on harvesting as far as there is light

**Drawbacks**

- High initial cost
- PV can't operate without light
- PV generates DC current: energy storage, like batteries, and inverters are needed
- Large area needed for large scale applications
- Cannot always generate stable output with ever-changing weather conditions

### 2.3.4 Solar Power

The sun radiates a large amount of energy to the earth surface which is equal to or more than 10000 times of current world energy consumption [22]. Two types of sunlight are radiated to the earth: direct radiation and other is diffuse radiation. Solar panel uses both of the radiation for producing power. For determining the solar power capacity in a specific area, data of yearly solar radiation is needed. By using annual solar radiation data the availability of solar energy can be estimated. PV cell absorbs this radiation and produce DC electrical power and can be illustrated by the following equation [40, 41].

$$P_{solar} = P_{STC} f_{PV} \left( \frac{G_T}{G_{STC}} \right) \left[ 1 + a_P \left( T_C - T_{C,STC} \right) \right] \ldots\ldots\ldots \quad (2.5)$$

Where, $P_{STC}$ denotes the output power PV cell at test conditions, $f_{PV}$ is the derating factor, $G_T$ (W/m$^2$) indicates the solar radiation incident, and $G_{STC}$ (W/m$^2$) is the radiation in standard test conditions (1000 W/m$^2$), $a_p$ represents the temperature coefficient (%/$^0$C) which indicates effect of temperature on the performance of the solar panel which is influenced by the temperature The last bracket which contains the temperature coefficient represents the, $T_C$ ($^0$C) indicates the real time temperature..

## 2.4 Conclusion

The knowledge on the basic theory of the wind and solar technology is very important for power system analysis. RE sources have both advantages and disadvantages which are summarized in this chapter. Moreover, there are different types of cost involve in the calculation of the overall cost of a power plant which is described in this chapter.

# CHAPTER III

# Methodology

## 3.1 Introduction

This chapter begins with the presentation of the proposed method for evaluating the optimum design of hybrid power system. A methodology has been developed for determining the optimum design of RE based hybrid power plant. Various necessary data have been collected from the meteorological department and other reliable sources. By collecting and investigating the input parameters, a suitable algorithm has been developed. This chapter then concentrates on the feasibility of RES-based systems to supply electricity to five different locations in Bangladesh.

## 3.2 Proposed Model

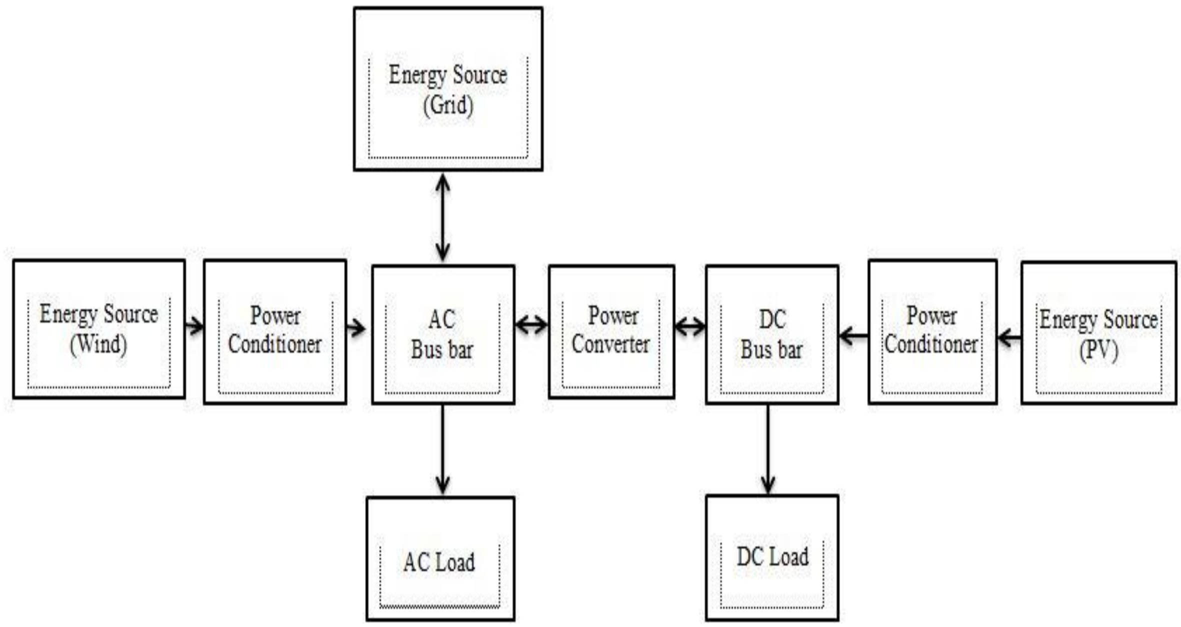



**Fig. 3.1:** Grid connected hybrid power system model

For this research, it is essential to collect some necessary data such as average daily load demand, types of green energy that are available for different locations, monthly average solar radiation and clearness index from NASA surface meteorology and solar energy database and average wind flow from the meteorological department of Bangladesh [12]. The typical arrangement of the hybrid power system of this research is shown in Fig. 3.1 which includes energy sources and loads. Simulations are carried out using software tools [13, 14]. The considered six different locations in Bangladesh are namely Kuakata, Magnamaghat, Sitakunda, Dinajpur and Rangpur and KUET.

### 3.2.1 Flow Chart of the Proposed Methodology

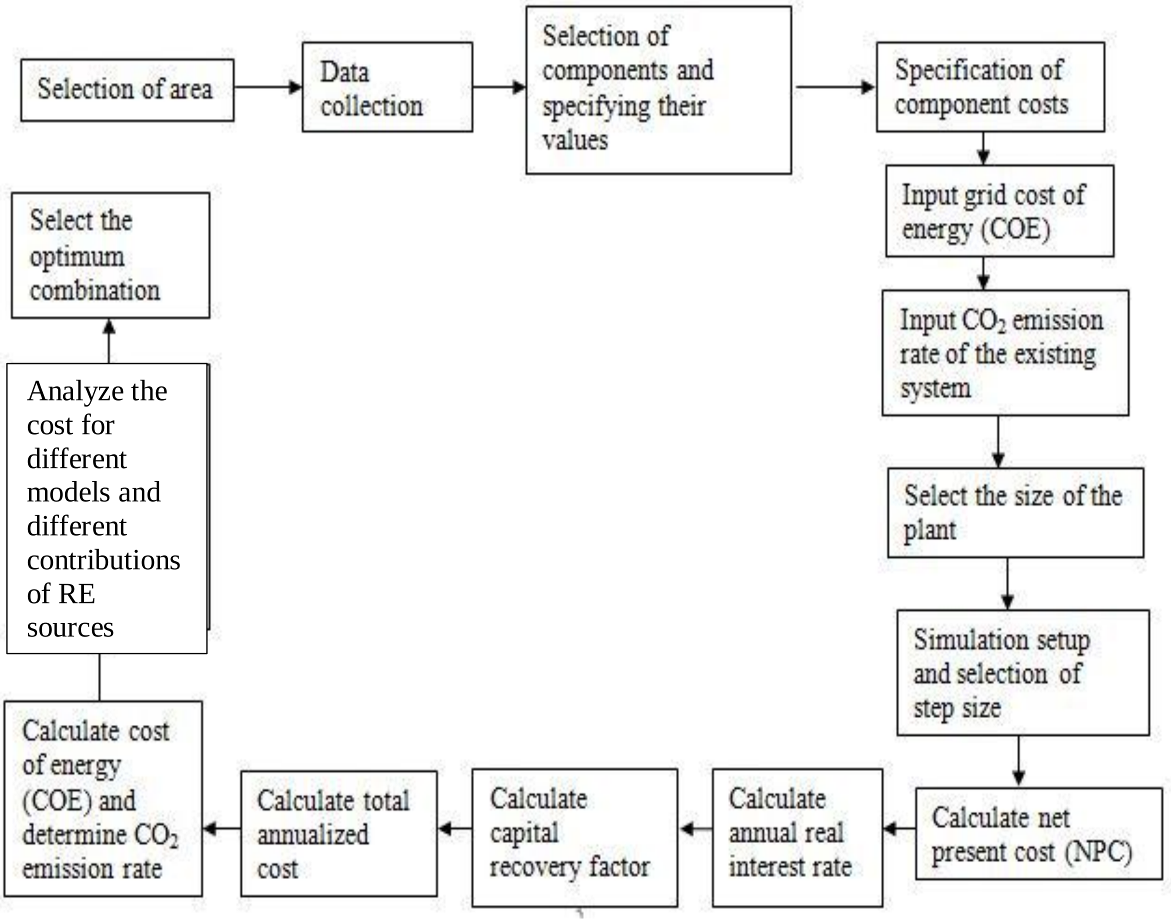



**Fig. 3.2:** Flowchart of the proposed methodology

The flowchart of the proposed methodology is shown in Fig. 3.2. According to the methodology, the simulation results are calculated for finding the cost of energy (COE), net present cost (NPC), total annualizes cost, annual real interest rate, and capital recovery factor (CRF) and greenhouse gas emission in terms of tons/year. From the calculations, an optimum combination of RE sources is determined to get the minimum cost. In the first step, it is essential to select the area where the analysis will be carried out. The next step involves the selection of energy sources for example in this case wind and solar. The wind flow pattern and solar radiation data are needed in this step. This step also includes calculation of load demands. After that equipment have been selected and their costs are specified. Then the cost of energy from utility and $CO_2$ emission rate of the grid are given as input to the simulator. At this step, the size of the plant is selected and model is designed. Then cost calculations are carried out as described in Chapter 2. Finally, on the basis of the lowest NPC, the optimum combination of RE sources for different models is determined by varying their contributions. Next section describes the resource and load estimation for the considered areas in Bangladesh.

### 3.2.2 Wind Energy Available in Bangladesh:

The coastal area of Bangladesh is suitable for the production of electricity as there is strong wind flow coming from the Indian Ocean. This wind blows over Bangladesh from March to September [42]. Fig 3.3 shows wind map of Bangladesh at about 20 locations that are collected from NASA SSE data set. From this figure, it can be seen that the coastal area of Bangladesh is dominated by the wind potential. Most of the average wind speed is almost 5 m/s. In the presence of high wind flow, there is huge scope for harvesting wind energy that is very needed at this time.

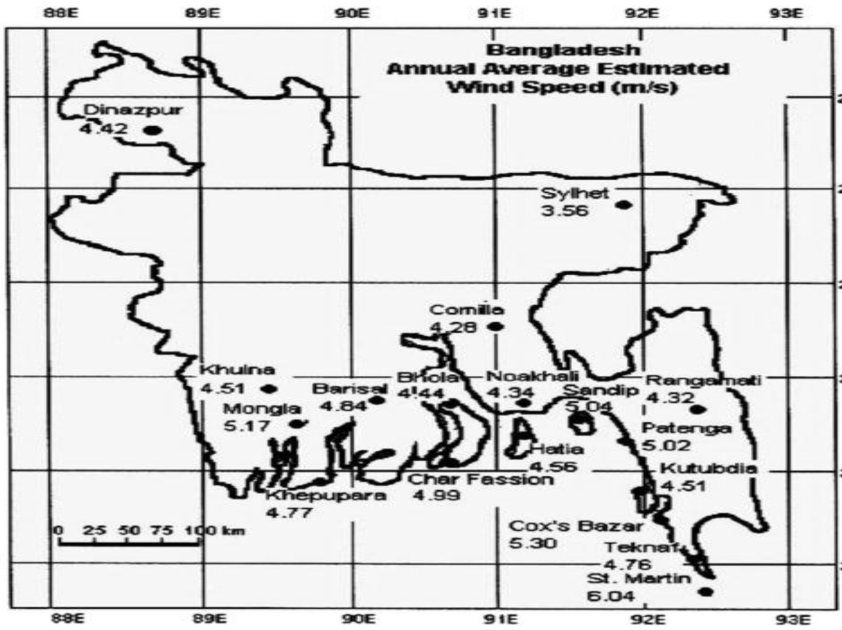



**Fig.3.3:** Wind speed scenario of Bangladesh at 50 m height [43].

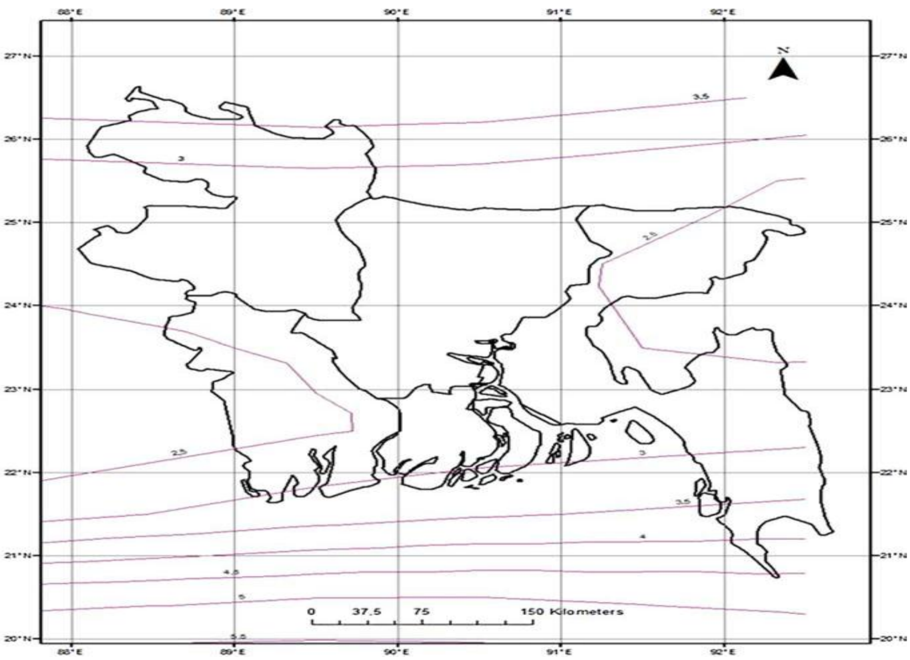



**Fig. 3.4:** Wind direction of Bangladesh at 50 m height [43].

Figure 3.4 shows the wind direction that flows over the Bangladesh. It is clearly seen that a large amount of wind flows in the direction of west to south [44, 45]. It is very important to find out a reliable source of data for carried out the research and the NASA SSE database is the most useful and reliable source which could be used for RE resource estimation at the primary stage [46, 47]. At the initial stage, a set of data has been collected from NASA SSE for analyzing the availability of RE potential. From this data, it is found that only coastal region of Bangladesh is dominated by wind energy potential and this research has been carried out based on this location.

### 3.3 Wind Resources

The LGED assessed 20 locations all over Bangladesh under the WERM project at different heights [41]. In the present study, wind speed data from this project for Kuakata, Sitakundu and Magnamaghat from January 2006 to December 2006 have been evaluated. The analyses and the evaluations were performed in the department of Mechanical Engineering at Bangladesh University of Engineering and Technology (BUET) by a group of graduate and undergraduate students and some of the values were collected from their Project & Thesis works. Among the 20 wind monitoring stations of the WERM project, wind characteristics and potential were analyzed for Kuakata, Sitakunda, and Magnamaghat. This is because of the fact that in Bangladesh the possible WECS utility and wind energy availability are among the best matches in these areas. The details of the following 3 locations are presented in Figure 3.5.

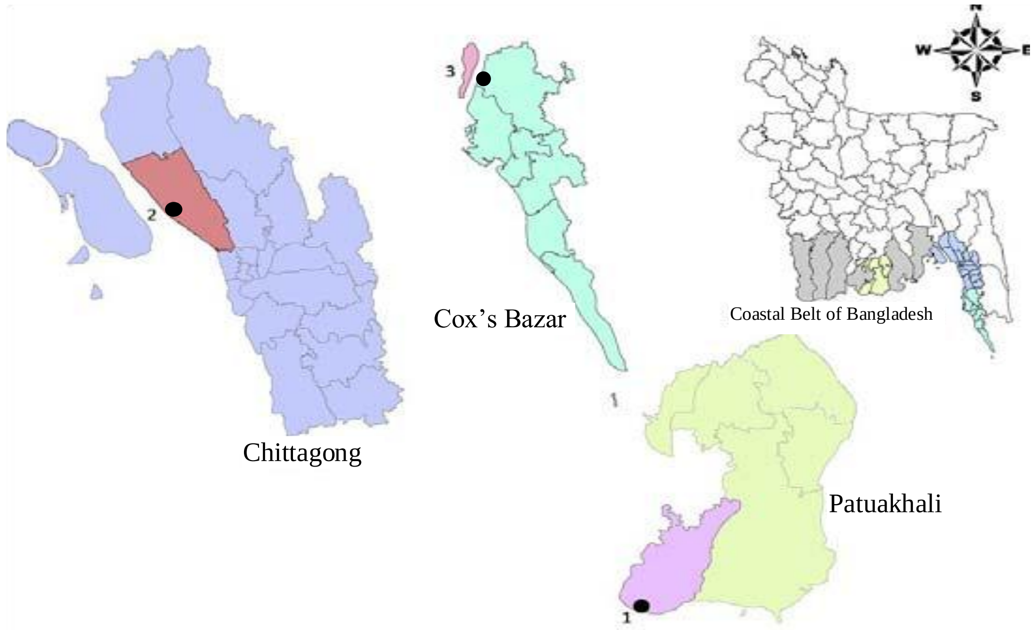



**Fig.3.5:** Location of 3 wind sites: 1. Kuakata 2. Sitakunda and 3. Magnamaghat [48].

Kuakata that is shown in Figure 3.5 (point 1) having geographical coordinates: 21.82°N, 90.12°E and it is the center of the southwest coastline of Bangladesh in Patuakhali district. It is situated 320 km from Dhaka and 70 km from Patuakhali. It is one of the most extraordinary tourist places in the world from where both sunrise and sunset can be observed.

Sitakunda having geographical coordinates: 122.65°N, 91.66° E is situated at the intersection of two coastlines making an obtuse angle with Chittagong district that is shown in Figure 3.5 (point 2). It is 212 km southeast from Dhaka and 44 km from Chittagong. The main activities are related to agriculture 24%, fishing 4%, industrial labor 5% and services 33%.

Magnama with coordinates: 21.81°N, 91.90°E is around the center of the southeast coastline in Cox's Bazar district that is shown in Figure 3.5 (point 3). The main activities are related to agriculture 55%, fishing 5% and industries 2%.

### 3.3.1 Wind Energy Resources in Kuakata

For the production of green energy, the coastal area of Bangladesh is most suitable because the situation of the coastal area is suited for green energy harvesting. The strong wind flow which comes from the Indian Ocean most of the month in a year thus wind flow is available here. This wind blows over Bangladesh from March to September. According to the meteorological department of Bangladesh, monthly average wind speed is observed 3 m/s to 8.3 m/s [49]. The wind speed is high from March to September and other months of a year (October to February) wind speed remains quite low. The peak wind speed occurs during the month of April and May [50]. Figure 3.6 shows the monthly average wind speed around the year at Kuakata. Figure 3.7 is representing the histogram of wind speed at Kuakata region. Wind speed histogram curve shows most of the density of wind speed is found at 4 m/s to 6 m/s.

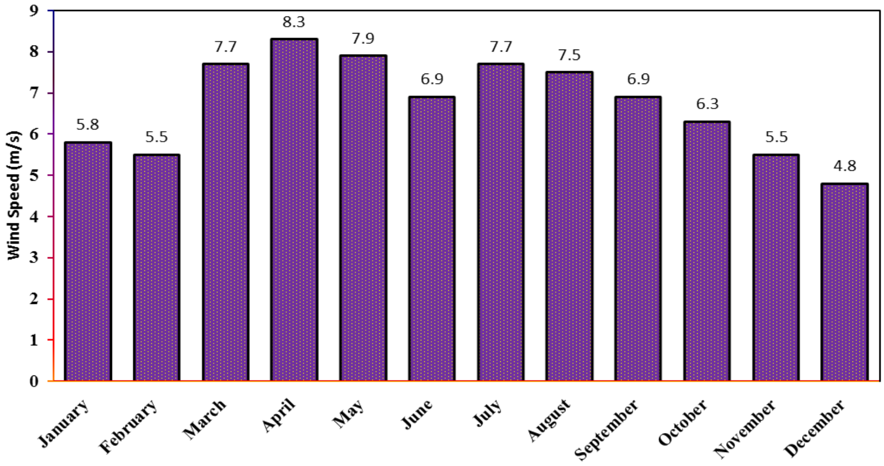



**Fig.3.6:** Monthly average daily wind speed (m/s) at Kuakata [50]

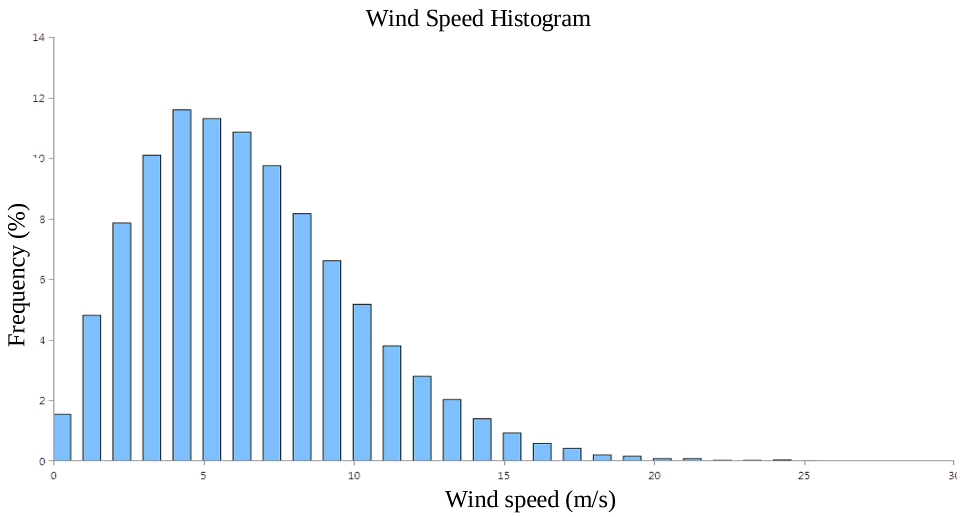



**Fig.3.7:** Wind Speed Histogram for Kuakata Region [50].

### 3.3.2 Wind Energy Resources in Sitakunda

According to the meteorological department of Bangladesh, monthly average wind speed is observed 3 m/s to 7 m/s. The wind speed is high during May to August and other months of a year (September to April) wind speed remains quite low. The peak wind speed occurs during the month of June and July [51, 52]. Fig. 3.8 shows the monthly average wind speed around the year at Sitakunda.

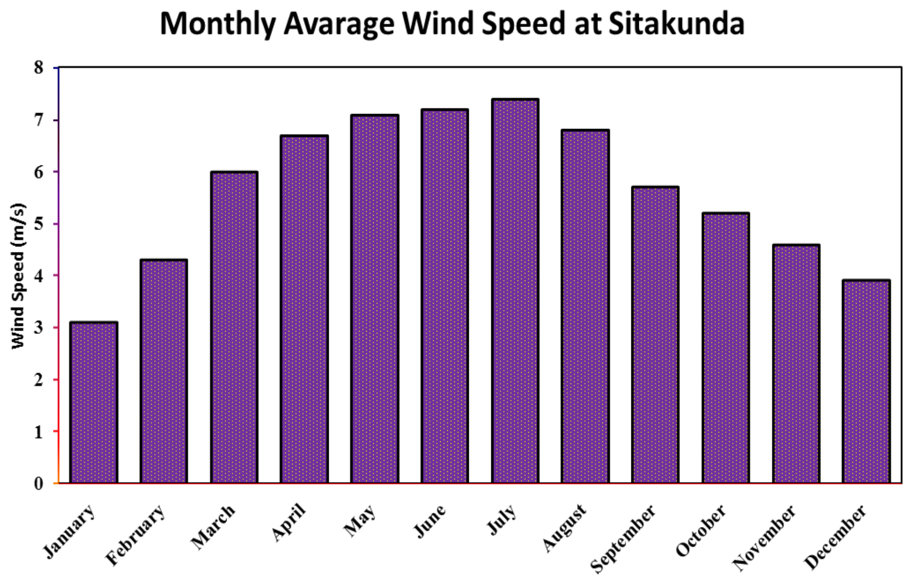



**Fig.3.8:** Monthly average daily wind speed (m/s) at Sitakunda [51, 52].

### 3.3.3 Wind Energy Resources in Magnamaghat, Cox's Bazar

Due to the unavailability of wind resource data especially wind speed data at a specific height, it is very difficult to estimate the wind data that is most similar to actual data. Bangladesh Meteorological Department implements the 20 monitoring station for measuring wind resource data. The previous study shows that poor range of wind speed data is available around the Bangladesh except for coastal region [53]. According to the meteorological department of Bangladesh, monthly average wind speed at Magnamaghat is observed 4 m/s to 8.5 m/s. The wind speed is high from March to September and other months of a year wind speed is found quite low. The peak wind speed is observed during the month of April and May [51]. Figure 3.9 shows the monthly average wind speed around the year at Magnamaghat, Cox's bazar.

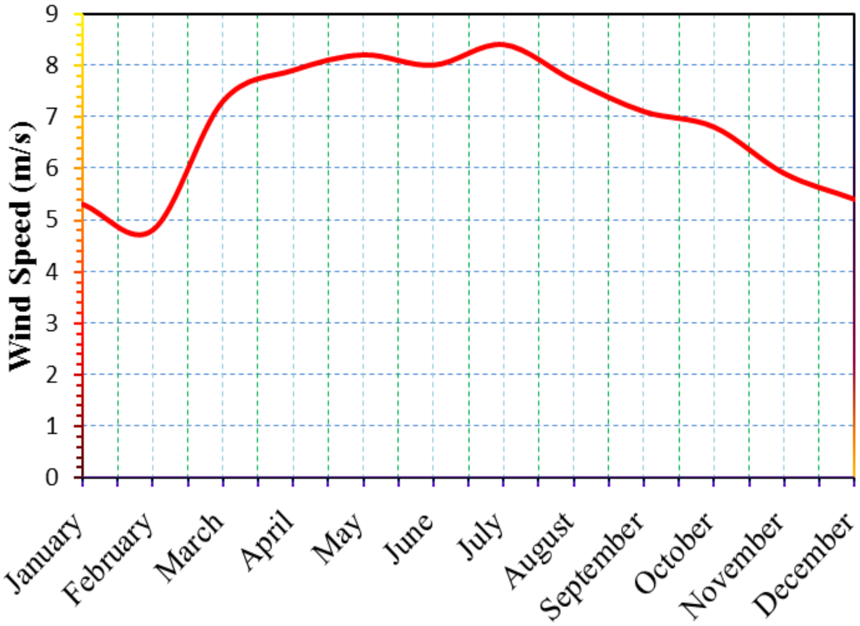



**Fig.3.9:** Monthly average daily wind speed (m/s) at Magnamaghat [51, 54].

### 3.3.4 Comparison of Monthly Variations of the Mean Wind Speed

In Kuakata, higher wind speed occurs during April to September but during October to March wind speed is much lower as indicated by the lower mean speed. For Sitakunda, wind speed follows the same pattern as Magnamaghat with the highest mean in July. For Kuakata the highest mean speed occurs in August but the pattern is like Sitakunda. Though Magnamaghat has more wind speed in the latter part of the year it has lower wind speeds in the earlier part of the year. A common trend is observed in all the locations that there are sharp changes in wind speeds during the months of March-April and July-August. This is due to the location of the country which is characterized by the tropical monsoon with reversal wind circulation. Figures 3.10 and 3.11 show the comparison of monthly average wind speed and annual average wind speed in three coastal areas, respectively.

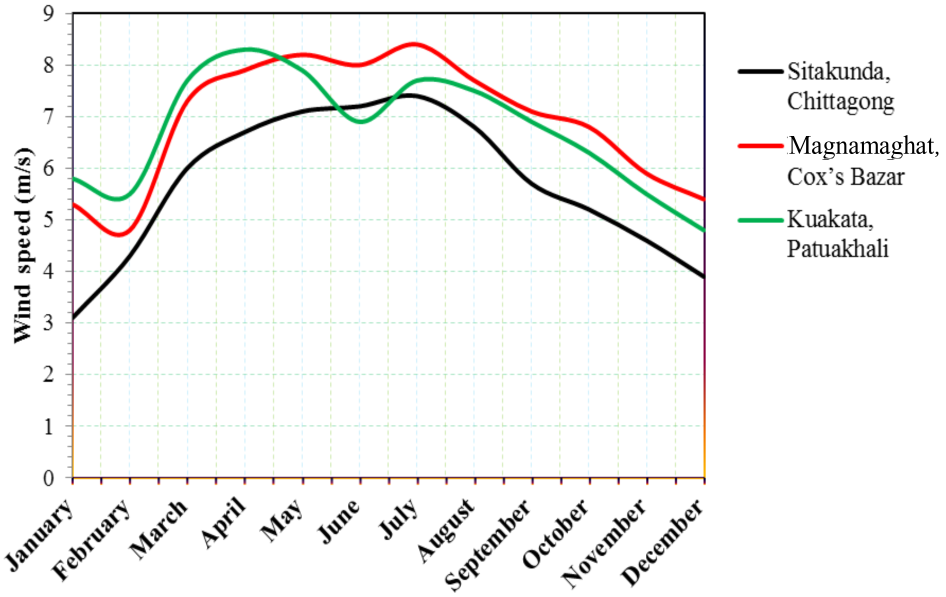



**Fig.3.10:** Monthly variation of mean wind speed at 50 m height [54]

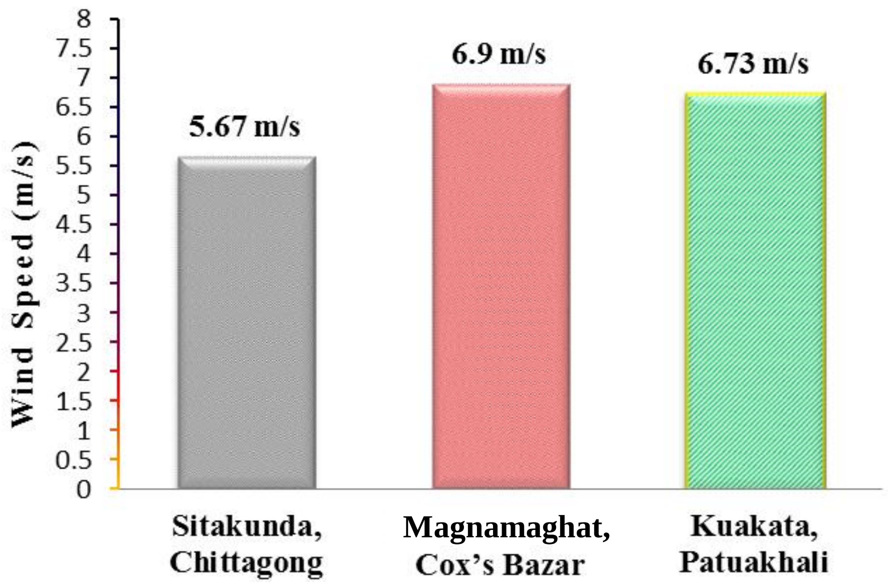



**Fig.3.11:** Annual average wind speed (m/s) at 50 m height for three different locations [54].

### 3.3.5 Wind Power Density for Sitakunda, Magnama, and Kuakata

Table 3.1 depicts the summary of wind speed sensor of different locations with power density. Figure 3.12 shows the monthly variation of the wind power density in the three locations calculated from Equation (2.2). An example of calculation of wind power density is given in Appendix. The seasonal effect is prominent in the monthly wind power density. For Kuakata, remarkable monthly changes in the wind power density have found from March to October with a maximum of 352 W/m$^2$ in April being about 5 times of the minimum 68 W/m$^2$ in December. For Sitakunda, similar monthly changes in the wind power density have found from March to September with a maximum of 249 W/m$^2$ in July being about 13 times of the minimum 18.3 W/m$^2$ in October. For Magnamaghat, peak wind power density have found from March to September with a maximum of 365 W/m$^2$ in July which is about 4 times of the minimum 91.6 W/m$^2$ in January. A detailed examination of Figure 3.12 has revealed the monthly variation of wind speed and power density for selected sites.

**Table-3.1:** Monthly variation of wind speed and power density for selected sites [54].

| Location | | Month | | | | | | | | | | | | Annual average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| **Kuakata** | Wind speed | 5.8 | 5.5 | 7.7 | 8.3 | 7.9 | 6.9 | 7.7 | 7.5 | 6.9 | 6.3 | 5.5 | 4.8 | 6.733 |
| | Power density (W/m$^2$) | 120 | 102 | 281 | 352 | 303 | 202 | 281 | 259 | 202 | 154 | 102.3 | 68.01 | 187.7 |
| **Magnamaghat** | Wind speed | 5.3 | 4.8 | 7.3 | 7.9 | 8.2 | 8 | 8.4 | 7.7 | 7.1 | 6.8 | 5.9 | 5.4 | 6.9 |
| | Power density (W/m$^2$) | 91.6 | 68 | 239 | 303 | 339 | 315 | 365 | 281 | 281 | 220 | 193.4 | 126.3 | 96.84 |
| **Sitakunda** | Wind speed | 3.1 | 4.3 | 6 | 6.7 | 7.1 | 7.2 | 7.4 | 6.8 | 5.7 | 5.2 | 4.6 | 3.9 | 5.667 |
| | Power density (W/m$^2$) | 18.3 | 49 | 133 | 185 | 220 | 230 | 249 | 193 | 114 | 86.5 | 59.86 | 36.48 | 111.9 |

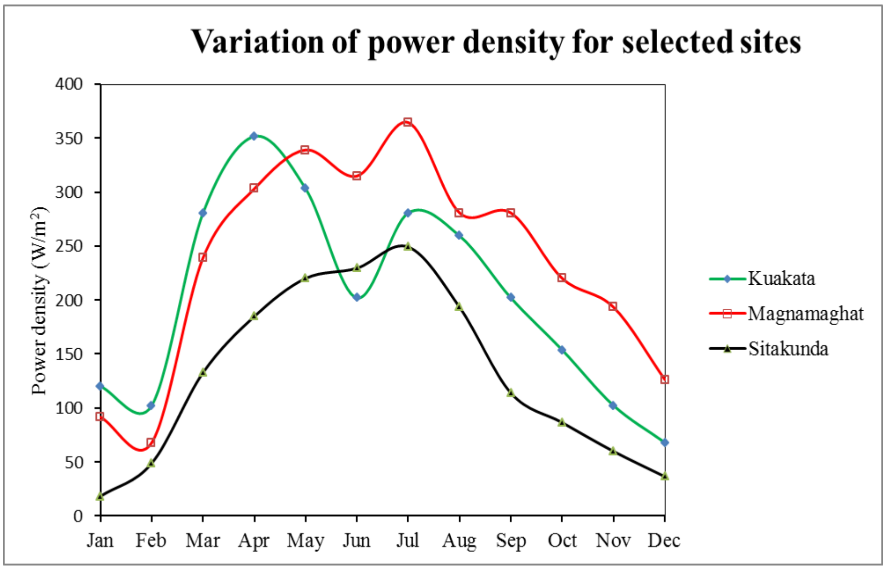



**Fig.3.12:** Monthly variation of the wind power density at 50 m height

### 3.4 Solar Energy Resources of Bangladesh

Bangladesh having geographical location between 20.30° and 26.38° North latitude and 88.04° and 92.44° East longitude is an ideal location for solar energy harvesting. From the radiation data, it is found that the daily solar radiation varies between 4 to 6.5 $kWh/m^2$ [41] over Bangladesh. This strong solar potential indicates that by implementing solar power system it is possible to electrify the maximum region of Bangladesh particularly in the northern part of Bangladesh. In this research, investigating and analyzing the solar potential has been done over the Bangladesh not only for power generation but also it is very urgent need to reduce the greenhouse gas [55]. Figure 3.13 shows the solar energy radiation in Bangladesh and Table 3.2 shows the average daily solar radiation that is measured by RERC of Dhaka University and NASA. It is found that data of two references have a little bit variation. The highest solar radiation is observed Dinajpur and Rajshahi.

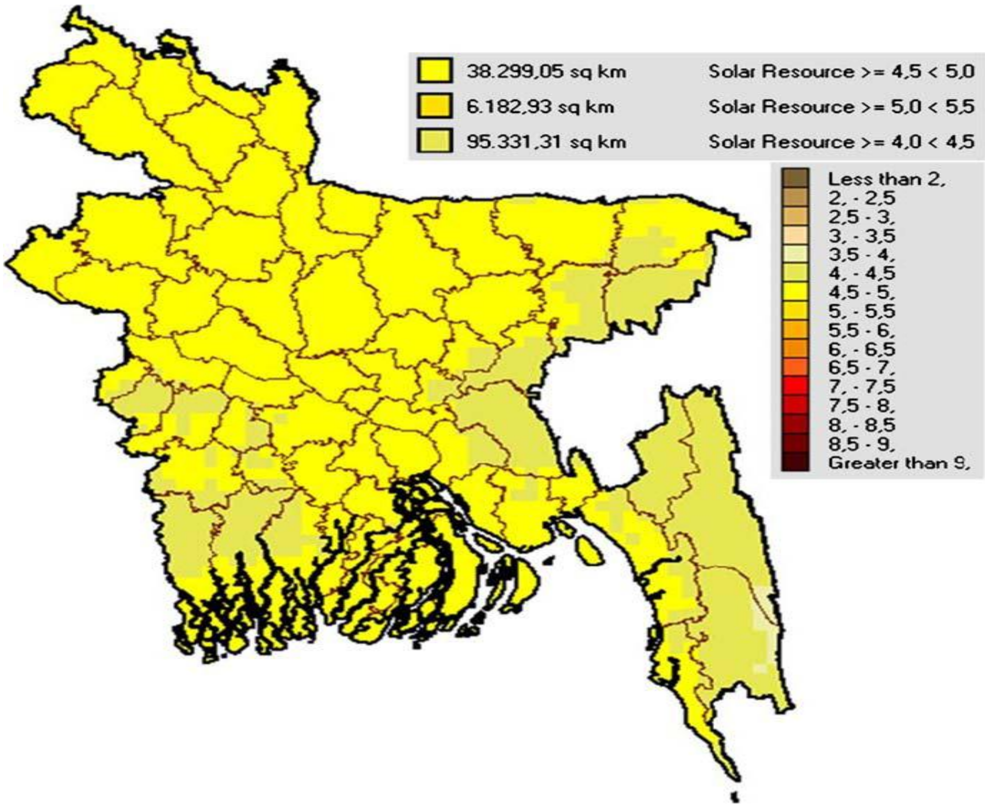



**Fig.3.13:** Solar radiation ($kWh/m^2/day$) and area of Bangladesh with the highest potential for solar energy utilization [41].

**Table -3.2:** Average daily solar radiation at 14 locations in Bangladesh [44, 45]

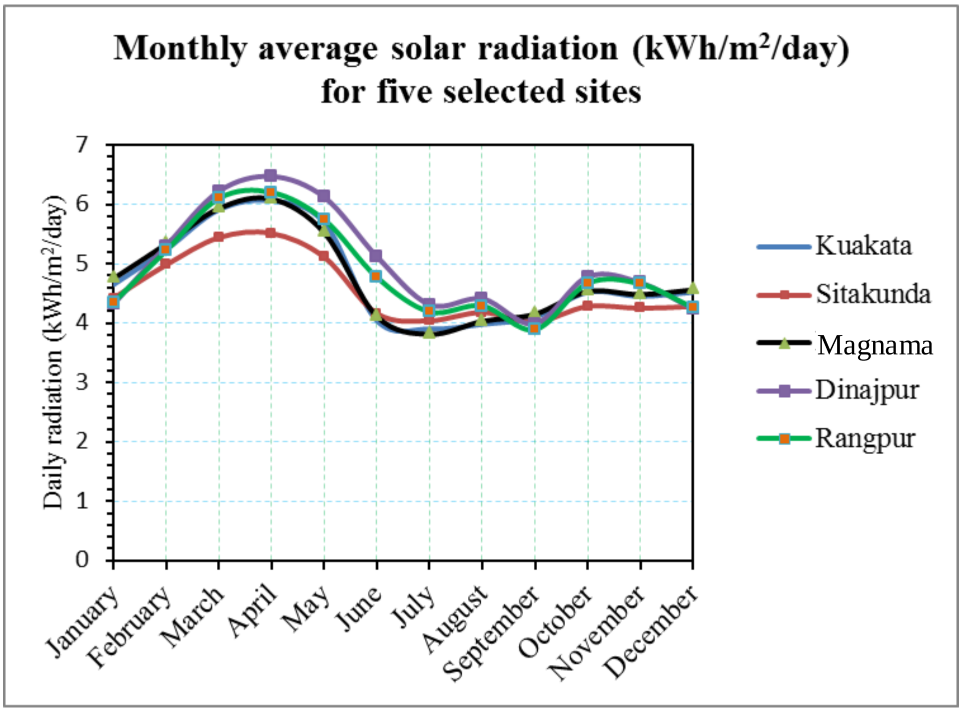
| Station name | Elevation (m) | Latitude (degrees) | Longitude (degrees) | Radiation (RERC) (kWh/m$^2$/day) | Radiation (NASA) (kWh/m$^2$/day) |
|---|---|---|---|---|---|
| Dhaka | 50 | 23.7 | 90.4 | 4.73 | 4.65 |
| Rajshahi | 56 | 24.4 | 88.6 | 5.00 | 4.87 |
| Sylhet | 225 | 24.9 | 91.9 | 4.54 | 4.57 |
| Khulna | 11 | 22.8 | 89.6 | - | 4.55 |
| Rangpur | 230 | 25.7 | 92 | - | 4.86 |
| Cox's Bazar | 76 | 21.4 | 92 | - | 4.77 |
| Dinajpur | 194 | 25.6 | 88.6 | - | 4.99 |
| Kaptai | 345 | 22.5 | 92.2 | - | 4.71 |
| Chitagong | 118 | 22.3 | 91.8 | - | 4.55 |
| Bogra | 59 | 24.8 | 89.4 | 4.85 | 4.74 |
| Barishal | 31 | 22.7 | 90.4 | 4.71 | 4.51 |
| Jessore | 23 | 23.2 | 89.2 | 4.85 | 4.67 |
| Mymenshingh | 114 | 24.8 | 90.4 | - | 4.64 |
| Sherpur | 308 | 25 | 90 | - | 4.67 |

### 3.4.1 Solar Energy at Kuakata and Other Four Locations

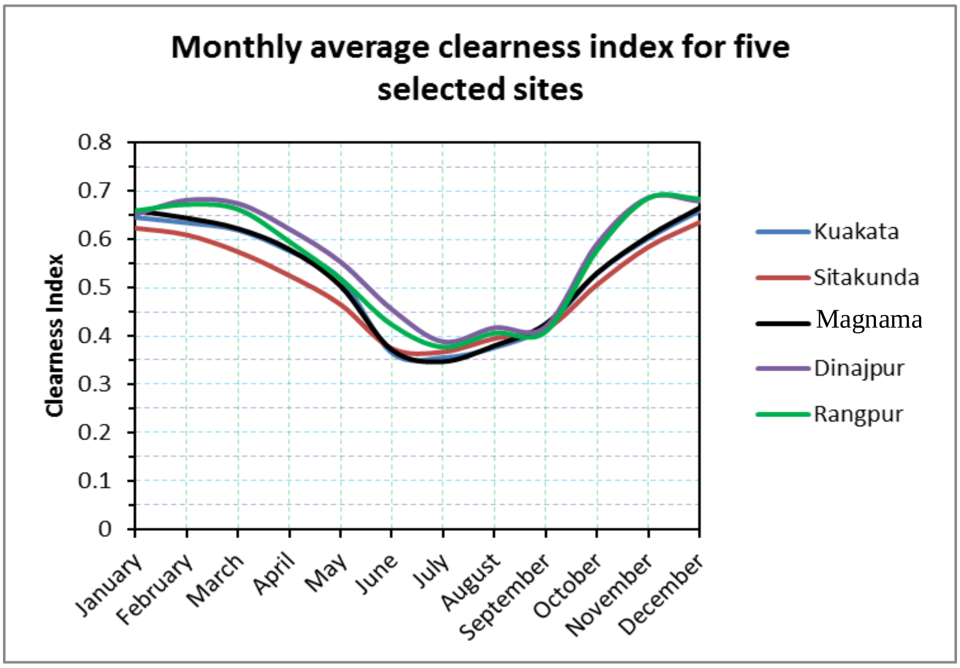
In this section, the data of monthly average daily solar radiation (kWh/m$^2$/day) clearness index for solar radiation acquired through National renewable energy lab and NASA surface meteorology and solar energy database is used as input to HOMER and are presented in Table 3.3. Homer software uses multiple databases regarding all these data, as well as NREL data for simulating and extracting the resulting data for the location to be studied. Some actual measured data from stations located is collected from RERC that shown in Table 3.2 which is really close to the NASA meteorological data [56]. The annual average solar radiation is estimated to be 4.76 kWh/m$^2$/day for Kuakata, 4.56 kWh/m$^2$/day for Sitakunda, 4.77 kWh/m$^2$/day for Magnama, 5.00 kWh/m$^2$/day for Dinajpur and 4.86 kWh/m$^2$/day for Rangpur. Table 3.3 shows the Monthly and annually average daily radiation (kWh/m2/day), clearness index for selected sites. The comparison of monthly and annual solar radiation and clearness index at five different locations is given in Fig. 3.14 and Fig. 3.15, respectively. From Figure 3.14 (a) and 3.14 (b) it is found that the highest solar potential occurs at Dinajpur from February to July and the peak value is observed 6.06 kWh/m$^2$/day in April. One the other hand, the lowest solar potential is found 4.02 kWh/m$^2$/day in September at Sitakunda as it is a coastal area. In winter season (July to January) all these five locations have the almost similar solar potential.

**Table-3.3:** Monthly and annually average daily radiation (kWh/m$^2$/day), clearness index for selected sites [11, 34, 56].

| Month | Kuakata | | Baroi Para Road,Sitakunda | | Magnama, Cox's Bazar | | Daptori Para, Dinajpur | | Rangpur | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Clearness Index | Daily Radiation kWh/m$^2$/day | Clearness Index | Daily Radiation kWh/m$^2$/day | Clearness Index | Daily Radiation kWh/m$^2$/day | Clearness Index | Daily Radiation kWh/m$^2$/day | Clearness Index | Daily Radiation kWh/m$^2$/day |
| Jan | 0.645 | 4.65 | 0.623 | 4.42 | 0.659 | 4.75 | 0.652 | 4.32 | 0.659 | 4.35 |
| Feb | 0.634 | 5.24 | 0.609 | 4.98 | 0.644 | 5.33 | 0.681 | 5.3 | 0.672 | 5.22 |
| Mar | 0.619 | 5.91 | 0.574 | 5.44 | 0.622 | 5.93 | 0.674 | 6.22 | 0.662 | 6.1 |
| Apr | 0.576 | 6.06 | 0.525 | 5.51 | 0.579 | 6.09 | 0.621 | 6.47 | 0.595 | 6.2 |
| May | 0.518 | 5.69 | 0.465 | 5.11 | 0.503 | 5.52 | 0.553 | 6.12 | 0.518 | 5.74 |
| Jun | 0.365 | 4.04 | 0.374 | 4.16 | 0.371 | 4.11 | 0.455 | 5.12 | 0.423 | 4.77 |
| Jul | 0.355 | 3.9 | 0.367 | 4.04 | 0.347 | 3.81 | 0.388 | 4.31 | 0.377 | 4.19 |
| Aug | 0.376 | 3.98 | 0.395 | 4.18 | 0.38 | 4.03 | 0.417 | 4.41 | 0.406 | 4.29 |
| Sep | 0.42 | 4.1 | 0.414 | 4.02 | 0.425 | 4.15 | 0.419 | 3.99 | 0.409 | 3.89 |
| Oct | 0.529 | 4.52 | 0.506 | 4.28 | 0.53 | 4.53 | 0.59 | 4.78 | 0.577 | 4.67 |
| Nov | 0.602 | 4.45 | 0.584 | 4.25 | 0.606 | 4.48 | 0.686 | 4.68 | 0.685 | 4.66 |
| Dec | 0.659 | 4.52 | 0.635 | 4.28 | 0.665 | 4.56 | 0.679 | 4.24 | 0.684 | 4.26 |
| Annual average | 0.524 | 4.75 | 0.505 | 4.555 | 0.527 | 4.774 | 0.567 | 5.00 | 0.555 | 4.8616 |




(a)




(b)

**Fig.3.14:** Comparison of (a) solar radiation and (b) clearness index at five locations.

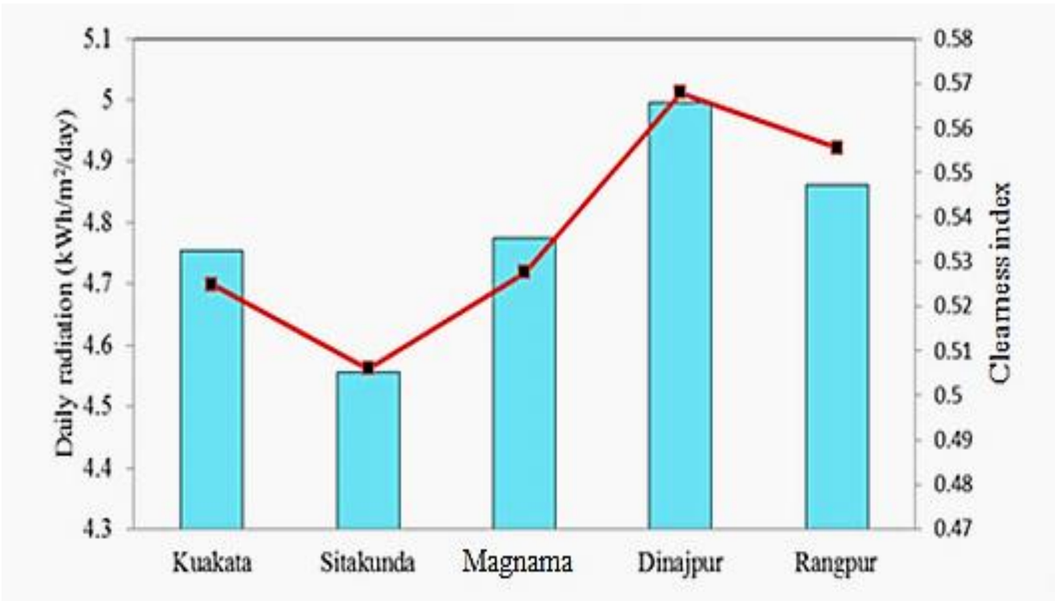



**Fig.3.15:** Annual average daily solar radiation with clearness index

### 3.5 Load Estimation for Proposed Region:

The estimation of the power demand was done a research on previously made case studies of rural electrification in developing countries [34], [57], [58], [59],[60]. In this thesis, the electric load demand is divided into the following three major categories like; household/domestic sector which includes of (lighting, TV, Radio, and baking appliances); Commercial loads (shops); community load which consists of (school lighting, health clinic which includes (vaccine refrigerator, communication radio, television, microscope, computer and printer) and deferrable load (water supply and irrigation systems, battery run auto rickshaw). The total electric load estimated for the listed appliances above were summed up to get the required load to be supplied by the system. The electricity consumption does not vary significantly almost the whole year although the load consumption season has been divided into two seasons namely summer season and winter season [61]. It is very important to know the actual rating of home appliances. Table 3.4 shows the basic home appliance rating that is used mostly in proposed area. The load estimation procedure for different location of Bangladesh is described in the next section.

**Table-3.4:** Name of home appliances with their ratings [62].

| Sl No. | Name and Rating of home Appliances | |
|---|---|---|
| 01 | Name of Appliances | Rating (Watts) |
| 02 | CFL Lamp | 11 , 15 , 20 |
| 03 | Tube Light | 20, 40 |
| 04 | Electric Iron | 750, 1000 |
| 05 | Microwave Oven | 1000, 1500 |
| 06 | Rice cooker | 1000 |
| 07 | Refrigerator (165 liters) | 180 |
| 08 | Refrigerator (210 liters) | 250 |
| 09 | Refrigerator (300 Lts) | 350 |
| 10 | Air-Conditioner (1 Ton) | 1500 |
| 11 | Air-Conditioner (1.5 Ton) | 2250 |
| 12 | Air-Conditioner (2 Ton) | 3000 |
| 13 | Table Fan/ Ceiling Fan/ Wall Fan | 60, 100 |
| 14 | Washing Machine with Heater | 1500 |
| 20 | Water pump | 373,746 |
| 15 | Television Small | 110 |
| 16 | Television BIG | 200 |
| 17 | Mixer cum Grinder | 200 |
| 18 | Computer (Laptop, Desktop, Desktop with printer) | 45, 110, 250 |
| 19 | Elevator [63] | 20 HP |

### 3.5.1 Electricity Demand at Dinajpur

For load estimation, it is very important to the brief background of proposed area for knowing the environmental and economic situation of that area. For Dinajpur, it is a city of Rangpur division situated in the northern part of Bangladesh. It is one of the ancient towns formed in Bangladesh. It is situated in 25$^{o}$37' N. latitude and 88$^{o}$39' E longitude on the eastern bank of the river Punarvhaba. It is bounded on the north by Suihari, Katapara, Bangi Bechapara, Pulhat, Koshba on the south, on the east of Sheikhupura and by the river Punarbhava on the west. The case study of this thesis involves served the load of an area of 300 households (average 5 people per household) located at Dhopa Para.

**Table-3.5:** Load consumption for high class, medium class, and low-class household

| Residential Load | | | | | | |
|---|---|---|---|---|---|---|
| Type | No of household | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| High class house hold | 50 | Light | 20 | 6 | 7 | 0.84 |
| | | Fan | 60 | 3 | 14 | 2.52 |
| | | TV | 110 | 1 | 8 | 0.88 |
| | | Computer | 110 | 1 | 3 | 0.33 |
| | | Iron | 750 | 1 | 1 | 0.75 |
| | | Rice cooker | 1000 | 1 | 2 | 2 |
| | | Refrigerator | 250 | 1 | 24 [64] | 6 |
| | | Water pump | 746 | 1 | 1 | 0.746 |
| | | Total kWh/day/high-class household | | | | 14.07 |
| Medium class house hold | 200 | Light | 20 | 4 | 7 | 0.56 |
| | | Fan | 60 | 2 | 10 | 1.2 |
| | | TV | 110 | 1 | 8 | 0.88 |
| | | Computer | 110 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 1 | 1 | 1 |
| | | Refrigerator | 250 | 0 | 0 | 0 |
| | | Water pump | 746 | 0 | 0 | 0 |
| | | Total kWh/day/medium class household | | | | 3.64 |
| Low class house hold | 50 | Light | 20 | 4 | 7 | 0.56 |
| | | Fan | 60 | 2 | 10 | 1.2 |
| | | TV | 110 | 1 | 8 | 0.88 |
| | | Computer | 110 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 0 |
| | | Water pump | 746 | 0 | 0 | 0 |
| | | Total kWh/day/low-class household | | | | 2.64 |

The energy access of households was categorized into three different categories based on economic condition. The first one is high-class household and the load consumption is estimated for this category is about 14.07 kWh / day. The second one is medium class household and the third one is low-class household. The load consumption of these three categories of household load and other loads are also presented in Table 3.5 and table 3.6.

**Table 3.6:** Load consumption for public (School, health center, street light), commercial load (shops) and deferrable load (Irrigation systems)

| Public and commercial load | | | | | | |
|---|---|---|---|---|---|---|
| Type | Quantity | Appliance type | Rating (W) | No of appliance | Run time h/day | kWh |
| School | 2 | Light | 20 | 15 | 3 | 0.9 |
| | | Fan | 60 | 15 | 5 | 4.5 |
| | | TV | 110 | 0 | 0 | 0 |
| | | Computer | 110 | 1 | 3 | 0.33 |
| | | Iron | 750 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 0 |
| | | Water pumps | 746 | 1 | 0.5 | 0.375 |
| | | Total kWh/day/school | | | | 6.105 |
| Health center | 1 | Light | 20 | 8 | 8 | 1.28 |
| | | Fan | 60 | 8 | 10 | 4.8 |
| | | TV | 110 | 1 | 8 | 0.88 |
| | | Computer | 110 | 0 | 3 | 0 |
| | | Lab equipment | 1000 | 1 | 12 | 12 |
| | | Others | 250 | 1 | 6 | 1.5 |
| | | Refrigerator | 250 | 1 | 8 | 2 |
| | | Water pump | 746 | 1 | 1 | 0.75 |
| | | Total kWh/day/health center | | | | 23.21 |
| Commercial load (shops) | 50 | Light | 20 | 2 | 6 | 0.24 |
| | | Fan | 60 | 1 | 10 | 0.6 |
| | | Rice cooker | 1000 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 1 | 24 | 6 |
| | | Water pump | 746 | 0 | 1 | 0 |
| | | Total kWh/day/shop | | | | 6.84 |
| Street light | | Light | 100 | 300 | 10 | 300 |
| | | Total kWh | | | | 300 |
| Irrigation pump | | Pump | 1100 | 90 | 8 | 792 |
| | | Total kWh for irrigation system | | | | 792 |
| Total kWh/day for Dinajpur | | | | | | **3032.92** |

**Table 3.7:** Hourly load consumption for Dhopa Para, Dinajpur.

| Total kWh/day for Dinajpur (summer season) | | Total kWh/day for Dinajpur (Winter season) | |
|---|---|---|---|
| Time (hour) | Consumption for March to October (Wh) | Time (hour) | Consumption for November to February (Wh) |
| 0:00 - 1:00 | 94000 | 0:00 - 1:00 | 154000 |
| 1:00 - 2:00 | 94000 | 1:00 - 2:00 | 154000 |
| 2:00 - 3:00 | 94000 | 2:00 - 3:00 | 154000 |
| 3:00 - 4:00 | 94000 | 3:00 - 4:00 | 154000 |
| 4:00 - 5:00 | 64000 | 4:00 - 5:00 | 124000 |
| 5:00 - 6:00 | 64000 | 5:00 - 6:00 | 124000 |
| 6:00 - 7:00 | 64250 | 6:00 - 7:00 | 124250 |
| 7:00 - 8:00 | 114000 | 7:00 - 8:00 | 175000 |
| 8:00 - 9:00 | 165520 | 8:00 - 9:00 | 64020 |
| 9:00 - 10:00 | 111120 | 9:00 - 10:00 | 29340 |
| 10:00 - 11:00 | 73870 | 10:00 - 11:00 | 29590 |
| 11:00 - 12:00 | 73620 | 11:00 - 12:00 | 29340 |
| 12:00 - 13:00 | 70940 | 12:00 - 13:00 | 26660 |
| 13:00 - 14:00 | 68730 | 13:00 - 14:00 | 26250 |
| 14:00 - 15:00 | 68730 | 14:00 - 15:00 | 26250 |
| 15:00 - 16:00 | 68480 | 15:00 - 16:00 | 26000 |
| 16:00 - 17:00 | 101730 | 16:00 - 17:00 | 59250 |
| 17:00 - 18:00 | 167090 | 17:00 - 18:00 | 124610 |
| 18:00 - 19:00 | 160000 | 18:00 - 19:00 | 117520 |
| 19:00 - 20:00 | 212250 | 19:00 - 20:00 | 272770 |
| 20:00 - 21:00 | 260020 | 20:00 - 21:00 | 121020 |
| 21:00 - 22:00 | 158500 | 21:00 - 22:00 | 119500 |
| 22:00 - 23:00 | 153000 | 22:00 - 23:00 | 114000 |
| 23:00 - 0:00 | 153000 | 23:00 - 0:00 | 213000 |
| Total (Wh) | 2748850 | Total (Wh) | 2562370 |
| Total (kWh/day) | 2748.85 | Total (kWh/day) | 2562.37 |

From this data, the hourly load consumption is prepared and it is presented in Table 3.7. The details daily consumption of that area is shown in Appendix A (Table A-1 and A-2). The hourly load data of two seasons are entered into Homer as input data.

### 3.5.2 Effect of Random Variability on Load:

Hour to hour and day to day random variability has been used because the daily and hourly noise inputs help to add randomness to the load data to make it more realistic. Figure 3.16 and 3.17 show how these noises will affect the average load profile. Firstly, take a look at load without any added noise. As shown on the plot in Figure 3.16 below of the first month of the year. Therefore, without any noise, the load profile repeats precisely day after day that is shown in Figure 3.16.

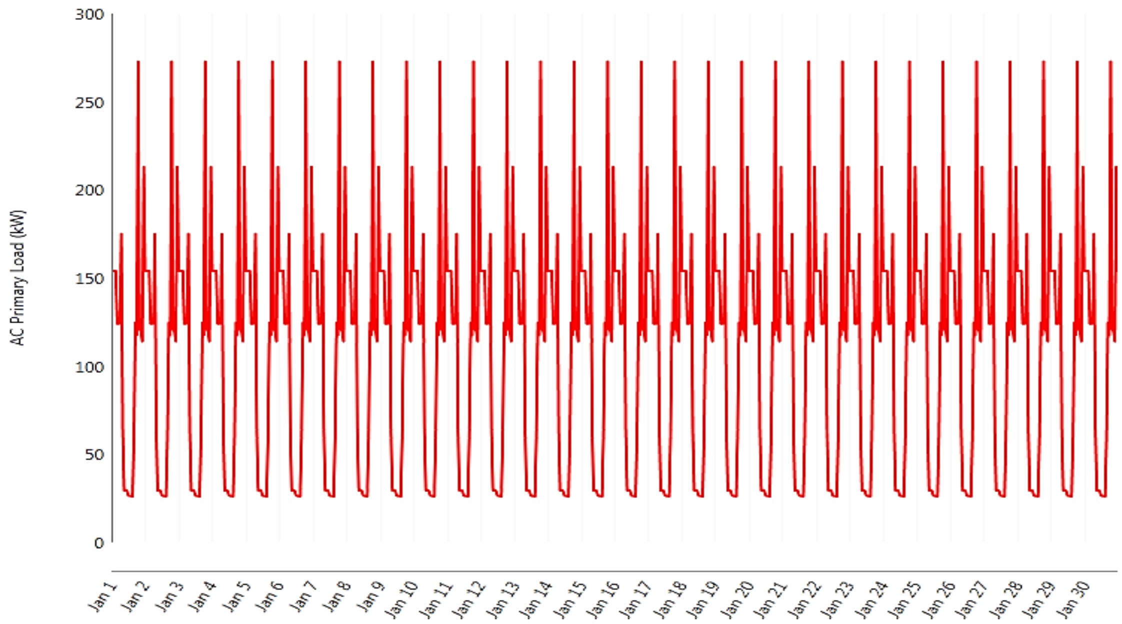



**Fig. 3.16:** Load consumption without random variability for January.

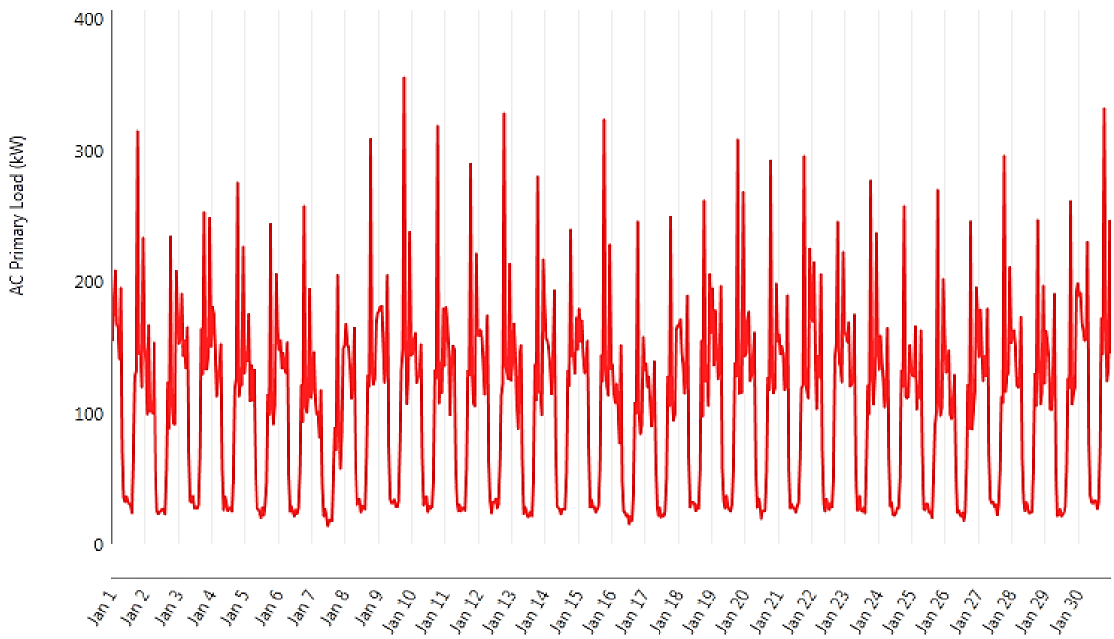



**Fig. 3.17:** Load consumption using 10% random variability for January.

In reality, the magnitude and the form of the load will change from day to day. This standard deviation comes up with more realistic load demand. With 10% daily noise and 10% hourly noise, a result of the plot is shown in the below Figure 3.17 for January. Daily noise will affect the size but the shape doesn't change where the hourly deviation affects the shape but without affecting its size. The mechanism for adding daily and hourly noise is simple. First HOMER brings together the 8760 hourly values of load data from the specified daily profiles. Then it multiplies each hourly value by a factor α [65].

$$\alpha = 1 + \delta_d + \delta_h \quad (3.1)$$

where; $\delta_d$ = daily perturbation factor and $\delta_h$ = hourly perturbation factor

Adding 10 % randomness to the load profile results increase in annual peak demand to 394.98 kW, annual average load 111.98 kWh and the load factor of 0.28. HOMER calculates the parameters, annual average of the daily demand, peak load and load factor based on the load profile and the random variability inputs given by estimation.

### 3.5.3 Electricity Demand at Chilmari

Chilmari is an Upazila of Kurigram District in the Division of Rangpur, Bangladesh having geographical location 25.5667°N 89.6917°E. About 20129 households are living there that is situated in the northern part of Bangladesh [66]. Statically shows that most of the people in Chilmari are living below the poverty level and most of the area does not have an access to electricity. Although some NGOs including BRAC, Grameen Shakti, RDRS, Pratyasha, and many others have installed about 6,500 solar power units in the char villages of greater Rangpur at a cost ranging from Tk 12,000 to Tk 45,000 for each unit depending on power generation capacities on down payment basis, but the per unit cost is high [67]. Only 400 households of Chilmari char area has been considered for load estimation. People of that area are divided into two sections; one is solvent and another is poor as a hypothetical basis. The daily consumption is found 5.38 kWh for every solvent family, 2.38 kWh is found for a poor family that is shown in Table 3.8.

**Table 3.8:** Load consumption for a household of Chilmari, Rangpur.

| Residential Load | | | | | | |
|---|---|---|---|---|---|---|
| **type** | no of household | appliance type | Rating (W) | No of appliance | Run time h/day | kWh |
| **Solvent family** | 200 (50 family use refrigerator) | Light | 20 | 4 | 7 | 0.56 |
| | | Fan | 60 | 2 | 12 | 1.44 |
| | | TV | 110 | 1 | 8 | 0.88 |
| | | Computer | 110 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 1 | 1 | 1 |
| | | Refrigerator | 250 | 1 | 6 | 1.5 |
| | | Water pumps | 746 | 1 | 0 | 0 |

Table 3.8: Load consumption for a household of Chilmari, Rangpur. (Continued...)

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Total kWh/day/medium class household | | | | 5.38 |
| **Poor family** | 200 | Light | 20 | 2 | 7 | 0.28 |
| | | Fan | 60 | 2 | 12 | 1.44 |
| | | TV | 110 | 1 | 6 | 0.66 |
| | | Computer | 110 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 0 |
| | | Water pumps | 746 | 0 | 0 | 0 |
| | | total kWh/day/low-class household | | | | 2.38 |

Table 3.9: Load consumption for school, health center, and shops

| **Public and commercial load** | | | | | | |
|---|---|---|---|---|---|---|
| **type** | No of school/others | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| **School** | 1 | Light | 20 | 15 | 3 | 0.9 |
| | | Fan | 60 | 15 | 4 | 3.6 |
| | | TV | 110 | 0 | 0 | 0 |
| | | Computer | 110 | 1 | 3 | 0.33 |
| | | Iron | 750 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 0 |
| | | Water pumps | 746 | 1 | 0.5 | 0.375 |
| | | Total kWh/day/high-class household | | | | 5.205 |
| **Health center** | 1 | Light | 20 | 8 | 8 | 1.28 |
| | | Fan | 60 | 8 | 10 | 4.8 |
| | | TV | 110 | 1 | 8 | 0.88 |
| | | Computer | 110 | 0 | 3 | 0 |
| | | lab equipment | 1000 | 1 | 5 | 5 |
| | | others | 250 | 1 | 6 | 1.5 |
| | | Refrigerator | 250 | 1 | 24 | 6 |
| | | Water pumps | 746 | 1 | 1 | 0.75 |
| | | Total kWh/day/high-class household | | | | 20.21 |
| **Commercial load (shops)** | 20 | Light | 20 | 2 | 6 | 0.24 |
| | | Fan | 60 | 1 | 10 | 0.6 |
| | | TV | 110 | 0 | 0 | 0 |
| | | Computer | 110 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 1 | 24 | 6 |
| | | Water pumps | 746 | 0 | 1 | 0 |
| | | Total kWh/day/shop | | | | 6.84 |

Table 3.10: Load consumption for street light and irrigation system

| Deferrable load | | | | | | |
|---|---|---|---|---|---|---|
| **Type** | | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| **Street light** | | Light | 100 | 50 | 10 | 50 |
| | | total kWh for street light | | | | 50 |
| **Irrigation pump for winter season** | | pump | 1100 | 40 | 10 | 440 |
| | | Total kWh for irrigation system | | | | 440 |

The three different loads are analytically presented in Tables 3.8, 3.9 and 3.10. Their selection were made based on the energy consumed on an hourly basis during a typical year. Figure 3.18 shows the hourly variation of load consumption in a year for Chilmari, Rangpur. After adding the random variability of 10% that is described in Sub-Section 3.5.2, it is observed that the annual peak load is 357.64 kW, the total annual scaled average primary load 2137 kWh/day and a load factor 0.25 is calculated. Hourly load consumption summary of the summer season (March to October) and winter season (November to February) in a year are depicted in Appendix A (Table A-3, A-4 and A-5).

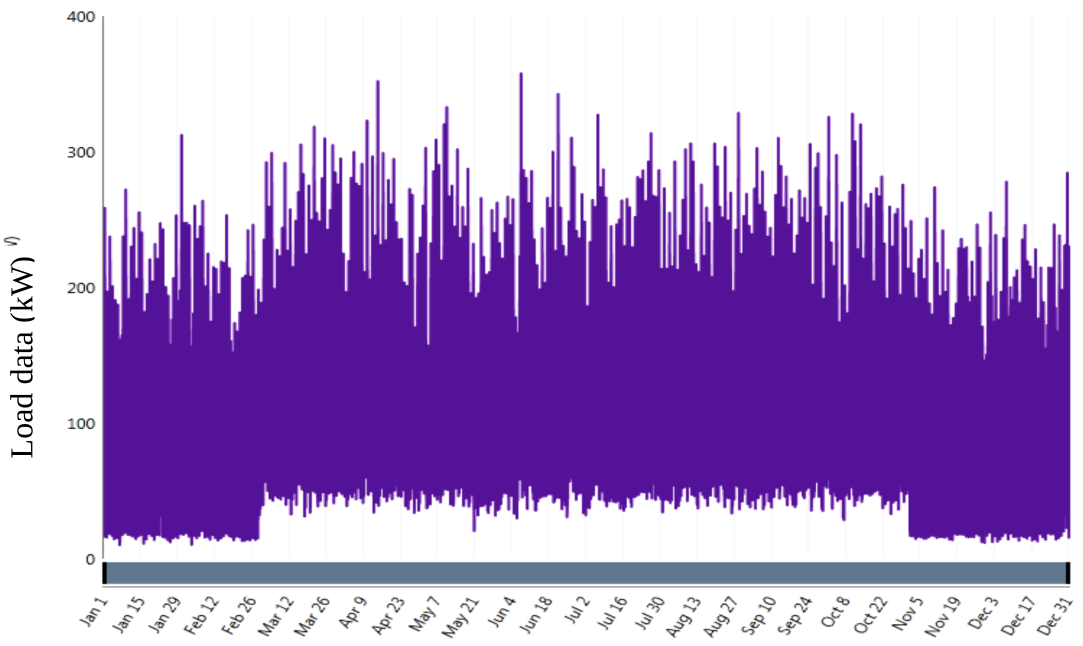



**Fig 3.18:** Hourly variation of load consumption in a year for Chilmari, Rangpur.

### 3.5.4 Electricity Demand at Kuakata

Kuakata (geographical coordinates: 21.82°N, 90.12°E) is around the center of the southwest coastline of Bangladesh in Patuakhali district. It is situated 320 km from Dhaka and 70 km from Patuakhali. It is one of the most extraordinary tourist places in the world from where both sunrise and sunset can be observed. In this section, the load consumption scenario of Kuakata region has been described. After collecting some data for load estimation, 200 families (medium class household), 50 shops, 15 tourist hotels, 200 battery run auto rickshaw and 100 street light with (100 W/light) has been considered. The load is grouped into two parts, one is load 1 which consists of houses, shops, and hotels loads, and another is load 2 which consists of battery run auto rickshaws.

#### 3.5.4.1 Residential Load Calculation for Kuakata

In this thesis, 50 solvent families and 150 poor families have been considered. The load consumption of a typical household with the average family size of 5 members is shown in Table 3.11 and Table 3.12 for a solvent and poor family, respectively.

Table 3.11: Load consumption for a solvent family in Kuakata

| A solvent family with average 5 family members | | | | | |
|---|---|---|---|---|---|
| **Type** | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| **Solvent** | Light (CFL) | 20 | 6 | 7 | 0.84 |
| | Fan | 60 | 3 | 12 | 2.16 |
| | TV | 110 | 1 | 8 | 0.88 |
| | Computer | 110 | 1 | 3 | 0.33 |
| | Iron | 750 | 1 | 0.5 | 0.375 |
| | Rice cooker | 1000 | 1 | 2 | 2 |
| | Refrigerator | 250 | 1 | 12 | 3 |
| | Water pumps | 746 | 1 | 0.5 | 0.373 |
| | Total kWh/day/Solvent family | | | | 9.96 |

Table 3.12: Load consumption for a poor family in Kuakata

| A poor family with average 5 members | | | | | |
|---|---|---|---|---|---|
| **Type** | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| **Poor** | Light | 20 | 2 | 7 | 0.28 |
| | Fan | 60 | 2 | 12 | 1.44 |
| | TV | 110 | 1 | 6 | 0.66 |
| | Total kWh/day/poor household | | | | 2.38 |

### 3.5.4.2 Commercial Load Estimation for Kuakata:

Kuakata is one of the most extraordinary tourist places in the world from where both sunrise and sunset can be observed. A large number of a tourist hotel, motel shops are available in that area. 15 tourist hotel (3 storied building with 8 rooms/floor) and 50 shops have been considered for load estimation purposes. The hourly electricity consumption of every hotel and shops are shown in Table 3.13 and Table 3.14. It is observed that every hotel consumed 29.77 kWh/day and every shop consumed 6.84 kWh/day.

Table 3.13: Load for tourist hotel in a day

| Hotel (3 storied building with 8 rooms/floor) | | | | | |
|---|---|---|---|---|---|
| **Type no of household** | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| **Hotel** | Light | 20 | 25 | 8 | 4 |
| | Fan | 60 | 25 | 12 | 18 |
| | TV | 110 | 5 | 8 | 4.4 |
| | Refrigerator | 250 | 1 | 12 | 3 |
| | Water pumps | 746 | 1 | 1 | 0.373 |
| **Total kWh/day/hotel** | | | | | 29.773 |

Table 3.14: Load for Shops and restaurants

| Shops and restaurants | | | | | |
|---|---|---|---|---|---|
| **Type** | Appliance type | Rating (W) | No of appliance | Runtime (h/day) | kWh |
| **Shops and restaurants** | Light | 20 | 2 | 6 | 0.24 |
| | Fan | 60 | 1 | 10 | 0.6 |
| | Refrigerator | 250 | 1 | 24 | 6 |
| **Total kWh/day/shop** | | | | | 6.84 |

### 3.5.4.3 Load Estimation for Charging the Battery Run Auto Rickshaw:

A battery operated auto-rickshaw popularly known as 'Easy-bike' is newly added to the transportation sector of Bangladesh. Easy-bikes are operated by rechargeable lead-acid batteries as their sources of power. These batteries are charged with electricity taken from the domestic or commercial lines which indirectly burdens the national grid. Therefore, there is a very urgent need to find a new way for charging the auto-rickshaw. That's why in this research 250 battery run auto rickshaw is added as DC load equipment. Every battery operated auto-rickshaw consumed on an average 8 - 11 kWh of electricity per day during charging their batteries and charging time approximately 8 hours per day. In this thesis, an average value 9.62 kWh is estimated for auto rickshaw load [68]. Figures 3.19 and 3.20 indicate the yearly load profile for two different loads respectively. The daily average load profile for two types of the load is shown in Figures 3.21 and 3.22, respectively in which 17:00 to 23:00 h time period has been observed as peak demand for domestic load and 23.00 to 06.00 h for charging of the battery of auto rickshaw. The peak value of demand requirement determines the size of the system. From these two figures, the combined load demand for Kuakata region can be calculated and it is given below. Average units consumed per day (kWh/d) 3512.7, average load demand (kW) 146.36, peak load (kW) 387.27 and load factor 0.38. Hourly load consumption summary of the summer season (March to October) and winter season (November to February) in a year are depicted in Appendix A (Table A-6 and A-7).

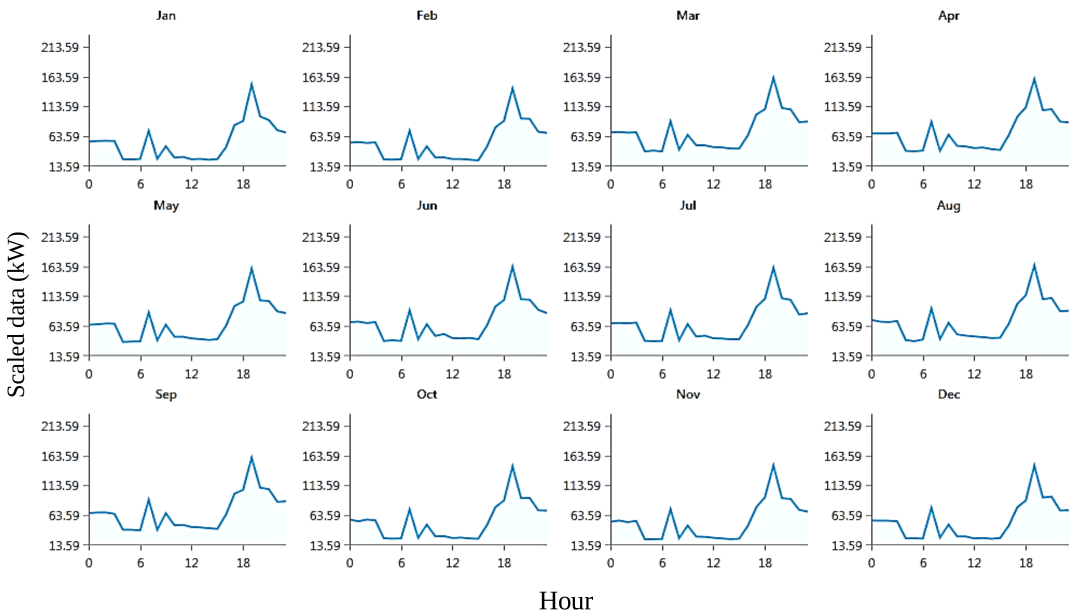



**Fig 3.19:** Hourly load profile for household load at Kuakata (load 1)

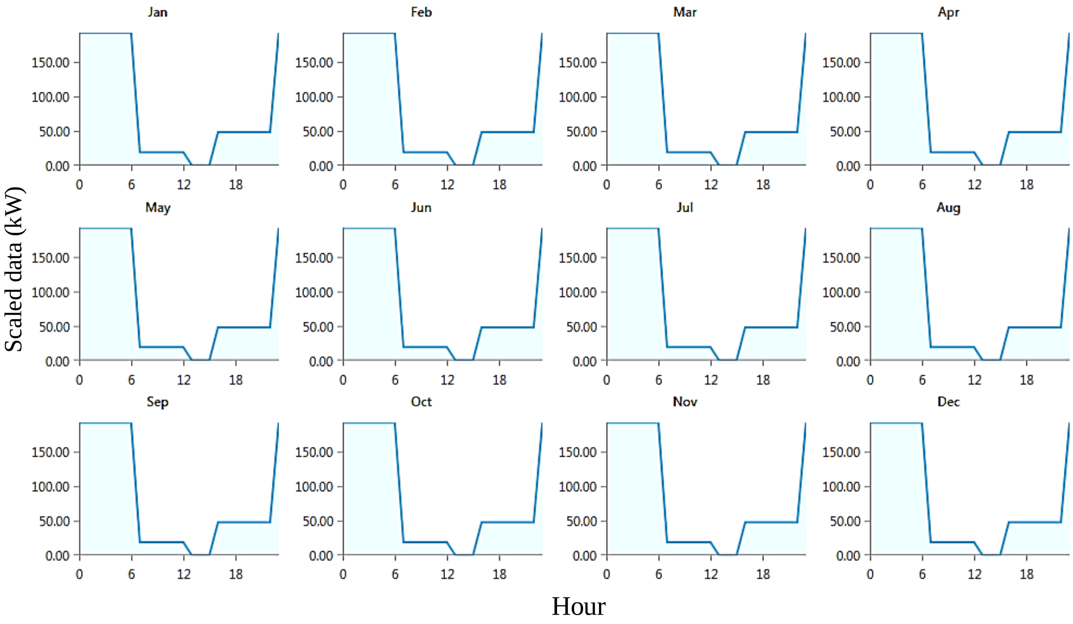



**Fig 3.20:** Hourly load profile for battery run auto rickshaw at Kuakata (load 2)

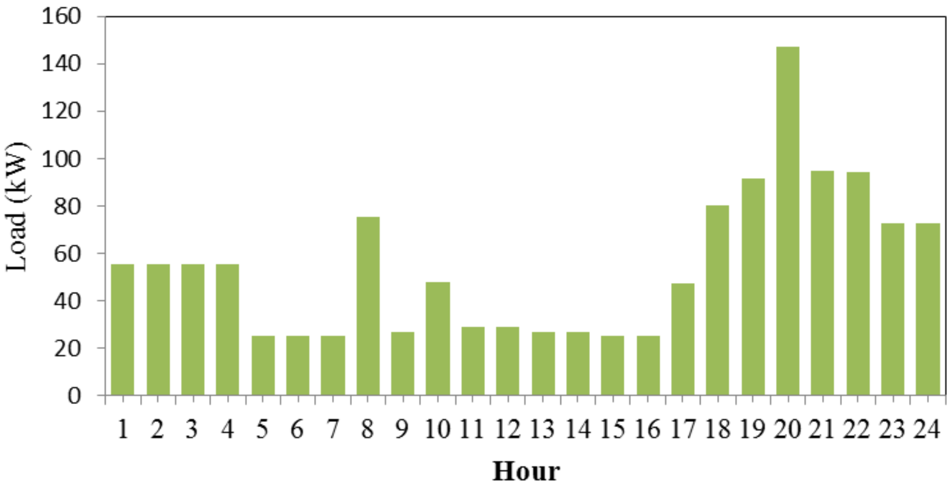



**Fig. 3.21:** Daily load profile for household (load 1)

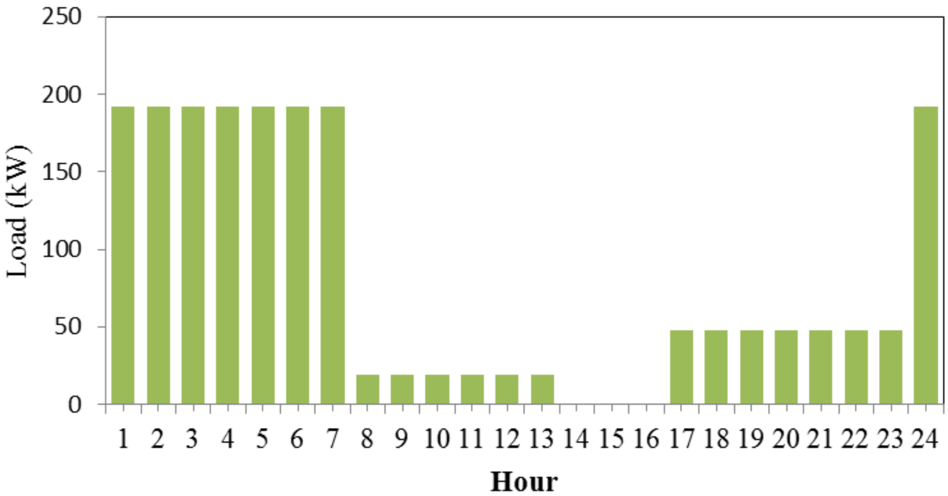



**Fig. 3.22:** Daily load profile for charging the auto-rickshaw (load 2)

### 3.5.5 Electricity Demand at Magnama, Pekua in Cox's Bazar.

The rural economic situation of the country is below the poverty line and thus in this energy system design, the selection of appliances was reflected for the low wattage for the affordability of the provided electric energy. Magnama (coordinates: 21.87°N, 91.87°E) is around the center of the southeast coastline in Cox's Bazar district. The main activities are related to agriculture 55% fishing 5% and industries 2%. More than 1200 families are living in Magnama but only a very few of them are getting electricity [69]. Detail map of Pekua Upazila is shown in Figure 3.23.

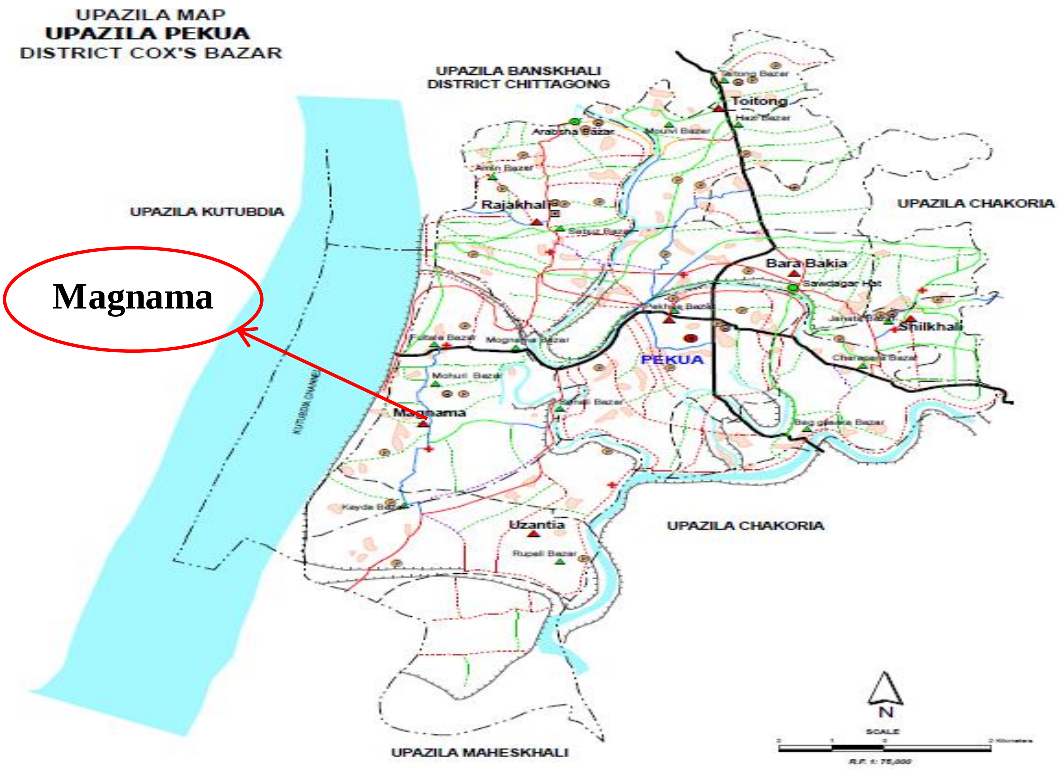



Fig 3.23: Magnama, Pekua at Cox's Bazar [69].

Based on economic aspects three types of family that are rich, solvent and poor family lives in Magnama [61]. In this research, 100 families have been considered as a rich family having four light bulbs, three ceiling fans, one small TV, one refrigerator and one water pump for each family. 700 families have been estimated as a solvent family having four lights, two fans and one TV set for each family. In the poor category, 400 families have been considered having two lights and one fan of each family [65, 70]. According to the load estimation, 50 shops, one community health center, one school and 100 street lights are also considered for that region [71]. For generating more accurate hourly load profile 10% hour to hour noise and 10% day to day noise has been considered [65]. Tables 3.15 and 3.16 show the load consumption scenario of for Magnama, Pekua.

Table 3.15: Load consumption for household of Magnama, Pekua

| **Residential Load at Magnama, Pekua** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | No of household | Appliance type | Rating (W) | No of appliance | total power (W) | Runtime (h/day) | kWh |
| **Rich** | 100 | Light | 20 | 4 | 8000 | 7 | 56 |
| | | Fan | 60 | 3 | 18000 | 12 | 216 |
| | | TV | 110 | 1 | 11000 | 8 | 88 |
| | | Rice cooker | 1000 | 1 | 100000 | 2 | 200 |
| | | Refrigerator | 250 | 1 | 25000 | 12 | 300 |
| | | Water pumps | 746 | 1 | 74600 | 0.5 | 37.3 |
| | | Total kWh consumed by very solvent family | | | | | 897.3 |
| **Solvent** | 700 | Light | 20 | 4 | 56000 | 7 | 392 |
| | | Fan | 60 | 2 | 84000 | 12 | 1008 |
| | | TV | 110 | 1 | 77000 | 8 | 616 |
| | | Total kWh consumed by solvent family | | | | | 2016 |
| **Poor** | 400 | Light | 20 | 2 | 16000 | 7 | 112 |
| | | Fan | 60 | 1 | 24000 | 12 | 288 |
| **Total** | 1200 | Total kWh consumed by poor family | | | | | 400 |

Table 3.16: Load consumption for Public and commercial load at Magnama, Pekua

| **Public and commercial load at Magnama, Pekua** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | No of center | Appliance type | Rating (W) | No of appliance | total power (W) | Runtime (h/day) | kWh |
| **School** | 1 | Light | 20 | 15 | 300 | 3 | 0.9 |
| | | Fan | 60 | 15 | 900 | 4 | 3.6 |
| | | Computer | 110 | 1 | 110 | 3 | 0.33 |
| | | Total kWh/day for school | | | | | 4.83 |
| **Health center** | 1 | Light | 20 | 8 | 160 | 8 | 1.28 |
| | | Fan | 60 | 4 | 240 | 10 | 2.4 |
| | | TV | 110 | 1 | 110 | 8 | 0.88 |
| | | Refrigerator | 250 | 1 | 250 | 24 | 6 |
| | | Water pump | 746 | 1 | 746 | 1 | 0.746 |
| | | Total kWh/day for health center | | | | | 11.30 |
| **Commercial load (shops)** | 50 (50% of the total shops have Refrigerator) | Light | 20 | 2 | 2000 | 6 | 12 |
| | | Fan | 60 | 1 | 3000 | 10 | 30 |
| | | Refrigerator | 250 | 1 | 12500 | 24 | 300 |
| | | Total kWh/day | | | | | 342 |
| **deferrable load** | | | | | | | |
| **Street light** | 1 | Light | 100 | 300 | 30000 | 10 | 300 |
| | | Total kWh | | | | | 4182.6 |

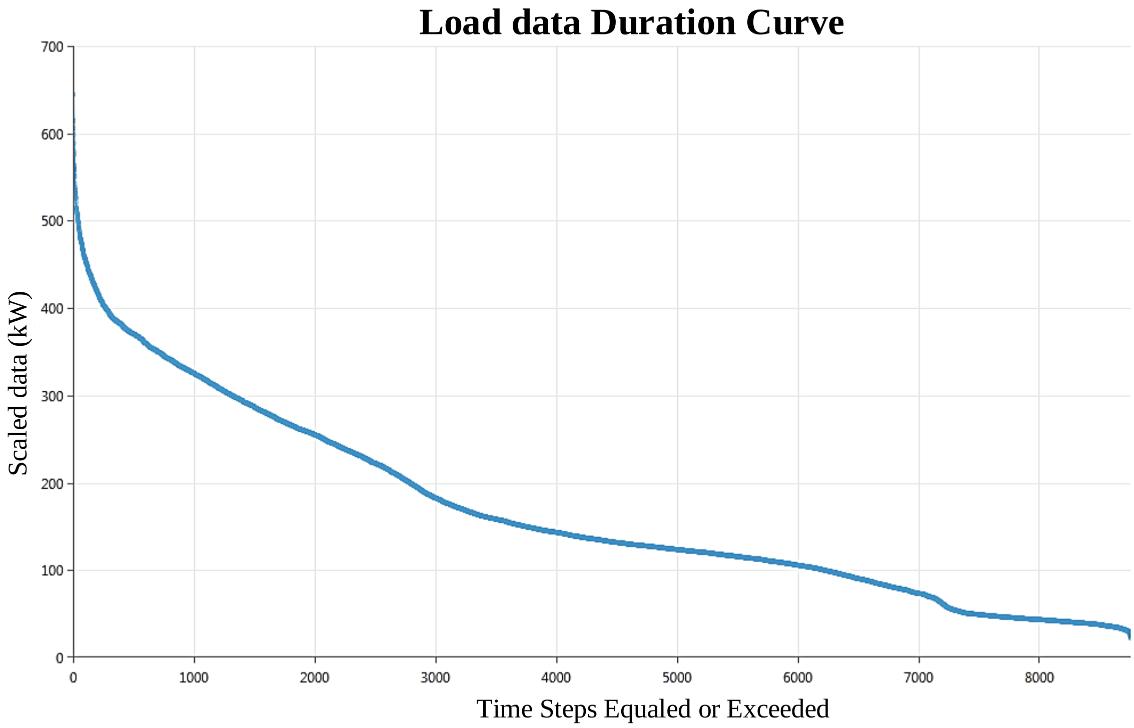



Fig 3.24: AC primary load duration curve for Magnama, Cox's Bazar (kW)

Figure 3.24 shows the load duration curve in a year for Magnama.This curve indicates that how much load are lies in a specific time interval during a year. With adding the 10% random variability the peak load is observed 644.48 kW, average load 167.88 kW, and average load 4029 kWh/day. The hourly load consumption and seasonal load consumption table are shown in Appendix A (Table A-8 and A-9), respectively.

### 3.5.6 Electricity Demand at Sitakunda

For the size optimization to be done, the load curve during the day and the year should be determined. Sitakunda having coordinates: 122.65°N, 91.66° E is situated at the intersection of two coastlines making an obtuse angle with Chittagong district. It is 212 km southeast from Dhaka and 44 km from Chittagong. The main activities are related to agriculture 24%, fishing 4%, industrial labor 5% and services 33% [72]. Like other places of Bangladesh Sitakunda, widely known to be a gateway of country's largest commercial hub Chittagong, has a strong historical background which highlights the blessings of nature with scenic beauty, favoring huge potentialities of this region for trade and commerce. In fact, Sitakunda is one of the oldest sites of human habitation in Bangladesh.

It is also the home of the country's first eco-park, as well as alternative energy projects, especially wind energy and geothermal power [73]. The energy sources of Sitakunda have been described in the previous section. For load estimation of Sitakunda, 400 families with various categories, one hospital, two tourist hotels, one school, and during winter season 60 irrigation pumps have been considered. The load consumption scenario of Sitakunda has been shown in Table 3.17 and Table 3.18.

Table 3.17: Estimation of load consumption for household at Sitakunda

| **Residential Load** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | No of household | Appliance type | Rating (W) | No of appliance | total power (W) | Runtime (h/day) | kWh |
| **High class house hold** | 50 | Light | 20 | 5 | 5000 | 7 | 35 |
| | | Fan | 60 | 3 | 9000 | 12 | 108 |
| | | TV | 110 | 1 | 5500 | 8 | 44 |
| | | Computer | 110 | 0 | 0 | 3 | 0 |
| | | Iron | 750 | 0 | 0 | 0.5 | 0 |
| | | Rice cooker | 1000 | 1 | 50000 | 2 | 100 |
| | | Refrigerator | 250 | 1 | 12500 | 12 | 150 |
| | | Water pumps | 746 | 1 | 37300 | 0.5 | 18.65 |
| | | Total kWh/day | | | | | 455.65 |
| **Medium class house hold** | 200 | Light | 20 | 4 | 16000 | 7 | 112 |
| | | Fan | 60 | 2 | 24000 | 12 | 288 |
| | | TV | 110 | 1 | 22000 | 8 | 176 |
| | | Computer | 110 | 0 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 1 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 24 | 0 |
| | | Water pumps | 746 | 0 | 0 | 0 | 0 |
| | | Total kWh/day | | | | | 576 |
| **Low class house hold** | 100 | Light | 20 | 2 | 4000 | 7 | 28 |
| | | Fan | 60 | 1 | 6000 | 12 | 72 |
| | | TV | 110 | 0 | 0 | 6 | 0 |
| | | Computer | 110 | 0 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 |
| | | Water pumps | 746 | 0 | 0 | 0 | 0 |
| | | **Total kWh/day** | | | | | **100** |

Table 3.18: Public and commercial load estimation at Sitakunda

| Public and commercial load | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Type** | No of center | Appliance type | Rating (W) | No of appliance | Total power (W) | Runtime (h/day) | kWh |
| **School** | 1 | Light | 20 | 15 | 300 | 3 | 0.9 |
| | | Fan | 60 | 15 | 900 | 4 | 3.6 |
| | | TV | 110 | 0 | 0 | 0 | 0 |
| | | Computer | 110 | 1 | 110 | 3 | 0.33 |
| | | Iron | 750 | 0 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 |
| | | Water pumps | 746 | 0 | 0 | 0.5 | 0 |
| | | Total kWh/day for school | | | | | 4.83 |
| **Tourist hotel** | 2 | Light | 20 | 25 | 1000 | 8 | 8 |
| | | Fan | 60 | 25 | 3000 | 12 | 36 |
| | | TV | 110 | 5 | 1100 | 6 | 6.6 |
| | | Computer | 110 | 0 | 0 | 3 | 0 |
| | | lab equipment | 1000 | 0 | 0 | 5 | 0 |
| | | others | 250 | 0 | 0 | 6 | 0 |
| | | Refrigerator | 250 | 1 | 500 | 24 | 12 |
| | | Water pumps | 746 | 1 | 1492 | 1 | 1.492 |
| | | Total kWh/day for health center | | | | | 64.092 |
| **Commercial load (shops)** | 50 | Light | 20 | 2 | 2000 | 6 | 12 |
| | | Fan | 60 | 1 | 3000 | 10 | 30 |
| | | TV | 110 | 0 | 0 | 0 | 0 |
| | | Computer | 110 | 0 | 0 | 0 | 0 |
| | | Iron | 750 | 0 | 0 | 0 | 0 |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 |
| | | Refrigerator | 250 | 1 | 12500 | 24 | 300 |
| | | Water pumps | 746 | 0 | 0 | 1 | 0 |
| | | Total kWh/day for shops | | | | | 342 |
| Deferrable load | | | | | | | |
| **Street light** | 1 | Light | 100 | 300 | 30000 | 10 | 300 |

Figure 3.25 shows the hourly load profile for Sitakunda in a year, there is a peak load is 216.76 kW and from the load estimation, the average daily load is found 1778.8 kWh. The detail estimated hourly load consumption is shown in Appendix A (Table A-9).

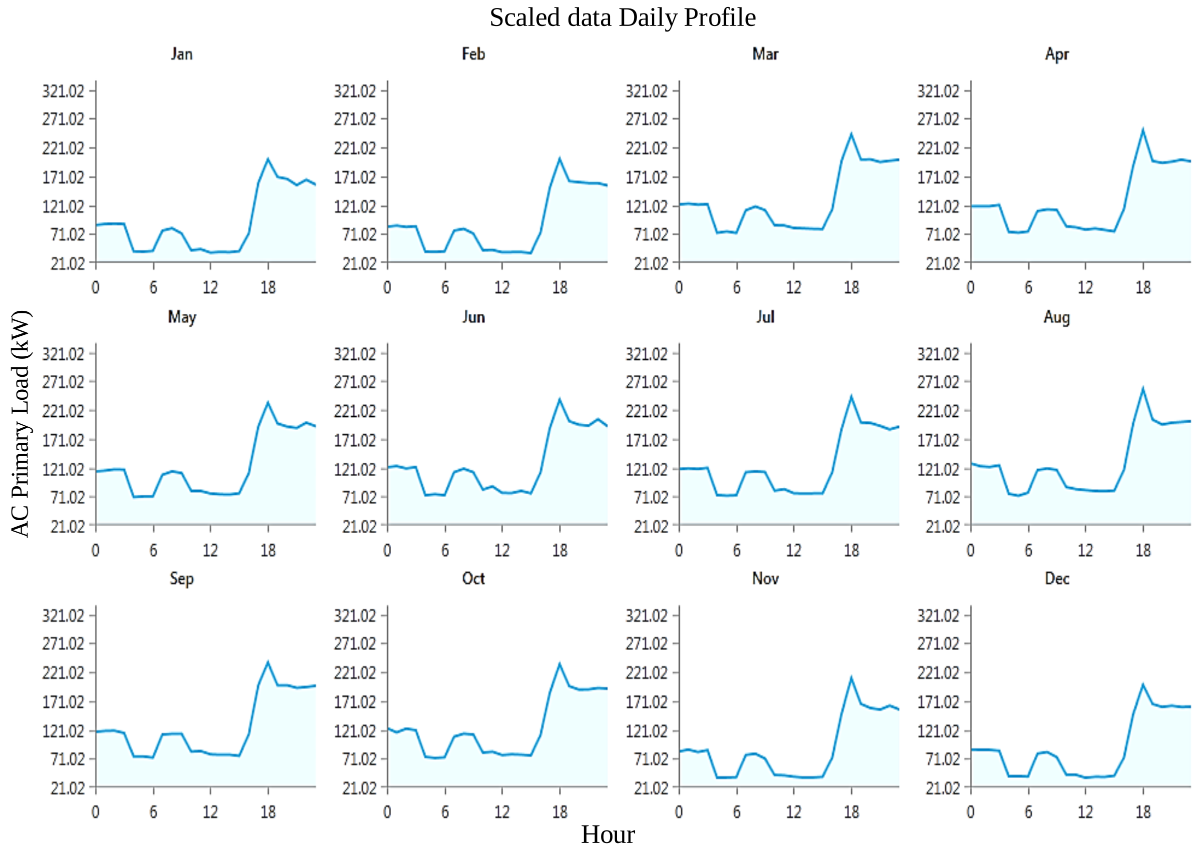


Fig 3.25: Hourly Load profile for a year

## 3.6 Economic Factors and Other Costs

The key parameters for economic modeling in HOMER are the discount rate or interest on capital, fixed capital costs, fixed operation and maintenance costs, and project lifecycle in years.

### 3.6.1 Discount Rate and Inflation Rate:

The interest rate is also known as the discount rate. Now discount rate is used to find out the present value of an expected cash flow which is going to happen in the future [74]. The average value of last few years of interest rate in Bangladesh is considred in this thesis [75]. For sensitivity analysis, the interest rate is taken as 11.78, 10 and 5 [61,65]. Inflation rate and real interest have been taken as 5.71 and 5.74 for economic analysis [75].

### 3.6.2 System Fixed Capital Cost

The fixed capital cost of the system is normally allocated for building a house for keeping the battery bank, charge controllers, generator, inverter and other relevant electrical instruments and constructing the distribution lines throughout the village. It also includes the site preparation cost, labor cost, engineering design cost and other various costs. An estimate of the fixed capital cost including 3 km long three-phase distribution lines has been estimated as $ 19320 [60, 65, and 76].

### 3.6.3 System Fixed Operation and Maintenance Cost

System fixed O & M cost firstly includes labor cost and insurance costs. If a full-time engineer or a technician is working in the hybrid system place, then he has to be paid a monthly salary. Assuming a technician is a full time employing in the powerhouse annual fixed O & M cost has been taken as $ 3220/yr [76].

### 3.6.4 The Project Lifetime

It is the number of years the project is operated. HOMER uses this number to compute the annualized replacement cost and annualized capital cost of each component, as well as the total NPC of the system. In this project, the project lifetime has been taken as 25 years [65].

## 3.7 Selection of Component

The components are chosen from HOMER to perform the simulation. Figure 3.44 shows the grid connected hybrid power system design using HOMER which consists of PV array, wind generator, converter, load, and grid connection. In order to estimate the system performance under different situations, HOMER simulates the result of the grid connected and off grid arrangements at the same area and same load based on different criteria such as the estimated installation cost, replacement cost, operation and maintenance cost, interest, and cost of energy. The major components of the different models designed here are a wind turbine, PV, battery bank, and a power converter. For economic analysis, the following values are used. For component selection processes, the various component parameters have been analyzed and a brief comparison has been performed. Finally, the components are selected as they have robust characteristics that are described in next section.

### 3.7.1 Selection of Solar PV

Representative solar panel costs were difficult to determine, because they change rapidly with time, country and area. In order, though, to use reliable economic inputs, after contacting several company [76], [77], [78], [79], [80] with analyzing their quotation and specification , FIMEXT Corporation offers a suitable quotation and specification and then the final cost values were decided $1554/kWp [77] . Tables 3.19 and 3.20 show the cost quotation and technical specification, respectively for 100 kWp on-grid solar system that is collected from FIMEXT Corporation. This cost also includes various equipment cost, installation cost, shifting cost, maintenance cost, grid tied converter cost. The replacement cost of solar panel is estimated 67% of the total capital cost [59] and replacement cost is estimated $26/100 kWp solar panel [76].

Table 3.19: Technical specification for 100 kWp on-grid solar system [79]

| Name of the equipment | Specifications | Capacity | Warranty |
|---|---|---|---|
| Solar panel | • Made by solar land<br>• Technology multi crystalline<br>• Cell efficiency 16-16.5%, lower nominal operating cell temperature (NOCT)<br>• High-quality EVA, TPT and other raw material<br>• Toughened glass with the thickness of 3.2mm<br>• Stable output power<br>• Positive power tolerance<br>• Waterproof, compressive resistance and long life. | 100 kWp on-grid panel | 20 years |
| protecting device | • Fuse<br>• Circuit breaker<br>• Lightning protection | | 2 years |
| Inverter | • On-grid pure sine wave<br>• Efficiency more than 98%<br>• Topology; Transformerless | 25/20 kW on-grid inverter 4/5 pcs<br>Brand: HUAWEI | 5 years |
| Cables and Structure | • Highly protected cable<br>• Standard structure | SS screw<br>(BRB cable) | 2 years for cable and structure |

Table 3.20: Cost quotation for 100 kWp on-grid solar system [79]

| 100 kWp on-grid solar system [ 1 dollar = 78 BDT ] | | | |
|---|---|---|---|
| System | size (kWp) | Total payable | System price |
| With Sun tracker | 100 | BDT 3, 45, 00, 000.00 | 345 BDT/watt or 4.42 $/watt |
| Without Sun tracker | 100 | BDT 1,38,00,000.00 | 138 BDT/watt or 1.77 $/watt |

### 3.7.2 Selection of Wind Turbine

In this section, firstly characteristics of wind turbines have been analyzed. After analyzing various data, a H21.0-100kW has been selected for their robust characteristics. What is more, regarding the wind turbine, a locally manufactured one following the AR22.0-100 kW model was initially selected [78], but then considered as a not so good choice, because of the relatively weak wind potential of the site, where this low cost but also low efficiency could not offer much to the micro-grid. Figure 3.26 shows the H21.0-100kW wind turbine manufactured by HUMMER at 30 m height. Also, Tables 3.21 and 3.22 indicate the technical and economical specification for an H21.0-100kW wind turbine.

Fig 3.26: H21.0-100kW wind turbine (30 m) [81].

Table 3.21: H21.0-100kW technical specifications [81]

| | |
|---|---|
| Configuration | 3 Blades, Horizontal axis, Upwind |
| Rotor Diameter | Φ21.0 m |
| Blade Length | 10.0 m |
| Swept Area | 346.36 $m^2$ |
| Direction of Rotation | Clockwise (facing blades) |
| Blade Material | Fiberglass reinforced composite, Resin Transfer Molding (RTM) |
| Rated Power | 100 KW, 10.5 m/s |
| Direct Voltage | 660V, DC |
| Direct Current | 151.52 A, DC |
| Start-up Wind Speed | 2.5 m/s |
| Rated rotating rate | 60 r/min |
| Working Wind Speed | 1.5-20 m/s |
| Survival Wind Speed | 50 m/s |
| Alternator | Permanent magnet alternator, SCF technology |
| Alternator Weight | 2236 kgs |
| Generator Efficiency | >0.93 |
| Wind Energy Utilizing Ratio | 0.45 Cp |
| Energy monitoring & User control<br><br>Gearbox | Siemens touch screen, Siemens PLC controller, internet telecom & remote monitoring<br>None, Direct drive generator design |
| Pitch Control System | Siemens servo motor drive 3pcs blades |
| Yawing System | Siemens servo motor drive to yaw |
| Hydraulic Braking System | Siemens servo motor drive braking cylinder, rotor blade brake & yaw brake |
| Dogvane/Anemometer | Ultrasonic, have electrical heating function |
| Over Speed Protection | Pitch control |
| Shutting Down Method | Blades feathering 90o degree, Hydraulic braking rotor blade |

The installed cost of a wind power project is dominated by the capital cost for the wind turbines (including towers and installation) and this can be as much as 84% of the total installed cost. Figure 3.27 shows the capital cost for a typical onshore wind power system and turbine. Wind turbine costs include the turbine production, transportation, and installation of the turbine. The grid connection costs include cabling, substations, and buildings and the construction costs include transportation and installation of wind turbine and tower, construction wind turbine foundation (tower), and building roads and other related infrastructure required for installation of wind turbines. Other capital costs here include development and engineering costs, licensing procedures, consultancy and permits and monitoring systems [82]. In this thesis, the capital cost of a wind turbine is estimated $251758.93/ 100kW wind power system replacement cost is 75% of the total capital cost [59]. Operation and maintenance cost are 2 % of the total capital cost [34].

Table 3.22: Cost quotation sheet for 100 KW on-grid wind turbine systems [81]

| 100 KW on-grid wind turbine system, rotor diameter 21.0m | | | |
|---|---|---|---|
| Spec. | Parts | Comments | Unit Price<br>USD/set, FOB Shanghai |
| 100KW wind turbine, 3-phase on-grid inverter, including tower | Generator system (1 set) including: | | US$96,308.00 |
| | 1. Generator body | | |
| | 2. Nacelle | | |
| | 3. Ultrasonic dogvane/anemometer (1 pc) | Electric heating function | |
| | 4. Hydraulic brake | Standard configuration | |
| | 5. Blades (3 pcs) , rotor Dia: Φ21.0m, L: 10.0m | GRP, Resin Transfer Moulding | |
| | 6. Electric pitch control, including | Siemens servo motor | |
| | Control system (1set ) including: | | |
| | 1. PLC controller (1 pc), including, (Siemens remote controlling & network Communication system, Siemens remote touch-screen display) | | US$12,000.00 |
| | 2. Rectifier & dumping controller (1 pc) | | |
| | 3. Unloading resistor (1 pc) | | |
| | 4. VPN Router (1 pc) | | |
| | 5. Emergency power supply (1 pc) | | |
| | Inverter | Grid-tied | US$21,429.00 |
| | Freestanding Tower | Q345, Height 30.0m | US$29,692.00 |
| | Anchor cage | | US$1,714.00 |
| | **Total Amount** | | US$161,143.00 |

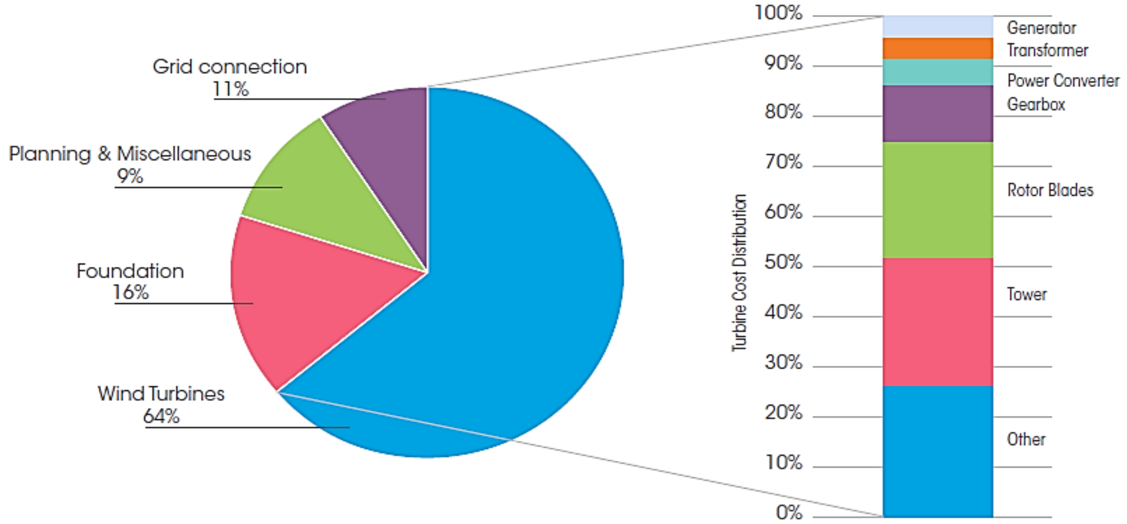



Fig. 3.27: Capital cost for a typical onshore wind power system and turbine [82].

### 3.7.3 Selection of Converter

An inverter is a vital element in any solar system where the AC is required. It converts the DC form of a solar system or wind system into AC form for AC appliances. A hybrid system needs an inverter to convert DC voltage from the batteries to AC voltage required by the load. Some aspect is needed to be taken into consideration when selecting an inverter for a certain application. Usually, the inverters used in renewable applications can be divided into two; an inverter for solar and another is for wind electric system [65]. In this thesis, the capital cost of the converter is taken $214/100 kW [81]. The replacement cost are 93 % of total capital have been used and operation and maintenance cost is estimated 1.2% of the capital cost [34]. Figures 3.28 and 3.29 show the SUN2000 Series solar inverter and their efficiency curve that is manufactured by HUAWEI [80]. Table 3.23 shows the technical specification for SUN2000 series solar inverter.


Fig: 3.28: Solar inverter for grid connection [80]

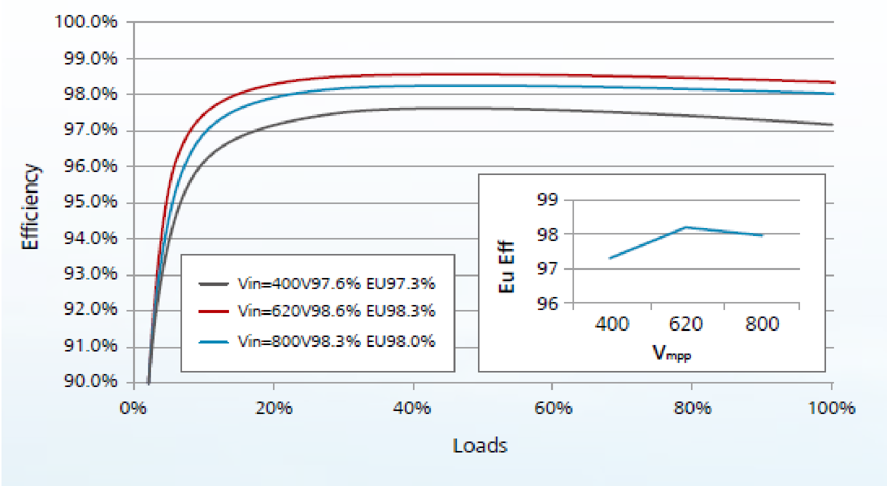



Fig: 3.29: Efficiency curve for converter [80]

Table 3.23: Technical specification of solar inverter

| Model name | Technical specification | Value |
|---|---|---|
| SUN 2000-23KRL | Efficiency | 98.6 |
| | Maximum DC input | 23600 W |
| | Maximum input voltage | 1000 V |
| | Maximum input current | 18 A |
| | Minimum operating voltage | 200 V |
| | Rated input voltage | 620 V |
| | AC output power | 23000 W |
| | Rated output voltage | 3*230 V/ 400 V+ N+ PE |
| | Maximum output current | 33.5 A |
| | Output frequency | 50 Hz/60 Hz |
| | Adjustable power factor | 0.8 leading |
| | Display | Graphic LCD |
| | Operating temperature range | -25$^{o}$C to +60$^{o}$C |
| | Self-consumption at night | < 1 W |
| | Warranty | 5 years<br>10/15/20/25 years optional |

### 3.7.4 Grid Parameter

In grid-connected design, a grid is used as a backup power component or excess power absorber. The grid supplies power when there is not enough RE power to meet the load demand and grid consumes power when an excessive power is available. The utility charge of the grid power has two modes. One is Unit purchase price and other is Unit sell price to the grid. Table 3.24 shows the grid per unit price scenario for different categories.

Table 3.24: REB ,PBS and OZPDCL unit price [83]

| Class of consumer | Category | | |
|---|---|---|---|
| Commercial (11 KV) | Slab | Taka/kWh | $/kWh |
| | Flat | 9.80 | 0.125641 |
| | Off Peak | 8.45 | 0.108333 |
| | Peak | 11.98 | 0.15359 |
| | Category | | |
| Irrigation system | Slab | Taka/kWh | $/kWh |
| | Flat | 3.82 | 0.048974 |
| | Category | | |
| Class A and Class A-1: Medium voltage residential user (11 KV) | Slab | Taka/kWh | $/kWh |
| | Life line : 1-50 unit | 3.36-3.87 | 0.043-0.049 |
| | First step: 1-75 unit | 3.80 | 0.048718 |
| | Second step: 76-200 unit | 5.14 | 0.065897 |
| | Third step: 201-300 unit | 5.36 | 0.068718 |
| | fourth step: 301-400 unit | 5.63 | 0.072179 |
| | Fifth step: 401-600 unit | 8.70 | 0.111538 |
| | sixth step: 600- unit | 9.98 | 0.127949 |
| Class F: Medium voltage general purpose (11 KV) | Category | | |
| | Slab | Taka/kWh | $/kWh |
| | Flat | 7.57 | 0.097 |
| | Off Peak | 6.88 | 0.088 |
| | Peak | 9.57 | 0.122 |
| | Demand Charge = 26000 Taka or USD 333.33 | | |

This is a very argumental issue because no fixed sell back price is declared by power development board of Bangladesh. A sensibility analysis has performed by assuming various sell back price and observed equity payback year. Finally, the most suitable sell back price should be an offer to PDB for implementing these projects **[77].**

### 3.7.5 Land Requirement for Plant Installation:

For solar system, 100 $ft^2$ per 100 kW is needed for plant installation. So, rooftops are the best suited for implementing 1 MW, 2 MW even 3 MW plant. On the other hand, for a wind turbine, a 500 $ft^2$ land area is needed for a 100 kW wind turbine [77][78][79][81].

## 3.8 Basic Theory for Cost Calculation

The performance analysis of a system to cover the desirable load alone is nowadays insufficient for its selection. Economic issues are crucial when making the final choice of the combination of components during the design of a unit.

### 3.8.1 Net Present Cost (NPC)

The NPC means the present value of all component (operating and maintenance cost) that is installed in the plant, minus the present value of all the revenues that it earns over the plant lifespan [2,11, 32].

### 3.8.2 Total Annualized Cost

The total net present cost in a year is called the total annualized cost. It expressed as [2,11, 32]:

$$C_{yr,\ total} = CRF\ (i,\ R_{plant\text{-}life}) \times C_{NPC,\ total} \qquad (3.2)$$

where $C_{NPC,\ total}$, i, CRF, and $R_{plant\text{-}life}$ represents the total net present cost in dollar, the annual real interest rate, capital recovery factor and the plant lifetime in year, respectively.

### 3.8.3 Capital Recovery Factor (CRF)

It is a ratio which is needed to calculate the present value of a series of equal yearly cash flows. It can be expressed as [2,11, 32]:

$$CRF(i,n) = \frac{i \times (1+i)^n}{(1+i)^{n-1}} \qquad (3.3)$$

where n = number of years and i = the real interest rate in a year.

### 3.8.4 Annual Real Interest Rate

It is the discount rate which is used to convert between one-time costs and yearly costs. It is calculated as follows [2,11, 32].

$$i = \frac{i' - F}{1 + F} \quad (3.4)$$

Where, i, i' and F is the real interest rate, nominal interest rate, and annual inflation rate, respectively.

### 3.8.5 Cost of Energy (COE)

It is defined as the mean value of cost per kWh of useful electrical energy produced by the plant. It is expressed as the ratio of electricity production cost in a year to the total electrical load served by the system. The electricity production cost includes plant installation cost and operation and maintenance cost. Total electrical loads are divided into AC primary load and DC primary load. It is calculated by the following equation [2,11, 32].

$$\text{COE} = \frac{C_{yr,total}}{AC_{load} + DC_{load}} \quad (3.5)$$

where, $C_{yr,total}$ $AC_{load}$ and $DC_{load}$ is the total annualized cost, AC primary load and DC primary load, respectively.

## 3.9 Conclusion

This chapter provides a flowchart of the proposed methodology. The steps involve getting the cost-effective solution is described. The comparative analysis of RE source in five different locations is carried out and load demand is calculated. It is seen that Kuakata, Sitakunda, and Magnamaghat are dominated by wind resource whereas Dinajpur and Rangpur are dominated by solar energy. The equipment needed to implement the proposed model is described along with their cost. Finally, the proposed model have been designed using software tool namely HOMER.

# CHAPTER IV

# Simulation Results

### 4.1 Introduction

In this chapter, results of the proposed PV-wind hybrid power generation system for Kuakata area are presented. The detail simulation results for other four regions are shown in Appendix B and Appendix C. Outputs of the analysis have been tabulated and graphically shown. From the tabulated data finally, a brief comparison has been made on the basis of COE, NPC, the percentage of a renewable fraction, total contribution RE on a grid system, total annualized cost, and greenhouse gas emission for the proposed model. The results of the investigations are presented as follows.

### 4.2 Optimum Results for Kuakata

For selecting the best mixer of solar and wind components analyses have been performed with varying the number of the wind turbine and PV module for both off-grid and on-grid mode. Tables 4.1, 4.2 and 4.3 show the optimization results for 1 MW, 2MW, and 3 MW capacity hybrid power system model, respectively with a different share of renewable energies. For 1 MW grid connected system, the minimum NPC is obtained $2043668 whereas for the off-grid system it is $6839339. Figure 4.1 shows the NPC vs. PV-Wind ratio. It has been seen that the NPC values of the system are decreased with the increase in the capacity of PV unit and after some simulation, it is increasing rapidly. Also, with the increase of the PV unit and decrease of the wind turbine, the capital cost of the system is decreased as a wind turbine has a higher price compared to a PV unit. The COE is increases for all system models. Figures 4.2 and 4.3 show the graphs of NPC values with respect to PV-Wind contribution ratio for 2 MW and 3 MW system model, respectively. For 1 MW model, it is seen that the COE and NPC are varied from $0.04362/kWh to $0.407181/kWh and 2.049761million dollar to 6.839339 million dollars, respectively. For

2 MW and 3 MW model, the COE and NPC are varied from $0.026971/kWh to $0.450324/kWh, $0.021024/kWh to $0.650553/kWh, and 2.378619 million dollars to 7.565056 million dollars, 2750290 million dollars to 10.928550 million dollars, respectively. Finally, on the basis of lowest NPC, 1:9 PV-wind capacity ratio for 1 MW, 4:16 PV-wind capacity ration for 2 MW and 5:25 PV-wind ratio for 3 MW model are noticed as the optimum result.

Table 4.1. Simulation results for finding optimal design for 1 MW

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Grid connected | 0 | 10 | 0 | 999999 | 400 | 0.04362 | 2049761 | 2603450 | 89 | - 1032057 |
| Grid connected | 100 | 9 | 0 | 999999 | 400 | 0.045405 | 2043668 | 2485665 | 87 | -937352 |
| Grid connected | 200 | 8 | 0 | 999999 | 400 | 0.047574 | 2047025 | 2367880 | 86 | -838754 |
| Grid connected | 300 | 7 | 0 | 999999 | 400 | 0.049956 | 2053557 | 2250095 | 84 | -739601 |
| Grid connected | 400 | 6 | 0 | 999999 | 400 | 0.052533 | 2063060 | 2132310 | 82 | -640274 |
| Grid connected | 500 | 5 | 0 | 999999 | 400 | 0.055395 | 2078781 | 2014525 | 79 | -539504 |
| Grid connected | 600 | 4 | 0 | 999999 | 400 | 0.059548 | 2121031 | 1896740 | 76 | -425785 |
| Grid connected | 700 | 3 | 0 | 999999 | 500 | 0.063325 | 2176623 | 1800355 | 72 | -331332 |
| Grid connected | 800 | 2 | 0 | 999999 | 600 | 0.067138 | 2247318 | 1703970 | 67 | -234947 |
| Grid connected | 900 | 1 | 0 | 999999 | 600 | 0.071663 | 2326035 | 1586185 | 60 | -117239 |
| Grid connected | 1000 | 0 | 0 | 999999 | 700 | 0.074722 | 2411865 | 1489800 | 53 | -23507.4 |
| Only Grid system | 0 | 0 | 0 | 999999 | 400 | 0.122097 | 2051167 | 85600 | 0 | 761617.8 |
| Off Grid | 100 | 9 | 8542 (Battery) | 0 | 500 | 0.407181 | 6839339 | 4215465 | 100 | 0 |

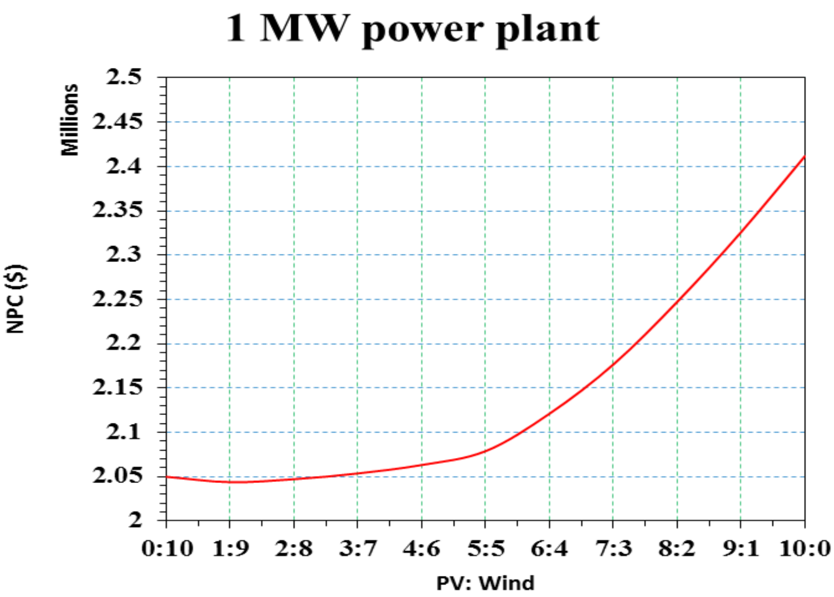



Fig. 4.1. The NPC vs. PV-Wind ratio

Table 4.2: Simulation results for finding optimal design for 2 MW

| PV (kW) | H21.0-100kW | Grid (kW) | Converter (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) | Grid/Energy Purchased (kWh) | Grid/Energy Sold (kWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 20 | 999999 | 400 | 0.026971 | 2378619 | 5121300 | 96.79281 | -2825745 | 215871.4 | 5448733 |
| 100 | 19 | 999999 | 400 | 0.027514 | 2365877 | 5003515 | 96.60049 | -2731040 | 223099.2 | 5280581 |
| 200 | 18 | 999999 | 400 | 0.028196 | 2360568 | 4885730 | 96.36249 | -2632442 | 232415.9 | 5107309 |
| 300 | 17 | 999999 | 400 | 0.028934 | 2356797 | 4767945 | 96.0872 | -2533289 | 243244.2 | 4934520 |
| 400 | 16 | 999999 | 400 | 0.029719 | 2353829 | 4650160 | 95.77546 | -2433962 | 255365.5 | 4762703 |
| 500 | 15 | 999999 | 400 | 0.030595 | 2353910 | 4532375 | 95.41869 | -2333192 | 269007.9 | 4589735 |
| 600 | 14 | 999999 | 400 | 0.031953 | 2376723 | 4414590 | 94.98789 | -2219473 | 284526.2 | 4394661 |
| 700 | 13 | 999999 | 500 | 0.033295 | 2407909 | 4318205 | 94.52452 | -2125020 | 302222.4 | 4237445 |
| 800 | 12 | 999999 | 600 | 0.034783 | 2443275 | 4221820 | 93.98998 | -2028635 | 322199.4 | 4078931 |
| 900 | 11 | 999999 | 600 | 0.036577 | 2475561 | 4104035 | 93.32912 | -1910927 | 344580.6 | 3883334 |
| 1000 | 10 | 999999 | 700 | 0.038159 | 2508446 | 4007650 | 92.63081 | -1817195 | 369712.7 | 3734889 |
| 1100 | 9 | 999999 | 800 | 0.0399 | 2545371 | 3911265 | 91.82352 | -1721837 | 398096 | 3586684 |
| 1200 | 8 | 999999 | 800 | 0.042157 | 2584882 | 3793480 | 90.8005 | -1602196 | 430504.1 | 3397534 |
| 1300 | 7 | 999999 | 900 | 0.044034 | 2621792 | 3697095 | 89.707 | -1508891 | 467722 | 3261965 |
| 1400 | 6 | 999999 | 1000 | 0.046074 | 2663608 | 3600710 | 88.41235 | -1414164 | 511271 | 3130093 |
| 1500 | 5 | 999999 | 1100 | 0.048249 | 2710623 | 3504325 | 86.84841 | -1318475 | 563890.6 | 3005511 |
| 1600 | 4 | 999999 | 1100 | 0.050969 | 2759862 | 3386540 | 84.81352 | -1200348 | 627592.1 | 2850458 |
| 1700 | 3 | 999999 | 1200 | 0.053224 | 2814362 | 3290155 | 82.52339 | -1106057 | 705297.3 | 2753552 |
| 1800 | 2 | 999999 | 1300 | 0.055455 | 2881834 | 3193770 | 79.52476 | -1010858 | 812079.4 | 2684040 |
| 1900 | 1 | 999999 | 1300 | 0.058244 | 2960787 | 3075985 | 75.60423 | -891600 | 946484.5 | 2597595 |
| 2000 | 0 | 999999 | 1400 | 0.06024 | 3043064 | 2979600 | 71.56703 | -797622 | 1096203 | 2573280 |
| 400 (off grid) | 16 | 3023 (battery) | 400 | 0.450324 | 7565056 | 5254760 | 100 | 0 | 16.52367 | 233154.2 |

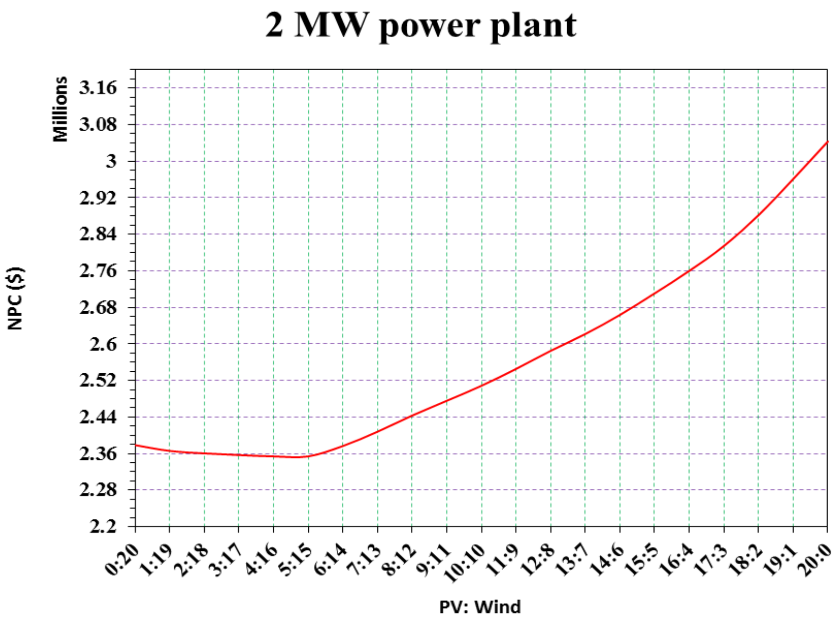



Fig. 4.2. The NPC vs. PV-Wind ratio

Table 4.3: Simulation results for finding optimal design for 3 MW

| PV (kW) | H21.0-100kW | Grid (kW) | Converter (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$(kg/yr) | Grid/Energy Purchased (kWh) | Grid/Energy Sold (kWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 999999 | 400 | 0.021024 | 2750290 | 7639150 | 98 | -4619420 | 147592.3 | 8702074 |
| 100 | 29 | 999999 | 400 | 0.021281 | 2735784 | 7521365 | 98 | -4524715 | 150331.9 | 8529434 |
| 200 | 28 | 999999 | 400 | 0.021616 | 2728307 | 7403580 | 98 | -4426117 | 154132.3 | 8350646 |
| 300 | 27 | 999999 | 400 | 0.021975 | 2721998 | 7285795 | 98 | -4326964 | 158505.3 | 8171402 |
| 400 | 26 | 999999 | 400 | 0.022352 | 2716173 | 7168010 | 98 | -4227637 | 163357.2 | 7992315 |
| 500 | 25 | 999999 | 400 | 0.022771 | 2713041 | 7050225 | 98 | -4126867 | 168826.3 | 7811173 |
| 600 | 24 | 999999 | 400 | 0.023458 | 2732093 | 6932440 | 98 | -4013148 | 174777.4 | 7606533 |
| 700 | 23 | 999999 | 500 | 0.024146 | 2758876 | 6836055 | 97 | -3918695 | 181269.9 | 7438113 |
| 800 | 22 | 999999 | 600 | 0.024901 | 2789187 | 6739670 | 97 | -3822310 | 188388.7 | 7266740 |
| 900 | 21 | 999999 | 600 | 0.025771 | 2815694 | 6621885 | 97 | -3704602 | 196069.4 | 7056444 |
| 1000 | 20 | 999999 | 700 | 0.026538 | 2841970 | 6525500 | 97 | -3610870 | 204387.7 | 6891185 |
| 1100 | 19 | 999999 | 800 | 0.027373 | 2871333 | 6429115 | 97 | -3515512 | 213532.3 | 6723741 |
| 1200 | 18 | 999999 | 800 | 0.028416 | 2902076 | 6311330 | 97 | -3395871 | 223635.6 | 6512286 |
| 1300 | 17 | 999999 | 900 | 0.029285 | 2928783 | 6214945 | 96 | -3302566 | 234895 | 6350759 |
| 1400 | 16 | 999999 | 1000 | 0.030226 | 2958381 | 6118560 | 96 | -3207839 | 247362.2 | 6187805 |
| 1500 | 15 | 999999 | 1100 | 0.031233 | 2990146 | 6022175 | 96 | -3112150 | 261185.6 | 6024426 |
| 1600 | 14 | 999999 | 1100 | 0.032453 | 3020474 | 5904390 | 96 | -2994023 | 276775.8 | 5821262 |
| 1700 | 13 | 999999 | 1200 | 0.033525 | 3051419 | 5808005 | 95 | -2899732 | 294559.8 | 5664435 |
| 1800 | 12 | 999999 | 1300 | 0.034672 | 3084802 | 5711620 | 95 | -2804533 | 314618.5 | 5508199 |
| 1900 | 11 | 999999 | 1300 | 0.03612 | 3119742 | 5593835 | 94 | -2685275 | 337051.4 | 5309783 |
| 2000 | 10 | 999999 | 1400 | 0.037349 | 3153041 | 5497450 | 94 | -2591297 | 362172.2 | 5160870 |
| 2100 | 9 | 999999 | 1500 | 0.038661 | 3189078 | 5401065 | 93 | -2496432 | 390426.1 | 5013448 |
| 2200 | 8 | 999999 | 1600 | 0.04005 | 3227784 | 5304680 | 93 | -2400932 | 422724.6 | 4868895 |
| 2300 | 7 | 999999 | 1600 | 0.041772 | 3266874 | 5186895 | 92 | -2282599 | 459717.1 | 4686752 |

Table 4.3. Simulation result for finding the optimal design for 3 MW (continued..)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2400 | 6 | 999999 | 1700 | 0.043258 | 3308342 | 5090510 | 91 | -2187999 | 502930.4 | 4554780 |
| 2500 | 5 | 999999 | 1800 | 0.044812 | 3354341 | 4994125 | 90 | -2092825 | 555190.9 | 4430792 |
| 2600 | 4 | 999999 | 1800 | 0.046778 | 3405087 | 4876340 | 88 | -1973709 | 618453.8 | 4273470 |
| 2700 | 3 | 999999 | 1900 | 0.048376 | 3459347 | 4779955 | 87 | -1879349 | 695249.9 | 4175525 |
| 2800 | 2 | 999999 | 2000 | 0.049952 | 3525746 | 4683570 | 85 | -1784387 | 800325.6 | 4104746 |
| 2900 | 1 | 999999 | 2000 | 0.051935 | 3604498 | 4565785 | 82 | -1664655 | 932174.8 | 4014870 |
| 3000 | 0 | 999999 | 2000 | 0.054081 | 3694043 | 4448000 | 79 | -1541456 | 1076496 | 3931044 |
| 500 (Off grid) | 25 | 2750 (battery) | 900 | 0.650553 | 10928550 | 7707225 | 100 | 0 | 0 | 0 |

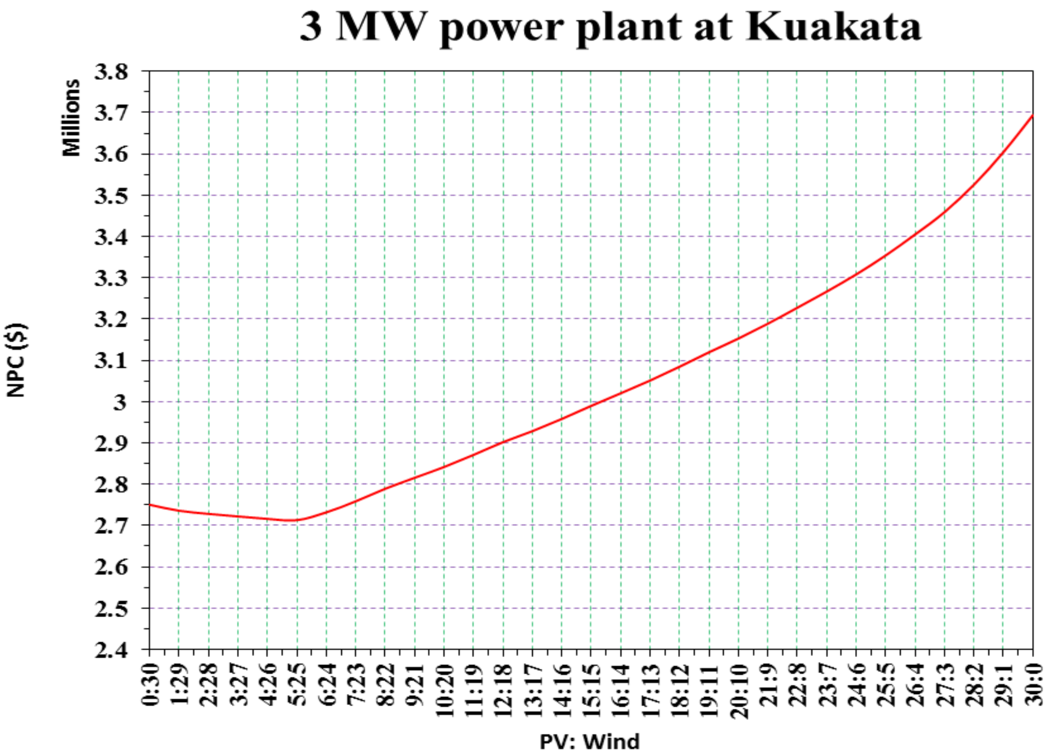



Fig. 4.3. The NPC vs. PV-Wind ratio.

### 4.2.1 Hub Height Selection for Kuakata Region

For proper modeling of wind energy system, the selection of hub height is very important because an extra height may cause physical damage of plant or low hub height cannot produce the desired output. Figures 4.4 and 4.5 show that NPC and total capital cost for wind turbine and COE at 30 m, 40 m, and 50 m hub height. From these two figures, one intersection point can be found that determines optimum point for the desired hub height that is about 47 m.

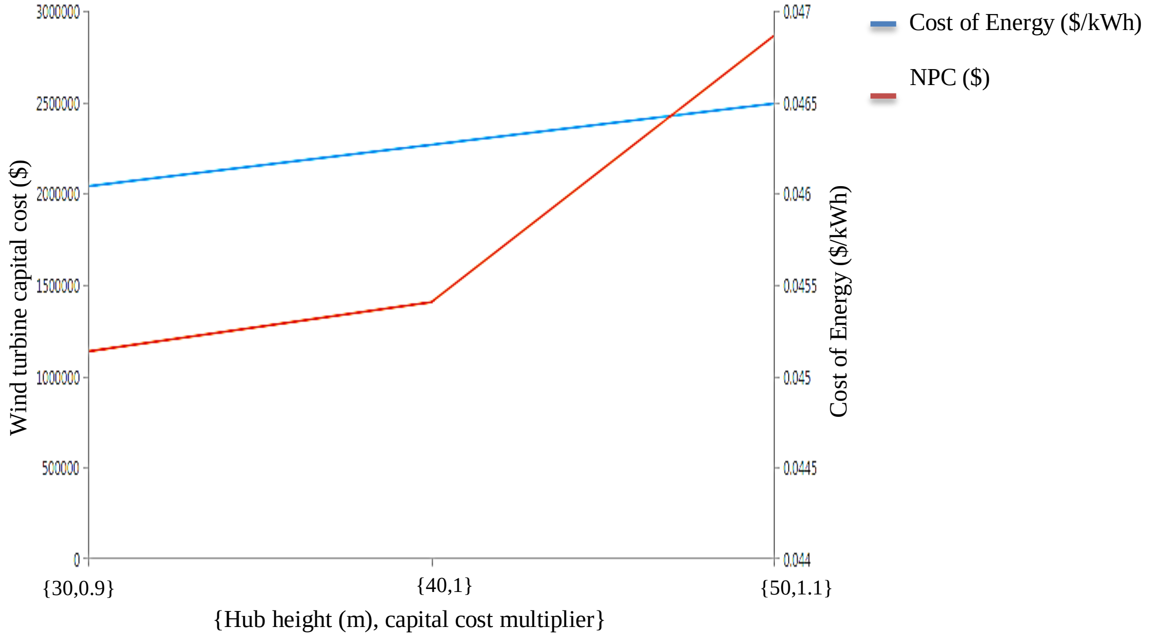



Fig.4.4: Wind turbine capital cost, cost of energy with respect to hub height (m)

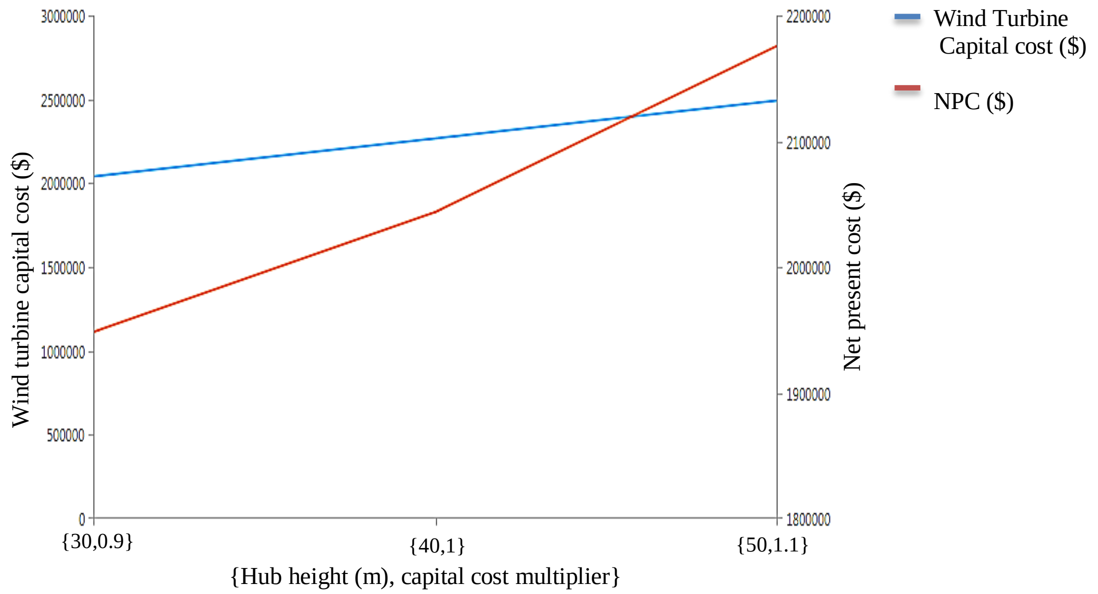



Fig.4.5: Wind turbine capital cost, NPC with respect to hub height (m)

### 4.2.2 Cost Summary for Kuakata (1 MW)

Table 4.4 shows the total NPC for Kuakata region, respectively. From the calculation total NPC is obtained as $2,043,668 for 1 MW grid connected power plant. It is also introducing cost effectiveness of the proposed hybrid model. Figures 4.6 and 4.7 show the cost summary and cash flow summary for 1 MW plant system at Kuakata. The individual component costs are given in cost summary plot. The cash flow describes the capital, operating and replacement cost including salvage.

Table 4.4: NPC (Net present cost) for 1 MW power plant at Kuakata

| Net Present Costs (1 MW grid connected) | | | | | | |
|---|---|---|---|---|---|---|
| Component | Capital | Replacement | O&M | Fuel | Salvage | Total |
| **Solar Land PV** | 134,000 | 0 | 34,067 | 0 | 0 | 168,067 |
| **H21.0-100kW** | 2,266,065 | 556,383 | 593,748 | 0 | -315,642 | 3,100,554 |
| **Grid** | 0 | 0 | -1,428,113 | 0 | 0 | -1,428,113 |
| **HOMER Cycle Charging** | 0 | 0 | 0 | 0 | 0 | 0 |
| **HUAWEI system converter** | 85,600 | 71,963 | 13,312 | 0 | -9,905 | 160,970 |
| **Other** | 0 | 0 | 42,191 | 0 | 0 | 42,191 |
| **System total** | 2,485,665 | 628,345 | -744,795 | 0 | -325,547 | 2,043,668 |

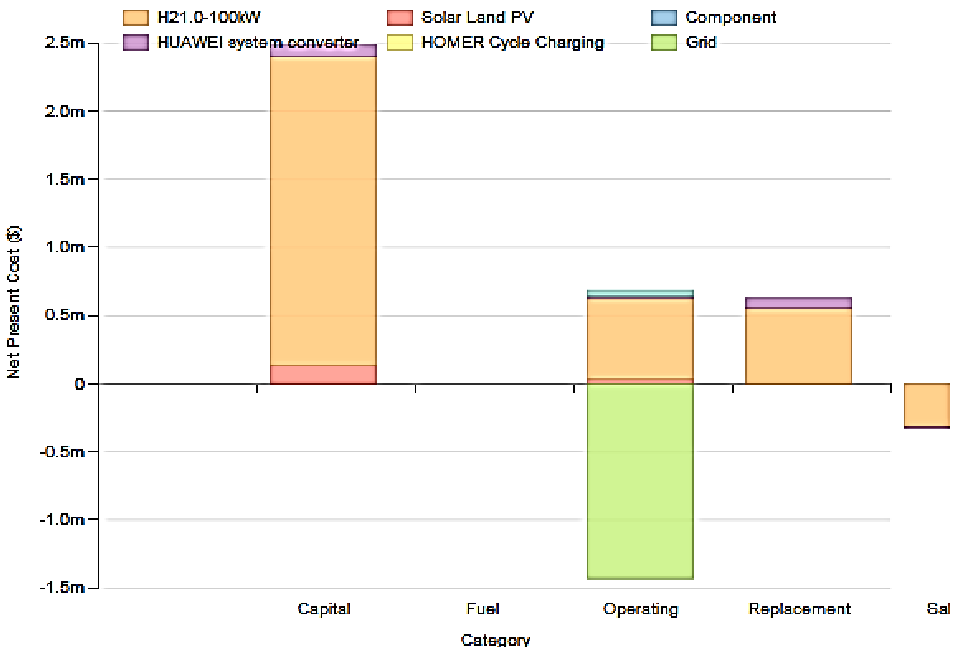



Fig 4.6: Cost summary ($)

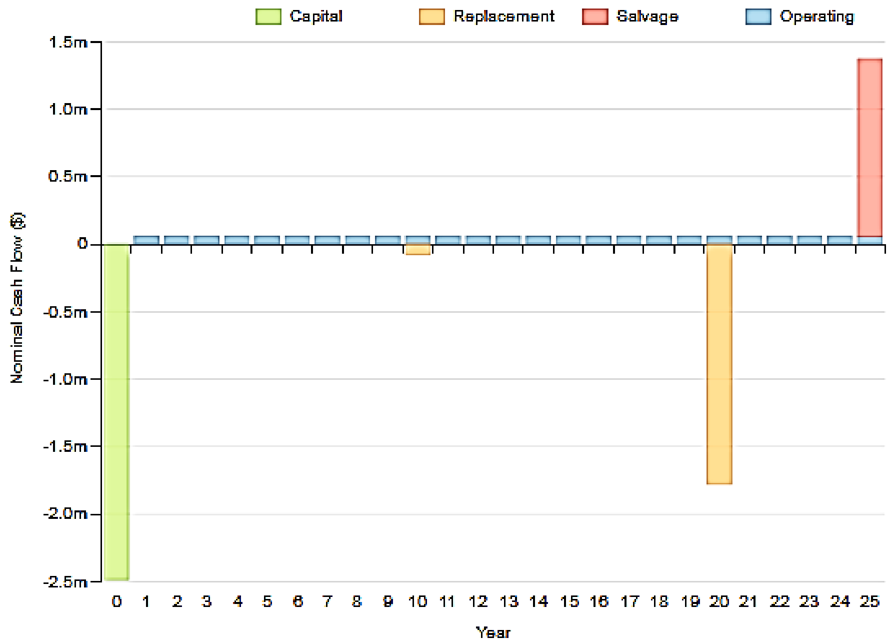



Fig 4.7: Cash Flow Summary

### 4.2.3 Renewable Fraction (1 MW)

Figure 4.8 shows the monthly average electric production of various components for 88% renewable fraction rate where the major contribution is coming from a wind turbine. An 84% renewable energy comes from the wind energy and a 4% renewable energy is coming from PV cell.

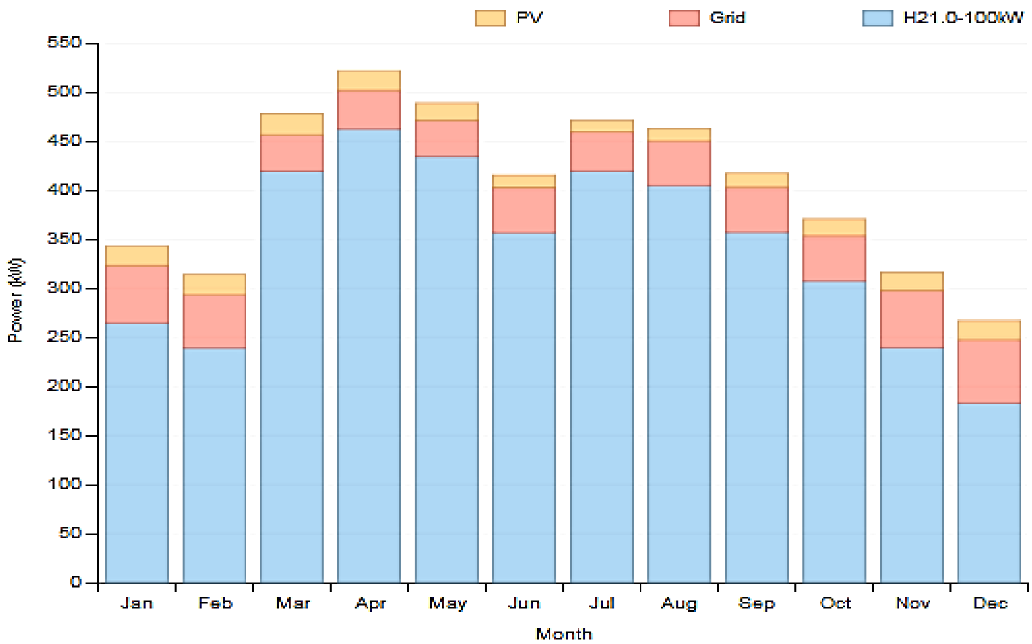



Fig. 4.8: Monthly average electricity production for final model (Renewable fraction 88%).

### 4.2.4 Output Analysis (1 MW)

Figures 4.9 and 4.10 demonstrate the primary load vs. renewable contribution on the systems for two different months. The black line indicates primary load and the red line shows RE contribution for a specific month. From these two figures, it is clear that in winter season renewable contribution is matched with the load that is load factor is quite high. In Figure 4.10 renewable energy production (red line) is much higher than the load due to the availability of RE resources during summer.

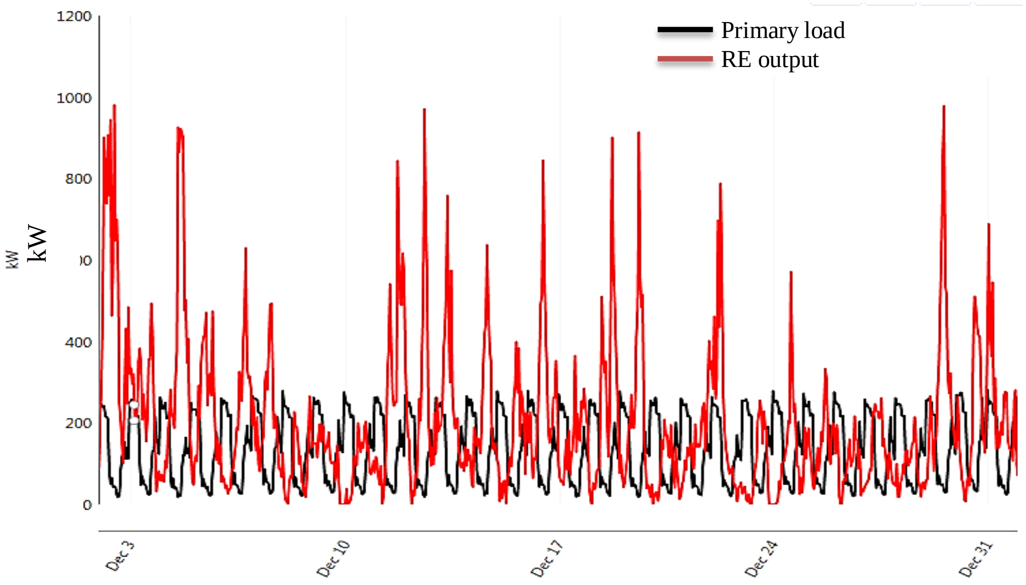



Fig 4.9: Primary load vs. renewable contribution for December

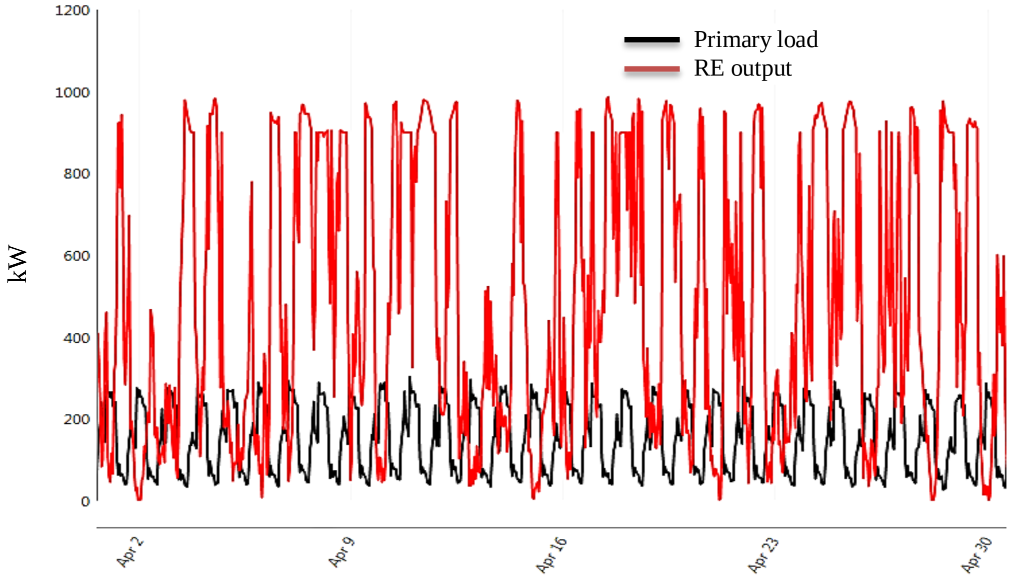



Fig 4.10: Primary load vs. renewable contribution for April

Fig. 4.11 shows the daily profile of the total renewable output in a year. It also shows the highest renewable penetration season is summer season because the proposed region has greater wind energy potential than the other renewable energies. This figure also indicates which time is better for renewable energy harvesting that is 10 am to 5 pm.

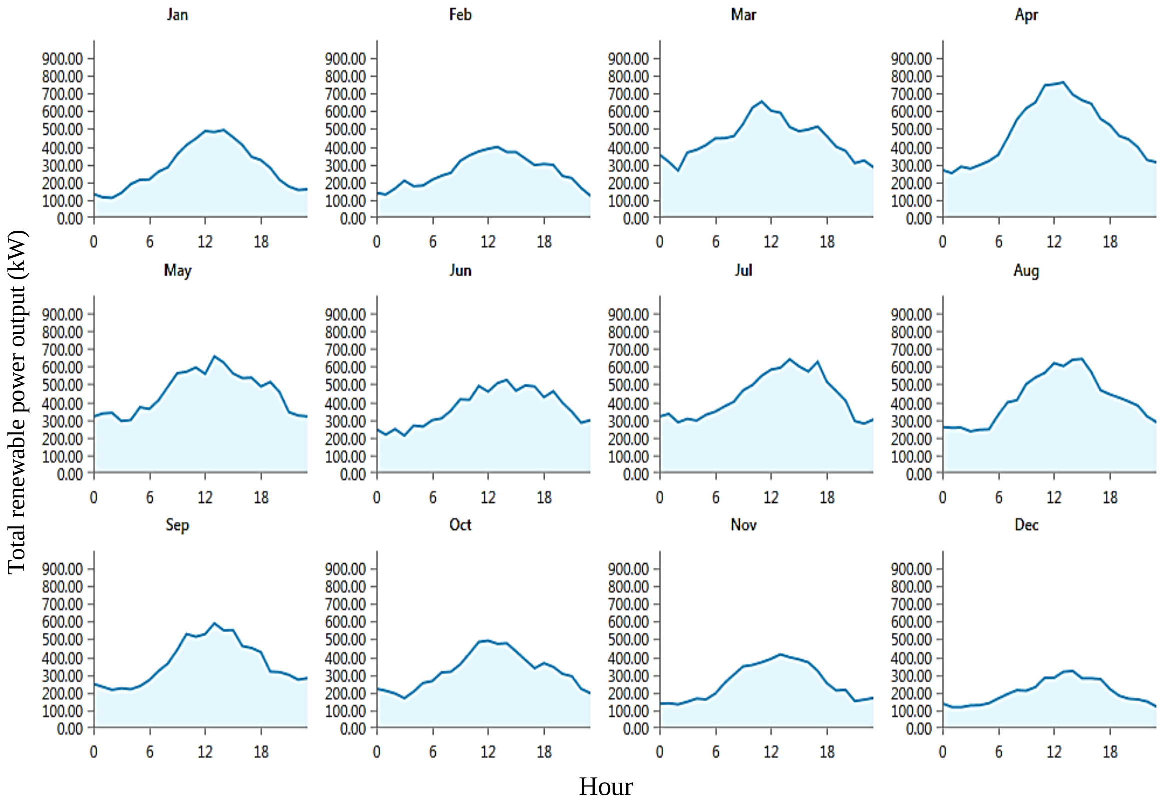



Fig 4.11: Total Renewable Output (Daily profile)

Figures 4.12 and 4.13 show Load vs. RE contribution for April 14 and December 14, respectively. The red line indicates the renewable contribution and black line introduces the primary load. From these figures, it is very clear to understand that when the highest RE is available, it serves the load and the system sells the remaining power to the grid. On the other hand, in winter season renewable resources cannot serve power to the load individually. Figure 4.14 shows the primary load vs total renewable contribution as a function of percentage for April. The black line indicates primary load and the blue line indicates renewable penetration (%). From this figure, it is clear that from 6 am to 6 pm 100% renewable contribution occurs. Figures 4.15 and 4.16 indicate energy sold to the grid vs. purchases from the grid for December and July, respectively. The green line represents the sold energy and black line indicates the purchase energy. The amount of sold energy to the grid is quite high in July than the December.

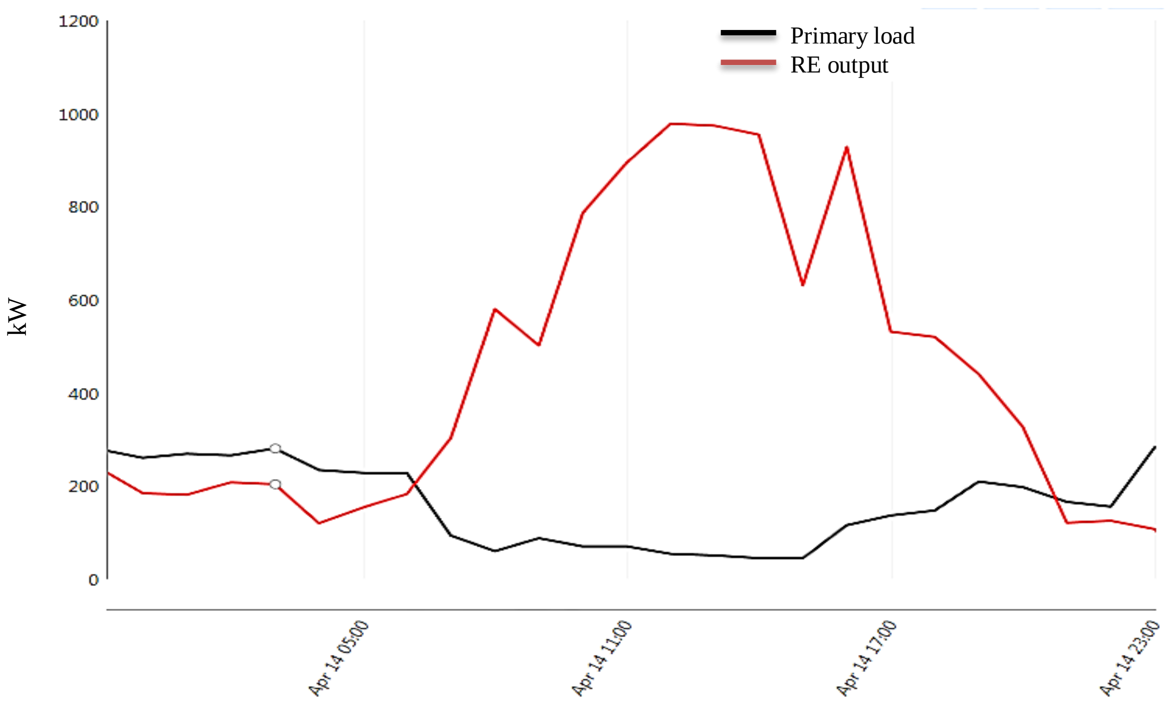



Fig 4.12: primary load and renewable contribution for 14th April

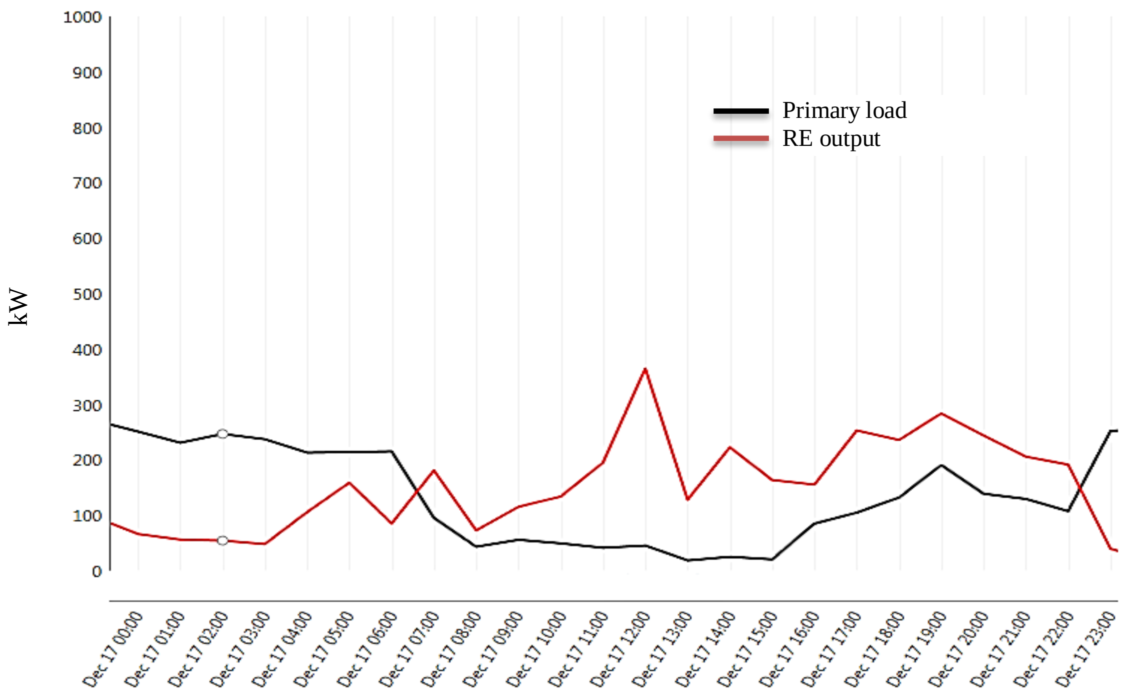



Fig 4.13: primary load and total renewable contribution for 17th December

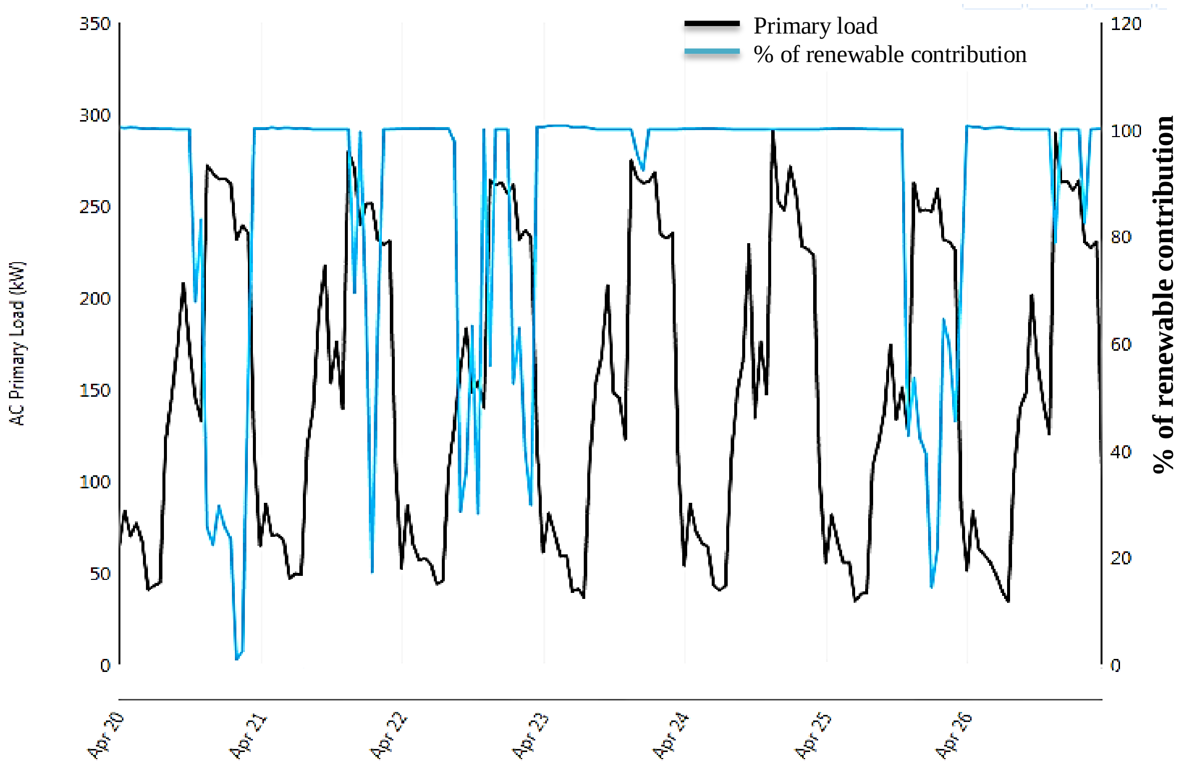



Fig 4.14: Primary load vs. total renewable contribution as a function of percentage for April

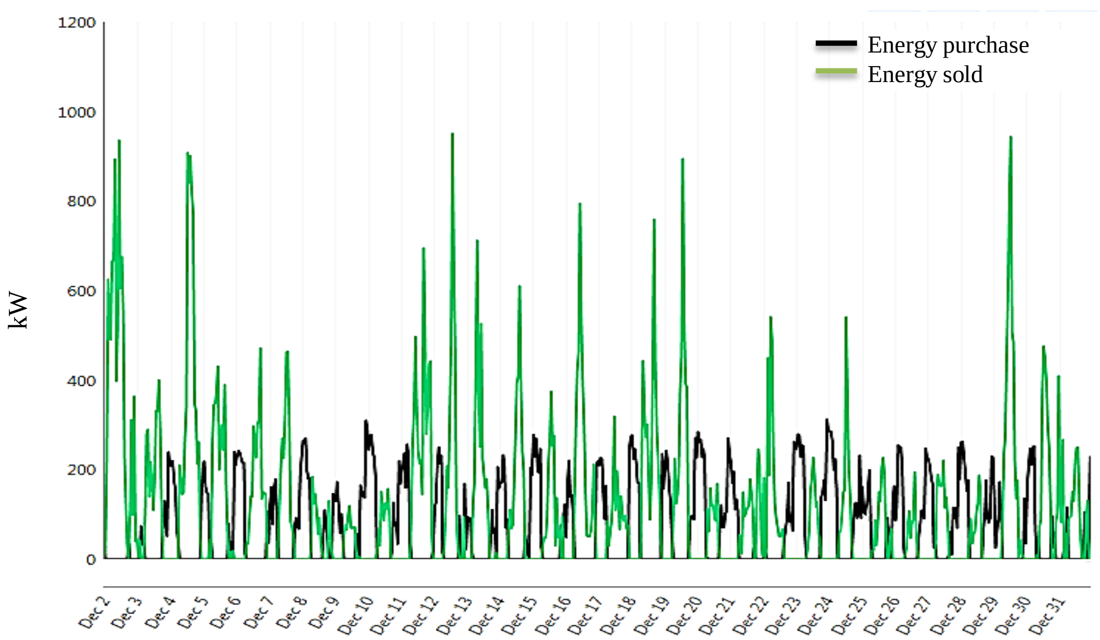



**Fig. 4.15: Energy sold to the grid vs. purchases from the grid for December.**

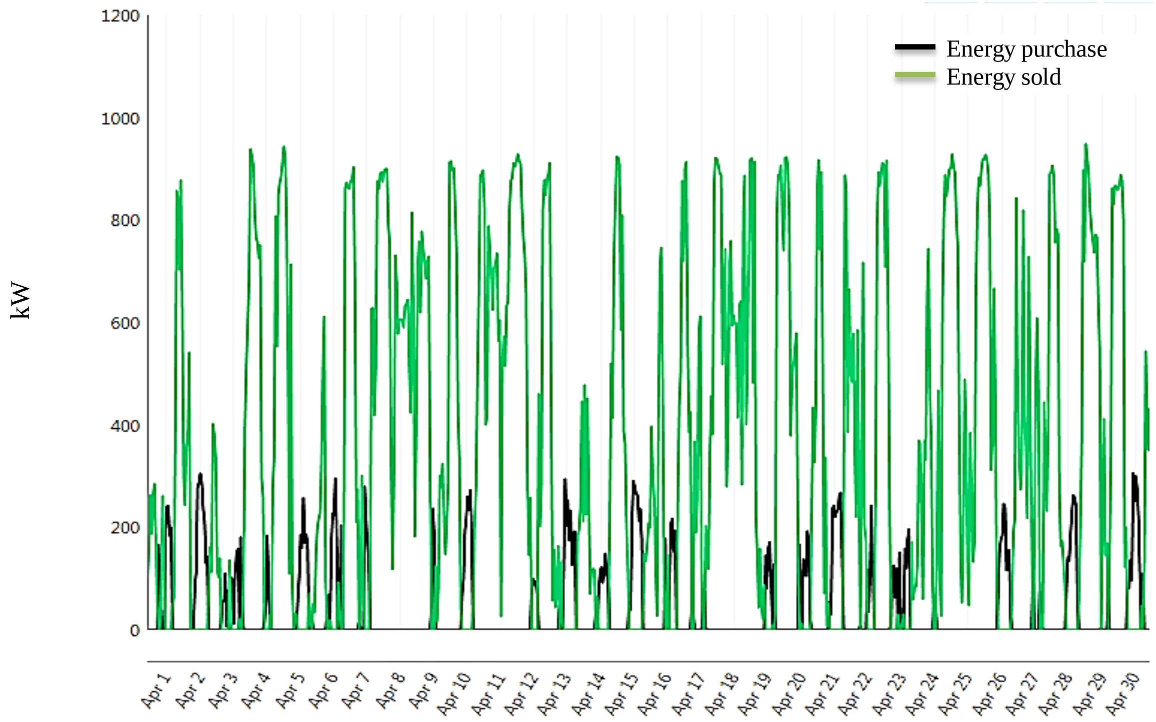



**Fig. 4.16: Energy sold to the grid and purchased from the grid for April.**

### 4.2.5 Environmental Impact

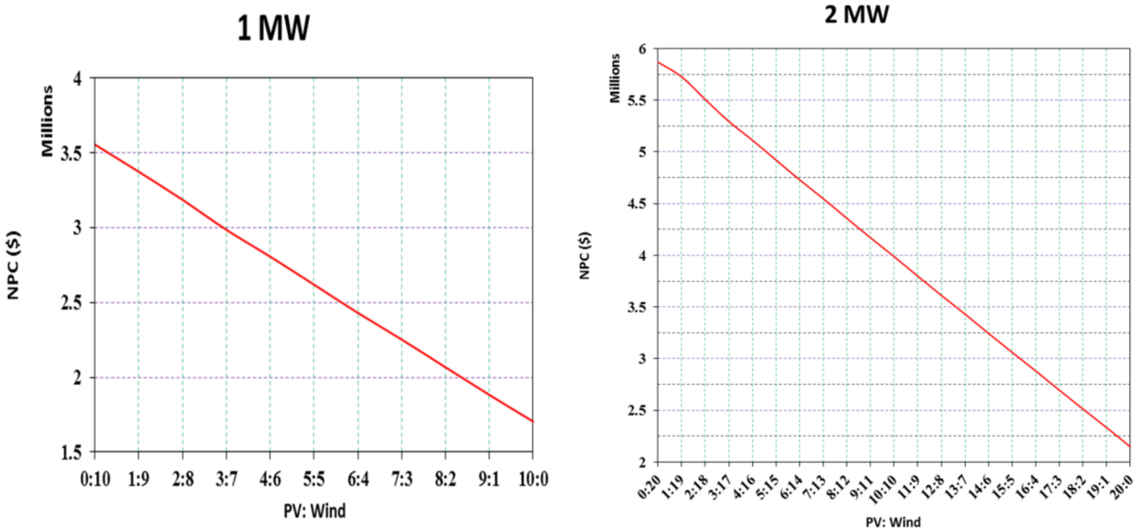
The factor of $CO_2$ emission rate for Bangladesh is found 540 g/kWh [84]. The $CO_2$ emission with the various contribution of renewable energy is shown in Table. 4.5. From which it can be investigated that the emission decreases as the size of the plant increases. The result shows that 1 MW power plant emits -937352 kg $CO_2$ per year while -2433962 kg/yr and -4126867 kg/ $CO_2$ emits per year by 2 MW and 3 MW power plants, respectively. Here, the negative $CO_2$ emission is observed for all cases because this system sells more power than it purchases from the grid as it has an excess of electricity.

Table 4.5: The $CO_2$ emission for Kuakata

| System | $CO_2$ emission (kg/yr) |
|---|---|
| 1 MW | -937352 |
| 2 MW | -2433962 |
| 3 MW | -4126867 |

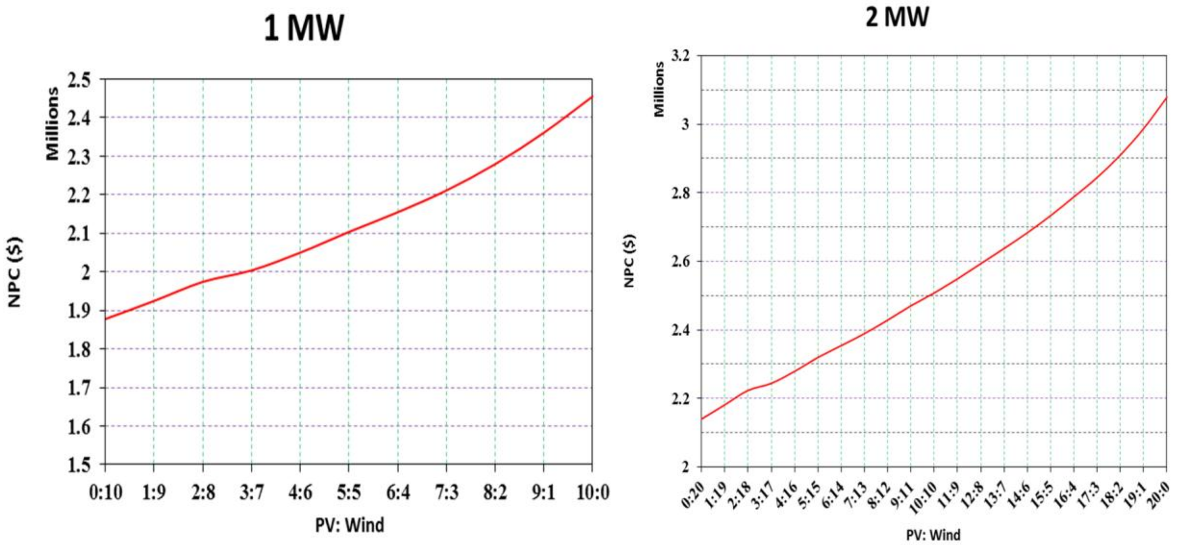
### 4.2.6 Results for other Four Locations

In this section, output results for other four locations have been showed. For better understanding, the details result for these four locations are described in the Appendix B & C.




(a) (b)

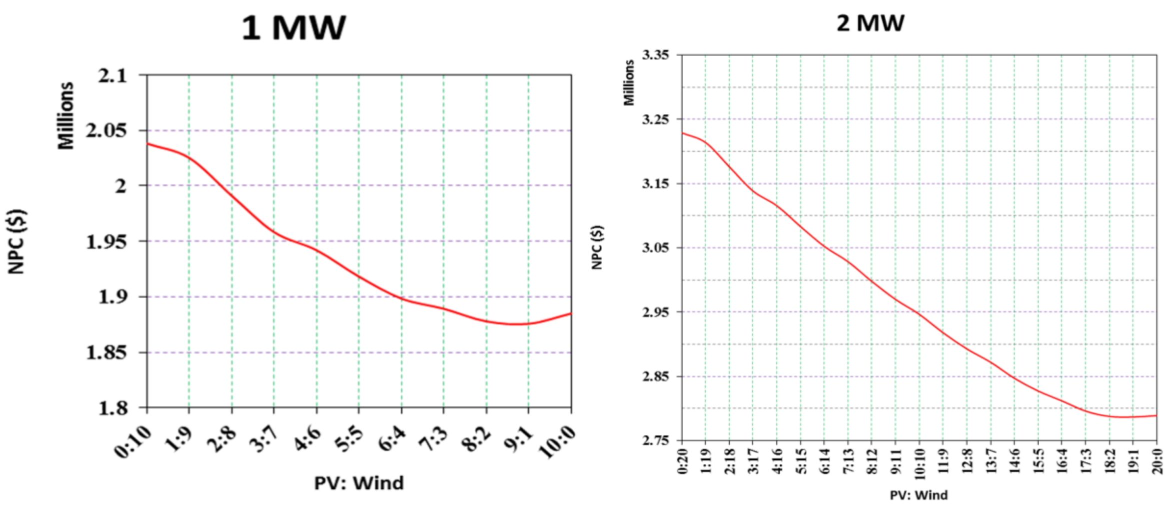
Fig. 4.17: NPC($) vs. PV-Wind ratio for Dinajpur region (a) Result for 1 MW power plant (b) Result for 2 MW plant




(a) (b)

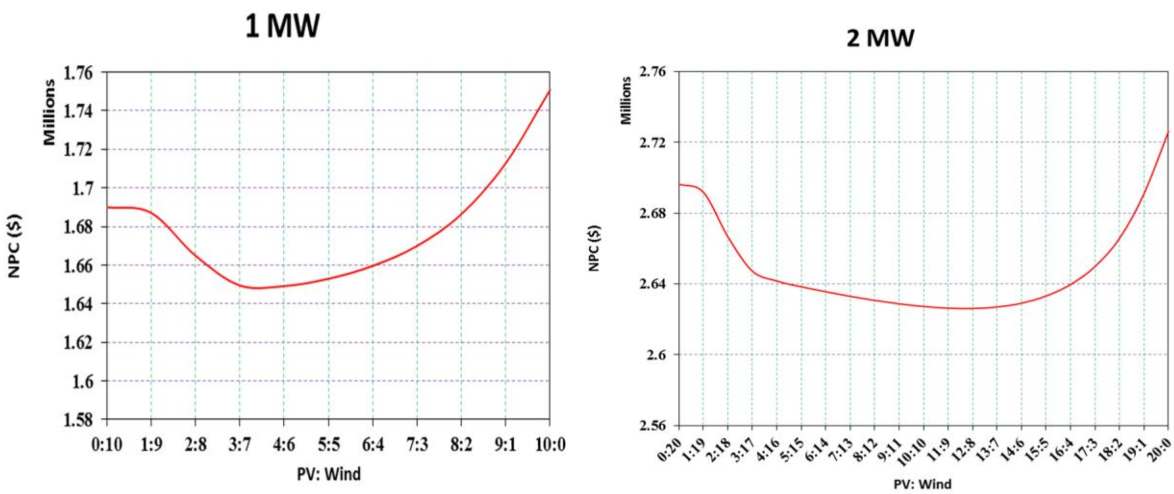
Fig. 4.18: NPC($) vs. PV-Wind ratio for Magnama region (a) Result for 1 MW power plant (b) Result for 2 MW plant

Figure 4.17 shows the output results for Dinajpur region. From this figure, it is clear that Dinajpur has high solar potential. With the increase of solar PV contribution, the NPC are decreased rapidly both 1 MW and 2 MW power plants. That means wind turbine is not suited in that area. Magnama region is situated in the coastal region of Bangladesh which has high wind potential and this area is not suited for PV power generation that is shown in Figure 4.18. The different types of result are observed for Rangpur and Sitakunada. For Rangpur region, the suitable ratio of PV panel and wind turbine is found as 9:1 for 1 MW and 19:1 for 2 MW power systems that are shown in Figure 4.19. On the other hand for Sitakunda it is 2:3 for 0.5 MW, 4:6 for 1 MW and 12:8 for 2 MW respectively that is shown in Figure 4.20.




(a) (b)

Fig. 4.19: NPC($) vs. PV-Wind ratio for Chillmari region (a) Result for 1 MW power plant (b) Result for 2 MW plant




(a) (b)

Fig. 4.20: NPC($) vs. PV-Wind ratio for Sitakunda region (a) Result for 1 MW power plant (b) Result for 2 MW plant

### 4.3 Comparative Result for Proposed Five Models

Comparative results for optimum results are performed for 0.5 MW, 1 MW, 2 MW and 3 MW that is described in this section. Also, other results are shown in the Appendix section. Outputs of the considered five locations have been analyzed based on the system architecture, the cost of the proposed plant, the percentage of renewable energy contribution to load, GHG emission and after that all data have been tabulated.

#### 4.3.1 Comparison Based on System Architecture

Table 4.4 shows the system architecture comparison for five locations with rated capacity and the average capacity of various components. Every grid connected hybrid power system uses the PV array, wind turbine, converter with different capacity because some areas have high solar energy potentials like Dinajpur and Rangpur. So, in these two locations contributions of solar systems are quite high rather than wind energy. On the other hand, where wind energy potential is high that means coastal area namely Kuakata, Sitakunda and Magnama, the contribution of wind energy is greater than the solar energy.

Table 4.6: System architecture comparison for five locations

| Area | Size | PV Capacity (kW) | Wind Turbine capacity (kW) | Optimum PV:Wind ratio | Grid (kW) |
|---|---|---|---|---|---|
| Kuakata | 1 MW | 800 | 200 | 4:1 | 999999 |
| | 1.5 MW | 1000 | 500 | 2:1 | |
| | 2 MW | 1500 | 500 | 3:1 | |
| | 3 MW | 2400 | 600 | 4:1 | |
| Magnamaghat | 1 MW | 0 | 1000 | 0:10 | |
| | 2 MW | 0 | 2000 | 0:20 | |
| Sitakunda | 0.5 MW | 200 | 300 | 2:3 | |
| | 1 MW | 400 | 600 | 2:3 | |
| | 2 MW | 1200 | 800 | 3:2 | |
| Dinajpur | 0.5 MW | 500 | 0 | 5:0 | |
| | 1 MW | 1000 | 0 | 10:0 | |
| | 2 MW | 2000 | 0 | 20:0 | |
| Rangpur | 1 MW | 900 | 100 | 9:1 | |
| | 2 MW | 1900 | 100 | 19:1 | |

### 4.3.2 Comparison Based on Cost Analysis

In this section, only two system sizes have been used for comparative analysis that is 1 MW and 2 MW. System cost for others model is shown in the Appendix section. For 1 MW system model, the lowest net present cost is found at Sitakunda that is $1649163 and highest NPC is found in Kuakata that is $2043668. For 2 MW system model, the lowest net present cost is found at Magmana that is $ 2139587 and highest NPC is found in Rangpur that is $ 2786766. On the other hand, the minimum cost of energy is found in Magnama for both cases that are $ 0.037/kWh and $0.023/kWh for 1 MW and 2 MW, respectively. Also, the COE for every region is much lower than the grid levelized cost of energy of average grid unit price [76]. Figures 4.21 and 4.22 show the total NPC and COE for five locations.

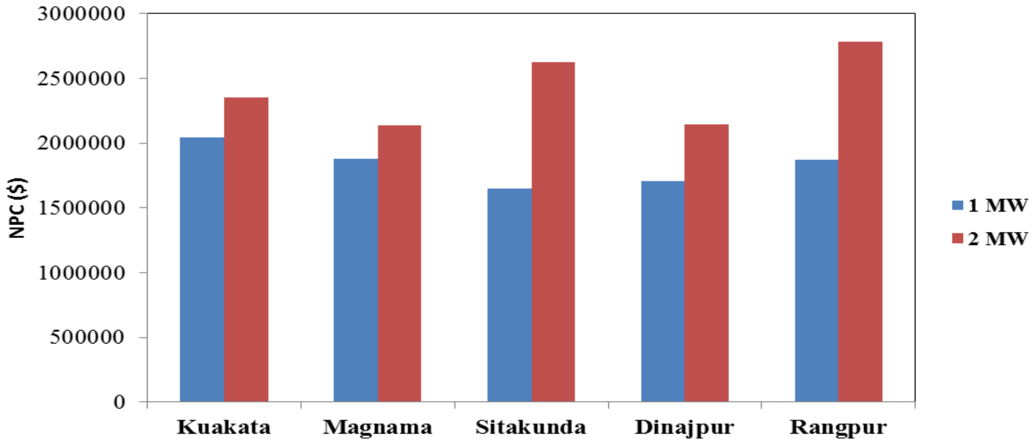



Figure 4.21: Net present cost (NPC) for five locations

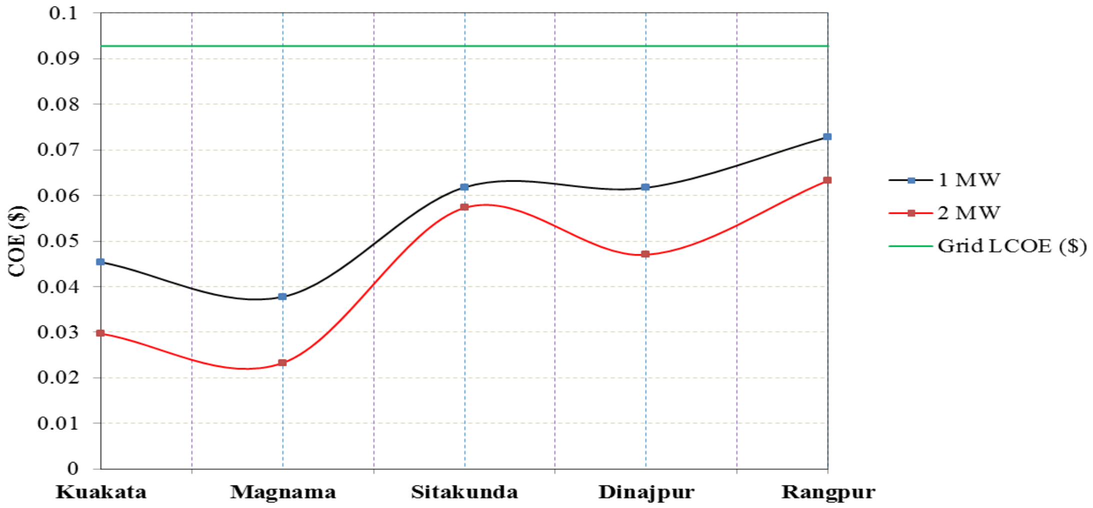



Figure 4.22: COE in terms of $/kWh for five considered area.

### 4.3.3 Comparison Based on $CO_2$ Emission for 1 MW Power Plant

This section describes the environmental impact for these five hybrid renewable energy based power plant. Table 4.7 shows the total GHG emission on earth for different systems like grid connected hybrid system and only grid system. $CO_2$ emissions of all models give negative value because every hybrid model sells more energy to the grid than the purchases from the grid annually. The highest value is found at Magnama that is -1039876 kg/yr for 1 MW and -2873867 kg/yr for 2 MW, respectively. By installing the proposed power plant it is possible to reduce a large amount of $CO_2$ gas from the environment.

Table 4.7: Comparison of $CO_2$ emission for 1 MW power plant

| **Area** | **$CO_2$ emission (kg/yr)** | |
|---|---|---|
| | 1 MW | 2 MW |
| **Kuakata** | -937352 | -2433962 |
| **Magnamaghat** | -1039876 | -2873867 |
| **Sitakunda** | -686638 | -1492764 |
| **Dinajpur** | -289246 | -1169745 |
| **Rangpur** | -402079 | -1161993 |

### 4.4 Conclusion

This chapter provides output data for various models and gives the comparative result. Various comparisons are made by analyzing outputs. It is found that the proposed model can reduce the cost and $CO_2$ emission effectively.

# CHAPTER V

# A Case Study for KUET

## 5.1 Introduction:

In this chapter, the techno-economic optimization process is described focusing on the optimum configuration of the hybrid power system in terms of different generation capacities which is assessed through the HOMER. The aim of this simulation is to provide a basic but representative idea of the configuration of the microgrid. Initially, the power demand in Khulna University of Engineering and Technology (KUET) area is collected and the process of designing the model is described with the initial choice of the various parameters, as well as the considered constraints and parameters. Finally, the results of the analysis are shown. During the whole process, the main difficulty was to find reliable data about the costs of the equipment regarding the purchase, transportation, and maintenance because of not only for their high volatility and variability between different places in even the same country but also because the prices change from one year to the other. The HOMER software is a tool to design, model and optimize stand-alone and grid-connected power systems [32]. It is widely used for techno-economic analysis of microgrids, as it can simulate a range of different conventional as well as renewable energy technologies and assess the technical and economic feasibility of them. The inputs to the HOMER model are climate data, electrical load, technical and economic parameters of the equipment used for generation and storage, sensitivity variables, dispatch strategy, and some more constraints. Based on the inputs, the model performs a simulation of the operation of the system making the energy balance calculations for each one of the 8760 hours of the year, resulting in the optimal system size and control strategy based on the lowest net present cost (NPC).

## 5.2 Background of KUET

Since the topic of this chapter has been chosen a case study about KUET area, including some information about the situation in this area it is very important to describe a background of KUET for better understanding the real situation of power system scenario to the readers. KUET is one of the leading public universities of Bangladesh giving special emphasis in the engineering and technological education and research. KUET is well known for offering very high quality educational, research and developmental programs in the major disciplines of engineering as well as basic sciences [85]. It has a sober objective to achieve excellence in quality education, research and progression to address the present needs of the country as well as the south-western region to make it as the "Center of Excellence". It is situated at Fulbarigate, the north-west part of the Khulna city, which is the third largest south-western divisional city in Bangladesh. The campus of this university stands at North-West corner of Khulna City Corporation and geographical location is $22^0$54.3'N, $89^0$29.8'E and about 12 Km from the city center, in the midst of an impressive natural beauty having vast greenery spreading over an area of 101 acres land [85]. KUET offers engineering education in both undergraduate and post-graduate levels, and also offers degree and conducts research in basic sciences at post-graduate level. At present, around 5000 students are studying in KUET's in 18 academic departments under 3 faculties with about 282 faculty members, 103 officers, and 284 office staff. The physical infrastructure is total 41 buildings including Halls of residence, Academic Buildings, and Institutes, Workshops, Playgrounds, Cafeteria, Auditorium, Teachers quarters, etc. are structured in a much-planed way and are being improved day by day.

### 5.2.1 Power System Scenario of KUET

The campus is mainly provided power by Mirerdanga sub-station of West Zone Power Distribution Company Limited. It has an expressed electricity line feeder for continuous electric supply with about 1 km of 11 kV transmission lines, six transformers having total capacity 1860 kVA that are situated in the substation and other locations to steps down the 11 kV into 0.4 kV/0.22 kV. The KUET authority pays 169252.8 USD in every year for power consumption [86]. The main goal of this research is to minimize the total electric bill by producing green energy in KUET campus. Figure 5.1 shows the single line diagram of the distribution network of KUET and it provides a better understanding of the power system arrangement in that location.

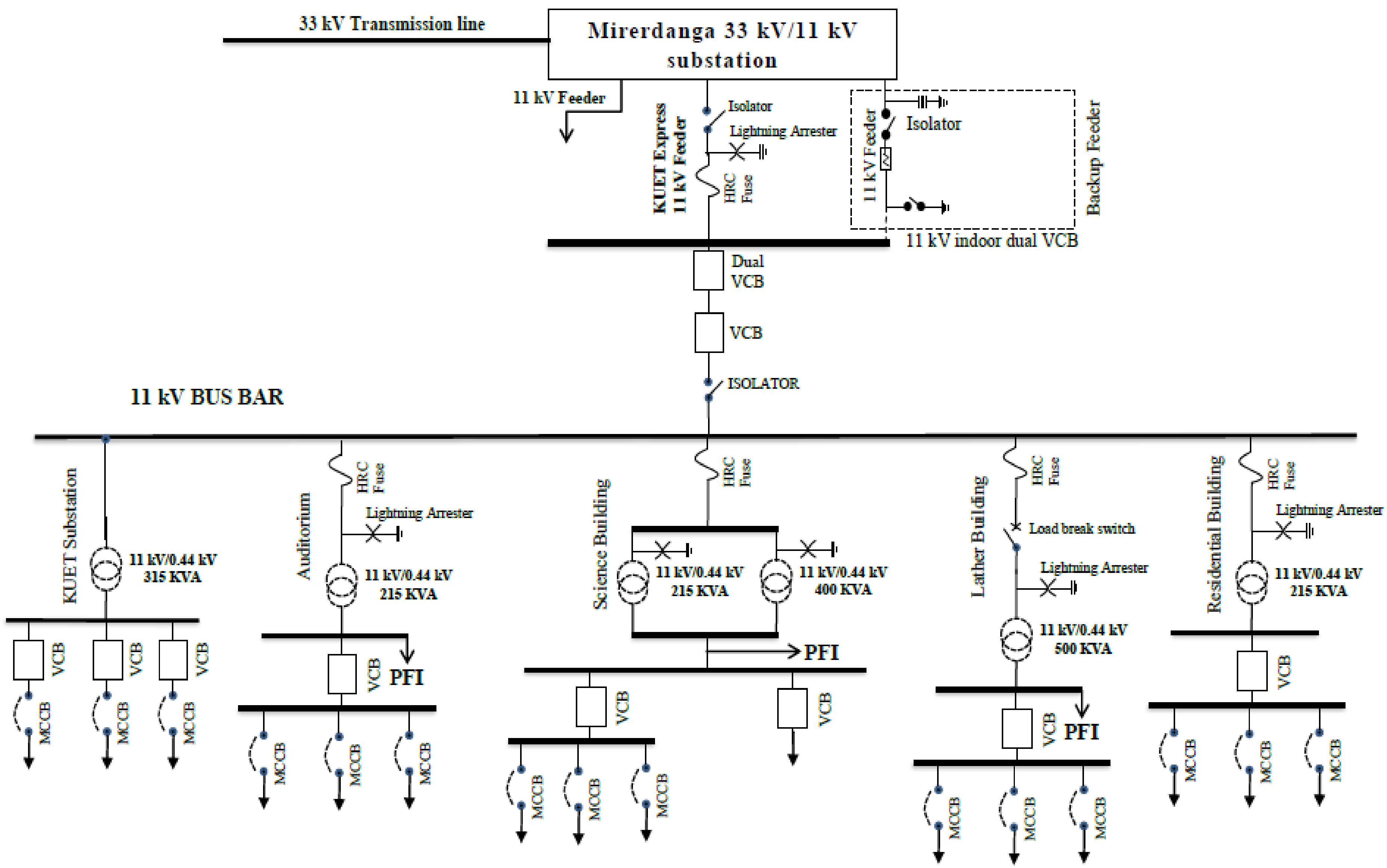



Fig 5.1: Single line diagram of distribution network of KUET

## 5.3 Load Calculation

For the load calculation to be done, the connected load and the actual load should be determined. For determining the connected load the campus area is divided into four functional zones: (i) Residential zone for the faculties and staff (ii) Residential zone for the students (iii) Academic zone for the academic buildings & workshops, and (iv) Cultural-cum-social and recreational zones. The actual load of that area is collected from Mirerdanga sub-station which is needed for calculating the various load characteristics.

### 5.3.1 Connected Load Calculation

Generally, this has been a difficult task to estimate the accurate load that is used in that area. The estimation of the total equipment was done after dividing KUET area into four important zones. For connected load calculation, it is very important to know the rating of home appliances that is used in the proposed area. Tables 5.1, 5.2, 5.3 and 5.4 show the connected load for four important zones. Finally, the total connected load has been calculated and it is about 1683.39 kW.

Table 5.1: Connected load for residential area (faculties and staff)

| Connected Load for Residential Area | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Building No. | Name | Description | Number of connected equipment | | | | | | | | | | | Total connected Load (kW) |
| | | | Light | Fan | TV | Computer | Air conditioner | Rice cooker | Washing machine | Microwave Oven | Electric Iron | Refrigerator | | |
| 1 | Residence of VC | 2 storied building, 7 rooms, 1 dining, 1 drawing, 1 kitchen, 4 bathrooms. | 7 tubes, 7 CFL | 9 | 2 | 1 | 4 tons | 2 | 1 | 1 | 1 | 2 | 13.73 |
| 2,3 | Quarter (2 storied building) | 6 rooms, 1 drawing, 1 kitchen, 4 bathrooms. | 6 tubes, 6 CFL | 6 | 2 | 2 | × | 2 | 2 | 2 | 2 | 3 | 20.58 |
| 4 | Dormitory (4 storied building) | 72 rooms, 2 dining, 2 common rooms, 1 kitchen, 8 bathroom spaces | 98 tubes, 40 CFL | 90 | 2 | 72 desktop , 50 laptop | × | × | × | × | 10 | 2 | 39.27 |
| 5 - 19 | Quarter (3 storied building, 6 unit each | 12 Rooms, 6 drawing, 6 dining, 12 bathrooms, 6 kitchen | 24 tubes, 18 CFL | 24 | 6 | 6 | × | 12 | 2 | 6 | 6 | 8 | 534.3 |
| Total Connected Load for residential area = | | | | | | | | | | | | | 607.88 |

Table 5.2: Connected load for others building

| Connected load for others building | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Number of connected equipment | | | | | | | Total connected Load(kW) |
| | | Light | Fan | Computer/ TV | Air conditioner | Other Equipment | Refrigerator | | |
| Engineering Building | 3 storied building, 40 rooms, 3 bathroom space. | 36 tubes, 20 CFL | 36 | 36 desktop | 6 tons | × | 1 | | 17.21 |
| Central mosque | × | 15 tubes, 10 CFL | 64 | × | × | Sound System (1) | × | | 5.09 |
| Water Treatment Plant | 2 Rooms | 4 tubes, 4 CFL | 4 | × | × | Water Pump (1) | × | | 7.94 |
| Guest House | 2 storied building, 20 rooms, 1 dining , 1 kitchen, 1 drawing | 28 tubes, 20 CFL | 26 | 20 TV | 12 tons | × | 1 | | 23.53 |
| Stuff Club | 2 storied building, 10 rooms, 1 dining | 15 tubes, 10 CFL | 10 | 1 TV | 6 tons | × | × | | 10.51 |
| KUET School | 2 building, 10 class rooms, 2 labs, 10 teachers rooms, 1 office rooms, 2 bathroom space. | 38 tubes, 10 CFL | 70 | 10 desktop | 2 tons | × | 4 lift | | 10.02 |
| Hit Engine Lab | 2 storied building, 4 labs, 1 office room. | 10 tubes, 4 CFL | 17 | × | 2 | Lab equipment's | × | | 5.6 |
| ME workshop | 1 storied building, 2 labs, 1 office room. | 5 tubes, 2 CFL | 8 | × | × | Lab equipment's | × | | 2.22 |
| Cafeteria | 2 Rooms, 1 kitchen | 7 tubes, 2 CFL | 12 | × | × | Blender (1) | 1 | | 1.24 |
| Bank and Post office | 5 Rooms | 8 tubes, 2 CFL | 7 | 7 | 1 | AT machine (4) | 1 | | 3.05 |
| Street Light | | 60 tubes, 20 CFL | × | × | × | × | × | | 2.8 |
| Total Connected Load for Others buildings = | | | | | | | | | 89.21 |

Table 5.3: Load for academic area of KUET

| Load for academic area of KUET | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Name | Description | Number of connected equipment | | | | | | | Total connected Load(kW) |
| | | Light | Fan | Computer | Air conditioner | Multimedia set | Refrigerator/ Lift | | |
| EEE Building | 3 storied building, 8 class rooms,<br>4 labs, 16 teachers rooms,<br>3 office rooms, 1 seminar room,<br>3 bathroom space. | 93 tubes, 20 CFL | 118 | 68 desktop | 12 tons | 6 | 1 | | 40.6 |
| CE Building | 3 storied building, 8 class rooms,<br>4 labs, 16 teachers rooms,<br>3 office rooms, 1 seminar room,<br>3 bathroom space. | 93 tubes, 20 CFL | 118 | 68 desktop | 12 tons | 6 | 1 | | 40.6 |
| ME Building | 3 storied building, 8 class rooms,<br>4 labs, 16 teachers rooms,<br>3 office rooms, 1 seminar room,<br>3 bathroom space. | 93 tubes, 20 CFL | 118 | 68 desktop | 12 tons | 6 | 1 | | 40.6 |
| Science Building | 3 storied building, 8 class rooms,<br>4 labs, 16 teachers rooms,<br>3 office rooms, 1 seminar room,<br>3 bathroom space. | 93 tubes, 20 CFL | 118 | 68 desktop | 12 tons | 6 | 1 | | 40.6 |
| Administrative Building | 3 storied building, 30 Office rooms, rooms, 1 bathroom space. | 60 tubes, 20 CFL | 60 | 40 desktop | 6 tons | × | × | | 25.4 |
| New Academic Building | 5 storied building, 110 class rooms, 10 labs, 72 teachers rooms, 20 office rooms,<br>2 seminar room, 1central library, 1 central computer center, 10 bathroom space. | 560 tubes, 100 CFL | 692 | 152 desktop | 40 tons | 30 | 4 lifts | | 154.96 |
| Leather Building | 2 storied building, 8 class rooms,<br>3 labs, 12 teachers rooms,<br>3 office rooms, 1 seminar room,<br>2 bathroom space. | 76 tubes, 20 CFL | 90 | 30 | 6 | 4 | 1 | | 23.03 |
| Total Connected Load for Academic area = | | | | | | | | | 365.79 |

Table 5.4: Connected load for Residence of Student (Hall)

| Connected load for Residence of Student (Hall) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Hall Name | Description | Number of connected equipment | | | | | | | Total connected Load (kW) |
| | | Light | Ceiling Fan, Table Fan | TV | Computer | Rice cooker | Refrigerator | | |
| Begum Rokeya Hall (Ladies hall) | 4 storied building, 56 rooms, 1 Office room,1 dining, 1 kitchen, 1 common Room, 8 bathroom space. | 128 tubes , 25 CFL | 80 , 224 | 1 | 112 desktop , 90 laptop | 56 | 1 | | 97.33 |
| Bangabandhu Sheikh Mujibur Rahman Hall | 5 storied building, 120 rooms, 1 Office room,4 PG Room, 2 dining, 2 kitchens, 2 Common Room, 1 prayer room, 1 Library, 4 Multiple Room, 20 bathroom space. | 334 tubes, 120 CFL | 194, 480 | 2 | 320 desktop, 160 laptop | 12 0 | 2 | | 156.6 |
| Khan Jahan Ali Hall | 3 storied building, 48 rooms, 1 Office room, 1 dining, 1 kitchen, 1 TV Room, 6 bathroom space. | 120 tubes, 40 CFL | 66, 192 | 1 | 100 desktop , 92 laptop | 48 | 1 | | 85.34 |
| Lalon Shah Hall | 3 storied building, 50 rooms, 1 Office room, 1 dining, 1 kitchen, 1 TV Room, 6 bathroom space. | 122 tubes, 18 CFL | 70 , 204 | 1 | 110 desktop , 94 laptop | 51 | 1 | | 88.14 |
| Fazlul Haque Hall | 3 storied building, 54 rooms, 1 Office room, 1 dining, 1 kitchen, 1 TV Room, 1 Guest Room, 1 Common Room, 6 bathroom space. | 138 tubes, 40 CFL | 80 | 1 | 116 desktop , 100 laptop | 54 | 1 | | 96.54 |
| Rashid Hall | 3 storied building, 54 rooms, 1 Office room, 1 dining, 1 kitchen, 1 TV Room, 1 Guest Room, 1 Common Room, 6 bathroom space. | 138 tubes, 40 CFL | 80 | 1 | 116 desktop, 100 laptop | 54 | 1 | | 96.54 |
| Total Connected Load for Residence of Student (Hall) = | | | | | | | | | 620.49 |

### 5.3.2 Actual Load for KUET Area

It is important to know the actual condition and characteristics of load and others variables for a specific area. For load calculation purposes, load data has been collected from WZPDCOL and from this data has been observed for a year by dividing it into two seasons April-September and October-March. Though June and July are in a period of pick month but at this time KUET has vacation, therefore minimum load is observed during this period that is shown in Tables 5.5 and 5.6. From collected data it is observed that the average daily load (kWh/day) is 6718.5 kWh /day, hourly average is 279.94 kW/hour and peak load is observed at mid time of any day and it is about 770.33 kW in April.

Table 5.5: Monthly average load for **January-June**

| Monthly average Load for KUET area | | | | | | |
|---|---|---|---|---|---|---|
| Hour | January | February | March | April | May | June |
| 0 | 140.061 | 210.091 | 262.614 | 332.644 | 350.152 | 122.553 |
| 1 | 140.061 | 210.091 | 210.091 | 332.644 | 315.137 | 105.046 |
| 2 | 140.061 | 210.091 | 210.091 | 332.644 | 315.137 | 105.046 |
| 3 | 105.046 | 210.091 | 210.091 | 332.644 | 280.122 | 140.061 |
| 4 | 105.046 | 210.091 | 210.091 | 262.614 | 262.614 | 122.553 |
| 5 | 105.046 | 140.061 | 140.061 | 262.614 | 245.106 | 105.046 |
| 6 | 105.046 | 122.553 | 140.061 | 262.614 | 280.122 | 105.046 |
| 7 | 140.061 | 140.061 | 192.584 | 315.137 | 280.122 | 122.553 |
| 8 | 192.584 | 192.584 | 280.122 | 350.152 | 332.644 | 122.553 |
| 9 | 192.584 | 227.599 | 245.106 | 560.243 | 490.213 | 122.553 |
| 10 | 192.584 | 262.614 | 315.137 | 612.766 | 752.827 | 122.553 |
| 11 | 245.106 | 297.629 | 385.167 | 682.796 | 682.796 | 122.553 |
| 12 | 262.614 | 332.644 | 385.167 | 770.334 | 735.319 | 140.061 |
| 13 | 297.629 | 262.614 | 437.69 | 577.751 | 630.274 | 140.061 |
| 14 | 245.106 | 297.629 | 280.122 | 507.72 | 612.766 | 140.061 |
| 15 | 140.061 | 262.614 | 297.629 | 630.274 | 612.766 | 140.061 |
| 16 | 140.061 | 262.614 | 297.629 | 630.274 | 612.766 | 140.061 |
| 17 | 140.061 | 210.091 | 262.614 | 385.167 | 437.69 | 140.061 |
| 18 | 140.061 | 210.091 | 332.644 | 367.66 | 402.675 | 140.061 |
| 19 | 210.091 | 262.614 | 332.644 | 420.182 | 437.69 | 122.553 |
| 20 | 210.091 | 297.629 | 332.644 | 420.182 | 402.675 | 140.061 |
| 21 | 210.091 | 332.644 | 297.629 | 367.66 | 437.69 | 140.061 |
| 22 | 210.091 | 332.644 | 262.614 | 332.644 | 350.152 | 140.061 |
| 23 | 210.091 | 262.614 | 262.614 | 332.644 | 385.167 | 140.061 |

Table 5.6: Monthly average load for **July- December**

| Hour | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| 0 | 227.599 | 332.644 | 332.644 | 245.106 | 140.061 | 192.584 |
| 1 | 210.091 | 297.629 | 297.629 | 245.106 | 140.061 | 192.584 |
| 2 | 210.091 | 297.629 | 297.629 | 192.584 | 140.061 | 140.061 |
| 3 | 192.584 | 262.614 | 280.122 | 192.584 | 105.046 | 122.553 |
| 4 | 192.584 | 262.614 | 262.614 | 140.061 | 105.046 | 122.553 |
| 5 | 192.584 | 262.614 | 262.614 | 140.061 | 105.046 | 105.046 |
| 6 | 157.568 | 210.091 | 262.614 | 140.061 | 122.553 | 122.553 |
| 7 | 227.599 | 315.137 | 262.614 | 262.614 | 192.584 | 140.061 |
| 8 | 227.599 | 315.137 | 297.629 | 262.614 | 192.584 | 210.091 |
| 9 | 280.122 | 437.69 | 437.69 | 297.629 | 192.584 | 210.091 |
| 10 | 280.122 | 490.213 | 525.228 | 367.66 | 245.106 | 210.091 |
| 11 | 367.66 | 595.258 | 577.751 | 385.167 | 280.122 | 210.091 |
| 12 | 385.167 | 612.766 | 560.243 | 385.167 | 350.152 | 297.629 |
| 13 | 297.629 | 490.213 | 612.766 | 367.66 | 315.137 | 262.614 |
| 14 | 297.629 | 490.213 | 612.766 | 367.66 | 210.091 | 262.614 |
| 15 | 332.644 | 525.228 | 542.736 | 315.137 | 210.091 | 210.091 |
| 16 | 227.599 | 332.644 | 490.213 | 245.106 | 210.091 | 140.061 |
| 17 | 227.599 | 332.644 | 332.644 | 245.106 | 140.061 | 122.553 |
| 18 | 210.091 | 297.629 | 297.629 | 245.106 | 210.091 | 192.584 |
| 19 | 210.091 | 297.629 | 297.629 | 280.122 | 262.614 | 192.584 |
| 20 | 227.599 | 332.644 | 385.167 | 280.122 | 262.614 | 245.106 |
| 21 | 245.106 | 367.66 | 367.66 | 315.137 | 262.614 | 245.106 |
| 22 | 227.599 | 332.644 | 385.167 | 315.137 | 210.091 | 192.584 |
| 23 | 227.599 | 332.644 | 332.644 | 280.122 | 210.091 | 192.584 |

## 5.4 Various Factors of Power Systems

In this section, the various factors of power system such as connected load, maximum demand, demand factor, load factor, power factor, diversity factor, plant capacity factor are described with detail calculation for the specific area needed for power plant design.

### 5.4.1 Connected Load:

For calculating the connected load it is very important to know the total number of building, which type of equipment is used and how many equipment are present in that area. After estimating the number of equipment uses in every building and multiplied by their own rating the total connected load has been found. Tables 5.1, 5.2, 5.3 and 5.4 show the estimated number of equipment and connected load of every building for residential area of faculties and staff, others recreational buildings, academic buildings, residence of student (halls), respectively. Finally, the total connected load has been found and it is approximately 1683.39 kW.

### 5.4.2 Maximum Demand:

It is the greatest demand of load on the power station during a given period. It sometimes also called as "system peak". It is also called maximum demand [87]. The load on the power station varies from time to time. The maximum of all the demands that have occurred during a given period is the maximum demand. From Tables 5.5 and 5.6, it can be observed that the maximum demand occurs in July and it is 770.33 kW.

### 5.4.3 Demand Factor:

Demand factor is the ratio of the maximum load of a system to the total connected load of that system. For connecting the load to the transmission line, the demand factor permits a feeder-circuit ampere to be less than the total current of the sum of all branch-circuit loads that is connected to the feeder. Demand factor can be defined by the following equation [87].

$$\text{Demand Factor} = \frac{\text{Maximum load during a given period}}{\text{Total connected load on the system}} \quad \text{(5.1)}$$

Demand factor is always less than one. Lower demand factor means the less system capacity required to serve the connected load. In this research at the proposed area, connected load is 1683.39 kW with a maximum demand of 770.33 kW, thus the demand factor = 770.33 kW / 1683.39 kW = 45.76%.

### 5.4.4 Load Factor

Load factor can be calculated for a single day or month or yearly basis. The cost of energy will be lower for higher load factor because higher load factor implies that load duration curve is a relatively steady state in the pattern. In low load factor sudden increase of demand occurs as a result capacity of power system should set-up at a higher value. Electrical rates are designed so that customers with high load factor are charged less overall per kWh [88]. Load factor can be defined by the following equation

$$\text{Load Factor} = \frac{\text{Average load}}{\text{Maximum load during a given period}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.2)}$$

$$\text{Load factor of KUET area} = \frac{279.94}{770.33}$$

$$= 0.36$$

From the equation (5.2) it can be said that the value of load factor is always less than one as maximum demand is always more than average demand.

### 5.4.5 Power Factor

The ratio of the real power to the apparent power in a given circuit is called the power factor of an AC electrical power system [89, 90]. Power factor can be defined as by the following equation

$$\text{Power Factor} = \frac{\text{real power flowing to the load}}{\text{apparent power in the circuit}} = \frac{\text{kW}}{\text{KVA}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5.3)}$$

In another word, cosine angle of the angle between voltage and current is called power factor of a circuit. When this angle goes down to minimum value then the power factor becomes maximum level. With the increase of the phase difference between voltage and current, the power factor decreases. The capacity of the circuit to perform in a given period is called real power and the product of the voltage and current is called apparent power. When the load generates power which flows back to the source then negative power factor is occurred [91, 92]. As KUET has a constant load, the fluctuation of power factor is not wide. It ranges between 0.92 to 0.96 [86].

### 5.4.6 Diversity Factor:

The diversity factor is defined as the ratio of the sum of individual maximum demand to maximum demand of the system. In other words, the ratio of installed load to the running load is called diversity factor which can be illustrated by the following equation [87].

$$\text{Diversity factor} = \frac{\textbf{the}\text{ sum of individual maximum demands}}{\text{maximum demand of the system}} = \frac{\text{installed load}}{\text{running load}} \ldots\ldots\ (5.4)$$

Since installed load of a power system is greater than the running load, the diversity factor is always greater than one. The equation (5.4) also demonstrates that at higher diversity factor the cost of generation of power will be lower [87]. Suppose that one main feeder has two sub feeders; the sub feeder-1 has a demand of 36 kW and the sub feeder-2 has a demand of 43 kW and the maximum demand of the main feeder is 70 kW.

Total individual maximum demand =36+43=79 kW.
Maximum demand of whole system=70 kW
So, diversity factor of the system= 79/70 =1.128

### 5.4.7 Plant Capacity Factor and Renewable Energy

The plant capacity factor can be defined as the ratio of average demand to the plant capacity of the power system or it can be expressed as by the following equation [93, 94].

$$\text{Plant capacity Factor} = \frac{\text{Actual energy produced}}{\text{Maximum energy that could have been produced}}$$

$$= \frac{\text{Average demand}}{\text{Plant capacity}} \ldots\ldots\ (5.5)$$

The RE based power plant has lower plant capacity factor. When RE based power plant is in operation the output of that system may not be available due to the unavailability of RE sources although at this time the plant may capable of generating electricity. By the availability of wind resources, the capacity factor is determined. At present, capacity factors of wind farms vary between 25% and 45%, though recently by using tall hub height, the capacity factor of wind firm have been improved to 55% and in future, it is possible to reach at 65% of the capacity factor by implementing 140-meter towers [93, 94]. The capacity factor of the solar firm is lower because of the variability of solar radiation due to night, seasonal changes, and the cloudy environment. A 15% capacity factor is observed at Sacramento [95]. However, according to the Solar PACES program of the International Energy Agency (IEA), the higher capacity factor is observed by implementing solar power plants at only summer season to serve the excess load that is needed for cooling purposes at Spain and the south-western United States [96].

## 5.5 System Architecture/Methodology

This project investigates the implementation of an autonomous grid connected hybrid power system to serve the load at KUET. The microgrid consists of photovoltaic arrays, wind turbine, converter, power conditioner that keep the input voltage at the same level, grid system which act as a bidirectional system and serves the needs of the households, academic building, residential building, schools, etc. It is represented by Figure 5.2. The goal is to achieve a reliable and efficient operation of the micro-grid, covering the consumers' needs and successfully managing the power inside it. In order to achieve this, a representative model of the power system is essential. A valid, flexible and reliable model provides the basis for assessing the operation of a system like this, detecting its flaws, implementing different strategies and making the necessary adjustments to establish a system offering a good quality service to the people. In order to design a power system, the first thing to be done is to decide on the power demand, the consumption the system should satisfy and the potential extra services it should provide. The next step is to design the system which will be able to cover these loads; a process carried out in the HOMER software resulting in a techno-economically optimized configuration. This has as a prerequisite for finding data about local costs and equipment that is being traded in the region so that the result is as close to the real conditions as possible. Figure 5.3 shows the complete flow diagram for analyzing the renewable energy based hybrid power system. The flow chart shows how, in different contexts, the best techno-economic combination of RE resources are achieved through the modeling and simulation using HOMER software to combine the input data; the load profile, renewable energy resources and the equipment's cost for best configuration. The key components of this model shown in the flow chart of are the initial site assessment, data bank analysis, component selection, and grid parameters with their $CO_2$ emission rate to develop a methodology for finding the best techno-economic combination of RE resources in a hybrid power system for the proposed area.

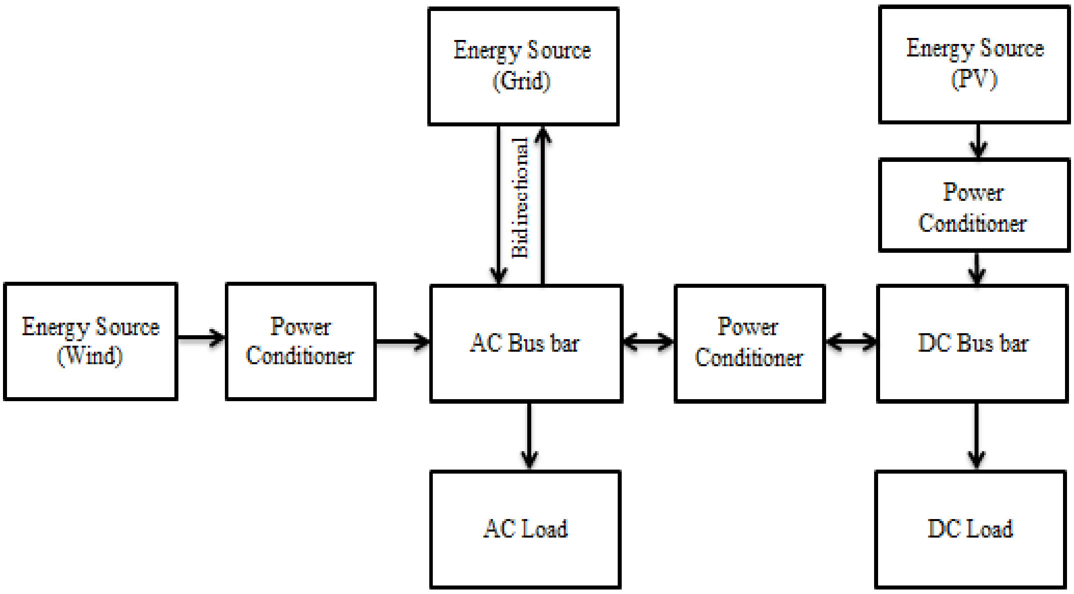



Fig 5.2: Block diagram of hybrid power plant model

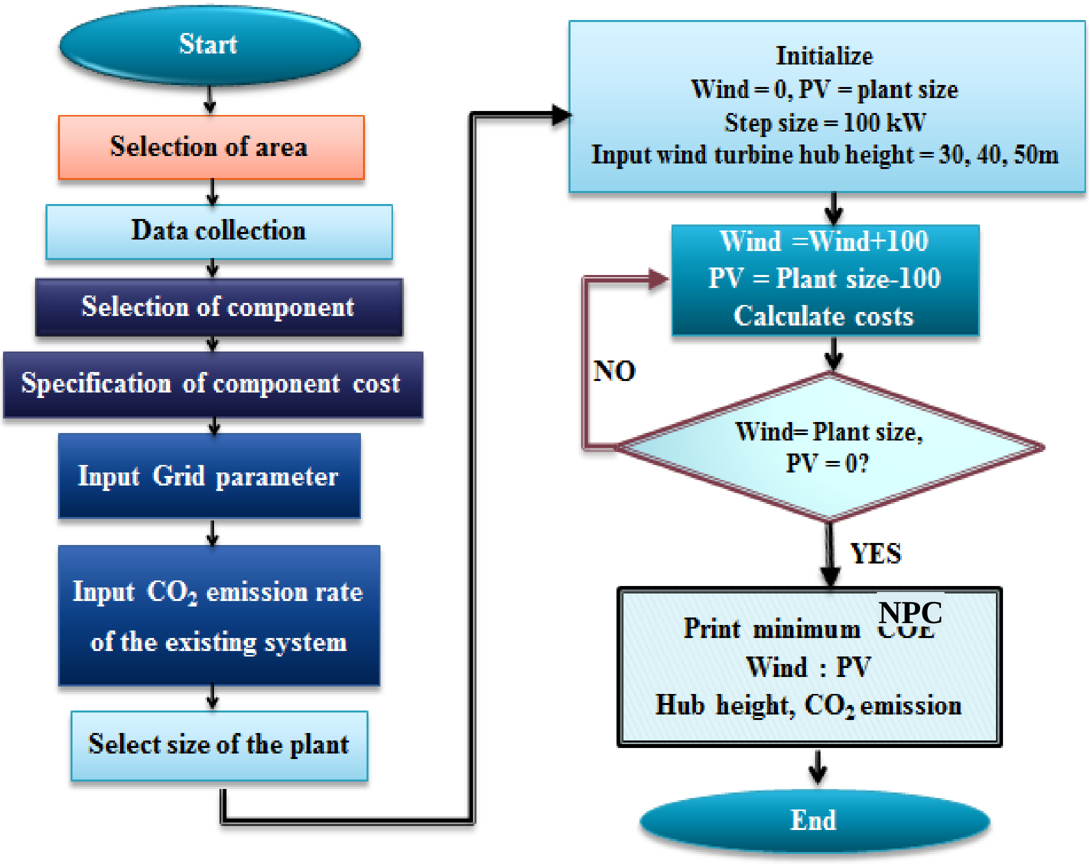



Fig 5.3: Flow chart of the proposed methodology

### 5.5.1 Area Selection and Land Requirement

The rooftop system is best for solar-based power system because of better solar irradiation, less dusty environment, the floor is ready to use as well as secure place [97]. As wind energy depends on wind speed and direction of wind flow, so it is important to plan where it should be implemented. For better performance, the wind turbine should be faced to south as maximum wind flow is observed from south to north at KUET. Although the wind flow is not quite high at KUET but it is enough to produce wind power [98]. For solar system, 100 $ft^2$ per 100 kW is needed for plant installation. The rooftops of the new academic building have enough space for implementing 1 MW, 2 MW even 3 MW plant. On the other hand, a 500 $ft^2$ land area is needed for 100 kW wind turbine [77, 78, 81].

### 5.5.2 Renewable Energy Resources in Khulna

Bangladesh is a country of great potential in RESs, mainly hydro, geothermal and solar, as well as wind and biomass in some parts of the country. In this case, the power sources will be a photovoltaic generator and wind turbine along with the grid system as a backup the source. The solar radiation, clearness index and wind speed data were acquired through various sources used as input to HOMER and are presented in the next section.

### 5.5.3 Wind Energy Resources

The wind energy potentials in Khulna region were collected and evaluated from Meteoblue [99]. Data collected over a period of years were used to statistically analyze wind speed distributions. It is important to know the number of hours per month or per year during which the given wind speeds occurred, i.e. the frequency distribution of wind speeds. In order to get this frequency distribution, it is necessary to divide the wind speed domain into a number of intervals. Then starting at the first interval, the number of hours is counted in the period concerned that the wind speed was in this interval. This velocity frequency distribution as the relative frequency is obtained from the velocity interval. Figure 5.4 shows the frequency distribution of wind speeds in Khulna from January to December above 20 m height. It also shows how many days within one month can reach certain wind speeds. For April to July, it is quite high but calm winds from August to March are obtained. Figure 5.5 shows the wind rose for Khulna region and it also indicates how many hours per year the wind blows from the indicated direction. From this figure, the maximum wind direction in a year is found South to North and South-South-East to North-North-West.

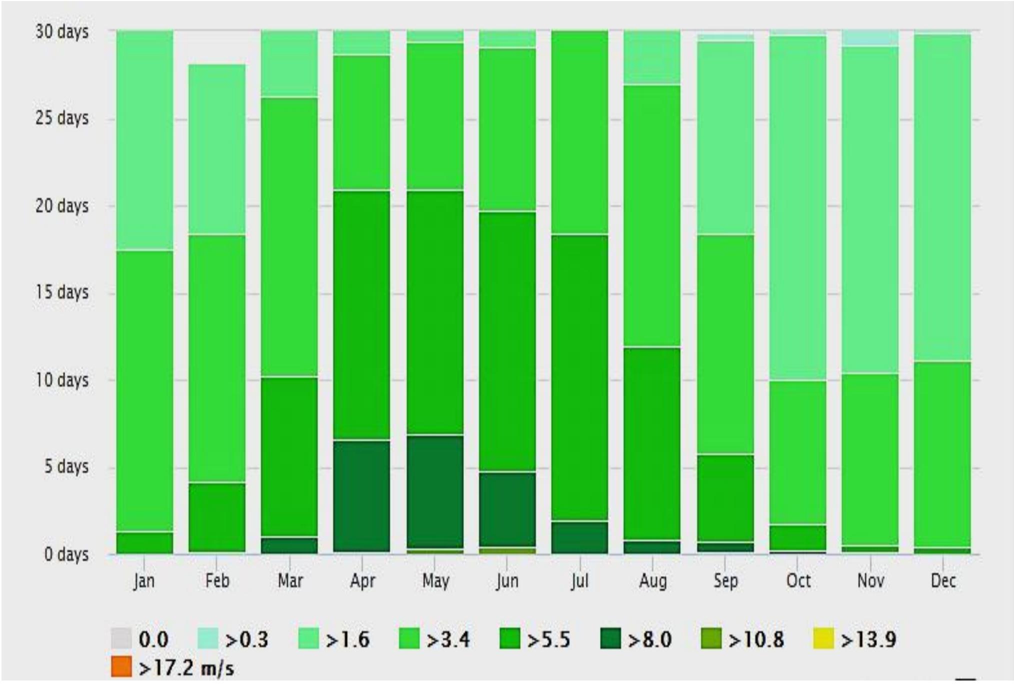



Fig.5.4: Frequency distribution of wind speeds in Khulna (Above 20 m height) [99].

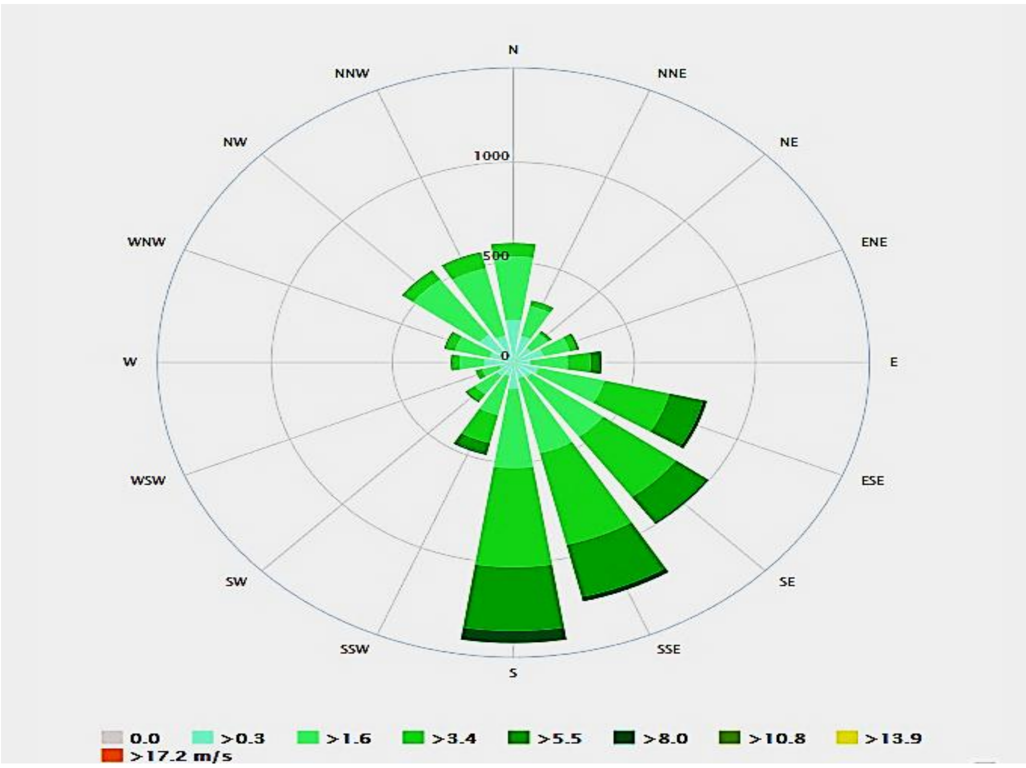



Fig.5.5: Wind Direction over a year in Khulna region [99].

### 5.5.4 Solar Energy Resources

For assessing the option of using solar (photovoltaic) power, solar resources need to be considered. The solar resource information used for the selected location at $22^0$54.3'N, $89^0$29.8'E was taken from the NASA Surface Meteorology [56]. Table 5.7 shows the monthly average daily solar radiation and clearness index for KUET area.

Table 5.7: Monthly average daily solar radiation and clearness index for KUET area

| month | Clearness Index | Daily Radiation(kWh/m$^2$/day) |
|---|---|---|
| **January** | 0.602 | 4.254 |
| **February** | 0.59 | 4.807 |
| **March** | 0.601 | 5.691 |
| **April** | 0.578 | 6.07 |
| **May** | 0.52 | 5.726 |
| **June** | 0.419 | 4.658 |
| **July** | 0.363 | 3.995 |
| **August** | 0.408 | 4.317 |
| **September** | 0.435 | 4.223 |
| **October** | 0.583 | 4.918 |
| **November** | 0.593 | 4.304 |
| **December** | 0.615 | 4.127 |
| **Average** | 0.525583 | 4.7575 |

Data on the monthly averages of the daily radiation and clearness index are plotted in Figure 5.6. The clearness is a measure of the fraction of the solar radiation that is transmitted through the atmosphere to the earth's surface. The annual average solar radiation was found to be 4.76 kWh/m$^2$/day and the average clearness index was found to be 0.525. From this figure, the peak solar radiation is observed in April but highest clearness index is found in the month of December.

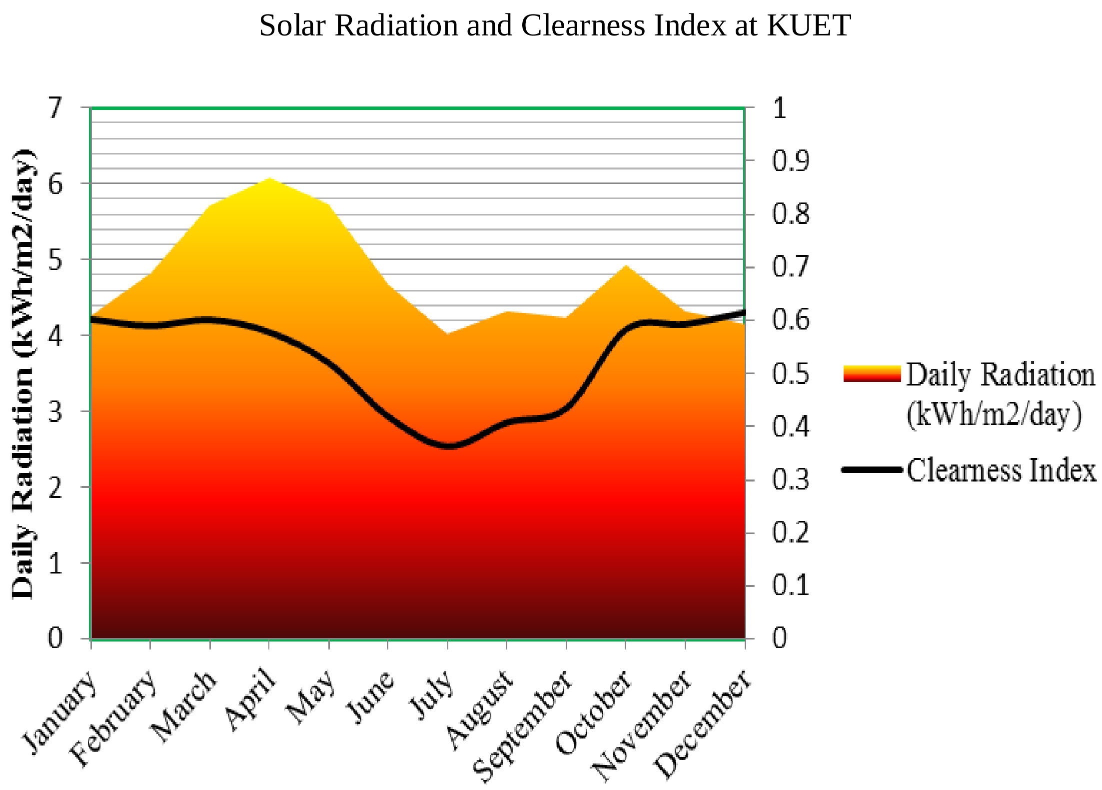



Fig.5.6: Monthly average daily solar radiation (kWh/m$^2$/day) and Clearness Index at KUET

### 5.5.5 Converter Size Selection for Specific Solar Panel

In this section, results of the techno-economical optimization for converter are presented and further adjustments and considerations are discussed. In previous case studies on renewable energy based power plant, the system uses the same size of the converter with the solar capacity. For a 100 kW solar panel, a 100 kW converter is used [100][101]. In this section, the analysis has been carried out for finding a best suited converter for the specific solar panel and results are shown in Appendix section. It is clear that for cost effective design, the converter does not need to be the same size of the solar panel. It may be lower than the solar panel. For every 100 kW solar panels, for a specific area, simulation process has been performed four times. Finally, suitable converter size for specific solar panel which is the most cost effective is obtained. Table 5.8 shows the suitable converter size for the selected solar panel.

Table 5.8: Converter size selection for specific solar panel

| PV (kW) | Converter (kW) | COE ($) | NPC ($) | Initial capital ($) |
|---|---|---|---|---|
| 100 | 75 | 0.1012662 | 3210298 | 171594.8 |
| 200 | 150 | 0.1025169 | 3250559 | 343189.5 |
| 300 | 225 | 0.103568 | 3292331 | 514784.3 |
| 400 | 275 | 0.1042126 | 3337955 | 681021.8 |
| 500 | 350 | 0.1038996 | 3389215 | 852616.5 |
| 600 | 425 | 0.1030072 | 3445495 | 1024211 |
| 700 | 475 | 0.102192 | 3505426 | 1190449 |
| 800 | 550 | 0.1006815 | 3567184 | 1362044 |
| 900 | 625 | 0.0989942 | 3631707 | 1533638 |
| 1000 | 700 | 0.09712553 | 3699248 | 1705233 |
| 1100 | 750 | 0.09565477 | 3768507 | 1871471 |
| 1200 | 825 | 0.09366576 | 3839668 | 2043065 |
| 1300 | 900 | 0.09171402 | 3912352 | 2214660 |
| 1400 | 950 | 0.09025752 | 3985851 | 2380898 |
| 1500 | 1025 | 0.08843579 | 4059938 | 2552492 |
| 1600 | 1100 | 0.08671102 | 4134701 | 2724087 |
| 1700 | 1175 | 0.08508768 | 4209953 | 2895682 |
| 1800 | 1225 | 0.0838865 | 4285570 | 3061919 |
| 1900 | 1300 | 0.08240982 | 4361467 | 3233514 |
| 2000 | 1375 | 0.08102023 | 4437711 | 3405109 |
| 2100 | 1450 | 0.07971068 | 4514279 | 3576704 |
| 2200 | 1500 | 0.07874536 | 4591065 | 3742941 |
| 2300 | 1575 | 0.07755716 | 4667945 | 3914536 |
| 2400 | 1650 | 0.07643634 | 4745048 | 4086131 |
| 2500 | 1725 | 0.07537708 | 4822362 | 4257725 |
| 2600 | 1775 | 0.07460269 | 4899778 | 4423963 |
| 2700 | 1850 | 0.07363683 | 4977262 | 4595558 |
| 2800 | 1925 | 0.0727224 | 5054894 | 4767152 |
| 2900 | 2000 | 0.07185455 | 5132685 | 4938747 |
| 3000 | 2050 | 0.07122537 | 5210530 | 5104985 |

### 5.5.6 Hybrid System Modeling

This section presents the modeling of a hybrid system using the optimization software called HOMER. The model starts by putting the important inputs (resources data and the costs) that demonstrate the technical specifications which are described briefly in the previous section, which is relevant for modeling the system in HOMER. Figure 5.7 shows the scheme of the hybrid power system modeled using HOMER software.

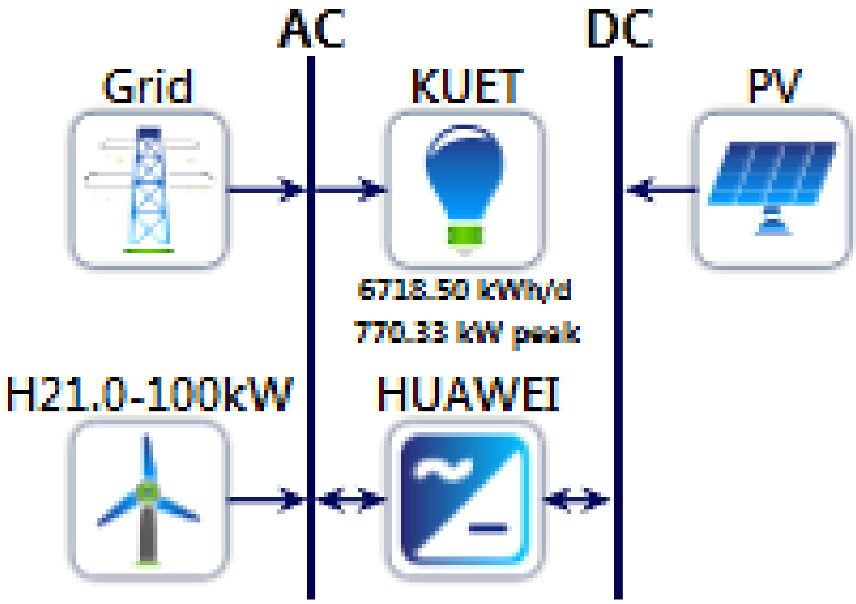



**Fig.5.7:** The scheme of the hybrid power system

## 5.6 Simulation Results for Various System Models

In this section, the results of the techno-economical optimization are presented. The simulation has been done in four steps by varying the plant size. For every step, after running the simulation by varying the PV-wind ratio and observing the output of every simulation, optimum results have been found for the specific plant size. The output results are tabulated in Tables 5.9, 5.10, 5.11, and 5.12 for 1 MW, 1.5, 2 MW and 3 MW power plant, respectively. For 1 MW power plant, the best PV-Wind ratio is observed 8:2 as they have minimum Net present cost (NPC) that is shown in Figure 5.8. Also, 10:5 is found as the best mixer of PV-Wind for 1.5 MW power plant which is shown in Figure 5.9. The optimum PV-Wind ratio for 2 MW and 3 MW is observed 15:5 and 24:6, respectively. Figures 5.10 and 5.11 show the optimum solution for 2 MW and 3 MW power plants, respectively.

Table 5.9: Simulation results for 1 MW power plant

| PV (kW) | H21.0-100kW | Grid (kW) | HUAWEI (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| 0 | 10 | 999999 | 0 | 0.105306 | 3369868 | 1800009 | 54.65211 | 595347.8 |
| 100 | 9 | 999999 | 75 | 0.106205 | 3348473 | 1791602 | 55.54696 | 594037.9 |
| 200 | 8 | 999999 | 150 | 0.10685 | 3329087 | 1783196 | 56.28692 | 592727.9 |
| 300 | 7 | 999999 | 225 | 0.106991 | 3313378 | 1774790 | 56.70608 | 591418.1 |
| 400 | 6 | 999999 | 275 | 0.106763 | 3301030 | 1761027 | 56.38049 | 598442.1 |
| 500 | 5 | 999999 | 350 | 0.105693 | 3293267 | 1752621 | 56.04335 | 596800.4 |
| 600 | 4 | 999999 | 425 | 0.104214 | 3288930 | 1744215 | 55.42092 | 595274.6 |
| 700 | 3 | 999999 | 475 | 0.102919 | 3286988 | 1730451 | 54.30345 | 603308.1 |
| 800 | 2 | 999999 | 550 | 0.100918 | 3286825 | 1722045 | 53.35004 | 601536.4 |
| 900 | 1 | 999999 | 700 | 0.097944 | 3299848 | 1729711 | 52.87681 | 577574.6 |
| 1000 | 0 | 999999 | 700 | 0.096509 | 3292687 | 1705233 | 51.10453 | 598253.1 |

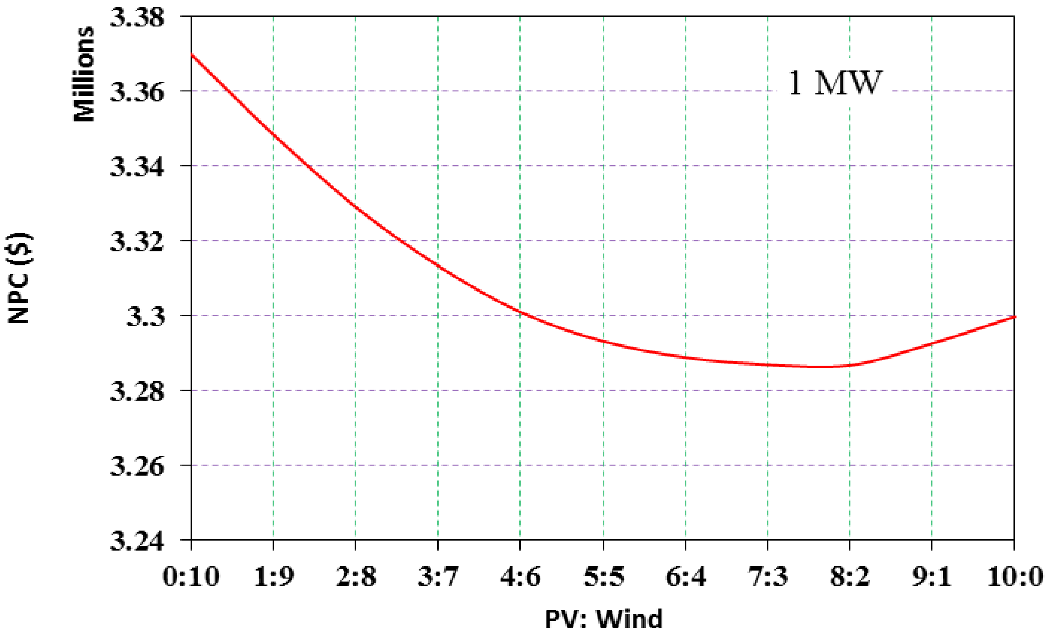



Fig: 5.8: NPC ($) vs. PV-wind ratio for 1 MW power plant

Table 5.10: Simulation results for 1.5 MW power plant

| PV (kW) | H21.0 100kW | Grid (kW) | HUAWEI (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ emission (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| **0** | 15 | 999999 | 0 | 0.100022 | 3698378 | 2700013 | 70.94868 | 118109.3 |
| **100** | 14 | 999999 | 75 | 0.100874 | 3675690 | 2691607 | 72.06008 | 116799.4 |
| **200** | 13 | 999999 | 150 | 0.101477 | 3655412 | 2683201 | 72.95973 | 115489.5 |
| **300** | 12 | 999999 | 225 | 0.101662 | 3638904 | 2674795 | 73.49146 | 114179.6 |
| **400** | 11 | 999999 | 275 | 0.101718 | 3624272 | 2661031 | 73.46776 | 121203.6 |
| **500** | 10 | 999999 | 350 | 0.101149 | 3613618 | 2652625 | 73.35631 | 119562 |
| **600** | 9 | 999999 | 425 | 0.10034 | 3605392 | 2644219 | 73.01363 | 118036.1 |
| **700** | 8 | 999999 | 475 | 0.099746 | 3598854 | 2630456 | 72.30505 | 126069.6 |
| **800** | 7 | 999999 | 550 | 0.098503 | 3594221 | 2622050 | 71.58532 | 124298 |
| **900** | 6 | 999999 | 625 | 0.097104 | 3591590 | 2613643 | 70.7027 | 122630.3 |
| **1000** | 5 | 999999 | 700 | 0.095578 | 3590705 | 2605237 | 69.68772 | 121014.6 |
| **1100** | 4 | 999999 | 750 | 0.094389 | 3590880 | 2591474 | 68.42551 | 129146.1 |
| **1200** | 3 | 999999 | 825 | 0.092652 | 3592798 | 2583068 | 67.21312 | 127392.3 |
| **1300** | 2 | 999999 | 900 | 0.090878 | 3596013 | 2574662 | 65.94554 | 125713.3 |
| **1400** | 1 | 999999 | 950 | 0.089483 | 3600327 | 2560898 | 64.47645 | 134030 |
| **1500** | 0 | 999999 | 1025 | 0.087668 | 3605265 | 2552492 | 63.16243 | 132229.7 |

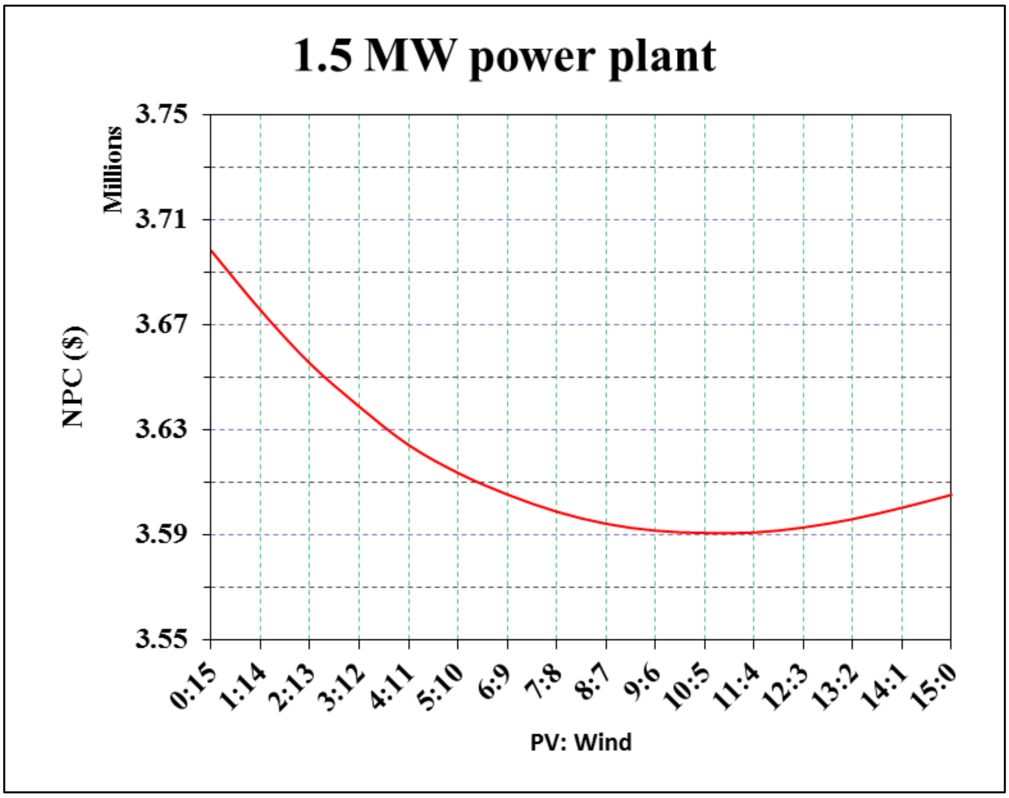



Fig: 5.9: NPC ($) vs. PV-wind ratio for 1.5 MW power plant

Table 5.11: Simulation results for 2 MW power plant

| PV (kW) | H21.0-100kW | Grid (kW) | HUAWEI (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ emission (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| **0** | 20 | 999999 | 0 | 0.093879 | 4050880 | 3600017 | 81 | -359129 |
| **100** | 19 | 999999 | 75 | 0.094477 | 4028798 | 3591611 | 82 | -360439 |
| **200** | 18 | 999999 | 150 | 0.094852 | 4009384 | 3583205 | 82 | -361749 |
| **300** | 17 | 999999 | 225 | 0.094955 | 3993088 | 3574799 | 83 | -363059 |
| **400** | 16 | 999999 | 275 | 0.095043 | 3977712 | 3561035 | 83 | -356035 |
| **500** | 15 | 999999 | 350 | 0.094682 | 3965835 | 3552629 | 83 | -357677 |
| **600** | 14 | 999999 | 425 | 0.09418 | 3955837 | 3544223 | 83 | -359202 |
| **700** | 13 | 999999 | 475 | 0.093905 | 3946878 | 3530460 | 82 | -351169 |
| **800** | 12 | 999999 | 550 | 0.09313 | 3939486 | 3522054 | 82 | -352941 |
| **900** | 11 | 999999 | 625 | 0.092271 | 3933449 | 3513648 | 81 | -354608 |
| **1000** | 10 | 999999 | 700 | 0.091339 | 3928577 | 3505242 | 81 | -356224 |
| **1100** | 9 | 999999 | 750 | 0.090708 | 3924278 | 3491478 | 80 | -348092 |
| **1200** | 8 | 999999 | 825 | 0.089634 | 3921206 | 3483072 | 79 | -349846 |
| **1300** | 7 | 999999 | 900 | 0.088508 | 3919263 | 3474666 | 78 | -351525 |
| **1400** | 6 | 999999 | 950 | 0.087693 | 3918286 | 3460903 | 77 | -343209 |
| **1500** | 5 | 999999 | 1025 | 0.086455 | 3918217 | 3452497 | 76 | -345009 |
| **1600** | 4 | 999999 | 1100 | 0.085193 | 3919116 | 3444091 | 75 | -346752 |
| **1700** | 3 | 999999 | 1175 | 0.083889 | 3921292 | 3435684 | 74 | -348440 |
| **1800** | 2 | 999999 | 1225 | 0.082879 | 3924436 | 3421921 | 73 | -340135 |
| **1900** | 1 | 999999 | 1300 | 0.081515 | 3928434 | 3413515 | 71 | -341921 |
| **2000** | 0 | 999999 | 1375 | 0.080162 | 3933146 | 3405109 | 70 | -343658 |

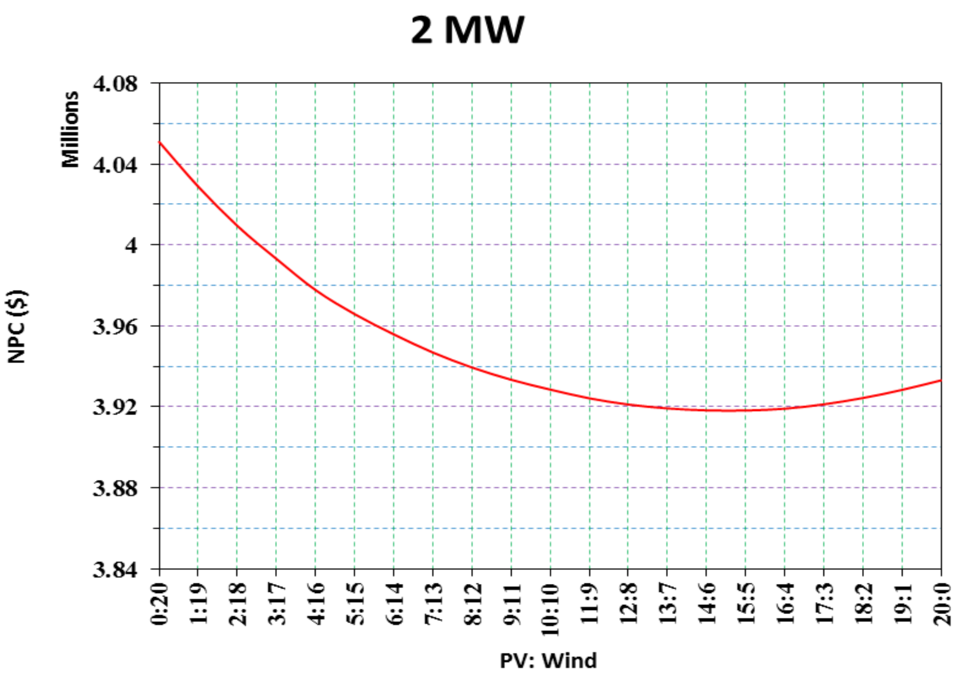



Fig: 5.10: NPC ($) vs. PV-wind ratio for 2 MW power plant

Table 5.12: Simulation results for 3 MW power plant at KUET

| PV (kW) | H21.0 - 100kW | Grid (kW) | HUAWEI (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ emission (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| 0 | 30 | 999999 | 0 | 0.08331 | 4797675 | 5400026 | 91.10784 | -1313606 |
| 100 | 29 | 999999 | 75 | 0.08353 | 4777985 | 5391620 | 91.76632 | -1314916 |
| 200 | 28 | 999999 | 150 | 0.083628 | 4760516 | 5383214 | 92.2534 | -1316226 |
| 300 | 27 | 999999 | 225 | 0.083601 | 4745282 | 5374807 | 92.56263 | -1317536 |
| 400 | 26 | 999999 | 275 | 0.083631 | 4729823 | 5361044 | 92.6706 | -1310512 |
| 500 | 25 | 999999 | 350 | 0.083404 | 4717361 | 5352638 | 92.71595 | -1312153 |
| 600 | 24 | 999999 | 425 | 0.08312 | 4706194 | 5344232 | 92.66895 | -1313679 |
| 700 | 23 | 999999 | 475 | 0.08303 | 4695280 | 5330469 | 92.52372 | -1305646 |
| 800 | 22 | 999999 | 550 | 0.08265 | 4685257 | 5322062 | 92.35475 | -1307417 |
| 900 | 21 | 999999 | 625 | 0.082247 | 4675939 | 5313656 | 92.14153 | -1309085 |
| 1000 | 20 | 999999 | 700 | 0.081825 | 4667148 | 5305250 | 91.8931 | -1310701 |
| 1100 | 19 | 999999 | 750 | 0.081632 | 4658370 | 5291487 | 91.5876 | -1302569 |
| 1200 | 18 | 999999 | 825 | 0.081165 | 4650138 | 5283081 | 91.28155 | -1304323 |
| 1300 | 17 | 999999 | 900 | 0.080683 | 4642454 | 5274675 | 90.94305 | -1306002 |
| 1400 | 16 | 999999 | 950 | 0.080438 | 4635167 | 5260911 | 90.54417 | -1297685 |
| 1500 | 15 | 999999 | 1025 | 0.079912 | 4628137 | 5252505 | 90.14634 | -1299486 |
| 1600 | 14 | 999999 | 1100 | 0.079371 | 4621660 | 5244099 | 89.71622 | -1301229 |
| 1700 | 13 | 999999 | 1175 | 0.078814 | 4615755 | 5235693 | 89.25307 | -1302917 |
| 1800 | 12 | 999999 | 1225 | 0.07848 | 4610342 | 5221930 | 88.72049 | -1294612 |
| 1900 | 11 | 999999 | 1300 | 0.077874 | 4605400 | 5213524 | 88.18488 | -1296398 |
| 2000 | 10 | 999999 | 1375 | 0.077247 | 4601176 | 5205117 | 87.60854 | -1298135 |
| 2100 | 9 | 999999 | 1450 | 0.076598 | 4597702 | 5196711 | 86.99056 | -1299827 |
| 2200 | 8 | 999999 | 1500 | 0.076149 | 4595053 | 5182948 | 86.27866 | -1291533 |
| 2300 | 7 | 999999 | 1575 | 0.075434 | 4593209 | 5174542 | 85.55577 | -1293307 |
| 2400 | 6 | 999999 | 1650 | 0.074697 | 4592241 | 5166136 | 84.78943 | -1295040 |
| 2500 | 5 | 999999 | 1725 | 0.073934 | 4592298 | 5157730 | 83.9718 | -1296736 |
| 2600 | 4 | 999999 | 1775 | 0.073366 | 4593068 | 5143966 | 83.07082 | -1288451 |
| 2700 | 3 | 999999 | 1850 | 0.072555 | 4594743 | 5135560 | 82.17356 | -1290216 |
| 2800 | 2 | 999999 | 1925 | 0.071734 | 4597213 | 5127154 | 81.24928 | -1291946 |
| 2900 | 1 | 999999 | 2000 | 0.0709 | 4600563 | 5118748 | 80.2949 | -1293644 |
| 3000 | 0 | 999999 | 2050 | 0.070262 | 4604381 | 5104985 | 79.27441 | -1285365 |

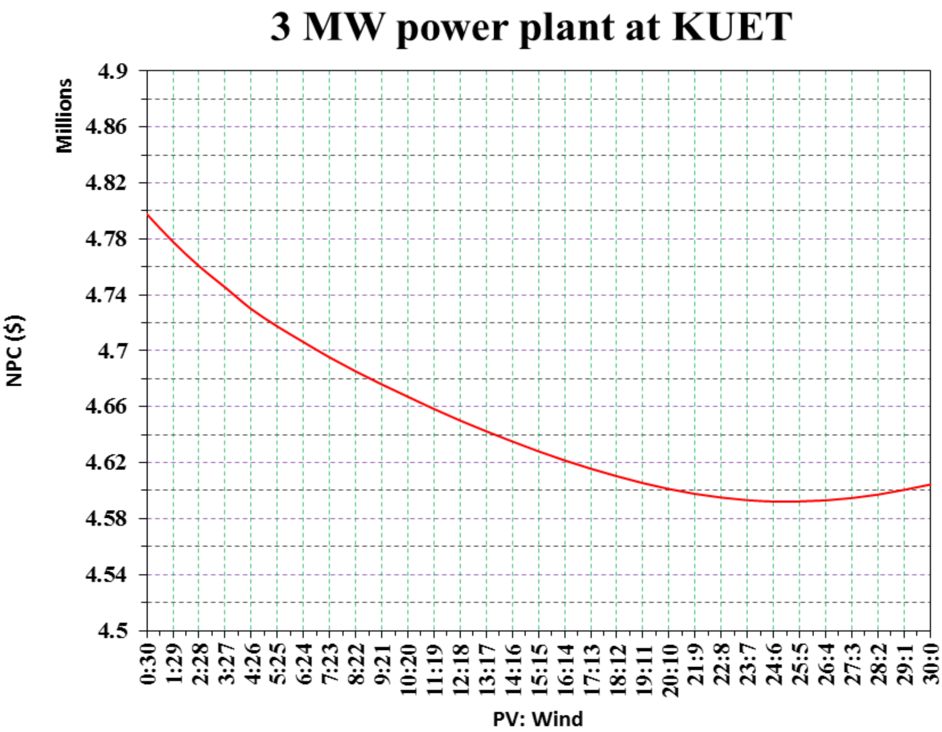



Fig: 5.11: NPC ($) vs. PV-wind ratio for 3 MW power plant

### 5.6.1 Comparison of Various System Models

In this section, a brief comparative result has been shown in Table 5.13 and Fig. 5.12 for better understanding to the reader as they can find which model is best with respect to various cost parameters. First column of the Table 5.13 indicates the proposed hybrid model "plant size" where solar power contributes 80% of the total renewable power generation for 1 MW plant but with the increase of the plant size, wind contribution increases hence solar contribution decreases which is shown in column two and three. Fifth column of the table "HUAWEI (kW)" shows the converter rating that is used for various power system models. From this results it can be clearly understood that using about 30% lower converter size than the PV capacity gives the greater economic benefits. Next columns of the table demonstrated chronologically the cost of energy (energy unit price in dollar), net present cost (NPC), initial capital cost that is plotted in Figure 5.12 which gives the simple description of the cost analysis of various models in one figure. Figure 5.12 clearly shows that with the increase of plant size from 1 MW to 3 MW, the cost of energy is falls $0.10 to $0.074 but net present cost of plant increases from $1.72 million to $5.16 million which is three times than the initial value. This figure also describes that the cost of energy of 1 MW power plant is slightly higher than the grid levelized unit price but after increasing the plant size it goes down under the levelized cost of energy. For 1.5 MW plant, the cost of energy is found almost same as the levelized cost of energy. But for 2 MW plant, the cost of energy is found almost 11% lower than the levelized cost value and for 3 MW plant it is about 24% lower value than the levelized cost of energy. Although for a 2 MW power plant COE is less than 1.5 MW plant however, NPC is quite high. Considering NPC and COE, it can be said that 1.5 MW is most suitable in the considered place.

Table 5.13: Comparative results for various system architecture.

| System | PV (kW) | H21.0-100kW | Grid (kW) | HUA WEI (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) |
|---|---|---|---|---|---|---|---|---|---|
| **1 MW** | 800 | 2 | 999999 | 550 | 0.100 | 3286825 | 1722045 | 53 | 601536.4 |
| **1.5 MW** | 1000 | 5 | 999999 | 700 | 0.095 | 3590705 | 2605237 | 69 | 121014.6 |
| **2 MW** | 1500 | 5 | 999999 | 1025 | 0.086 | 3918217 | 3452497 | 76 | -345009 |
| **3 MW** | 2400 | 6 | 999999 | 1650 | 0.074 | 4592241 | 5166136 | 84 | -1295040 |

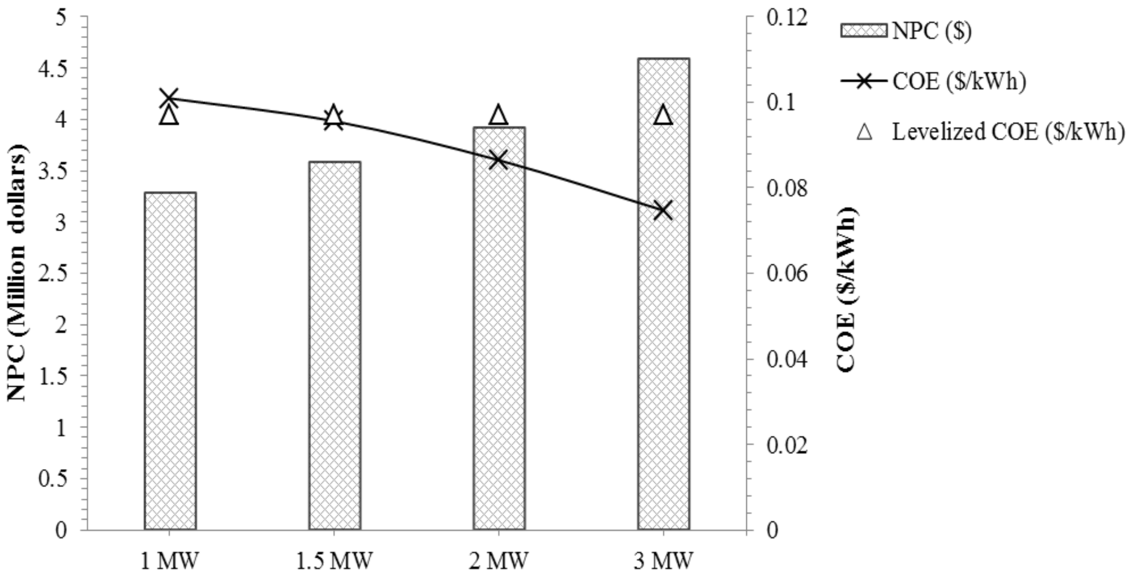



Fig: 5.12: NPC ($), COE ($/kWh) vs. PV-wind ratio for various system architectures

### 5.6.2 $CO_2$ Reduction

In Bangladesh, most of the powers are generated from natural gas which produces a huge amount of greenhouse gas at a rate of 540 kg/kWh. At present KUET consumers are using electricity from the utility grid system that produces about 1324 tons/yr $CO_2$. The insertion of grid-connected renewable based hybrid power system instead of the only grid system (existing system) would yield 601.53 tons of $CO_2$ emission for 1 MW hybrid power plant which is 55% less than the existing system. Table 5.14 shows the $CO_2$ emission for 1.5 MW is 121 tons, which is 90% less than the only grid system. For 2 MW and 3 MW power plants it is about 126% and 197% less than the existing system, respectively. For 2 MW and 3 MW plants, negative $CO_2$ occurs because the system sells more energy to the grid than the purchases.

Table 5.14: $CO_2$ emission for various system architectures.

| System | $CO_2$ (kg/yr) |
|---|---|
| **1 MW** | **601536.4** |
| **1.5 MW** | **121014.6** |
| **2 MW** | **-345009** |
| **3 MW** | **-1295040** |

### 5.7 Conclusion:

The crucial objective of this chapter was to find the best techno-economic solution for MW-scale renewable energy based hybrid power plant at KUET. Also, a suitable converter size for the specific solar panel has been determined. To determine the optimum result, the simulation results have been carried out on the basis of NPC and finally, a MW scale RE based hybrid power plant with suitable PV:Wind ratio for the specific area has been determined. For obtaining the best mixer of the wind turbine and the solar panel the PV and wind ratio is determined as 4:1 for 1 MW, 2:1 for 1.5 MW, 3:1 for 2 MW and 4:1 for 3 MW plant. As a final point, it can be concluded that this type of model can be able to save the Mega tone scale natural gas, able to reduce the COE, GHG emission as well as a dependency on grid systems.

# CHAPTER VI

# Conclusion

### 6.1 Conclusion

This thesis conducts a feasibility analysis to explore the potentialities of green energy at different locations in Bangladesh. The comparative analysis between off-grid and on-grid model shows that the grid-connected hybrid (PV/wind) system is more efficient and economic compared to the traditional hybrid system (PV/Wind/Battery) for the same load. From the simulation results, it is also investigated that the cost of energy of the proposed model is found less than the off-grid model and also less than the levelized grid cost of energy. Although the off-grid hybrid system uses 100% renewable energy, it needs an extra-large battery bank for storage of electricity. On the other hand, the excess output power of off-grid system goes unused. A grid connected hybrid system does not require an extra battery bank in normal operating condition and the excess power that is produced by renewable energy are added to the grid.

Initially, this thesis has been carried out by investigating the potentialities of green energy at the various location of Bangladesh particularly Kuakata, Magnamaghat, Sitakunda, Rangpur, Dinajpur, and Khulna. After that load estimation has been done by analyzing various studies for a particular region and adding random variability that makes the estimated load consumption in more realistic form. Insertion of a practical case like KUET area, load estimation of this research becomes more real. Considering the various parameters like component specification with their cost, financial aspects with ideal values, simulation works have been carried out. By analyzing the simulation result, it is found that the proposed 1 MW hybrid models with 87% renewable fraction are most suitable for Kuakata, 89% for Magnamaghat, 94% for Sitakunda, 68% for Dinajpur and

77% for Rangpur are economical and eco-friendly than the other models. For 2 MW hybrid power system model it's about 95%, 96%, 97%, 81% and 87%, respectively for the considered regions. For KUET area, the optimum solution is found 53%, 69%, 76% and 84% renewable fraction, repectively for 1 MW, 1.5 MW, 2 MW and 3 MW power system models. It can also be concluded that the proper utilization of renewable energy reduces an enormous amount of $CO_2$ emission in the atmosphere. It is investigated that although a hybrid model with 100% renewable fraction (off-grid) emits zero kg greenhouse gas, it is not always cost effective. Therefore, it can be said that the proposed grid connected hybrid power system is most suitable and cost effective as it offers several benefits.

## 6.2 Future Directions

This thesis includes only the potential of solar and wind energy in five locations of Bangladesh. The analysis could be extended to other renewable energy sources available in Bangladesh. The dynamic analysis with detail models of the RE resources could be conducted along with the application of different types of disturbances.

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# Appendix A

## Table A-1: Winter season load consumption scenario for Dinajpur.

| hourly load consumption for dinajpur (November to february) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residential Load | | | | | | time (h) | | | | | | | | | | | | | | | | | | | | | | | | |
| type | no of house hold | apliance type | Rating (W) | No of appliance | total power (W) | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 | |
| high class house hold | 50 | Light | 20 | 6 | 6000 | | | | | | | | | | | | | | | | | | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | |
| | | Fan | 60 | 3 | 9000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | TV | 110 | 1 | 5500 | | | | | | | | | | | | | | | | | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | |
| | | Computer | 110 | 1 | 5500 | | | | | | | | | | | | | | | | | | | | 5500 | 5500 | 5500 | | | |
| | | Iron | 750 | 1 | 37500 | | | | | | | | | | | | | | | | | | 37500 | | | | | | | |
| | | Rice coocker | 1000 | 1 | 50000 | | | | | | | | 50000 | | | | | | | | | | | | 50000 | | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 1 | 37500 | | | | | | | | | 37500 | | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| medium class house hold | 200 | Light | 20 | 4 | 16000 | | | | | | | | | | | | | | | | | | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | |
| | | Fan | 60 | 2 | 24000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | TV | 110 | 1 | 22000 | | | | | | | | | | | | | | | | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 1 | 200000 | | | | | | | | 100000 | | | | | | | | | | | | 100000 | | | | | |
| | | Refrigerator | 250 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/medium class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| low class house hold | 50 | Light | 20 | 4 | 4000 | | | | | | | | | | | | | | | | | | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | |
| | | Fan | 60 | 2 | 6000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | TV | 110 | 1 | 5500 | | | | | | | | | | | | | | | | | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/low class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Public and comercial load | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| School | 2 | Light | 20 | 15 | 600 | | | | | | | | | | 600 | 600 | 600 | | | | | | | | | | | | | |
| | | Fan | 60 | 15 | 1800 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | TV | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 1 | 220 | | | | | | | | | | 220 | 220 | 220 | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| health centre | 1 | Light | 20 | 8 | 160 | | | | | | | | | 160 | 160 | 160 | 160 | 160 | | | | | | 160 | 160 | 160 | | | | |
| | | Fan | 60 | 8 | 480 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | TV | 110 | 1 | 110 | | | | | | | | | 110 | 110 | 110 | 110 | | | | | | 110 | 110 | 110 | 110 | | | | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | lab equipment | 1000 | 1 | 1000 | | | | | | | | | | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | | | | |
| | | others | 250 | 1 | 250 | | | | | | | | | 250 | 250 | 250 | 250 | 250 | 250 | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 250 | | | | | | | 250 | | 250 | | 250 | | 250 | | 250 | | 250 | | 250 | | 250 | | | | |
| | | Water pumps | 750 | 1 | 750 | | | | | | | | | 750 | | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| commercial load (shops) | 50 | Light | 20 | 2 | 2000 | | | | | | | | | | 2000 | 2000 | 2000 | | | | | | 2000 | 2000 | 2000 | | | | | |
| | | Fan | 60 | 1 | 3000 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | TV | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/shop | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Street light | | Light | 100 | 300 | 30000 | 30000 | 30000 | 30000 | 30000 | | | | | | | | | | | | | | | 30000 | 30000 | 30000 | 30000 | 30000 | 30000 | |
| | | | total kWh | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| irrigation pump for winter season | | pump | 1100 | 90 | 99000 | 99000 | 99000 | 99000 | 99000 | 99000 | 99000 | 99000 | | | | | | | | | | | | | | | | | 99000 | |
| | | | total Wh | | | 154000 | 154000 | 154000 | 154000 | 124000 | 124000 | 124250 | 175000 | 64020 | 29340 | 29590 | 29340 | 26660 | 26250 | 26250 | 26000 | 59250 | 124610 | 117520 | 272770 | 121020 | 119500 | 114000 | 213000 | 2562370 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | kWh | 2562.37 |

# Table A-2: Summer season load consumption scenario for Dinajpur.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | hourly load consumption for dinajpur (March to October) | | | | | | | | | | | | | | | | | | | | | | | | |
| Residential Load | | | | | | time (h) | | | | | | | | | | | | | | | | | | | | | | | | |
| type | no of house hold | apliance type | Rating (W) | No of appliance | total power (W) | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 | |
| high class house hold | 50 | Light | 20 | 6 | 6000 | | | | | | | | | | | | | | | | | | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | |
| | | Fan | 60 | 3 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | |
| | | TV | 110 | 1 | 5500 | | | | | | | | | | | | | | | | | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | |
| | | Computer | 110 | 1 | 5500 | | | | | | | | | | | | | | | | | | | | 5500 | 5500 | 5500 | | | |
| | | Iron | 750 | 1 | 37500 | | | | | | | | | | | | | | | | | | 37500 | | | | | | | |
| | | Rice coocker | 1000 | 1 | 50000 | | | | | | | | 50000 | | | | | | | | | | | | 50000 | | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 1 | 37500 | | | | | | | | | | 37500 | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| medium class house hold | 200 | Light | 20 | 4 | 16000 | | | | | | | | | | | | | | | | | | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | |
| | | Fan | 60 | 2 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | 24000 | |
| | | TV | 110 | 1 | 22000 | | | | | | | | | | | | | | | | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 1 | 200000 | | | | | | | | | 100000 | | | | | | | | | | | | 100000 | | | | |
| | | Refrigerator | 250 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/medium class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| low class house hold | 50 | Light | 20 | 4 | 4000 | | | | | | | | | | | | | | | | | | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | 4000 | |
| | | Fan | 60 | 2 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | 6000 | |
| | | TV | 110 | 1 | 5500 | | | | | | | | | | | | | | | | | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | 5500 | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/low class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Public and comercial load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| School | 2 | Light | 20 | 15 | 600 | | | | | | | | | | 600 | 600 | 600 | | | | | | | | | | | | | |
| | | Fan | 60 | 15 | 1800 | | | | | | | | | | 1800 | 1800 | 1800 | 1800 | | | | | | | | | | | | |
| | | TV | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 1 | 220 | | | | | | | | | | 220 | 220 | 220 | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| health centre | 1 | Light | 20 | 8 | 160 | | | | | | | | | 160 | 160 | 160 | 160 | 160 | | | | | | 160 | 160 | 160 | | | | |
| | | Fan | 60 | 8 | 480 | | | | | | | | | | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | | | | | |
| | | TV | 110 | 1 | 110 | | | | | | | | | 110 | 110 | 110 | 110 | | | | | | 110 | 110 | 110 | 110 | | | | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | lab equipment | 1000 | 1 | 1000 | | | | | | | | | | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | | | | |
| | | others | 250 | 1 | 250 | | | | | | | | | 250 | 250 | 250 | 250 | 250 | 250 | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 250 | | | | | | | 250 | | 250 | | 250 | | 250 | | 250 | | 250 | | 250 | | 250 | | | | |
| | | Water pumps | 750 | 1 | 750 | | | | | | | | | 750 | | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| commercial load (shops) | 50 | Light | 20 | 2 | 2000 | | | | | | | | | | 2000 | 2000 | 2000 | | | | | | 2000 | 2000 | 2000 | | | | | |
| | | Fan | 60 | 1 | 3000 | | | | | | | | | | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | | | | | | |
| | | TV | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice coocker | 1000 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day/shop | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Street light | | Light | 100 | 300 | 30000 | 30000 | 30000 | 30000 | 30000 | | | | | | | | | | | | | | | 30000 | 30000 | 30000 | 30000 | 30000 | 30000 | |
| | | total kWh | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| irrigation pump for winter season | | pump | 1100 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total Wh | | | | 94000 | 94000 | 94000 | 94000 | 64000 | 64000 | 64250 | 114000 | 165520 | 111120 | 73870 | 73620 | 70940 | 68730 | 68730 | 68480 | 101730 | 167090 | 160000 | 212250 | 260020 | 158500 | 153000 | 153000 | 2748850 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | kWh | 2748.85 |

**Table A-3: Hourly load consumption scenario for Chilmari, Rangpur.**

| **Total kWh/day for Dinajpur (summer season)** | | | | **Total kWh/day for Dinajpur (Winter season)** | | | |
|---|---|---|---|---|---|---|---|
| **Time (hour)** | | | Consumption for March to October (kWh) | Time (hour) | | | Consumption for November to February (kWh) |
| **0:00** | - | 1:00 | 79.25 | 0:00 | - | 1:00 | 91.75 |
| **1:00** | - | 2:00 | 79.25 | 1:00 | - | 2:00 | 91.75 |
| **2:00** | - | 3:00 | 79.25 | 2:00 | - | 3:00 | 91.75 |
| **3:00** | - | 4:00 | 79.25 | 3:00 | - | 4:00 | 91.75 |
| **4:00** | - | 5:00 | 49.25 | 4:00 | - | 5:00 | 61.75 |
| **5:00** | - | 6:00 | 49.25 | 5:00 | - | 6:00 | 61.75 |
| **6:00** | - | 7:00 | 49.25 | 6:00 | - | 7:00 | 61.75 |
| **7:00** | - | 8:00 | 49.25 | 7:00 | - | 8:00 | 61.75 |
| **8:00** | - | 9:00 | 150.52 | 8:00 | - | 9:00 | 163.02 |
| **9:00** | - | 10:00 | 57.56 | 9:00 | - | 10:00 | 64.48 |
| **10:00** | - | 11:00 | 57.56 | 10:00 | - | 11:00 | 20.48 |
| **11:00** | - | 12:00 | 57.56 | 11:00 | - | 12:00 | 20.48 |
| **12:00** | - | 13:00 | 55.04 | 12:00 | - | 13:00 | 19.16 |
| **13:00** | - | 14:00 | 53.98 | 13:00 | - | 14:00 | 19 |
| **14:00** | - | 15:00 | 52.73 | 14:00 | - | 15:00 | 17.75 |
| **15:00** | - | 16:00 | 52.73 | 15:00 | - | 16:00 | 17.75 |
| **16:00** | - | 17:00 | 96.73 | 16:00 | - | 17:00 | 61.75 |
| **17:00** | - | 18:00 | 130.84 | 17:00 | - | 18:00 | 86.66 |
| **18:00** | - | 19:00 | 161 | 18:00 | - | 19:00 | 116.82 |
| **19:00** | - | 20:00 | 157.52 | 19:00 | - | 20:00 | 116.82 |
| **20:00** | - | 21:00 | 255.52 | 20:00 | - | 21:00 | 216.02 |
| **21:00** | - | 22:00 | 155 | 21:00 | - | 22:00 | 115.5 |
| **22:00** | - | 23:00 | 133 | 22:00 | - | 23:00 | 93.5 |
| **23:00** | - | 0:00 | 133 | 23:00 | - | 0:00 | 93.5 |
| | | Total (kWh) | 2274.29 | | | Total (kWh/day) | 1856.69 |

# Table A-4: winter season load consumption scenario for Chilmari, Rangpur.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hourly load consumption for rangpur (November to february) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Residential Load | | | | | | | | time (h) | | | | | | | | | | | | | | | | | | | | | | | | |
| type | no of house hold | appliance type | Rating (W) | No of appliance | total power (W) | Run time (h/day) | kWh | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 | |
| high class house hold | 0 | Light | 20 | 6 | 0 | 7 | 0 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Fan | 60 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | TV | 110 | 1 | 0 | 8 | 0 | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Computer | 110 | 1 | 0 | 3 | 0 | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | |
| | | Iron | 750 | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | 0 | | | | | | | |
| | | Rice cooker | 1000 | 1 | 0 | 2 | 0 | | | | | | | | 0 | | | | | | | | | | | | 0 | | | | | |
| | | Refrigerator | 250 | 1 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Water pumps | 750 | 1 | 0 | 1 | 0 | | | | | | | | | | 0 | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| medium class house hold | 200 | Light | 20 | 4 | 16000 | 7 | 112 | | | | | | | | | | | | | | | | | | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | |
| | | Fan | 60 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | TV | 110 | 1 | 22000 | 8 | 176 | | | | | | | | | | | | | | | | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 1 | 200000 | 1 | 200 | | | | | | | | | 100000 | | | | | | | | | | | | 100000 | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 24 | 300 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for medium class house hold | | | | | 788 | | | | | | | | | | | | | | | | | | | | | | | | | |
| low class house hold | 200 | Light | 20 | 2 | 8000 | 7 | 56 | | | | | | | | | | | | | | | | | | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | |
| | | Fan | 60 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | TV | 110 | 1 | 22000 | 6 | 132 | | | | | | | | | | | | | | | | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | | | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for low class house hold | | | | | 188 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Public and comercial load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| School | 1 | Light | 20 | 15 | 300 | 3 | 0.9 | | | | | | | | | | 300 | 300 | 300 | | | | | | | | | | | | | |
| | | Fan | 60 | 0 | 0 | 4 | 0 | | | | | | | | | | 0 | 0 | 0 | 0 | | | | | | | | | | | | |
| | | TV | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 1 | 110 | 3 | 0.33 | | | | | | | | | | 110 | 110 | 110 | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | 0.5 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for school | | | | | 1.23 | | | | | | | | | | | | | | | | | | | | | | | | | |
| health centre | 1 | Light | 20 | 8 | 160 | 8 | 1.28 | | | | | | | | | 160 | 160 | 160 | 160 | 160 | | | | | | 160 | 160 | 160 | | | | |
| | | Fan | 60 | 0 | 0 | 10 | 0 | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | | TV | 110 | 1 | 110 | 8 | 0.88 | | | | | | | | | 110 | 110 | 110 | 110 | | | | | | 110 | 110 | 110 | 110 | | | | |
| | | Computer | 110 | 0 | 0 | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | lab equipment | 1000 | 1 | 1000 | 5 | 5 | | | | | | | | | | 1000 | 1000 | 1000 | 1000 | 1000 | | | | | | | | | | | |
| | | others | 250 | 1 | 250 | 6 | 1.5 | | | | | | | | | 250 | 250 | 250 | 250 | 250 | 250 | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 250 | 24 | 6 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | | | | |
| | | Water pumps | 750 | 1 | 750 | 1 | 0.75 | | | | | | | | | 750 | | | | | | | | | | | | | | | | |
| | | total kWh/day for health center | | | | | 15.41 | | | | | | | | | | | | | | | | | | | | | | | | | |
| commercial load (shops) | 20 | Light | 20 | 2 | 800 | 6 | 4.8 | | | | | | | | | | 800 | 800 | 800 | | | | | | 800 | 800 | 800 | | | | | |
| | | Fan | 60 | 0 | 0 | 10 | 0 | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | |
| | | TV | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 5000 | 24 | 120 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | 5000 | |
| | | Water pumps | 750 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day | | | | | 124.8 | | | | | | | | | | | | | | | | | | | | | | | | | |
| deferrable load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Street light | | Light | 100 | 300 | 30000 | 10 | 300 | 30000 | 30000 | 30000 | 30000 | | | | | | | | | | | | | | | 30000 | 30000 | 30000 | 30000 | 30000 | 30000 | |
| | | total kWh | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| irrigation pump for winter season | | pump | 1100 | 40 | 44000 | 10 | 440 | 44000 | 44000 | 44000 | 44000 | 44000 | 44000 | 44000 | 44000 | 44000 | 44000 | | | | | | | | | | | | | | | |
| | | total Wh | | | | | 1857.44 | 91750 | 91750 | 91750 | 91750 | 61750 | 61750 | 61750 | 61750 | 163020 | 64480 | 20480 | 20480 | 19160 | 19000 | 17750 | 17750 | 61750 | 86660 | 116820 | 116820 | 216020 | 115500 | 93500 | 93500 | 1856690 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | kWh | | 1856.69 |

**Table A-5: Summer season load consumption scenario for Chilmara, Rangpur.**

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hourly load consumption for rangpur (March to October) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Residential Load | | | | | | | | time (h) | | | | | | | | | | | | | | | | | | | | | | | | |
| type | no of house hold | apliance type | Rating (W) | No of appliance | total power (W) | Run time (h/day) | kWh | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 | |
| high class house hold | 0 | Light | 20 | 6 | 0 | 7 | 0 | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Fan | 60 | 3 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | TV | 110 | 1 | 0 | 8 | 0 | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Computer | 110 | 1 | 0 | 3 | 0 | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | |
| | | Iron | 750 | 1 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | 0 | | | | | | | |
| | | Rice cooker | 1000 | 1 | 0 | 2 | 0 | | | | | | | | 0 | | | | | | | | | | | | 0 | | | | | |
| | | Refrigerator | 250 | 1 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Water pumps | 750 | 1 | 0 | 1 | 0 | | | | | | | | | | 0 | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| medium class house hold | 200 | Light | 20 | 4 | 16000 | 7 | 112 | | | | | | | | | | | | | | | | | | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | |
| | | Fan | 60 | 2 | 24000 | 12 | 288 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | |
| | | TV | 110 | 1 | 22000 | 8 | 176 | | | | | | | | | | | | | | | | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 1 | 200000 | 1 | 200 | | | | | | | | | 100000 | | | | | | | | | | | | 100000 | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 24 | 300 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for medium class house hold | | | | | 1076 | | | | | | | | | | | | | | | | | | | | | | | | | |
| low class house hold | 200 | Light | 20 | 4 | 16000 | 7 | 112 | | | | | | | | | | | | | | | | | | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | |
| | | Fan | 60 | 2 | 24000 | 12 | 288 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | |
| | | TV | 110 | 1 | 22000 | 6 | 132 | | | | | | | | | | | | | | | | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | | | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for low class house hold | | | | | 532 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Public and comercial load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| School | 1 | Light | 20 | 15 | 300 | 3 | 0.9 | | | | | | | | | | 300 | 300 | 300 | | | | | | | | | | | | | |
| | | Fan | 60 | 15 | 900 | 4 | 3.6 | | | | | | | | | | 900 | 900 | 900 | 900 | | | | | | | | | | | | |
| | | TV | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 1 | 110 | 3 | 0.33 | | | | | | | | | | 110 | 110 | 110 | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 750 | 0 | 0 | 0.5 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for school | | | | | 4.83 | | | | | | | | | | | | | | | | | | | | | | | | | |
| health centre | 1 | Light | 20 | 8 | 160 | 8 | 1.28 | | | | | | | | | 160 | 160 | 160 | 160 | 160 | | | | | | 160 | 160 | 160 | | | | |
| | | Fan | 60 | 8 | 480 | 10 | 4.8 | | | | | | | | | | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | 480 | | | | | | |
| | | TV | 110 | 1 | 110 | 8 | 0.88 | | | | | | | | | 110 | 110 | 110 | 110 | | | | | | 110 | 110 | 110 | 110 | | | | |
| | | Computer | 110 | 0 | 0 | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | lab equipment | 1000 | 1 | 1000 | 5 | 5 | | | | | | | | | | 1000 | 1000 | 1000 | 1000 | 1000 | | | | | | | | | | | |
| | | others | 250 | 1 | 250 | 6 | 1.5 | | | | | | | | | 250 | 250 | 250 | 250 | 250 | 250 | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 250 | 24 | 6 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | | | | |
| | | Water pumps | 750 | 1 | 750 | 1 | 0.75 | | | | | | | | | 750 | | | | | | | | | | | | | | | | |
| | | total kWh/day for health center | | | | | 20.21 | | | | | | | | | | | | | | | | | | | | | | | | | |
| commercial load (shops) | 50 | Light | 20 | 2 | 2000 | 6 | 12 | | | | | | | | | | 2000 | 2000 | 2000 | | | | | | 2000 | 2000 | 2000 | | | | | |
| | | Fan | 60 | 1 | 3000 | 10 | 30 | | | | | | | | | | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | | | | | | |
| | | TV | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 24 | 300 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 750 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day | | | | | 342 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | differable load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Street light | | Light | 100 | 300 | 30000 | 10 | 300 | 30000 | 30000 | 30000 | 30000 | | | | | | | | | | | | | | | 30000 | 30000 | 30000 | 30000 | 30000 | 30000 | |
| | | total kWh | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| irrigation pump for winter season | | pump | 1100 | 0 | 0 | 14 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total Wh | | | | | 2275.04 | 79250 | 79250 | 79250 | 79250 | 49250 | 49250 | 49250 | 49250 | 150520 | 57560 | 57560 | 57560 | 55040 | 53980 | 52730 | 52730 | 96730 | 130840 | 161000 | 157520 | 255520 | 155000 | 133000 | 133000 | 2274290 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | kWh | 2274.29 |

**Table A-6: Hourly load consumption scenario for Kuakata.**

| **Total kWh/day for Kuakata (summer season)** | | | | **Total kWh/day for Kuakata (Winter season)** | | | |
|---|---|---|---|---|---|---|---|
| **Time (hour)** | | | Consumption for March to October (kWh) | Time (hour) | | | Consumption for November to February (kWh) |
| **0:00** | - | 1:00 | 68.75 | 0:00 | - | 1:00 | 55.25 |
| **1:00** | - | 2:00 | 68.75 | 1:00 | - | 2:00 | 55.25 |
| **2:00** | - | 3:00 | 68.75 | 2:00 | - | 3:00 | 55.25 |
| **3:00** | - | 4:00 | 68.75 | 3:00 | - | 4:00 | 55.25 |
| **4:00** | - | 5:00 | 38.75 | 4:00 | - | 5:00 | 25.25 |
| **5:00** | - | 6:00 | 38.75 | 5:00 | - | 6:00 | 25.25 |
| **6:00** | - | 7:00 | 38.75 | 6:00 | - | 7:00 | 25.25 |
| **7:00** | - | 8:00 | 88.75 | 7:00 | - | 8:00 | 75.25 |
| **8:00** | - | 9:00 | 40.02 | 8:00 | - | 9:00 | 26.52 |
| **9:00** | - | 10:00 | 65.81 | 9:00 | - | 10:00 | 47.93 |
| **10:00** | - | 11:00 | 47.06 | 10:00 | - | 11:00 | 29.18 |
| **11:00** | - | 12:00 | 47.06 | 11:00 | - | 12:00 | 29.18 |
| **12:00** | - | 13:00 | 44.54 | 12:00 | - | 13:00 | 26.66 |
| **13:00** | - | 14:00 | 43.48 | 13:00 | - | 14:00 | 26.5 |
| **14:00** | - | 15:00 | 42.23 | 14:00 | - | 15:00 | 25.25 |
| **15:00** | - | 16:00 | 42.23 | 15:00 | - | 16:00 | 25.25 |
| **16:00** | - | 17:00 | 64.23 | 16:00 | - | 17:00 | 47.25 |
| **17:00** | - | 18:00 | 97.09 | 17:00 | - | 18:00 | 80.11 |
| **18:00** | - | 19:00 | 108.5 | 18:00 | - | 19:00 | 91.52 |
| **19:00** | - | 20:00 | 160.52 | 19:00 | - | 20:00 | 147.02 |
| **20:00** | - | 21:00 | 108.52 | 20:00 | - | 21:00 | 95.02 |
| **21:00** | - | 22:00 | 108 | 21:00 | - | 22:00 | 94.5 |
| **22:00** | - | 23:00 | 86 | 22:00 | - | 23:00 | 72.5 |
| **23:00** | - | 0:00 | 86 | 23:00 | - | 0:00 | 72.5 |
| | | Total (kWh) | 1671.29 | | | Total (kWh/day) | 1308.89 |

**Table A-7: Hourly load consumption scenario for Battery run auto rickshaw**

| Total kWh/day for Kuakata (Battery run auto rickshaw) | | | |
|---|---|---|---|
| Duration | | | Load consumed (W) |
| 0:00 | - | 1:00 | 192.4 |
| 1:00 | - | 2:00 | 192.4 |
| 2:00 | - | 3:00 | 192.4 |
| 3:00 | - | 4:00 | 192.4 |
| 4:00 | - | 5:00 | 192.4 |
| 5:00 | - | 6:00 | 192.4 |
| 6:00 | - | 7:00 | 192.4 |
| 7:00 | - | 8:00 | 19.24 |
| 8:00 | - | 9:00 | 19.24 |
| 9:00 | - | 10:00 | 19.24 |
| 10:00 | - | 11:00 | 19.24 |
| 11:00 | - | 12:00 | 19.24 |
| 12:00 | - | 13:00 | 19.24 |
| 13:00 | - | 14:00 | 0 |
| 14:00 | - | 15:00 | 0 |
| 15:00 | - | 16:00 | 0 |
| 16:00 | - | 17:00 | 48.1 |
| 17:00 | - | 18:00 | 48.1 |
| 18:00 | - | 19:00 | 48.1 |
| 19:00 | - | 20:00 | 48.1 |
| 20:00 | - | 21:00 | 48.1 |
| 21:00 | - | 22:00 | 48.1 |
| 22:00 | - | 23:00 | 48.1 |
| 23:00 | - | 0:00 | 192.4 |
| | | Total (kWh/day) | 1991.34 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| hourly load consumption for (November to february) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Residential Load | | | | | | | | time (h) | | | | | | | | | | | | | | | | | | | | | | | | |
| type | no of house hold | appliance type | Rating (W) | No of appliance | total power (W) | Run time (h/day) | kWh | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 | 8:00 | 9:00 | 10:00 | 11:00 | 12:00 | 13:00 | 14:00 | 15:00 | 16:00 | 17:00 | 18:00 | 19:00 | 20:00 | 21:00 | 22:00 | 23:00 | |
| high class house hold | 100 | Light | 20 | 4 | 8000 | 7 | 56 | | | | | | | | | | | | | | | | | | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | |
| | | Fan | 60 | 3 | 18000 | 12 | 216 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | 9000 | |
| | | TV | 110 | 1 | 11000 | 8 | 88 | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Computer | 110 | 0 | 0 | 3 | 0 | | | | | | | | | | | | | | | | | | | | 0 | 0 | 0 | | | |
| | | Iron | 750 | 0 | 0 | 0.5 | 0 | | | | | | | | | | | | | | | | | | 0 | | | | | | | |
| | | Rice cooker | 1000 | 1 | 100000 | 2 | 200 | | | | | | | | 100000 | | | | | | | | | | | | 100000 | | | | | |
| | | Refrigerator | 250 | 1 | 25000 | 12 | 300 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | |
| | | Water pumps | 746 | 1 | 74600 | 0.5 | 37.3 | | | | | | | | | | 37300 | | | | | | | | | | | | | | | |
| | | total kWh/day/high class house hold | | | | | 897.3 | | | | | | | | | | | | | | | | | | | | | | | | | |
| medium class house hold | 700 | Light | 20 | 4 | 56000 | 7 | 392 | | | | | | | | | | | | | | | | | | 56000 | 56000 | 56000 | 56000 | 56000 | 56000 | 56000 | |
| | | Fan | 60 | 2 | 84000 | 12 | 1008 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | 42000 | |
| | | TV | 110 | 1 | 77000 | 8 | 616 | | | | | | | | | | | | | | | | | 77000 | 77000 | 77000 | 77000 | 77000 | 77000 | 77000 | 77000 | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 1 | 0 | | | | | | | | | 0 | | | | | | | | | | | | 0 | | | | |
| | | Refrigerator | 250 | 0 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | Water pumps | 746 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for medium class house hold | | | | | 2016 | | | | | | | | | | | | | | | | | | | | | | | | | |
| low class house hold | 400 | Light | 20 | 2 | 16000 | 7 | 112 | | | | | | | | | | | | | | | | | | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | 16000 | |
| | | Fan | 60 | 1 | 24000 | 12 | 288 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | 12000 | |
| | | TV | 110 | 0 | 0 | 6 | 0 | | | | | | | | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 746 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for low class house hold | | | | | 400 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Public and comercial load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| School | 1 | Light | 20 | 15 | 300 | 3 | 0.9 | | | | | | | | | | 300 | 300 | 300 | | | | | | | | | | | | | |
| | | Fan | 60 | 15 | 900 | 4 | 3.6 | | | | | | | | | | 900 | 900 | 900 | 900 | | | | | | | | | | | | |
| | | TV | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 1 | 110 | 3 | 0.33 | | | | | | | | | | 110 | 110 | 110 | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Water pumps | 746 | 0 | 0 | 0.5 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day for school | | | | | 4.83 | | | | | | | | | | | | | | | | | | | | | | | | | |
| health centre | 1 | Light | 20 | 8 | 160 | 8 | 1.28 | | | | | | | | | 160 | 160 | 160 | 160 | 160 | | | | | | 160 | 160 | 160 | | | | |
| | | Fan | 60 | 4 | 240 | 10 | 2.4 | | | | | | | | | | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | 240 | | | | | | |
| | | TV | 110 | 1 | 110 | 8 | 0.88 | | | | | | | | | 110 | 110 | 110 | 110 | | | | | | 110 | 110 | 110 | 110 | | | | |
| | | Computer | 110 | 0 | 0 | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | lab equipment | 0 | 1 | 0 | 5 | 0 | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | |
| | | others | 0 | 1 | 0 | 6 | 0 | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 250 | 24 | 6 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | | | | |
| | | Water pumps | 746 | 1 | 746 | 1 | 0.746 | | | | | | | | | 746 | | | | | | | | | | | | | | | | |
| | | total kWh/day for health center | | | | | 11.306 | | | | | | | | | | | | | | | | | | | | | | | | | |
| commercial load (shops)(50% of the shops have Refrigeration ) | 50 | Light | 20 | 2 | 2000 | 6 | 12 | | | | | | | | | | 2000 | 2000 | 2000 | | | | | | 2000 | 2000 | 2000 | | | | | |
| | | Fan | 60 | 1 | 3000 | 10 | 30 | | | | | | | | | | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | 3000 | | | | | | |
| | | TV | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Computer | 110 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Iron | 750 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Rice cooker | 1000 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | Refrigerator | 250 | 1 | 12500 | 24 | 300 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | 12500 | |
| | | Water pumps | 746 | 0 | 0 | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | total kWh/day | | | | | 342 | | | | | | | | | | | | | | | | | | | | | | | | | |
| deferrable load | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Street light | 1 | Light | 100 | 300 | 30000 | 10 | 300 | 30000 | 30000 | 30000 | 30000 | | | | | | | | | | | | | | | 30000 | 30000 | 30000 | 30000 | 30000 | 30000 | |
| | | total kWh | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Battery run auto rickshaw | 1 | battery chargning | 1200 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | 0 | |
| | | | | | | | | 130750 | 130750 | 130750 | 130750 | 100750 | 100750 | 100750 | 200750 | 101766 | 144870 | 107570 | 107570 | 105050 | 103990 | 103990 | 103990 | 180990 | 263100 | 293260 | 390020 | 288020 | 287500 | 287500 | 287500 | 4182686 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | kWh | 4182.686 |

# Table A-8: load consumption scenario for Magnama, Pekua.

**Table A-9: Seasonal load consumption for Magnama, Pekua.**

| Total kWh/day for Dinajpur (summer season) | | | | Total kWh/day for Dinajpur (Winter season) | | | |
|---|---|---|---|---|---|---|---|
| Time (hour) | | | Consumption for March to October (Wh) | Time (hour) | | | Consumption for November to February (Wh) |
| 0:00 | - | 1:00 | 130.75 | 0:00 | - | 1:00 | 67.75 |
| 1:00 | - | 2:00 | 130.75 | 1:00 | - | 2:00 | 67.75 |
| 2:00 | - | 3:00 | 130.75 | 2:00 | - | 3:00 | 67.75 |
| 3:00 | - | 4:00 | 130.75 | 3:00 | - | 4:00 | 67.75 |
| 4:00 | - | 5:00 | 100.75 | 4:00 | - | 5:00 | 37.75 |
| 5:00 | - | 6:00 | 100.75 | 5:00 | - | 6:00 | 37.75 |
| 6:00 | - | 7:00 | 100.75 | 6:00 | - | 7:00 | 37.75 |
| 7:00 | - | 8:00 | 200.75 | 7:00 | - | 8:00 | 137.75 |
| 8:00 | - | 9:00 | 101.766 | 8:00 | - | 9:00 | 38.766 |
| 9:00 | - | 10:00 | 144.87 | 9:00 | - | 10:00 | 77.73 |
| 10:00 | - | 11:00 | 107.57 | 10:00 | - | 11:00 | 40.43 |
| 11:00 | - | 12:00 | 107.57 | 11:00 | - | 12:00 | 40.43 |
| 12:00 | - | 13:00 | 105.05 | 12:00 | - | 13:00 | 37.91 |
| 13:00 | - | 14:00 | 103.99 | 13:00 | - | 14:00 | 37.75 |
| 14:00 | - | 15:00 | 103.99 | 14:00 | - | 15:00 | 37.75 |
| 15:00 | - | 16:00 | 103.99 | 15:00 | - | 16:00 | 37.75 |
| 16:00 | - | 17:00 | 180.99 | 16:00 | - | 17:00 | 114.75 |
| 17:00 | - | 18:00 | 263.1 | 17:00 | - | 18:00 | 196.86 |
| 18:00 | - | 19:00 | 293.26 | 18:00 | - | 19:00 | 227.02 |
| 19:00 | - | 20:00 | 390.02 | 19:00 | - | 20:00 | 327.02 |
| 20:00 | - | 21:00 | 288.02 | 20:00 | - | 21:00 | 225.02 |
| 21:00 | - | 22:00 | 287.5 | 21:00 | - | 22:00 | 224.5 |
| 22:00 | - | 23:00 | 287.5 | 22:00 | - | 23:00 | 224.5 |
| 23:00 | - | 0:00 | 287.5 | 23:00 | - | 0:00 | 224.5 |
| | | Total (kWh) | 4182.686 | | | Total (kWh/day) | 2634.686 |

### Table A-10: Hourly load consumption for Sitakunda.

| Total kWh/day for Dinajpur (summer season) | | | | Total kWh/day for Dinajpur (Winter season) | | | |
|---|---|---|---|---|---|---|---|
| Time (hour) | | | Consumption for March to October (Wh) | Time (hour) | | | Consumption for November to February (Wh) |
| 0:00 | - | 1:00 | 77 | 0:00 | - | 1:00 | 56 |
| 1:00 | - | 2:00 | 77 | 1:00 | - | 2:00 | 56 |
| 2:00 | - | 3:00 | 77 | 2:00 | - | 3:00 | 56 |
| 3:00 | - | 4:00 | 77 | 3:00 | - | 4:00 | 56 |
| 4:00 | - | 5:00 | 47 | 4:00 | - | 5:00 | 26 |
| 5:00 | - | 6:00 | 47 | 5:00 | - | 6:00 | 26 |
| 6:00 | - | 7:00 | 47 | 6:00 | - | 7:00 | 26 |
| 7:00 | - | 8:00 | 72 | 7:00 | - | 8:00 | 51 |
| 8:00 | - | 9:00 | 73.492 | 8:00 | - | 9:00 | 52.492 |
| 9:00 | - | 10:00 | 71.96 | 9:00 | - | 10:00 | 47.06 |
| 10:00 | - | 11:00 | 53.31 | 10:00 | - | 11:00 | 28.41 |
| 11:00 | - | 12:00 | 53.31 | 11:00 | - | 12:00 | 28.41 |
| 12:00 | - | 13:00 | 50.9 | 12:00 | - | 13:00 | 26 |
| 13:00 | - | 14:00 | 50 | 13:00 | - | 14:00 | 26 |
| 14:00 | - | 15:00 | 50 | 14:00 | - | 15:00 | 26 |
| 15:00 | - | 16:00 | 50 | 15:00 | - | 16:00 | 26 |
| 16:00 | - | 17:00 | 72 | 16:00 | - | 17:00 | 48 |
| 17:00 | - | 18:00 | 124 | 17:00 | - | 18:00 | 100 |
| 18:00 | - | 19:00 | 156.1 | 18:00 | - | 19:00 | 132.1 |
| 19:00 | - | 20:00 | 128.1 | 19:00 | - | 20:00 | 107.1 |
| 20:00 | - | 21:00 | 126.1 | 20:00 | - | 21:00 | 105.1 |
| 21:00 | - | 22:00 | 125.1 | 21:00 | - | 22:00 | 104.1 |
| 22:00 | - | 23:00 | 125.1 | 22:00 | - | 23:00 | 104.1 |
| 23:00 | - | 0:00 | 125.1 | 23:00 | - | 0:00 | 104.1 |
| | | Total (kWh) | 1955.572 | | | Total (kWh/day) | 1417.972 |

# Appendix B

### Table B-1: NPC (Net present cost) for 2 MW plant at Kuakata

| Net Present Costs (2 MW grid connected) | | | | | | |
|---|---|---|---|---|---|---|
| **Component** | **Capital** | **Replacement** | **O&M** | **Fuel** | **Salvage** | **Total** |
| Generic flat plate PV | 536,000 | 0 | 136,268 | 0 | 0 | 672,268 |
| H21.0-100kW | 4,028,560 | 989,125 | 1,055,552 | 0 | -561,141 | 5,512,096 |
| Grid | 0 | 0 | -4,033,695 | 0 | 0 | -4,033,695 |
| HOMER Cycle Charging | 0 | 0 | 0 | 0 | 0 | 0 |
| System Converter | 171,200 | 143,925 | 26,625 | 0 | -19,810 | 321,940 |
| Other | 0 | 0 | 42,191 | 0 | 0 | 42,191 |
| System | 4,735,760 | 1,133,050 | -2,773,060 | 0 | -580,951 | 2,514,799 |

### Table B-2: NPC (Net present cost) for 3 MW plant at Kuakata

| Net Present Costs (3 MW grid connected) | | | | | | |
|---|---|---|---|---|---|---|
| **Component** | **Capital** | **Replacement** | **O&M** | **Fuel** | **Salvage** | **Total** |
| Generic flat plate PV | 670,000 | 0 | 170,335 | 0 | 0 | 840,335 |
| H21.0-100kW | 6,294,625 | 1,545,507 | 1,649,300 | 0 | -876,783 | 8,612,649 |
| Grid | 0 | 0 | -6,943,104 | 0 | 0 | -6,943,104 |
| HOMER Cycle Charging | 0 | 0 | 0 | 0 | 0 | 0 |
| System Converter | 85,600 | 71,963 | 13,312 | 0 | -9,905 | 160,970 |
| Other | 0 | 0 | 42,191 | 0 | 0 | 42,191 |
| System | 7,050,225 | 1,617,470 | -5,067,966 | 0 | -886,688 | 2,713,040 |

### Table B-3: Contribution of individual component for Kuakata region

| Component | Plant size | **3 MW** | | **2 MW** | | **1 MW** | | **Units** |
|---|---|---|---|---|---|---|---|---|
| | **Quantity** | Value | | | | | | |
| Solar Land PV | Rated capacity | 500 | | 400 | | 100 | | kW |
| | Mean output | 86 | | 69 | | 17 | | kW |
| | Mean output | 2057.57 | | 1646.05 | | 411.51 | | kWh/d |
| | Capacity factor | 17.15 | | 17.15 | | 17.15 | | % |
| | Total generation | 751012 | | 600810 | | 150202 | | kWh/yr |
| | Minimum output | 0 | | 0 | | 0 | | kW |
| | Maximum output | 494.54 | | 395.63 | | 98.91 | | kW |
| | PV penetration | 58.58 | | 46.86 | | 11.72 | | % |
| | Hours of operation | 4367 | | 4367 | | 4367 | | hrs/yr |
| | Levelized cost | 0.085 | | 0.085 | | 0.085 | | $/kWh |
| | | | | | | | | |
| Wind Turbine: H21.0-100kW | Total rated capacity | 2500 | | 1600 | | 900 | | kW |
| | Mean output | 948 | | 607 | | 341 | | kW |
| | Capacity factor | 37.92 | | 37.92 | | 37.92 | | % |
| | Total generation | 8304051 | | 5314592 | | 2989458 | | kWh/yr |
| | Minimum output | 0 | | 0 | | 0 | | kW |
| | Maximum output | 2500 | | 1600 | | 900 | | kW |
| | Wind penetration | 647.68 | | 414.52 | | 233.16 | | % |
| | Hours of operation | 8617 | | 8617 | | 8617 | | hrs/yr |
| | Levelized cost | 0.079 | | 0.079 | | 0.079 | | $/kWh |
| Converter | | Inverter | Rectifier | Inverter | Rectifier | Inverter | Rectifier | |
| | Capacity | 400 | 392 | 800 | 784 | 400 | 392 | kW |
| | Mean output | 75 | 74 | 59 | 75 | 11 | 77 | kW |
| | Minimum output | 0 | 0 | 0 | 0 | 0 | 0 | kW |
| | Maximum output | 400 | 192 | 369 | 192 | 88 | 192 | kW |
| | Capacity factor | 19 | 19 | 7 | 9 | 3 | 19 | % |
| | Hours of operation | 3,604 | 5,156 | 3,499 | 5,261 | 2,803 | 5,957 | hrs/yr |
| | Energy in | 671,315 | 764,318 | 527,870 | 769,293 | 101,419 | 797,713 | kWh/yr |
| | Energy out | 657,889 | 649,671 | 517,313 | 653,899 | 99,391 | 678,056 | kWh/yr |
| | Losses | 13,426 | 114,648 | 10,557 | 115,394 | 2,028 | 119,657 | kWh/yr |

# Appendix C

**Table C-1: Simulation results for Sitakunda**

| 0.5 MW | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PV (kW) | H21.0-100kW | Grid (kW) | Converter (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) |
| 0 | 5 | 999999 | 0 | 0.069335 | 1211242 | 1258925 | 88.11429 | -283795 |
| 100 | 4 | 999999 | 100 | 0.074537 | 1213626 | 1162540 | 85.9187 | -225943 |
| 200 | 3 | 999999 | 100 | 0.079777 | 1201694 | 1044755 | 81.76856 | -157015 |
| 300 | 2 | 999999 | 200 | 0.084796 | 1202272 | 969770 | 76.4793 | -110240 |
| 400 | 1 | 999999 | 300 | 0.089143 | 1224548 | 830585 | 67.26948 | -30234.9 |
| 500 | 0 | 999999 | 300 | 0.087848 | 1242640 | 734200 | 57.67729 | 14360.06 |
| 1 MW | | | | | | | | |
| 0 | 10 | 999999 | 0 | 0.053179 | 1690032 | 2517850 | 96.87274 | -918192 |
| 100 | 9 | 999999 | 100 | 0.055468 | 1687110 | 2421465 | 96.60251 | -860340 |
| 200 | 8 | 999999 | 100 | 0.057699 | 1664929 | 2303680 | 96.03112 | -791412 |
| 300 | 7 | 999999 | 200 | 0.059248 | 1649497 | 2207295 | 95.31518 | -743037 |
| 400 | 6 | 999999 | 300 | 0.061812 | 1649163 | 2110910 | 94.33167 | -686638 |
| 500 | 5 | 999999 | 400 | 0.06469 | 1652967 | 2014525 | 93.01694 | -628932 |
| 600 | 4 | 999999 | 500 | 0.067721 | 1659616 | 1918140 | 91.25594 | -571081 |
| 700 | 3 | 999999 | 600 | 0.070805 | 1669981 | 1821755 | 88.86897 | -513230 |
| 800 | 2 | 999999 | 700 | 0.073749 | 1686436 | 1725370 | 85.52188 | -455378 |
| 900 | 1 | 999999 | 800 | 0.076192 | 1712845 | 1628985 | 80.74821 | -397526 |
| 1000 | 0 | 999999 | 900 | 0.077886 | 1750795 | 1532600 | 74.50996 | -339674 |
| 2 MW | | | | | | | | |
| 0 | 20 | 999999 | 0 | 0.043471 | 2696457 | 5035700 | 99.26323 | -2186985 |
| 100 | 19 | 999999 | 100 | 0.044412 | 2691948 | 4939315 | 99.26808 | -2129133 |
| 200 | 18 | 999999 | 100 | 0.045236 | 2666847 | 4821530 | 99.22289 | -2060205 |
| 300 | 17 | 999999 | 200 | 0.045798 | 2647392 | 4725145 | 99.16428 | -2011830 |
| 400 | 16 | 999999 | 300 | 0.046783 | 2641737 | 4628760 | 99.09013 | -1955431 |
| 500 | 15 | 999999 | 400 | 0.047882 | 2638478 | 4532375 | 99.0013 | -1897725 |
| 600 | 14 | 999999 | 500 | 0.049041 | 2635676 | 4435990 | 98.89494 | -1839874 |
| 700 | 13 | 999999 | 600 | 0.050258 | 2633087 | 4339605 | 98.76982 | -1782023 |
| 800 | 12 | 999999 | 700 | 0.051536 | 2630796 | 4243220 | 98.61885 | -1724171 |
| 900 | 11 | 999999 | 800 | 0.052877 | 2628849 | 4146835 | 98.437 | -1666319 |
| 1000 | 10 | 999999 | 900 | 0.054285 | 2627351 | 4050450 | 98.21474 | -1608468 |
| 1100 | 9 | 999999 | 1000 | 0.055761 | 2626401 | 3954065 | 97.94209 | -1550616 |
| 1200 | 8 | 999999 | 1100 | 0.057306 | 2626215 | 3857680 | 97.5997 | -1492764 |
| 1300 | 7 | 999999 | 1200 | 0.058917 | 2627042 | 3761295 | 97.16411 | -1434912 |
| 1400 | 6 | 999999 | 1300 | 0.060589 | 2629217 | 3664910 | 96.60343 | -1377061 |
| 1500 | 5 | 999999 | 1400 | 0.062308 | 2633254 | 3568525 | 95.87008 | -1319209 |
| 1600 | 4 | 999999 | 1500 | 0.064052 | 2639780 | 3472140 | 94.9049 | -1261357 |
| 1700 | 3 | 999999 | 1600 | 0.06578 | 2649946 | 3375755 | 93.60649 | -1203506 |
| 1800 | 2 | 999999 | 1700 | 0.067406 | 2665894 | 3279370 | 91.79729 | -1145654 |
| 1900 | 1 | 999999 | 1800 | 0.068785 | 2691120 | 3182985 | 89.20876 | -1087802 |
| 2000 | 0 | 999999 | 1900 | 0.069855 | 2726211 | 3086600 | 85.83396 | -1029950 |

## Table C-2: Simulation results for Dinajpur

| 0.5 MW | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PV (kW) | H21.0-100kW | Grid (kW) | Converter (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) |
| 0 | 5 | 999999 | 0 | 0.177115 | 2422260 | 1258575 | 37.29636 | -283795 |
| 100 | 4 | 999999 | 100 | 0.15599 | 2236964 | 1162260 | 41.79016 | -225943 |
| 200 | 3 | 999999 | 100 | 0.137844 | 2055960 | 1044545 | 43.05554 | -157015 |
| 300 | 2 | 999999 | 200 | 0.113098 | 1854367 | 948230 | 46.59816 | -110240 |
| 400 | 1 | 999999 | 300 | 0.094457 | 1672321 | 851915 | 48.73768 | -30234.9 |
| 500 | 0 | 999999 | 400 | 0.078784 | 1496855 | 755600 | 50.25818 | 14360.06 |
| 1 MW | | | | | | | | |
| 0 | 10 | 999999 | 0 | 0.217349 | 3554069 | 79137.91 | 2517150 | 62.38709 |
| 100 | 9 | 999999 | 100 | 0.197186 | 3372693 | 72646.07 | 2420835 | 64.733 |
| 200 | 8 | 999999 | 100 | 0.180052 | 3185325 | 67330.12 | 2303120 | 65.38319 |
| 300 | 7 | 999999 | 200 | 0.156724 | 2985044 | 59395.36 | 2206805 | 66.92722 |
| 400 | 6 | 999999 | 300 | 0.138838 | 2806172 | 53094.63 | 2110490 | 67.66032 |
| 500 | 5 | 999999 | 300 | 0.124333 | 2618507 | 47756.03 | 1992775 | 67.54697 |
| 600 | 4 | 999999 | 400 | 0.10816 | 2430651 | 40769.6 | 1896460 | 68.05184 |
| 700 | 3 | 999999 | 500 | 0.094638 | 2252483 | 34522.53 | 1800145 | 68.26098 |
| 800 | 2 | 999999 | 500 | 0.083479 | 2066847 | 29338.79 | 1682430 | 67.84914 |
| 900 | 1 | 999999 | 600 | 0.071796 | 1882756 | 22639.7 | 1586115 | 68.02563 |
| 1000 | 0 | 999999 | 700 | 0.061712 | 1704882 | 16415.1 | 1489800 | 68.06743 |
| 2 MW | | | | | | | | |
| 0 | 20 | 999999 | 0 | 0.242398 | 5867766 | 63610.32 | 5034300 | 84.28468 |
| 100 | 19 | 999999 | 200 | 0.229298 | 5726966 | 58581.93 | 4959385 | 85.17555 |
| 200 | 18 | 999999 | 200 | 0.213089 | 5507722 | 50833.21 | 4841670 | 85.67354 |
| 300 | 17 | 999999 | 200 | 0.19828 | 5294776 | 43565.16 | 4723955 | 85.93909 |
| 400 | 16 | 999999 | 300 | 0.184472 | 5112848 | 37031.2 | 4627640 | 86.14803 |
| 500 | 15 | 999999 | 300 | 0.1734 | 4921539 | 31414.49 | 4509925 | 86.06419 |
| 600 | 14 | 999999 | 400 | 0.159818 | 4729672 | 24121.91 | 4413610 | 86.14722 |
| 700 | 13 | 999999 | 500 | 0.148046 | 4547373 | 17559.6 | 4317295 | 86.10601 |
| 800 | 12 | 999999 | 500 | 0.138517 | 4357417 | 12046.13 | 4199580 | 85.82981 |
| 900 | 11 | 999999 | 600 | 0.127459 | 4169048 | 5020.553 | 4103265 | 85.72724 |
| 1000 | 10 | 999999 | 700 | 0.117593 | 3987062 | -1517.83 | 4006950 | 85.54885 |
| 1100 | 9 | 999999 | 700 | 0.109426 | 3798300 | -6940.19 | 3889235 | 85.15588 |
| 1200 | 8 | 999999 | 800 | 0.1003 | 3612244 | -13789.2 | 3792920 | 84.92744 |
| 1300 | 7 | 999999 | 900 | 0.092018 | 3431097 | -20263.6 | 3696605 | 84.63615 |
| 1400 | 6 | 999999 | 900 | 0.08499 | 3243746 | -25578.3 | 3578890 | 84.13644 |
| 1500 | 5 | 999999 | 1000 | 0.077386 | 3059833 | -32263.8 | 3482575 | 83.79411 |
| 1600 | 4 | 999999 | 1100 | 0.070422 | 2879901 | -38645.4 | 3386260 | 83.40564 |
| 1700 | 3 | 999999 | 1100 | 0.06438 | 2693969 | -43851.8 | 3268545 | 82.83405 |
| 1800 | 2 | 999999 | 1200 | 0.058038 | 2511625 | -50417.5 | 3172230 | 82.44389 |
| 1900 | 1 | 999999 | 1200 | 0.052786 | 2332121 | -55133.3 | 3054515 | 81.84106 |
| 2000 | 0 | 999999 | 1300 | 0.047019 | 2147176 | -61897.6 | 2958200 | 81.48504 |

## Table C-3: Simulation results for Rangpur

| PV (kW) | H21.0-100kW | Grid (kW) | SUN 2000-23KRL (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) |
|---|---|---|---|---|---|---|---|---|
| 1 MW | | | | | | | | |
| 0 | 10 | 999999 | 0 | 0.068045 | 2038146 | 2517850 | 93.3337 | -730951 |
| 100 | 9 | 999999 | 100 | 0.069313 | 2025153 | 2421465 | 92.95972 | -698169 |
| 200 | 8 | 999999 | 100 | 0.071263 | 1991175 | 2303680 | 92.14927 | -639936 |
| 300 | 7 | 999999 | 200 | 0.070725 | 1958259 | 2207295 | 91.36019 | -621327 |
| 400 | 6 | 999999 | 300 | 0.071138 | 1941989 | 2110910 | 90.2498 | -594170 |
| 500 | 5 | 999999 | 300 | 0.073267 | 1918195 | 1993125 | 88.499 | -533699 |
| 600 | 4 | 999999 | 400 | 0.072758 | 1898417 | 1896740 | 86.7552 | -511703 |
| 700 | 3 | 999999 | 500 | 0.07256 | 1889176 | 1800355 | 84.52529 | -485772 |
| 800 | 2 | 999999 | 500 | 0.074202 | 1877848 | 1682570 | 81.13007 | -424976 |
| 900 | 1 | 999999 | 600 | 0.072892 | 1875665 | 1586185 | 77.63191 | -402079 |
| 1000 | 0 | 999999 | 700 | 0.071574 | 1884952 | 1489800 | 73.51135 | -376666 |
| 2 MW | | | | | | | | |
| 0 | 20 | 999999 | 0 | 0.056735 | 3228824 | 5035700 | 98.24643 | -1883105 |
| 100 | 19 | 999999 | 100 | 0.05728 | 3213795 | 4939315 | 98.23492 | -1850322 |
| 200 | 18 | 999999 | 100 | 0.058055 | 3176188 | 4821530 | 98.16126 | -1792089 |
| 300 | 17 | 999999 | 200 | 0.057804 | 3138339 | 4725145 | 98.08422 | -1773481 |
| 400 | 16 | 999999 | 300 | 0.058035 | 3115463 | 4628760 | 97.97065 | -1746323 |
| 500 | 15 | 999999 | 300 | 0.058975 | 3083027 | 4510975 | 97.79881 | -1685853 |
| 600 | 14 | 999999 | 400 | 0.058901 | 3052166 | 4414590 | 97.63398 | -1663857 |
| 700 | 13 | 999999 | 500 | 0.059059 | 3028347 | 4318205 | 97.4388 | -1637925 |
| 800 | 12 | 999999 | 500 | 0.06007 | 2997705 | 4200420 | 97.16264 | -1577129 |
| 900 | 11 | 999999 | 600 | 0.060034 | 2969657 | 4104035 | 96.89871 | -1554233 |
| 1000 | 10 | 999999 | 700 | 0.060148 | 2946455 | 4007650 | 96.58829 | -1528820 |
| 1100 | 9 | 999999 | 700 | 0.061206 | 2917822 | 3889865 | 96.15185 | -1467910 |
| 1200 | 8 | 999999 | 800 | 0.061156 | 2892721 | 3793480 | 95.71272 | -1444609 |
| 1300 | 7 | 999999 | 900 | 0.061206 | 2871947 | 3697095 | 95.18195 | -1419456 |
| 1400 | 6 | 999999 | 900 | 0.062256 | 2847050 | 3579310 | 94.42926 | -1358530 |
| 1500 | 5 | 999999 | 1000 | 0.062116 | 2827208 | 3482925 | 93.62302 | -1334985 |
| 1600 | 4 | 999999 | 1000 | 0.063319 | 2811919 | 3365140 | 92.46752 | -1271153 |
| 1700 | 3 | 999999 | 1100 | 0.062916 | 2795913 | 3268755 | 91.19896 | -1249078 |
| 1800 | 2 | 999999 | 1200 | 0.062511 | 2787645 | 3172370 | 89.59049 | -1225361 |
| 1900 | 1 | 999999 | 1200 | 0.063327 | 2786766 | 3054585 | 87.2944 | -1161993 |
| 2000 | 0 | 999999 | 1300 | 0.062513 | 2788916 | 2958200 | 84.88644 | -1139568 |

### Table C-4: Simulation results for Magnama

| 1 MW | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PV (kW) | H21.0-100kW | Grid (kW) | Converter (kW) | COE ($) | NPC ($) | Initial capital ($) | Ren Frac (%) | $CO_2$ (kg/yr) |
| 0 | 10 | 999999 | 0 | 0.037762 | 1877869 | 2517850 | 89.48673 | -1039876 |
| 100 | 9 | 999999 | 100 | 0.040548 | 1924789 | 2421465 | 88.45948 | -936483 |
| 200 | 8 | 999999 | 100 | 0.044119 | 1974190 | 2303680 | 86.96968 | -809743 |
| 300 | 7 | 999999 | 200 | 0.046616 | 2003960 | 2207295 | 85.43886 | -719607 |
| 400 | 6 | 999999 | 300 | 0.049857 | 2050054 | 2110910 | 83.52692 | -621358 |
| 500 | 5 | 999999 | 400 | 0.053568 | 2103747 | 2014525 | 81.20883 | -520266 |
| 600 | 4 | 999999 | 400 | 0.058122 | 2154756 | 1896740 | 78.11134 | -399338 |
| 700 | 3 | 999999 | 500 | 0.062054 | 2211283 | 1800355 | 74.64513 | -302126 |
| 800 | 2 | 999999 | 600 | 0.066228 | 2279542 | 1703970 | 70.28106 | -202841 |
| 900 | 1 | 999999 | 600 | 0.071526 | 2361182 | 1586185 | 64.18138 | -79069.4 |
| 1000 | 0 | 999999 | 700 | 0.074717 | 2455148 | 1489800 | 57.33502 | 17666.21 |
| 2 MW | | | | | | | | |
| 0 | 20 | 999999 | 0 | 0.023269 | 2139587 | 5035700 | 96.79079 | -2873867 |
| 100 | 19 | 999999 | 100 | 0.024367 | 2181327 | 4939315 | 96.61703 | -2770475 |
| 200 | 18 | 999999 | 100 | 0.025688 | 2223364 | 4821530 | 96.37747 | -2643735 |
| 300 | 17 | 999999 | 200 | 0.026559 | 2243989 | 4725145 | 96.14204 | -2553599 |
| 400 | 16 | 999999 | 300 | 0.027708 | 2278951 | 4628760 | 95.8633 | -2455350 |
| 500 | 15 | 999999 | 400 | 0.029007 | 2319352 | 4532375 | 95.54086 | -2354258 |
| 600 | 14 | 999999 | 400 | 0.030487 | 2353856 | 4414590 | 95.14259 | -2233330 |
| 700 | 13 | 999999 | 500 | 0.031829 | 2388988 | 4318205 | 94.72733 | -2136118 |
| 800 | 12 | 999999 | 600 | 0.03332 | 2428510 | 4221820 | 94.2462 | -2036833 |
| 900 | 11 | 999999 | 600 | 0.035215 | 2470339 | 4104035 | 93.6397 | -1913061 |
| 1000 | 10 | 999999 | 700 | 0.036819 | 2507555 | 4007650 | 93.0031 | -1816325 |
| 1100 | 9 | 999999 | 800 | 0.038586 | 2548764 | 3911265 | 92.27374 | -1717851 |
| 1200 | 8 | 999999 | 900 | 0.040503 | 2593212 | 3814880 | 91.42582 | -1618316 |
| 1300 | 7 | 999999 | 900 | 0.042875 | 2637383 | 3697095 | 90.34774 | -1496339 |
| 1400 | 6 | 999999 | 1000 | 0.044977 | 2683296 | 3600710 | 89.1703 | -1398369 |
| 1500 | 5 | 999999 | 1100 | 0.047234 | 2733289 | 3504325 | 87.78603 | -1299467 |
| 1600 | 4 | 999999 | 1100 | 0.050138 | 2787852 | 3386540 | 85.9844 | -1176273 |
| 1700 | 3 | 999999 | 1200 | 0.052544 | 2844465 | 3290155 | 83.94063 | -1078663 |
| 1800 | 2 | 999999 | 1300 | 0.055016 | 2910124 | 3193770 | 81.38886 | -980144 |
| 1900 | 1 | 999999 | 1400 | 0.057452 | 2987649 | 3097385 | 78.16133 | -881024 |
| 2000 | 0 | 999999 | 1400 | 0.060329 | 3078703 | 2979600 | 73.83556 | -758784 |

**Calculations of wind power:**

Consider, Blade length, l= 52 m

Wind speed, v= 12 m/sec

Air density, ρ= 1.23 kg/$m^3$

Power Coefficient, $C_p$= 0.4

So A=$\pi r^2$=8495 $m^2$

Now putting the all value in the following equation

$$p_{power} = \frac{1}{2} A\rho v^3 C_P = 3.6 \text{ MW}$$

# List of Publications

[01] Md. Nurunnabi and N. K. Roy, “Renewable Energy Based Hybrid Power System: the Best Way to Keep the World Pollution Free from GHG,” 2nd International Conference on Electrical Information and Communication Technology (EICT), 10-12 December 2015, Khulna (IEEE explorer).

[02] Md. Nurunnabi and N. K. Roy, “Grid-Connected Hybrid Power System Design Using HOMER,” International Conference on Advances in Electrical Engineering (ICAEE), 17-19 December 2015, Dhaka (IEEE Explorer).

[03] Md. Nurunnabi and N. K. Roy, “Environmental and Socio-Economic Impacts of Renewable Energy,” submitted to IET Renewable Power Generation.

[04] Md. Nurunnabi and N. K. Roy, “Optimal Sizing of MW-Scale Hybrid Power System,” submitted to Renewable Energy-Elsevier.