Design and Validation of Wind Turbine's Power Simulation by Remote Controlled AC Motor.

by

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

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To My Parents

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ABSTRACT

A statistical analysis of 10 minutes interval wind data at 20 m height for different location of Bangladesh has been made. The data has been shorted in sequence of appropriate frequency as hourly, daily and monthly mean wind speed. The gusty wind behaviour has also been analyzed. The data has been presented and analyzed in velocity friquency bar graph, energy bar graph, velocity duration curve etc. Two important paramets Weibull shape factor "*k*" and Weibull scale factor "*c*" have been obtained from the data. Weibull function *F(v)*, Weibull probability density function *f(v),* velocity duration function *S(v)* and available energy in the wind (wh/m^2) have also been obtained from the wind data.

This paper also presents a way of determining the long lasting strongest gusts at the Sitakunda. While searching the wind power potential in the windy sites of Bangladesh for electricity generation, it has been found that Sitakunda have some unusual wind characteristics in August and September. In the irregular region of wind speed, the value of Weibull shape factor and Weibull scale factor was out of range. During analysis of wind data of Sitakunda, a long lasting strong gusty wind was obtained there.

Then a horizontal axis wind turbine has been designed for the selected site Kuakata. For the simulation of power in replaced of designed wind turbine a remote controlled motor has been coupled with a generator. The motor speed has been controlled by PWM signal in its ten steps. A couple microcontrollers have been used for the simulation. High radio frequency remote have been designed to control the motor. At any step, the motor RPM, generator output voltage and switch position has been digitally displayed in the LCD display screen.

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LIST OF ABBREVIATIONS

WECS	Wind Energy Conversion Systems
LGED	Local Government Engineering Department
BCAS	Bangladesh Centre for Advanced Studies
BUET	Bangladesh University of Engineering and Technology
BCSIR	Bangladesh Council of Scientific and Industrial Research
WWEA	World Wind Energy Association
BWDB	Bangladesh Water Development Board
BAEC	Bangladesh Atomic Energy Commission
REB	Rural Electricity Board
BRAC	Bangladesh Rural Advancement Committee
RF	Radio Frequency
IR	Infra red

LIST OF SYMBOLS

A	*Area*
B	*Number of blades*
C	*Blade chord*
c	*Scale parameter*
C_D	*Turbine overall drag coefficient*= $F_D/½\rho AV_\alpha^2$
C_l	*Blade lift coefficient*
C_{ld}	*Design lift coefficient*
C_P	*Turbine overall power coefficient*=$P_0/½\rho AV_\alpha^2$
D	*Rotor diameter*
h	*Height of turbine, hub height from ground level*
h_i	*frequency*
h_{ref}	*Height of a reference point from ground level*
k	*Shape parameter*
P	*Turbine power*
P_e	*Extracted power*
r	*Local blade radius*
r_{hub}	*Hub radius*
R	*Rotor radius*
$\overline{V}$	*Average wind speed*
λ_d	*Tip speed ratio*
λ_r	*Local design speed*
φ	*Angle of relative velocity*
β_T	*Twist angle*
α	*Angle of attack*
V_d	*Design velocity*
V_g	*Gust velocity*
K_g	*Gust factor*

There are three parts of this paper according to this sequence mention below.

PART – I

Analysis of Wind Speed Data

PART – II

Site Selection and Wind Turbine Design

PART – III

Power Simulation

Chapter 9

CONCLUSIONS & RECOMMENDATIONS

9.1 CONCLUSITIONS:

In regard to the present statistical wind data analysis, gust analysis, design of horizontal axis wind turbine and model for power simulation the following conclusions are drawn:

(i) Monthly mean wind speed of Kuakata was found to be relatively higher velocity (4.95 to 5.97 m/s) than that of the other sites. As a result our selected site is Kuakata for generation of electricity.

(ii) During the analysis of wind characterstics of Sitakunda a remarkable gusty wind of high intensity was observed which has been named as vilont storm – I.

(iii) Weibull shape factor "*k*" and Weibull scale factor "*c*" have gone out of range for the above mentioned gusty wind at Sitakunda. However, for the rest period the rang of *k* value is from 1.10 to 3.19 and that of *c* value is from 2.23 to 10.83.

(iv) A horizontal axis wind turbine was designed for the selected site Kuakata, Bangladesh. The same design procedure can be applied for any prospective wind site.

(v) The model for power simulation is a system for automation and remote control motor simulated to generator in which motor RPM, generator output voltage and step position shows digitally in the LCD screen. The motor speed was controlled by PWM signal in the microcontroller chip.

(vi) In the remote, the radio frequency is 13.56 MHz, which has some remarkable properties like high transimitivity, high reflectivity, multi-directional radio link etc. The radius of the remote is higher than any other conventional remote. It becomes active outside a wall or any other restrictions.

(vii) The analysis has been made for six prospective wind sites of Bangladesh considering only one year available data. However, for more realistic analysis wind for more than one year should be taken.

9.2 RECOMMENDATIONS:

The following recommendations are given for the future work:

(i) Only six prospective areas have been considered for the analysis in this study. Other areas of Bangladesh may also be selected for the wind data generation.

(ii) Cost-benefit analysis of wind electricity generation system with that of the other conventional system can be compared.

(iii) Prospect of different drag type and lift type wind turbines can be carried out.

(iv) Estimation of the rotor blade loading and stresses developed in the deformed blade due to blade flexibility may also be studied. The tip and hub loses may also be studied.

(v) It is recommended for future research to simulate this system with directly to wind tunnel by using a velocity measurement sensor. Then different velocity sense for the wind tunnel and the motor rotate according to the velocity and automatically step variation of the motor will occur.

--------- THE END --------

PART – I

ANALYSIS OF WIND DATA

Chapter 1

INTRODUCTION

1.1 Introduction, 1.2 Generation of wind, 1.3 Sea-breeze and land breeze, 1.4 Geographical and wind location of Bangladesh, 1.5 Outline of Methodology, 1.6 Objectives, 1.7 Scope of the thesis, 1.8 Review of Literature, 1.9 Historical uses of wind energy, 1.10 Present day wind electricity generation (WEG), 1.11 Growth of wind park in the world.

1.1 INTRODUCTION:

Wind energy is a non polluting cost-effective renewable energy source. The science of exploration of wind power is not a new one. For the past few centuries, people have been extracting energy from the wind in various ways. One means of converting wind energy to a more useful form is through the use of windmills. Wind power technology in Bangladesh has been growing significantly in the last decade. Capacity of wind turbines has been increased significantly and at the same time, the cost of generating power from wind has come down. For a long time, people have been using energy mainly from the fossil fuels in almost countries of the world. In some of the countries they are also utilizing uranium fuel, a source of nuclear energy. With the increasing demand of energy and for many other reasons, prices of these fuels are increasing day by day. So people are trying to find the alternative source of energy. Wind is a kind of energy source, which will never be finished. It is available almost all the time, in all the places and in large quantities all over the world. Again, fossil and uranium fuels will be finished once. These are not available in all the countries. Besides every nation wants to be self-dependent, none like to rely on imported fuel, which required huge amount of national exchequer. On the other hand, no effective and economic method has yet been developed to use the solar energy. As a result all over the world, people are taking keen interest to develop effective and economic devices to collect energy from the wind. A renewable energy policy entitled "Renewable Energy Policy of Bangladesh" has already been adopted by the Ministry of Power, Energy and Mineral Resources, Government of the People's Republic of Bangladesh [1]. There are many objectives of this policy such as scale up contributions of renewable energy to electricity production, harness the renewable energy resources and dissemination of renewable energy technologies in rural, pre-urban and urban areas, enabling environmental and legal support to encourage the use of renewable energy etc. The policy sets targets for developing renewable energy resources to meet 5% of the total power demand by 2015 and 10% by 2020 [1]. So, it is obvious that Bangladesh is encouraged to use renewable energy. Since we are in the initial stage of utility of wind energy, we should follow the steps implemented by other countries in the region. Two major areas of research in these countries are centered on electricity generation and water pumping [19-23, 25-27].

1.2 GENERATION OF WIND:

Due to unequal heating of the earth surface by the sun, the air above the earth surface is heated unequally resulting density difference or in other word pressure difference. The air of higher density flows towards the air of the lower density to replace it. This flow of air is called the **wind.** Since the wind is created due to the sun's energy, it is actually solar energy. Only 2% of all solar energy reaching the sun is converted to wind energy. The earth's surface where the sun's rays fall almost perpendicularly gets higher heat. As such the earth surface, near the equator i.e. the tropic gets more heat than the poles. This causes the cold surface air to move from the poles toward the equator to replace the hot air, which rises and moves in the upper atmosphere towards the poles. However, the rotation of the earth also affects this motion. Local or regional wind may be generated due to temperature differences. In case of mountains and valleys, the air in the mountain is heated by the sun at the day time. This heated air is replaced by the cooler air from the valley. But at night the air of the mountain becomes cooler due to radiation and flow in the reverse direction occurs, creating a mountain breeze. Regional or local wind may also occur along the coastal areas. At day time, much of the sun energy is absorbed by the sea water for evaporation, on the counter land absorbs less energy, as a result the air of the over the sun remains cooler than that over the land. This causes the air of the sea to move towards the land to replace the hot air at the day time. While at night the land cooler rapidly than water, so does the air above it and the flow of the air in reverse direction occurs at night. The alternate sea and land breezes are created at day and night time.

1.3 SEA-BREEZE AND LAND BREEZE:

A sea-breeze (or **onshore breeze**) is a wind from the sea that develops over land near coasts. It is formed by increasing temperature differences between the land and water which create a pressure minimum over the land due to its relative warmth and forces higher pressure, cooler air from the sea to move inland. Generally, air temperature gets cooler relative to nearby locations as one move closer to a large body of water.

The sea has a greater specific heat than land and therefore has a greater capacity for absorbing heat than the land, so the surface of the sea warms up slower than the land's surface. As the temperature of the surface of the land rises, the land heats the air above it. The warm air is less dense and so it rises. This rising air over the land lowers the sea level pressure by about 0.2%. The cooler air above the sea, now with higher sea level pressure, flows towards the land into the lower pressure, creating a cooler breeze near the coast. The strength of the sea breeze is directly proportional to the temperature difference between the land and the sea. If the environmental wind field is greater than 8 knots and opposing the direction of a possible sea breeze, the sea breeze is not likely to develop.

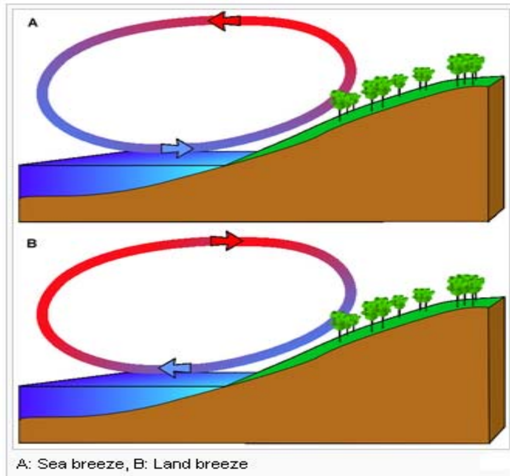


Fig.1.1: Sea-breeze and land breeze.

Land breeze, at night, the land cools off quicker than the ocean due to differences in their specific heat values, which forces the dying of the daytime sea breeze. If the land cools below that of the adjacent sea surface temperature, the pressure over the water will be lower than that of the land, setting up a land breeze as long as the environmental surface wind pattern is not strong enough to oppose it. If there is sufficient moisture and instability available, the land breeze can cause showers or even thunderstorms, over the water. Overnight thunderstorm development offshore due to the land breeze can be a good predictor for the activity on land the following day, as long as there are no expected changes to the weather pattern over the following 12–24 hours. This is mainly because the strength of the land breeze is weaker than the sea breeze. The land breeze will die once the land warms up again the next morning.

1.4 GEOGRAPHICAL AND WIND LOCATION OF BANGLADESH:

Bangladesh lies in the northeastern part of South Asia between 20º34´ and 26º38´ North latitude and 88º01´ to 92º42´ East longitude with an area of 143,998 square km and a population of about 156,050,883 (July 2009 est.) i.e. 156.6 million at 2010. India surrounds the country in three sides (West, North and East), sharing 3715.18 km of common border. It should be noted here that this is about 93% of Bangladesh's entire land borderline. The other neighbor being Myanmar, sharing mountainous border in the southeast. The Bay of Bengal lies to the south of Bangladesh. The costal zone of Bangladesh consists of about 710km coastline, the largest patch of natural mangrove forest shared with India and a long sea beach along the southeast [6].

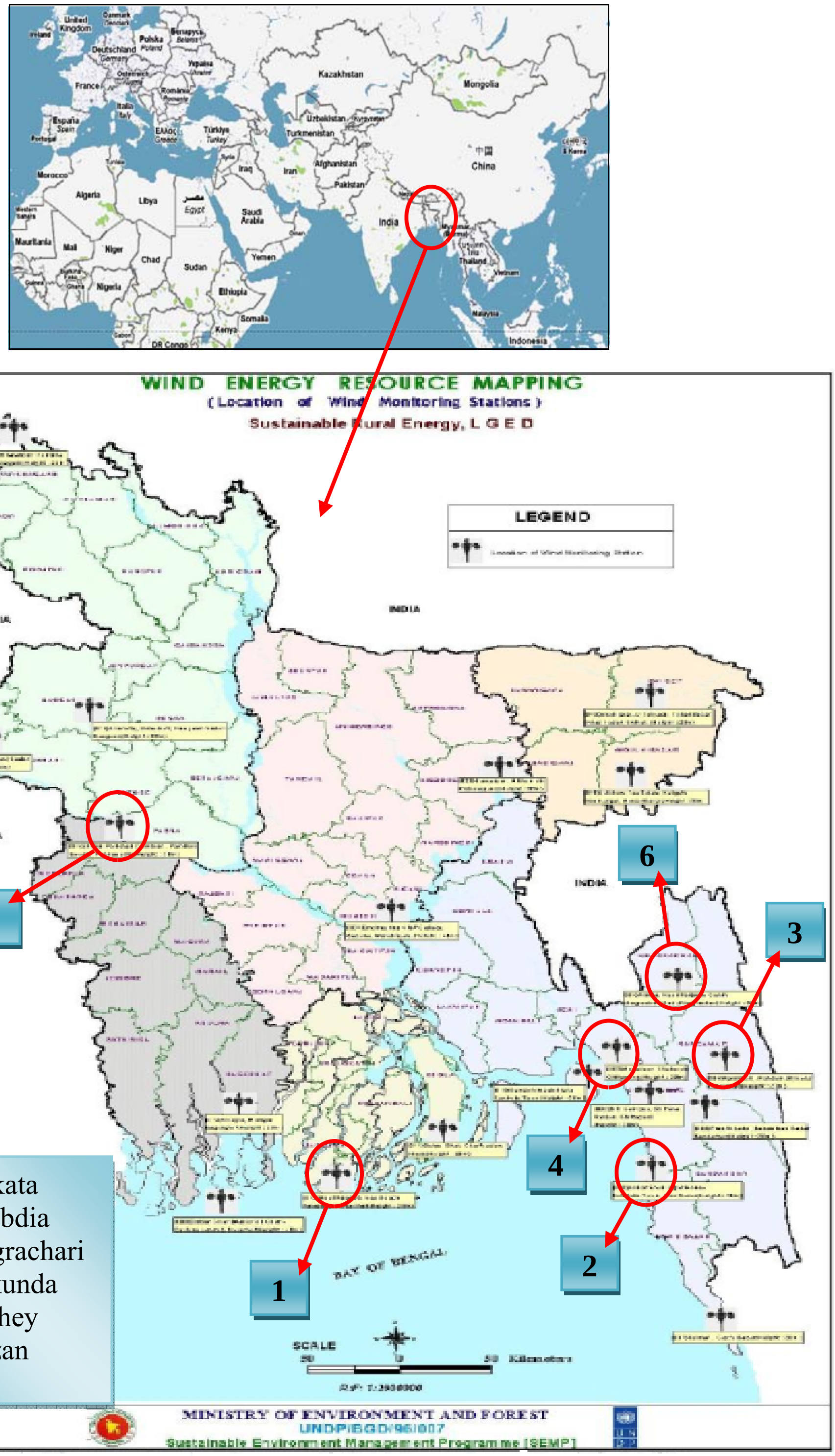
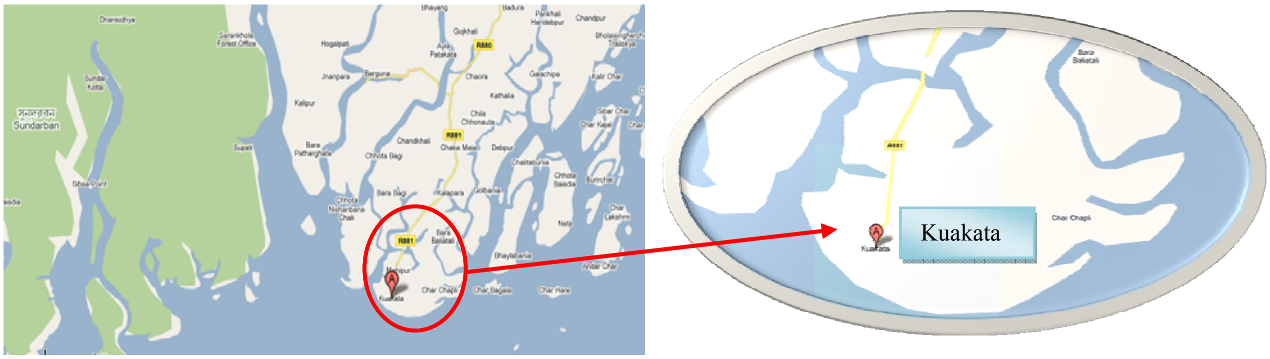


Fig. 1.2: Locations of Wind Sites in Bangladesh Map [13].

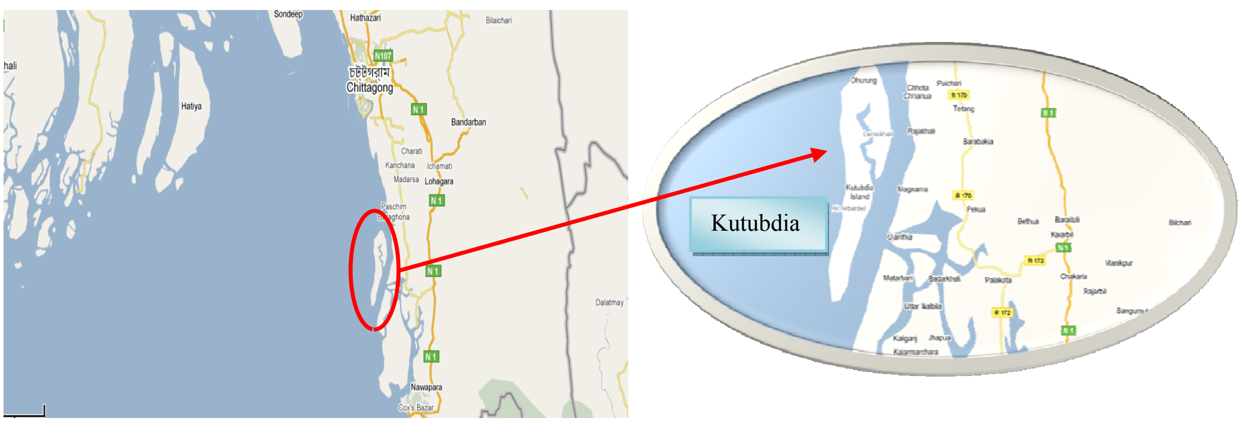
The station numbers were selected from the beginning according to this sequence, which is maintained through the entire thesis. The SRE project/LGED, in collaboration with BUET and has taken up a study on titled “Wind Energy Resource Mapping (WERM)”

[13]. The study has been designed in a more comprehensive way aiming at systematic observation on wind regime in initially 20 (twenty) different suitable locations including Chittagong Hill Tracts region over a longer period of time. Following **6 sites have been chosen** for this thesis work because of their completeness and reliability.

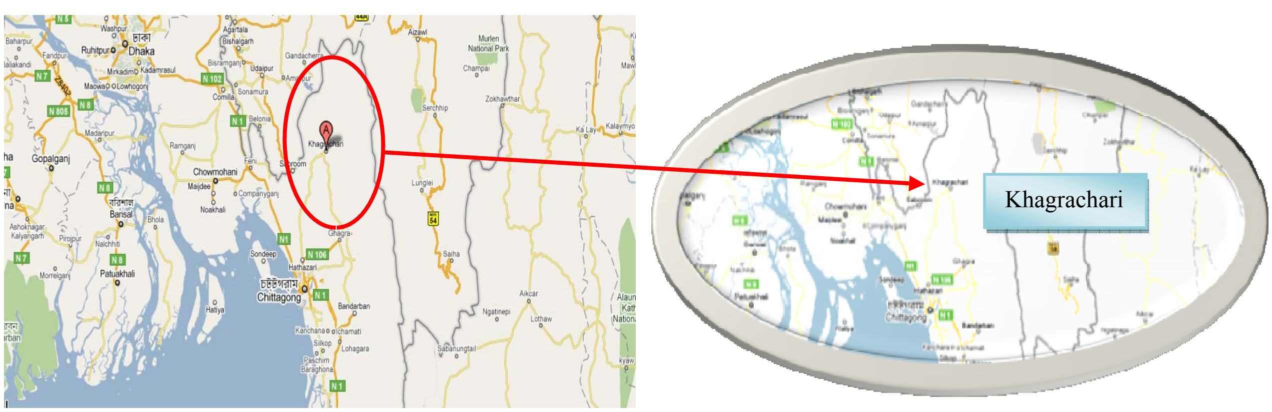
Kuakata: (21°54.76′ North Latitude 90°08.24′ East Longitude and station height is 30m)



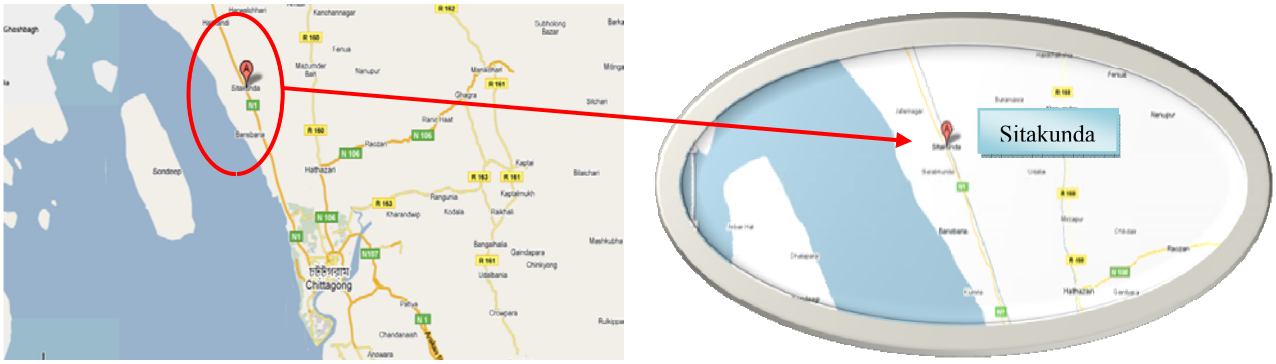
Kutubdia: (21°54.71′ North Latitude 91°52.43′ East Longitude and station height 20m)



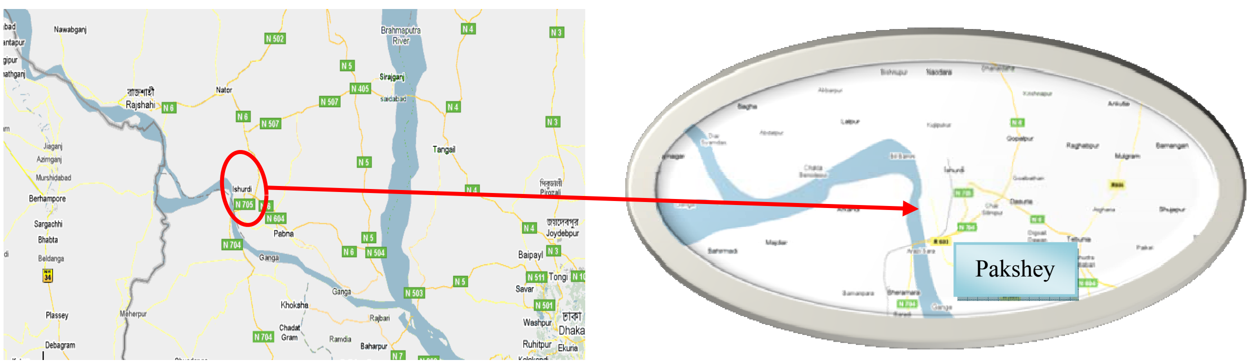
Khagrachari: (23°05.45′ North Latitude 91°57.67′ East Longitude and station height 20m).



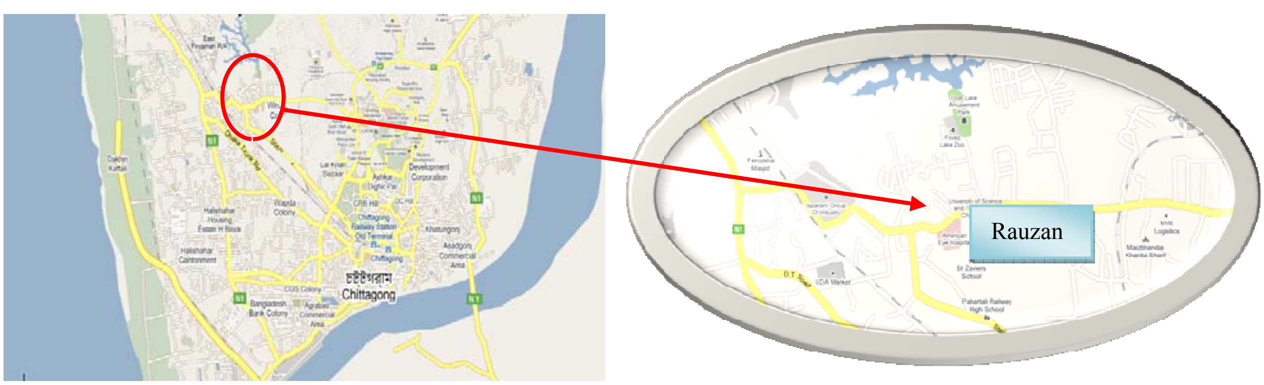
Sitakunda: (22°35.68′ North Latitude 91°42.52′ East Longitude and station height 30m)



Pakshey: (24°08.65′ North Latitude 89°06.53′ East Longitude and station height 30m)



Rauzan: [Pahartali] (22°30.27′ North Latitude 91°55.92′ East Longitude and station height is 20m).



Wind energy is more effective as it is free and almost available throughout. Recently, the utilization of wind power is increasing in many developed, as well as, under developed countries. Although the wind speed may vary from one location to another location. About twenty years ago, large numbers of experiments were done in the laboratory to develop the appropriate technology for utilization of wind energy. It was quite cost competitive with any thermal and coal power plants. Now a day, wind energy conversion systems (WECS) [40] have been extensively used in Germany, Denmark, Netherlands, UK, Russia, Brazil and Australia. Asian counties, like China, India and Indonesia have also been using this technology [54]. The wind resource assessments have been completed recently in Japan, Thailand, Srilanka and Malaysia. A few wind farms have been installed in Japan, Thailand and Srilanka. Malaysia is also going to install wind farms in wind prospective areas. Compared to other developing countries, Bangladesh is in its initial stage for utilizing WECS. Some organizations like LGED, BCAS, BUET, and BCSIR have already started measuring wind speeds at some typical locations of Bangladesh with modern equipments [30-31, 33]. To make proper use of wind energy, proper site selection and wind speed availability are to be considered first. The wind speed and its duration are the key factors to design and to determine the use of wind energy. So to generate accurate and more reliable wind speed data, the wind speed data monitoring system must be carried out before going to take any plan to implement either comprehensive or pilot plant in this regard. With a view to evaluating the actual pattern of wind energy, a typical location is chosen and wind speed is continuously monitored by means of an electronic and computer based apparatus.

1.5 OUTLINE OF METHODOLOGY:

First of all the raw wind data from January to December, 2006, above 10 m and 20 m height from the different wind sites of Bangladesh such as: Kuakata, Kutubdia, Sitakundu, Khagrachari, Pakshey, Rauzan has been collected from renewable energy dept., LGED etc. and sorted in sequence in appropriate frequency. The data are analyzed and converted into several useful parameters, like hourly mean, daily mean, weekly mean, monthly mean, and annual mean values. The wind speed data of each location will be fitted to Weibull function to find different performance parameters. The value of Weibull shape factor (k) and Weibull scale factor (c) will be calculated by different methods to select an appropriate wind turbine. These optimum wind turbines power characteristics will be simulated by a motor. (This simulated motor may be coupled to any device that would be otherwise driven by a wind turbine). For the simulation of a motor, an electronics circuits has been designed for controlling the speed in ten stages by Microprocessor chip and remote. The various features of the motor also display digitally. This setup will be validated for testing the designated wind turbine power characteristics in the laboratory.

1.6 OBJECTIVES:

The following are the main objectives of the present research:

a) To collect the raw data of wind from renewable energy dept., LGED for six wind sites of Bangladesh.
b) To analyze the wind data to find out hourly, daily, weekly, monthly and yearly average wind speed and gust speed to study various wind characteristics for those six stations.
c) To analyze the Weibull's parameters such as Weibull shape factor (*k*), Scale factor (*c*) for the selected wind sites.
d) To compare different wind parameters and find out total power available in the wind for power production of the selected sites.
e) To select an appropriate wind turbine (Type, number of blades, blade shape etc.) based on wind characteristics mentioned in (b).
f) To make a model for wind turbine's power simulation by a motor (which may be operated by remote) coupled with generator and digitally display of different characteristics of the system.

1.7 SCOPE OF THE THESIS:

The prime vision of this thesis work is to analyze the wind characteristics, designing a wind turbine for electricity generation and turbine power simulation by a remote controlled motor.

PART - I *(ANALYSIS OF WIND DATA)*

In Chapter - 1, the historical background of energy utilization is discussed and prospect of "Wind" as a source of energy is also presented. Next the methodology, aim and scope of the study are also given. Review of the existing literatures is also presented.

In chapter - 2, the ten minutes interval wind speed data (rough data) were sorted in the appropriate frequency like hourly, daily, weekly, monthly and annually mean wind speed for each selected stations. Then the calculated data is processed for Weibull distribution, the shape factor (*k*) and scale factor (*c*) are determined by three methods for each month. The total available energy in the wind also calculated here.

In chapter - 3, this chapter is very important where gust analysis have made and clearly discussed about irregular wind characteristics. Some modified forms of gust equation have been used and find out different parameters for the gust analysis. New classifications of wind class and ranging were made and analysis of such classification in reality.

In chapter - 4, all the wind data has been plotted for analysis and discuss separately for each site. This chapter is very important for realization of wind power potential in prospective wind sites of Bangladesh and site selection for electricity generation. All results and findings were shown in this chapter for data analysis of the selected sites.

PART-II ***(SITE SELECTION AND WIND TURBINE DESIGN)***

In chapter - 5, some parameters which are necessary for selection of wind sites for electricity generation and wind turbine design for that site have calculated and analyzed.

In chapter - 6, the theory and wind turbine design procedure has clearly discussed here. All necessary information is available in this chapter for design a wind turbine.

PART – III ***(POWER SIMULATION)***

In chapter - 7, experimental setup, working procedure and output result is discuss in this chapter and recommends for future development of this experimental setup.

In chapter - 8, in this chapter all discussions were made of this thesis.

In chapter - 9, in this chapter concluded of this thesis and give some recommendations for future works on this field.

1.8 REVIEW OF LITERATURE:

Some papers related to the present thesis work are mentioned below-

Hossain, M. A. and Islam, S. M. N. [2], started research on wind energy in Bangladesh as early as in 1979 in collaboration with Free University of Brussels (FUB), Belgium. Through contacts with the ministry of Co-operation and Development, Government of Belgium and Bangladesh Embassy in Brussels the project was initiated. The objectives of the project were to study wind energy in the prospective wind sites of Bangladesh and to determine an appropriate size and shape of the wind turbine rotor. A vertical axis wind turbine with three aerofoil blades was designed and a model was tested in the wind tunnel of Free University of Brussels. Subsequently prototypes were fabricated in Belgium and Bangladesh using the local materials and these were installed and tested without load. In this project, water lifting for irrigation was considered. For this purpose the wind data were obtained from the Naval Head Quarter in Chittagong and meteorological station in Cox's Bazar.

Also two other types of rotors, Savonius rotor and Sailwing rotor [3, 4] were designed, fabricated and installed to study their performance in the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology (BUET). In these cases positive displacement pump were operated for lifting water. The Progress and outline of the project are presented below.

Hossain, M. A. and Islam, M. Q. [3], mentioned that a vertical axis sailwing rotor having six sails has been fabricated using locally available materials and placed. It was used for water pumping for different static pressure head. The system was operable even at low available wind speed. The starting wind speed for the system is found to be about 1.5 m/s and the maximum efficiency is about five percent. The experiment was carried out on BUET, Dhaka.

Hossain, M. A. and Islam, M. Q. [4], have designed and manufactured a savonius rotor for pumping water with the help of empty oil drums for irrigation purposes in developing countries like Bangladesh. The rotors were capable to lift water for different total static lift with maximum overall efficiency of about six percent and discharge rate of about 2.8 L/min. It has been coupled with locally manufactured diaphragm pump and it was directly driven by crank and connecting rod. One of them was installed in front of Mechanical Engineering department, BUET. The cut in speed of the system was 1.5 m/s (3.55 mph) and it can pump reasonable amount of water even at low and variable wind speed.

Král [14] handled statistical estimates of the ten-minute wind velocity mean values and estimates of the gust wind maxima throughout the Czech Republic to find out the causes behind this difference and to propose the way to be taken to settle the contradiction. Some of the gust estimates are significantly higher than equivalent gusts determined by means of the peak velocity pressure model from the ten-minute mean velocity estimates.

Moisselin et al. [15] elaborated a new extreme wind speeds map; a homogenization tool is developed that allow the detection and the correction of breaks due to sensor change and modification of measurement environment. Breaks are detected on annual mean wind speed series. Daily maximal wind speed values for about 150 wind speed stations have been selected using this method.

Rajabi and Modarres [16, 17] prepared a paper that represented an analysis of wind velocity data relating to 11 extreme non-synoptic events obtained from velocity time series pertaining to flow over rural and coastal terrain. The data were measured at a number of locations within Northern Europe and in all cases a sufficient array of anemometry was present to obtain an indication of the velocity profile.

Alam, et al. [21] compared the performance of wind pumping systems (WPS) using centrifugal pumps, coupled by either mechanical or electrical drives. For mechanical transmission between centrifugal pump and wind turbine, overall system performance may be improved by running slowly a larger sized centrifugal pump. Matching of this type is likely to be most beneficial for shallow lifts.

Yongfen, W. [24] reported that almost 90% of the small wind turbines operating in China were found in the Autonomous Region of Inner Mongolia, where they had been used predominantly for battery charging. The wind region is not uniform across the region, however, and in many areas the electricity generated is available only for part of the time and involves unfavorable charge cycling, and hence shorter life of the batteries. The high price of the batteries then renders the systems uneconomic.

Suresh et al. [25-26] carried out the study includes system design, operational status, performance in the field and to carry out a financial study of deep well wind pumps installed under the demonstration program by Ministry of Non-conventional Energy Sources in India. Eight of the twenty-two systems surveyed were found functional and detailed technical evaluations were also carried out.

Sarkar et al. [27] collected the hourly wind speed data of the coastal area of Chittagong for the years 1978-81. From the hourly average wind speed, the hourly and monthly energy outputs were computed for three commercial machines (22 kW, 16 kW and 4 kW) having different cut-in wind speed. The 22kW machine was found to produce higher energy output per m^2 than the other two for the selected energy region. The hourly and monthly energy variation of the 22 kW machine was studied and the cost per kWh of energy produced by the machine was obtained.

Hussein, et al. [28] studied the characteristics of wind data for three recent years, recorded at 14 stations of the Bangladesh Meteorological Department. The data have been used to compute the monthly average wind speed and wind energy available for; the stations. Average values of monthly wind speed for 1931-1960 have been employed to obtain the energy availability from the energy pattern factor, and the two sets of results have been compared. It has been found that, for the Chittagong station, the frequency distributions have good fits of the Weibull type.

1.9 HISTORICAL USES OF WIND ENERGY:

No one knows when exactly the use of wind energy took place. The first breakthrough must have been the use of sails for navigation. Wind energy has been used to propel ships for a long time. In the past, many countries supported their prosperity on their ability to navigate, America being discovered by such type of navigated ships. Roughly wind was the only power to move ships until James Watt developed the steam. [21] Inshore Windmills were used from many centuries ago. There is an evidence of windmills being used for grinding grains by the Egyptians in the 36th BC. The Buddhist monks in Tibet had religious inscriptions (mantras) on drums which were rotated by the wind. A similar technique was known to have been used in Egyptian, Persian and early Christian places of worship. Hammurabi [21], emperor of the Babylonian Empire, used windmills for irrigation, around 17th century BC. Extensive use of windmills was made from the time of Hammaurabi till the 15th century AD. The Persian people utilized windmills extensively by the middle of the 7th century BC. The machine was mounted on a horizontal axis and used axially disposed sails. Some authors have suggested that the introduction of the windmills into Europe be due to the Crusades, when the Crusader returned from the Middle East. The first English windmills dates back to 1191AD and the first windmills for milling appeared in Holland in 1439 AD [21]. The multi-blade windmills appeared in the 14th century. However, in the Schauplatz de Wasser Kunste (Journal of Hydraulic Arts.) printed in Leipzing in 1724, an eight-bladed windmill could be found. The blades rotate about an axis changing their orientation as the wind varies its speed. The construction of such types of multi-blade machines started in America, in 1870. They were spread everywhere and then they returned to Europe in 1876. In the middle of the 15th century, a simple type of multi-blade windmill was developed to pump water from underground and was used during the America West colonization. It is believed that at least 6.5 millions of these units were constructed between 1830 and 1930 by different companies. A great number of these units are still under operation. The use of wind power started to drop during the Industrial Revolution, when the Steam Engine was invented and cheap fossil fuels become widely available.

1.10 PRESENT DAY WIND ELECTRIC GENERATORS (WEG):

Present day phase of wind electric generators (WEG) started with the oil crisis of Middle East during 1975, when renewed need was felt for the development of New and Renewable Sources of Energy. Work on the development of wind electric generators started in many countries notably Denmark, Germany, the USA, the UK, the Netherlands etc. This development took into two directions: one large size and other small size [29]. While most of the countries concentrated on development of large MW size wind electric generators, Denmark followed a different path and started with the development of a smaller size machine, which happen to be 55kW capacities. These machines appeared in the USA and Denmark during 1981 that were found to be techno-commercial viable and were manufactured in large scale. These were up rated progressively; keeping the basic design features almost the same as the Gedser design. Various sizes of machines, which were developed subsequently, are l00kW; 150kW, 200kW, 250kW, 300kW, 400kW, 500kW, 600kW and now even l000kW to 1500kW machines are being introduced [29]. Now a days, many countries, like Germany, the USA, the UK, Australia, Japan, China, even India are manufacturing very small capacities i.e. 25 watts to 10 kW WEGs for very low wind speeds (1 m/s~5 m/s).

1.11 GROWTH OF WIND PARKS IN THE WORLD:

The present total installed capacity in the world was about 6000MW by the year 1996. This installed capacity is increasing day by day in all over the world. It was 4900MW by 1995 [30]. The first wind parks are installed in California in the USA in 1981. This installed capacity was 10MW with 140 machines in 1981. This peaked to 1640MW in 1991.1n addition to the USA installation have also taken place in many other countries, such as, Germany, Denmark, Holland, the UK, USSR, China, India, Thailand etc. The details of installations are as follows:

Source: World Wind Energy Association.

Fig. 1.3: Total Installed World Wind Capacity (MW) and Prediction 2001-2010.

Wind energy continued its dynamic growth worldwide in the year 2006, according to figures released by the World Wind Energy Association about 14 900 MW were added in the past year making a global installed capacity of 73,904 MW by the end of December 2006. The added capacity equals a growth rate of 25 per cent, after 24 per cent in 2005. The currently installed wind power capacity generates more than one per cent of the global electricity consumption. Based on the accelerated development, World Wind Energy Association (WWEA) has increased its prediction for 2010 and expects now 160 000 MW to be installed by the end of 2010.

Five countries added more than 1000 MW: the USA (2454 MW), Germany (2194 MW), India (1840 MW) and Spain (1587 MW) were able to secure their leading market positions and China (1.45 MW) join the group of the now top five markets and is now number five in terms of added capacity, showing a market growth of 91 per cent. Five countries added more than 500 MW and showed excellent growth rates: France (810 MW, 107 per cent growth), Canada (768 MW, 112 per cent), Portugal (628 MW, 61 per cent) and the UK (610 MW, 45 per cent). The most dynamic market in 2006, Brazil, faced its long expected take off and added 208 MW, which equals a sevenfold increase of installed capacity within one year.

At present the USA is the 1st, Germany is the 2nd and India is the 3rd position in the world as the installed capacity of Wind parks. The wind parks installation can be classified into four groups according to the available average wind speed and WEGS sizes they are as follows:

1st Group Installation of WEGS (small scale) with capacities from 25W to 10 kW for Mechanical pumping, battery charger, lighting, radio and television within average wind speed of 2.5 m/s to 4.0 m/s.

2nd Group Installation of WEGS (medium scale) with capacities from 10 kW to 55 kW for pumping, cold storage, lighting etc. within average wind speed range of 4.0 m/s to 5.0 m/s.

3rd Group Installation of large scale WEGS with capacities from 55 kW and above for national grid connection with average wind speed of 5 m/s and above.

4th Group Wind installations operating in hybrid system i.e. wind with diesel, wind with solar, wind with gas generator, wind with Bio-gas generator etc. capacities with 5kW to 100 kW for low speed wind sites.

Chapter 2

STATISTICAL ANALYSIS OF WIND DATA

2.1 INTRODUCTION:

The wind energy potential in Bangladesh was evaluated from measurements of wind speed and direction at six wind speed monitoring stations. Data collected over a period of years were used to statistically analyze wind speed distributions. Weibull parameters, at the selected stations were calculated using three different methods. The theoretical values calculated from the analysis of the collected data performed well with the measured ones. Finally, the correlation between Weibull parameters and the measured wind speed values has been performed and analyzed for each station.

2.2. WIND DATA COLLECTION AND ADJUSTMENT:

The wind data of six prospective wind sides along the southern of four coast area two hilly area and one River delta region were chosen to analyze the wind power potentials in Bangladesh. The detailed locations of the six wind sites have been shown in the **Chapter – 1**. The wind speed changes with height and the available wind data at different sites are normally measured at different levels. So it is necessary to know the wind speed at wind turbine hub height. The wind power law has been recognized as a useful tool to transfer the anemometer data recorded at certain levels to the desired hub center

$$v = v_0 \left(\frac{z}{z_0}\right)^{\eta} \tag{2.1}$$

Where, v and v_0 are the average speed at z m and at the reference height z_0 = 10m above the ground respectively; and the parameter η is the wind speed power law coefficient. The value of the coefficient varies from less than 0.10 to 0.40 depending on the nature of terrain [45, 47]. A value of 0.17 for η may be used, in general, although this is applicable for the open terrain only. The value of η = 0.28 may be chosen for the terrain with trees and houses like the suburb area.

2.3. FREQUENCY DISTRIBUTION:

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, mostly of equal width of 1 m/s or 0.5 m/s. Then starting at the first interval of say 0-1 m/s, the number of hours is counted in the period concerned that the wind speed was in this interval. This velocity frequency distribution as relative frequency is obtained from the velocity interval. The velocity intervals are 1 m/s wide such as 0-1, 1-2, 2-3................m/s. One sample is presented here. Rests are shown in the **Appendix-A**.

Table 2.1: Frequency distribution of wind speeds in Kuakata, (January to December) (Above 20 m height)

Velocity interval	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
0-1	35	10	15	3	14	3	3	11	10	36	20	48
1-2	70	35	57	35	39	30	16	39	48	160	100	114
2-3	239	163	147	67	76	80	39	49	95	320	296	218
3-4	250	227	286	90	128	107	67	68	135	182	251	285
4-5	115	178	162	160	139	106	132	119	157	42	40	34
5-6	31	44	56	149	110	141	152	116	100	3	2	10
6-7	4	7	15	113	104	128	134	78	46	0	3	12
7-8		6	2	66	69	85	94	88	25	0	1	10
8-9		2	3	26	49	29	64	78	37	0	0	0
9-10			1	11	14	10	30	69	24	0	0	0
10-11					2	1	12	22	25	0	0	0
11-12							1	7	12	1	0	0
12-13									1		0	0
13-14									0		1	0
14-15									0		0	0
15-16									2		0	3
16-17									0		3	4
17-18									2		0	3
18-19									0		3	3
19-20									1		0	0
Total=	**744**	**672**	**744**	**720**	**744**	**720**	**744**	**744**	**720**	**744**	**720**	**744**

2.4 MONTHLY MEAN WIND SPEED:

Monthly mean wind speed is the averaging of all wind speeds through the whole month of the sites in meter per second. By this data it is easy to identify overall wind energy potential of the site through the month. Both 10 m and 20 m height wind data are calculated for find out monthly mean wind speed. Two samples are presented here. Rests of the sites has shown in the **Appendix-B**.

Table 2.2: Monthly mean wind speed from January-December, 2006

(Above 20 m height)

Location	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Kuakata	3.11	3.57	3.54	5.07	4.97	5.10	5.74	5.97	4.95	2.57	3.01	3.22
Kutubdia	3.11	2.80	3.15	3.77	4.24	4.53	5.42	4.74	3.39	2.25	2.85	2.65
Khagrachari	2.85	3.45	3.88	4.16	3.44	4.67	3.36	3.1	3.19	2.38	2.53	2.37
Sitakunda	2.72	3.17	3.36	4.41	4.46	4.8	5.35	5.15	10.1	2.25	2.64	2.32
Pakshey	2.55	2.33	2.53	3.26	3.04	2.93	3.5	3.83	3.26	1.89	2.02	2.2
Rauzan	1.55	2.08	2.09	2.94	2.74	4.55	3.14	2.79	2.14	1.21	1.33	1.2

The weekly average wind speed of each location has also been calculated for this thesis work both in 10 m and 20 m height. It has not shown here. All data for weekly average wind speed has shown in the **Appendix-B**.

2.5 HOURLY AVERAGE WIND SPEED:

It is the hourly average of the wind during the whole day through the month. In this research work the hourly average wind speed is calculated for each month (January to December) of each site. But from the monthly mean wind speed and weekly mean wind speed, it is clear that the wind speed above 20 m height is higher than 10 m height. So, for next step only 20 m height wind velocity is considered for further analysis. One sample is presented here and rests of them are shown in **Appendix-B**.

Table 2.3: Hourly mean wind speed in m/s for Kuakata (Jan - Dec), 2006, (Above 20 m height)

Site	Hour	month											
		Jan	**Feb**	**Ma**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Kuakata	**1**	2.84	3.76	3.14	5.06	4.91	5.48	5.55	5.86	4.7	2.69	2.53	2.8
	2	2.9	3.78	3.3	4.94	5.02	5.34	5.65	5.88	4.74	2.8	2.71	2.76
	3	2.93	3.65	3.43	4.85	5.22	5.11	5.7	5.61	4.65	2.63	2.71	3.36
	4	3.11	3.52	3.35	4.74	4.88	4.98	5.75	5.72	4.64	2.59	2.96	3.17
	5	3.3	3.6	3.39	4.93	5.03	4.98	5.67	5.72	4.63	2.39	4.06	3.68
	6	3.46	3.72	3.25	4.92	5.06	4.87	5.55	5.71	4.74	2.51	3	4.15
	7	3.53	3.58	3.27	4.86	4.57	4.82	5.5	5.63	4.48	2.6	3.36	3.58
	8	3.46	3.6	2.86	4.77	4.53	4.75	5.33	5.71	4.53	2.3	3.2	3.74
	9	3.01	3.00	2.87	4.86	4.61	4.85	5.53	5.67	4.94	2.41	3.37	3.11
	10	3.02	2.82	3.21	4.9	4.61	5.16	5.81	5.83	4.87	2.47	2.61	2.34
	11	3.27	3.01	3.32	4.95	4.55	4.9	6.02	6.02	4.95	2.51	3.41	2.44
	12	3.42	3.17	3.61	5.19	4.65	4.92	5.99	5.91	4.99	2.56	4.18	2.75
	13	3.47	3.67	3.9	5.13	4.57	5.13	5.59	6.53	5.06	2.57	2.94	3.58
	14	3.55	3.63	3.95	4.92	4.85	4.98	5.47	6.49	5.09	2.71	3.18	3.26
	15	3.5	3.7	4.01	5.11	4.93	4.84	5.55	6.33	5.06	2.78	3.32	3.43
	16	3.57	3.63	4.13	5.29	5.16	5	5.56	6.44	5.25	2.75	3.2	3.26
	17	3.11	3.49	4.17	5.22	5.34	5.14	5.77	6.28	5.31	2.45	2.83	4.55
	18	2.8	3.67	3.98	5.11	5.15	5.06	5.94	6.07	5.55	2.32	2.68	3.87
	19	2.73	3.73	3.74	5.05	5.45	5.13	6.19	5.93	5.46	2.33	2.58	4.74
	20	2.72	3.9	3.75	5.14	5.43	5.06	6.06	5.88	5.33	2.41	2.54	2.37
	21	2.68	3.87	3.8	5.12	5.36	5.06	6.04	5.89	5.25	2.79	2.6	2.44
	22	2.66	3.79	3.81	5.35	5.19	5.17	5.86	5.97	5.01	2.72	2.7	2.39
	23	2.82	3.78	3.48	5.6	5.06	5.39	5.96	5.92	4.89	2.7	2.99	2.87
	24	2.85	3.71	3.27	5.59	5.05	5.56	5.63	6	4.71	2.74	2.54	2.6
Total =		**3.11**	**3.57**	**3.54**	**5.07**	**4.97**	**5.1**	**5.74**	**5.97**	**4.95**	**2.57**	**3.01**	**3.22**

2.6 DAILY AVERAGE WIND SPEED:

Daily average wind speed is the averaging of all wind speed of a particular day at the starting from the day to the end of the day i.e. time count 0^{th} min to 2350^{th} min (hh/mm). By this data, it can be easily identify the daily status of wind speed of a particular site. The mean speed (day basis) for Kuakata is given below, rest are shown in **Appendix-C**.

Table 2.4: Daily average wind speed in m/s for Kuakata (Jan - Dec), 2006. (above 20 m height)

Location	Date	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Kuakata,2006	1	3.27	3.33	3.80	4.50	4.52	5.73	7.89	6.84	3.36	2.30	2.93	4.17
	2	2.64	3.28	3.11	5.69	4.63	4.34	9.45	9.29	3.06	2.23	2.61	3.62
	3	2.84	2.63	3.24	7.21	4.87	2.58	9.08	9.13	8.87	2.88	2.54	4.04
	4	3.54	2.75	2.44	8.26	5.78	2.48	8.41	7.19	8.31	3.51	3.34	7.45
	5	4.16	3.16	2.98	7.31	5.15	4.55	7.07	5.35	4.88	2.85	2.87	2.91
	6	3.71	3.31	3.29	5.46	6.61	7.01	7.09	4.87	3.61	3.06	3.10	2.08
	7	3.19	2.72	2.81	5.12	6.12	7.02	6.27	5.35	5.00	1.64	2.20	2.63
	8	3.51	2.44	2.64	6.02	4.53	5.85	5.31	3.61	5.30	2.34	3.49	6.89
	9	3.95	3.16	3.29	3.66	4.23	7.45	5.32	3.66	4.01	2.24	1.31	2.86
	10	4.02	2.76	3.09	7.33	5.42	5.71	5.48	3.22	4.64	2.70	2.90	1.81
	11	3.09	2.81	5.01	7.39	5.99	6.38	4.41	6.33	5.74	3.18	2.11	2.05
	12	3.47	2.47	2.64	6.65	7.45	7.22	4.01	8.75	4.89	2.47	3.09	5.46
	13	2.54	2.25	2.52	5.65	5.11	7.55	3.93	4.17	3.09	3.41	2.98	4.25
	14	2.22	4.06	3.07	5.26	4.45	5.89	3.73	2.34	3.88	2.96	2.56	3.67
	15	2.25	4.72	3.62	4.97	2.94	5.08	4.51	4.52	3.66	2.07	2.93	3.39
	16	1.78	5.79	3.30	5.45	3.33	6.18	6.35	8.89	4.08	1.50	2.65	1.93
	17	1.99	5.13	3.19	5.69	3.23	5.33	5.35	7.34	2.87	1.98	2.95	2.26
	18	2.90	3.35	3.54	3.47	4.15	4.06	5.09	5.32	2.64	2.22	3.06	3.09
	19	1.65	3.89	4.21	4.05	4.29	2.84	5.94	3.81	5.91	1.80	2.58	1.26
	20	2.07	4.58	3.94	2.52	3.55	2.77	6.90	2.40	8.02	2.36	3.24	2.31
	21	2.85	4.08	3.81	2.78	2.32	6.07	7.44	5.17	9.52	1.99	2.72	2.27
	22	3.32	4.06	5.44	4.73	2.91	5.54	6.01	9.05	8.22	3.02	2.91	2.39
	23	2.66	3.81	3.99	3.98	2.74	6.45	4.46	9.15	9.09	2.99	2.64	2.18
	24	3.86	4.01	3.49	3.64	2.84	4.03	4.75	6.82	5.13	3.04	2.95	3.64
	25	5.08	3.94	4.68	3.57	3.15	2.61	4.54	5.89	4.35	3.07	3.05	3.51
	26	4.08	3.79	5.52	4.69	6.78	3.03	4.18	4.87	2.04	2.29	3.01	3.17
	27	2.91	4.29	4.70	3.11	7.32	3.97	4.13	4.04	1.97	2.42	4.75	1.96
	28	2.67	3.41	2.69	2.95	6.97	4.69	5.11	7.00	3.41	2.06	2.84	2.06
	29	3.55		3.02	3.55	6.31	4.56	7.09	8.77	4.93	2.75	3.22	3.67
	30	3.25		3.06	4.71	8.28	5.26	5.21	7.19	4.09	3.29	5.76	3.36
	31	3.22		3.69		8.01		3.23	4.72		3.12		3.37
Total Average		**3.11**	**3.57**	**3.54**	**5.07**	**4.97**	**5.1**	**5.74**	**5.97**	**4.95**	**2.57**	**3.01**	**3.22**

2.7. DATA PROCESSING FOR WEIBULL DISTRIBUTION:

This frequency distribution is further processed for Weibull Distribution to have the shape factor (k) and scale factor (c). There are many distributions to analyses any raw data. But for the wind regime Weibull Distribution fits very closely because of its flexibility in nature. Depending on the value of '*k*', the Weibull Function becomes Normal Distribution, Raleigh Distribution and exponential one. It is one of the most powerful tools to analyses wind regime for any site. From the graph of relative cumulative frequency versus non-dimensional velocity i.e. class velocity/mean velocity (v/v_{mean}) the shape of the Weibull Function can be obtained practically. How to process this data towards Weibull function is described in the following Table-2.5. One sample table of January 2006 for Kuakata for this purpose is presented below. Details are given in **Appendix-D**.

Table 2.5: Data processing for Weibull Distribution from the raw observed data.

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, " E" (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	$T-h_i$	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	35	744	0.047	35	0.047	709	0.953	0.5	0.4375
1-2	70	744	0.094	105	0.141	674	0.859	1.5	23.625
2-3	239	744	0.321	344	0.462	505	0.538	2.5	373.4375
3-4	250	744	0.336	594	0.798	494	0.202	3.5	1071.875
4-5	115	744	0.154	709	0.953	629	0.047	4.5	1047.938
5-6	31	744	0.041	740	0.995	713	0.005	5.5	515.7625
6-7	4	744	0.005	744	1	740	0.000	6.5	109.85
Total	**744**								**3142.925**

2.8: ESTIMATION OF THE WEIBULL PARAMETERS FROM THE PROCESSED DATA:

The Weibull distribution shows its usefulness when the wind data of reference station are being used to predict the wind regime in the surrounding of that station. The idea is that only annual or monthly average wind speeds are sufficient to predict the complete frequency distribution of the year or the month. This section deals with methods to extract the Weibull parameter *k* and c from a given set of data [8]. There are several methods by which *k* and *c* can be determined. Three different methods are described below.

a) Weibull paper/ Regression analysis
b) Standard - deviation analysis
c) Energy pattern factor analysis.

2.8.a: Weibull Paper:

Weibull paper method is the method where practical relative cumulative data is plotted against the velocity intervals in log-log paper. The Weibull Function is obtained as a straight line on the log-log graph paper and the slope of this line represents the value of k, the shape parameter of the Weibull function [8]. This method has been described detail in **Appendix-E**; the calculated Weibull parameter *k* and *c* by using Weibull paper method has shown in the **Appendix-E**.

2.8.b: Standard Deviation Analysis Method:

This method also detail described in **Appendix-E**. In short, the final expression for standard deviation calculation is presented below-

$$\sigma^2 = \frac{\sum (V_n)^2 - \frac{\left(\sum V_n\right)^2}{N}}{N-1} \tag{2.2}$$

Then corresponding *k* value can be found from **Appendix Fig E.2** and *c* can be find out from **A. Table E – 1.** Values of *k* and *c* from Standard Deviation method for each station for each month has shown in **Appendix-E**.

2.8.c: Energy Pattern Factor Method:

As this method has been described in **Appendix-E**, the energy pattern factor of a given set of N hourly data V_n can be determined with the following equation,

$$k_E = \frac{\frac{1}{N}\sum_{n=1}^{N}(V_n)^3}{\left(\frac{1}{N}\sum_{n=1}^{N}V_n\right)^3} \tag{2.3}$$

Using the above expression, the Weibull shape parameter (*k*) can be easily found out by using **Appendix Fig E -3** and the value of scale factor (*c*) can be find out from **A. Table E - 3**. Value of *k* and *c* by this method for each station for each month has shown in **Appendix –E**.

2.9 CLOSEST VALUE OF WEIBULL FACTOR "*k*" AND "*c*"

By applying different methods for find out the Weibull parameters are given below where *k* is a dimensionless number and *c* in m/s. One sample is presented here and rests of them are shown in **Appendix-E**.

Table 2.6: Closest values of *k* and *c*.

	Weibull paper method		Std. deviation method		Energy method	
Month	***k***	***c***	***k***	***c***	***k***	***c***
January	2.50	3.51	2.85	3.48	2.92	3.42
February	3.00	4.02	3.38	3.99	3.31	3.96
March	3.10	3.98	3.09	3.98	3.04	3.92
April	2.55	5.58	3.01	5.65	3.05	5.56
May	2.40	5.60	2.50	5.60	2.64	5.48
June	2.70	5.74	2.89	5.75	3.00	5.66
July	2.83	6.50	3.32	6.48	3.12	6.42
August	2.18	6.90	2.32	6.67	2.58	6.52
September	2.10	5.95	2.45	5.46	1.95	5.46
October	2.70	2.83	2.72	2.89	2.71	2.83
November	2.93	3.35	1.80	3.30	1.43	3.24
December	2.15	3.50	1.40	3.41	1.21	3.44

3.10: PARAMETERS FOR CALCULATED DATA:

After calculating the parameters of Weibull Function, the calculated Weibull density Function f (v), Weibull Function F (v) and Velocity Duration Function S (v) are checked with the observed data. All the observed and calculated data are given in **Appendix-D**. A graphical comparison between the observed & calculated Weibull Density Function f(v) and that of Weibull Function F(v) are also presented and discussed in **Chapter-4**.

Table 2.7: Calculated Data for Kuakata, January, ***k* =2.92, *c* = 3.42**

Velocity, m/s	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1- $e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency, hrs	Cumulative velocity Frequency, hrs	Velocity Duration	Mean Velocity, m/s	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
0-1	0.078	0.027	0.973	58.2935	20.2414	723.759	0.5	0.728669
1-2	0.247	0.188	0.812	184.04	140.178	603.822	1.5	62.11361
2-3	0.336	0.494	0.506	249.716	367.862	376.138	2.5	390.1819
3-4	0.238	0.794	0.206	176.753	590.756	153.244	3.5	757.828
4-5	0.085	0.952	0.048	63.5511	708.102	35.8983	4.5	579.1094
5-6	0.014	0.994	0.006	10.7073	739.738	4.2619	5.5	178.1428
6-7	0.001	1	3E-04	0.76499	743.774	0.22649	6.5	21.00862
							Total Energy =	**1989.113**

Chapter 3

ANALYSIS OF WIND GUST

3.1 Introduction, 3.2 Wind gust, 3.3 Gust analysis, 3.4 Find out Weibull parameters, 3.5 Mean wind speed analysis, 3.6 Wind class and ranging.

3.1 INTRODUCTION:

In meteorology, winds are often referred to according to their strength, and the direction the wind is blowing *from*. Short bursts of high speed wind are termed **gusts**. Strong winds of intermediate duration (around one minute) are termed squalls. Long-duration winds have various names associated with their average strength, such as breeze, gale, storm, hurricane, and typhoon. Wind occurs on a range of scales, from thunderstorm flows lasting tens of minutes, to local breezes generated by heating of land surfaces and lasting a few hours, to global winds resulting from the difference in absorption of solar energy between the climate zones on Earth. The two main causes of large scale atmospheric circulation are the differential heating between the equator and the poles, and the rotation of the planet (Coriolis Effect). Within the tropics, thermal low circulations over terrain and high plateaus can drive monsoon circulations. In coastal areas the sea breeze/land breeze cycle can define local winds; in areas that have variable terrain, mountain and valley breezes can dominate local winds [5, 7].

Wind is the flow of gases on a large scale. On Earth, wind consists of the bulk movement of air. It is caused by differences in pressure. When a difference in pressure exists, the air is accelerated from higher to lower pressure. On a rotating planet the air will be deflected by the Coriolis effcet, except exactly on the equator. Globally, the two major driving factors of large scale winds (the atmospheric circulation) are the differential heating between the equator and the poles (difference in absorption of solar energy leading to buoyancy forces) and the rotation of the planet. Outside the tropics and aloft from frictional effects of the surface, the large-scale winds tend to approach geostrophic balance. Near the Earth's surface, friction causes the wind to be slower than it would be otherwise. Surface friction also causes winds to blow more inward into low pressure areas.

3.2 WIND GUST:

Gusts are reported when the peak wind speed reaches at least 16 knots and the variation in wind speed between the peaks and lulls is at least 9 knots. The duration of a gust is usually less than 20 seconds [39].

The **knot** is a unit of speed equal to one nautical mile per hour, which is equal to exactly 1.852 km/h and approximately 1.151 mph and 0.514 m/s.

3.3 GUST ANALYSIS:

The estimation of wind gusts based on hourly mean wind speed values has been initially suggested to be processed as follows [5, 7, and 17]:

$$V_g = K_g V_{mean} \tag{3.1}$$

Where, V_g is the gust speed (m/s), *i.e.* the instantaneous maximal wind speed in a measuring interval (T) of 1 hour, V_{mean} is the hourly mean wind speed (m/s) and K_g is the gust factor. The gust factor is defined as,

$$K_g = 1 + \frac{2.28}{\ln\left(\frac{z}{\eta}\right)} \tag{3.2}$$

Where, z (m) is the height above ground and η is the roughness length (m) [34-38], which depends on terrain characteristics. At Sitakunda and other prospective sites, wind measurements were performed at usual heights above ground, 20 m *i.e.* z =20. The value of the roughness length, η = 0.28 m. In Eqt. (3.2), the log wind profile is used to define the gust. The mean wind speed as a function of height above the ground can be computed by the logarithmic profile -

$$V_{mean} = \frac{u^*}{K} \ln\left(\frac{z}{\eta}\right) \tag{3.3}$$

Where, K is the Von-Karman constant, approximately equal to K = 0.4; u^* is the friction velocity. The peak gust speed (V_g) at height z is computed using Durst's statistical model as follows [8]:

$$V_g(z) = V_{mean}(z) + g(T)\sigma_v(z) \tag{3.4}$$

Where, $g(T)$ is the gust peak factor, which is a function of T and $\sigma_v(z) = \sqrt{\beta} u^*$ is the root-mean-square value of the longitudinal fluctuating wind speed at height z, in which β is a terrain dependent coefficient. For $g(T)$, the Eurocode uses alternatively factors of 3.7 and 3.5 [8]. With the help of Eqts. (3.1), (3.3) and (3.4), the following gust factor equation is obtained.

$$K_g = \frac{V_g}{V_{mean}} = 1 + g(T)I(z) \tag{3.5}$$

Where, $I(z)$ is the longitudinal turbulence intensity and it is defined as:

$$I(z) = \frac{\sigma_v(z)}{V_{maen}\,(z)} \tag{3.6}$$

Eqts. (3.4), (3.5) and (3.6) indicate that the constant 2.28 in (3.2) is calculated as:

$$2.28 = g(T)\sqrt{\beta}k \tag{3.7}$$

Under this assumption when ten-minute data were not available for the prospective sites, the recommended Eqt. (3.1) were modified as follows and tested [5]:

$$V_g = K_g \overline{V_{max}} \tag{3.8}$$

Where, K_g is the same parameter value as in Equ. (3.2), $\overline{V_{max}}$ is the maximal mean hourly speed for a particular month and V_g is the expected maximal gust on the same day.

The values of the maximal monthly gusts estimated on the basis of equation (3.8) have been compared with the measured maximal monthly gusts. It has been established that this equation should be further modified for all maximal mean hourly wind speed classes. The modification of equation (3.8) has been carried out for all wind speed classes. All equations, derived individually for every maximal mean hourly wind speed class, have the following form [5]:

$$V_g = K_g \overline{V_{max}} + C \tag{3.9}$$

Where, C is the constant, which is different for each particular wind speed class. Constant C represents the mean difference between the individual measured wind gusts in the particular speed class considered and the associated wind gusts calculated by using Eqt. (3.8).

3.4 FIND OUT OF WEIBULL PARAMETERS

Weibull Parameters i.e *'k'* is a dimensionless number and scale factor *'c'* in m/s [7, 42].

Table - 3.1: Value of *k* and *c* by various methods.

Weibull Paper method

Site	Month	***k***	***c***
Sitakunda	Jan	2.05	2.80
	Feb	2.60	4.00
	Mar	2.45	3.60
	Apr	2.10	4.97
	May	1.90	5.03
	Jun	2.00	5.43
	Jul	2.20	6.02
	Aug	1.95	5.66
	Sep	1.32	10.83
	Oct	1.90	2.56
	Nov	2.75	3.00
	Dec	2.00	2.60

Standard deviation method

Site	Month	***k***	***c***
Sitakunda	Jan	1.81	2.72
	Feb	2.50	3.97
	Mar	2.55	3.82
	Apr	2.40	4.98
	May	2.41	5.04
	Jun	2.32	5.43
	Jul	3.19	4.88
	Aug	2.09	3.47
	Sep	1.10	2.23
	Oct	2.19	2.57
	Nov	2.85	2.97
	Dec	2.14	2.64

Energy method

Site	Month	***k***	***c***
Sitakunda	Jan	1.91	2.67
	Feb	2.58	3.88
	Mar	2.58	3.74
	Apr	2.40	4.97
	May	2.42	5.04
	Jun	2.28	5.43
	Jul	3.00	5.97
	Aug	>Range	>Range
	Sep	>Range	>Range
	Oct	2.52	2.56
	Nov	2.89	2.92
	Dec	2.26	2.58

The Table – 3.1 represent the monthly variation of Weibull shape factor *k* and Weibull scale factor *c* at Sitakunda by three methods. In the Weibull paper method, used daily mean wind speed data of a month plotted in a Weibull graph paper and maintain the procedure to get the value of *k* in *k* scale and the value of *c* corresponding of the value of *k*. But in standard deviation and energy pattern factor method used only monthly mean wind speed data for calculating the value of *k* and *c*. At August and September in Table – 3.1 by energy pattern factor method, the value of *k* was not obtained because in this two month have some unusual wind behavior. This unusual wind behavior further has been analyzed and irregular wind gust was found there. Figs. 3.1 and 3.2 is the graphical representation of the Table – 3.1 has given below -

Monthly variation of *k* and *c* is presented in Figs. 3.1 and 3.2 respectively; it has been shown that the value of Weibull shape factor *k* and scale factor *c* in August and September is out of range by energy method. Because, in August maximum hourly mean wind velocity was recorded of about 96 m/s and in September continuous 180 hours wind velocity was higher than 42 m/s.

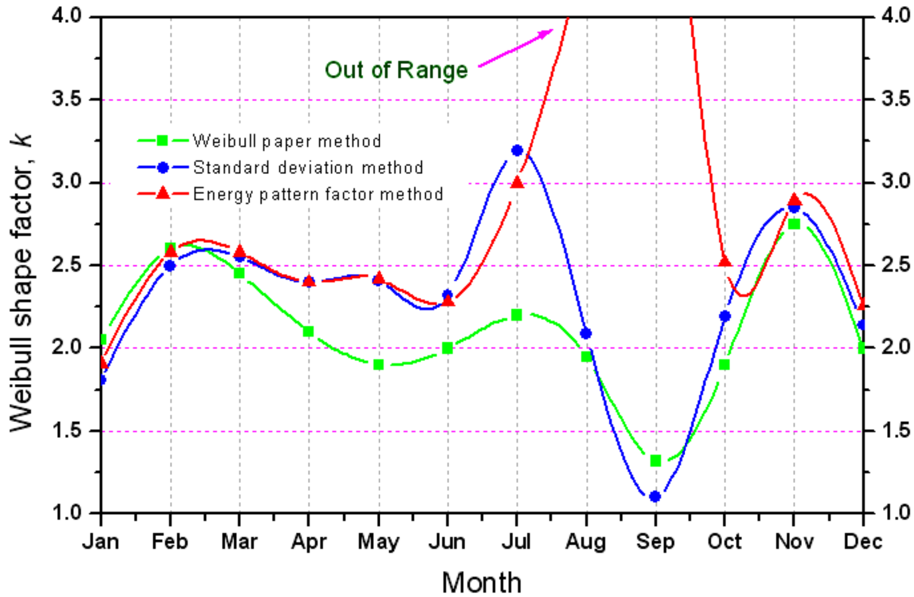


Fig. 3.1: Variation of "*k"* in different month at Sitakunda.

From the above **Fig. 3.1**, it has been shown that the value of Weibull shape factor "*k*" at August and September is out of range by energy method.

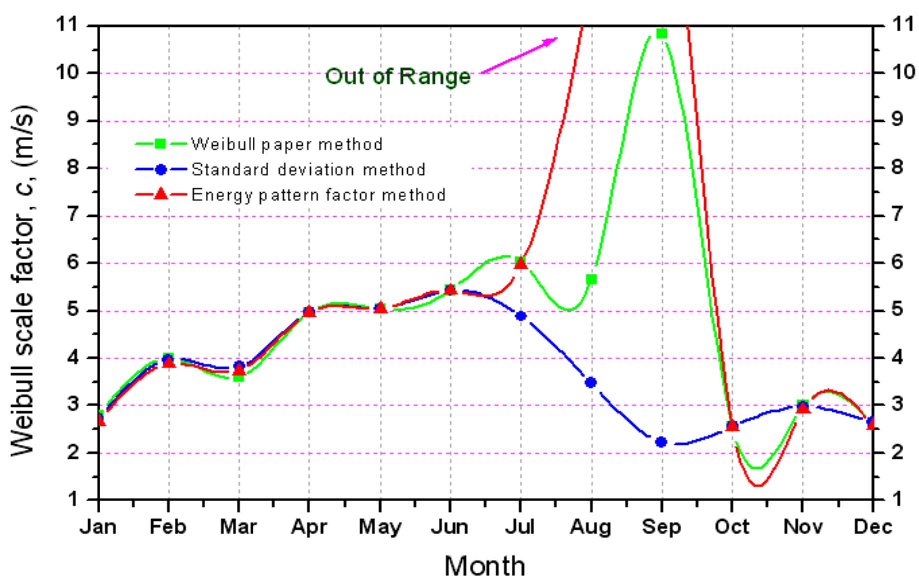


Fig. 3.2: Variation of "*c"* in different month at Sitakunda.

So, the values of '*k'* and '*c'* obtained by energy method for the months of August and September are higher than the regular range. These are due to the irregularity of wind velocity and high magnitude of wind gust that are very harm full for wind turbine, constructions and power transmission lines etc. [5, 7, 43-44].

3.5 MEAN WIND SPEED ANALYSIS

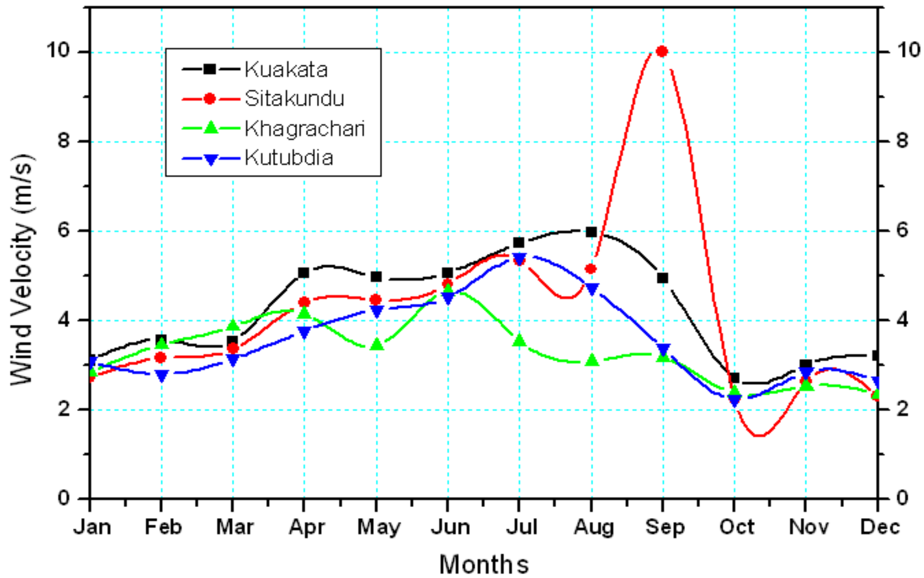


Fig.3.3: Monthly variation of wind speed.

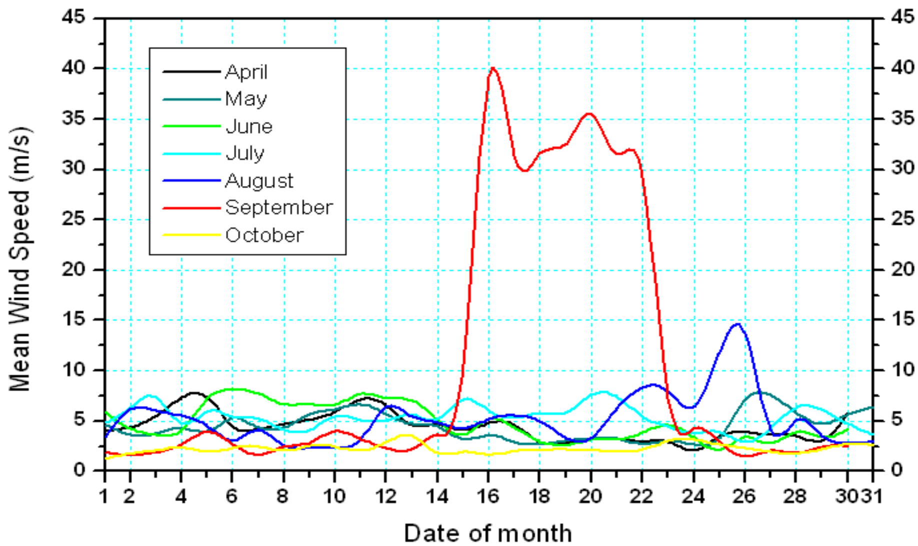


Fig.3.4: Daily variation of wind speed.

In the present study, the hourly measured time-series (shorted of 10 min interval data) wind speed data of the four prospective wind sites have been statistically analyzed. The monthly and daily mean wind speed values calculated from the available data are presented in Figs. 3.3 and 3.4, respectively. From Fig. 3.3, it can easily identifiable that the wind characteristics at Sitakunda are irregular where maximum wind speed is 10.01 m/s. Fig. 3.4 shows that the daily mean wind speed at August and September (14^{th} to 28^{th}) is very rough and maximum daily mean wind speed is about 15 and 40 m/s, respectively.

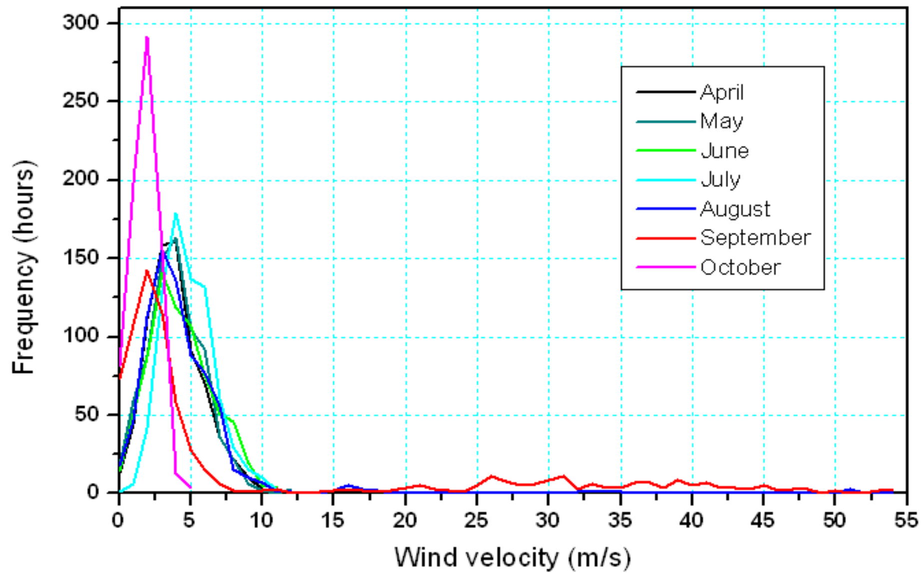


Fig.3.5: Frequency distribution of wind speed.

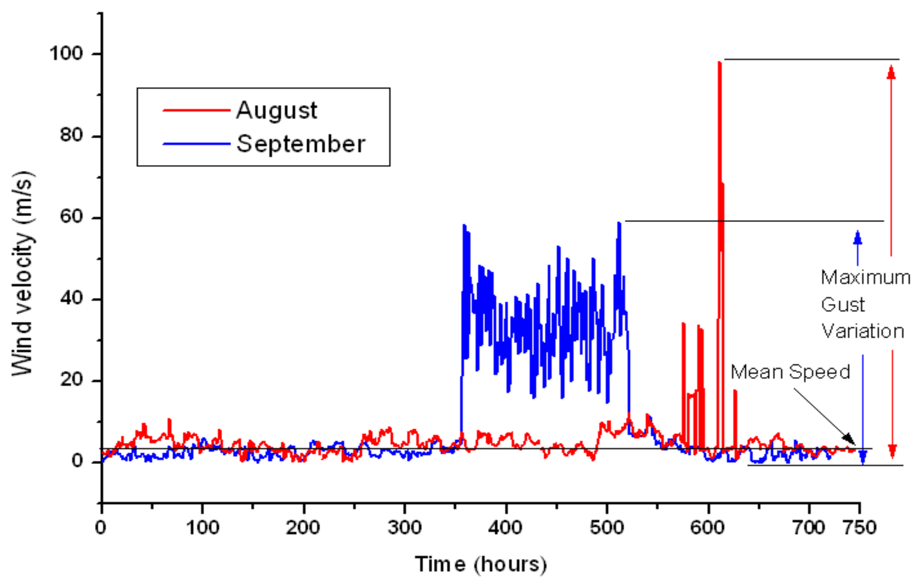


Fig.3.6: Time variation of wind speed.

Frequency distribution against wind speed is plotted in Fig. 3.5, which shows that most of the months have wind speed 2-5 m/s with a higher frequency. The higher value of wind speeds of about 10 to 54 m/s with some noticeable frequency have found in August and September. Fig. 3.6 shows the time variation of wind speed at August and September in which irregular wind gust region have clearly shown. This figure shows that in September 350th to 530th hours *i.e.* 180 hours continuous hourly mean wind speed is higher than 42 m/s and in August, 570th to 625th hours wind speed is irregular but 607th to 611th this 4 hours wind speed is maximum of about 96 m/s. So, definitely in these portions of the curve some unusual wind characteristics exist.

3.6 WIND CLASS AND RANGING

Table - 3.2: The means of the maximal hourly values of measured wind speed (AV; m s–1), measured hourly wind gusts (AG; m s–1), AG/AV ratio and AG–AV difference, and the constant *C* value (m s–1) in the gust equation (23), per particular speed class, with N cases in hours of September of which in n per cent of cases (%) the calculated gust was considerably weaker than the measured one Sitakunda.

Wind class	Range	case	mean values (m/sec)				Constant	n
	m/s	N	*AG*	*AV*	*AG/AV*	*AG - AV*	*C*	%
Wind of medium intensity	8.0 – 10.7	6	16.1	9.2	1.8	6.9	1.9	0
Strong Wind	10.8 - 13.8	4	20.3	12.1	1.7	8.1	1.6	0
Very Strong Wind	13.9 - 17.1	6	26.2	16.1	1.6	10.1	1.3	0
Gale	17.2 - 20.7	9	31.9	19.4	1.6	12.5	2	22.2
Storm	20.8 - 24.4	8	37.4	23.1	1.6	14.3	1.8	25
Violent Storm	24.5-28.4	24	43.8	26.8	1.6	17	2.5	12.5
Violent Storm - I	28.5-33.99	28	52.3	31.3	1.7	21.1	4.1	39.3
Hurricane	> 34.00	83	86.8	42.1	2.1	44.6	21.8	96.4

Table - 3.3: Same as Table 3.2, Sitakunda, August

Wind class	Range	case	mean values (m/sec)				Constant	n
	m/s	N	*AG*	*AV*	*AG/AV*	*AG - AV*	*C*	%
Wind of medium intensity	8.0 – 10.7	31	16	9.1	1.8	6.9	2	35.5
Strong Wind	10.8 - 13.8	3	18.6	11.8	1.6	6.8	0.4	0
Very Strong Wind	13.9 - 17.1	6	26.1	16.5	1.6	9.6	0.7	0
Gale	17.2 - 20.7	8	30.4	18.6	1.6	11.8	1.7	12.5
Storm	20.8 - 24.4	0	0	0	0	0	0	0
Violent Storm	24.5-28.4	0	0	0	0	0	0	0
Violent Storm - I	28.5-33.99	2	52.2	32.8	1.6	19.4	1.6	0
Hurricane	> 34.00	4	151.6	63.6	2.4	88	53.5	100

The first step in the analysis of the measured gusts and the maximal mean hourly wind speeds was the analysis of their averaged values (AG and AV, respectively). Each pair of maximal measured monthly instantaneous speed (G) and maximal monthly mean hourly wind speed ($\overline{V_{max}}$) for the same day was grouped in one of the predefined classes. The classes were determined on the basis of the values of $\overline{V_{max}}$. The $\overline{V_{max}}$ classes and the speed range have been defined in such a way that each particular $\overline{V_{max}}$ speed class corresponds to the adequate wind strength class of the Beaufort scale. For each class, all $\overline{V_{max}}$ values have been averaged (the result of averaging is the AV value), as well as all the »associated« G values (the result of averaging is the AG value).

The analysis of the average measured gusts (AG) and the average maximal mean hourly wind speeds (AV) per maximal mean hourly speed class has shown that a relative (AG/AV) difference is remarkable during August and September. However, their absolute difference (AG–AV) is also remarkable; the difference is considerably greater in the case of September than in the case of August (**Tables 3.2 and 3.3**) except hurricane case because only two frequency of gust speed recess 105.99 and 151.59 m/s. For particular wind speed classes, the average gust and average maximal mean hourly wind speed ratio (AG/AV) showed to be, on the average, higher by about 20% for September than for August. The absolute difference (AG–AV) in the particular speed classes reaches a maximum average of 44.6 m s^{-1} for September and 88 m s^{-1} for August.

In the August and September cases, constant C values differ substantially from speed class to speed class. Its values are much greater in the case of September than in the case of August, except hurricane case as described above which indicates that during September a short-lasting gust speed is much higher than the highest mean hourly speed characterizing the same day. For September, positive constant C values have been established for all speed classes, which mean that the gust speed is slightly higher than the one calculated by equation (3.8). From **Table-3.3**, for August, no frequency not found in the cases of storm and violent storm but the height value of C can be found in the case of hurricane because a short duration of wind speed recess about 96 m/s. For the period August to September, at the Sitakunda observed, a percentage (n) is presented of the cases which have been modelled (using equation (3.9)) as substantially lower, i.e. at least 5 m/s lower than the corresponding measured wind gusts (**Tables 3.2 and 3.3**).

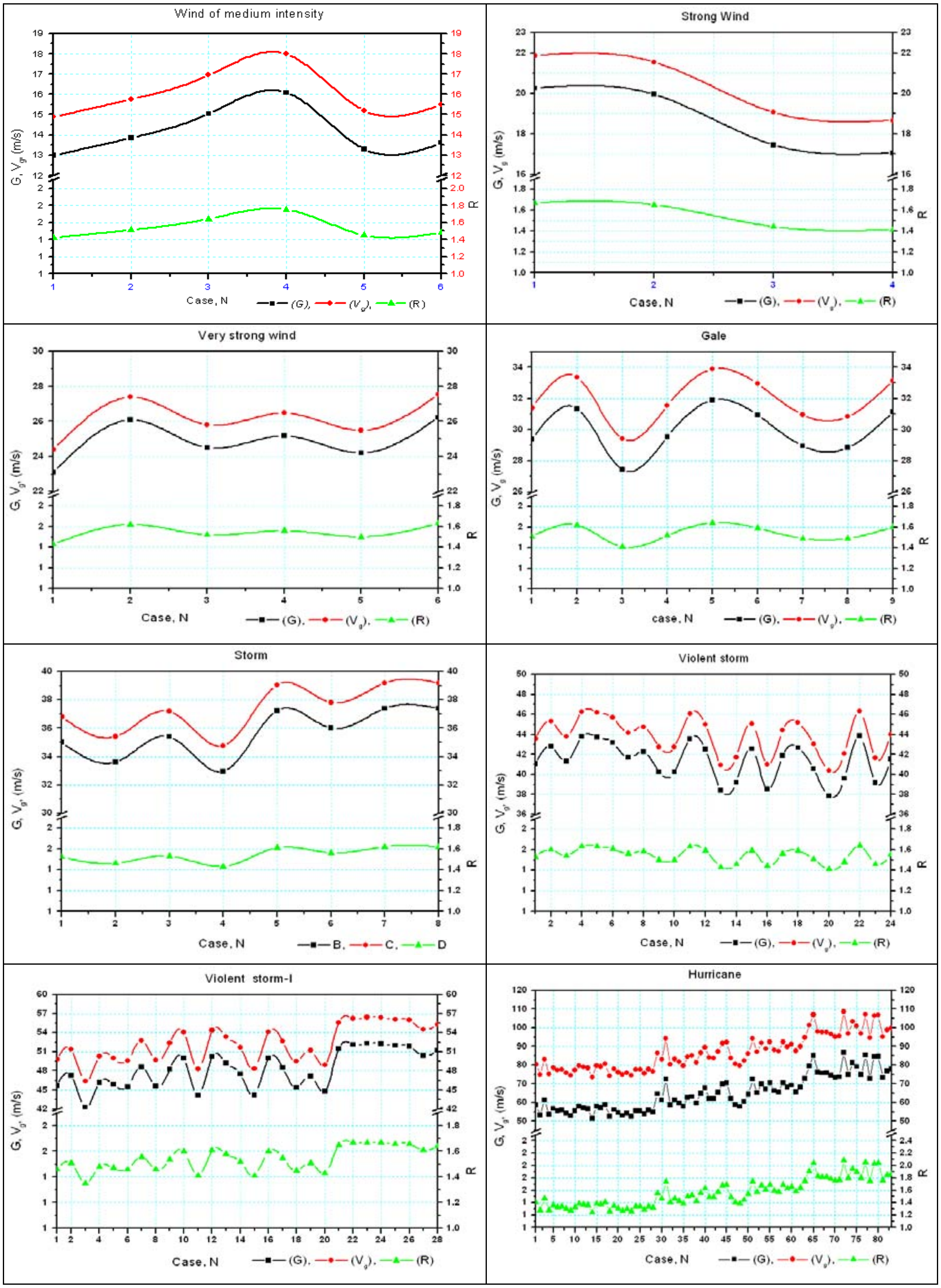


Fig. 3.7: The speed of the measured (*G*) and modelled (V_g using Equ(15)) gusts and the ratio between the measured gust and the maximal hourly mean ($\overline{V_{max}}$) of measured wind speed ($R=G/\overline{V_{max}}$) during September.

In above Fig.3.7, all speed classes are plotted and analyzed which has shown that all V_g values are higher than the value of *G* and *R* is plotted in the bottom portion of the graphs. In the case of hurricane the gust speed varies between 70 m/s to 110 m/s which is so harmful for wind turbine, constructions, power transmission lines and overall life for human beings and all.

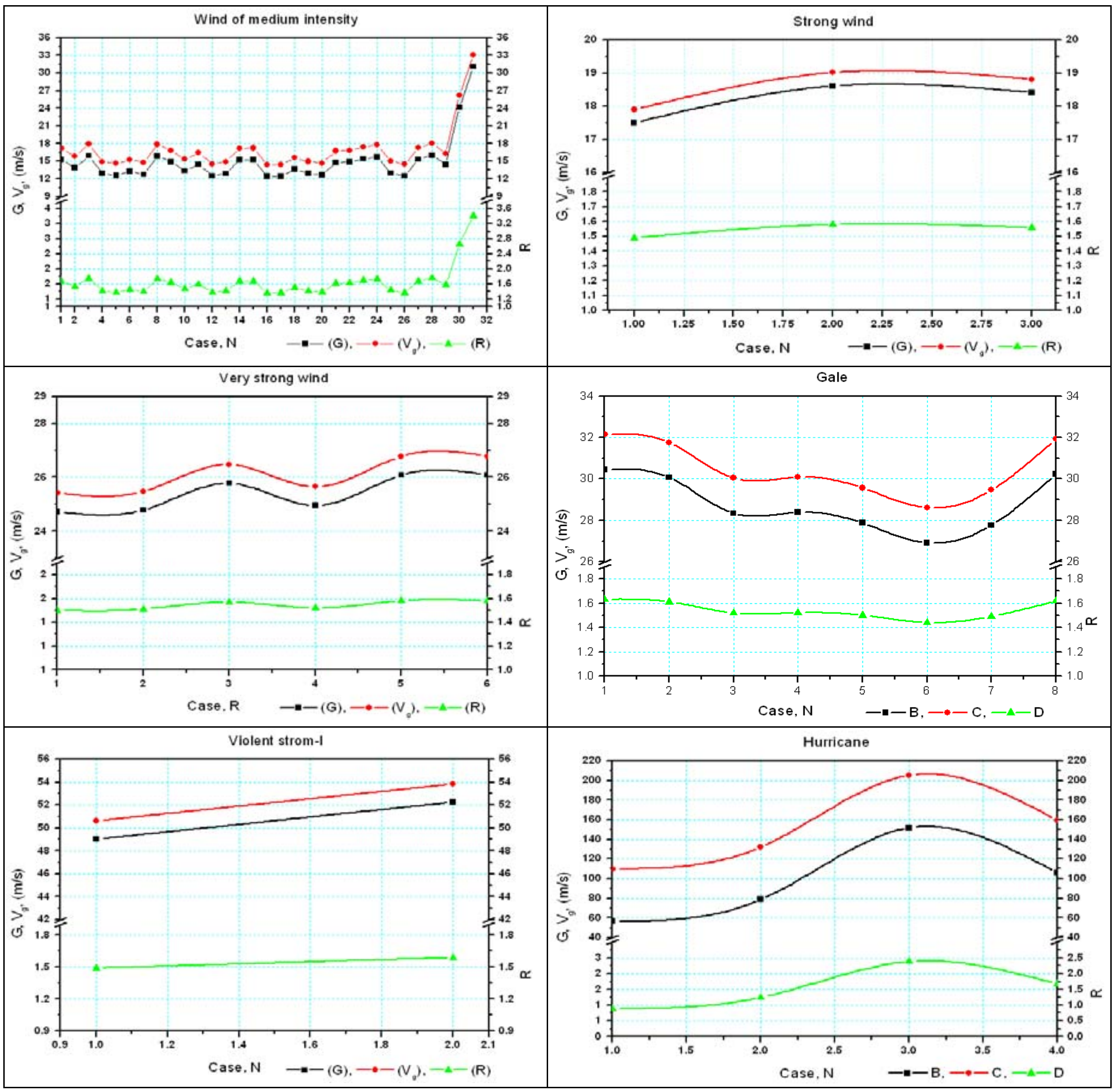


Fig. 3.8: The speed of the measured (G) and modelled (V_g using Equ.(3.9)) gusts and the ratio between the measured gust and the maximal hourly mean ($\overline{V}_{max}$) of measured wind speed ($R=G/\overline{V}_{max}$) during August.

In above Fig.3.8, it is clear that the higher frequency is in the wind of medium intensity case but in the hurricane the frequency is only four but so higher intensity with short time interval about (607^{th} to 611^{th}) these four hours interval from Fig.3.6.

In the thesis work used tem-minutes interval wind speed data from 20 m height above the ground. These data has been sorted in the appropriate frequency like hourly, daily, weekly, monthly and annually mean wind speed. The wind gust has been found and analyzed on August and September at Sitakunda. During the classification and ranging of wind speed some wind data has been found which has higher than violent storm but lowers than hurricane class wind. So, those type of wind has been given a new class violent storm–I. In Sitakunda at September hurricane class wind is higher number of frequency and in August hurricane class wind frequency is lower but higher magnitude of intensity. It can damage all ecological balance and all. Another thing is that, in August no wind velocity was found in the case of storm and violent storm wind class. Due to these unusual wind behavior the Weibull shape factor k and Weibull scale factor c has out of range by energy pattern factor method. But it has been found that the rest of the month the value of k remains in between 1.10 to 3.19 and that of c remains between 2.23 to 10.83. The most of the Weibull functions follow very close to the Raleigh function $k = 2$ for the selected site.

Chapter 4

RESULTS OF WIND DATA ANALYSIS

For my work, there are six wind stations data has been collected and analyzed (both 10 m and 20 m height) for searching the wind energy potential in Bangladesh. But some preliminary decision has been taken for which data should be appropriate for analysis has given below -

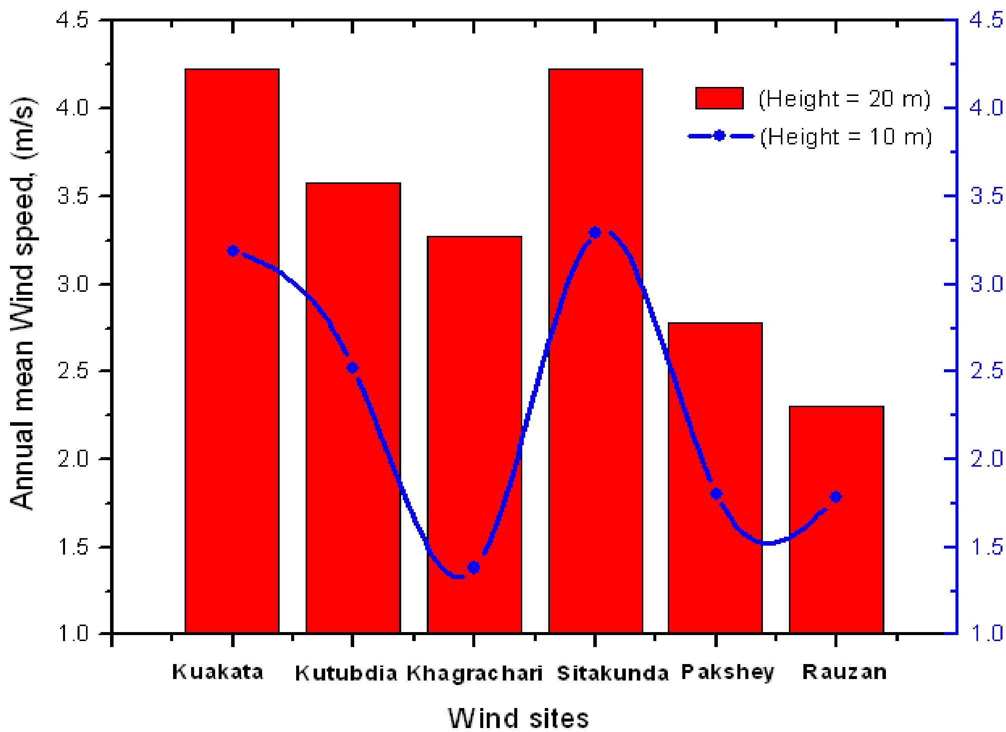


Fig. 4.1: Annual mean wind speed for the selected wind sites above 10 m and 20 m height.

From the above figure it has been clearly shown that the annual mean wind speed above 20 m height is higher than 10 m because of the friction of earth surface. So, 20 m height wind speed data is more appropriate for the analysis of wind power potential. Although monthly mean and weekly mean wind speed data for 10 m height also calculated for taking more accurate decision about height which has shown in **Appendix– B**. For the next steps of the analysis only used 20 m height data.

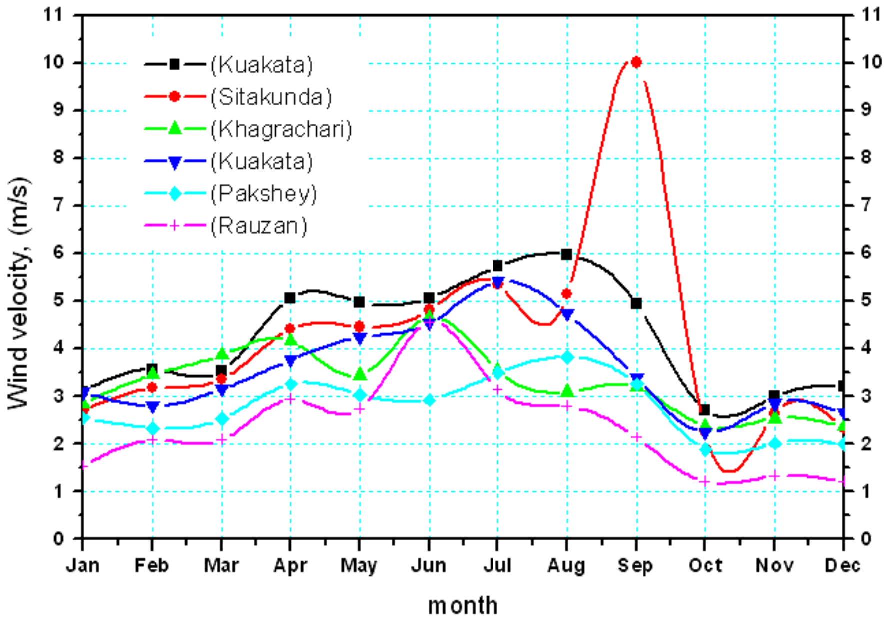


Fig. 4.2: Monthly variation of wind speed for different wind sites.

Another decision has been taken from the above **Fig. 4.2** which has shown that Sitakunda has some irregular wind characteristics. So, separately Sitakunda data and its unusual wind characteristics has been analyzed in **Chapter – 3.**

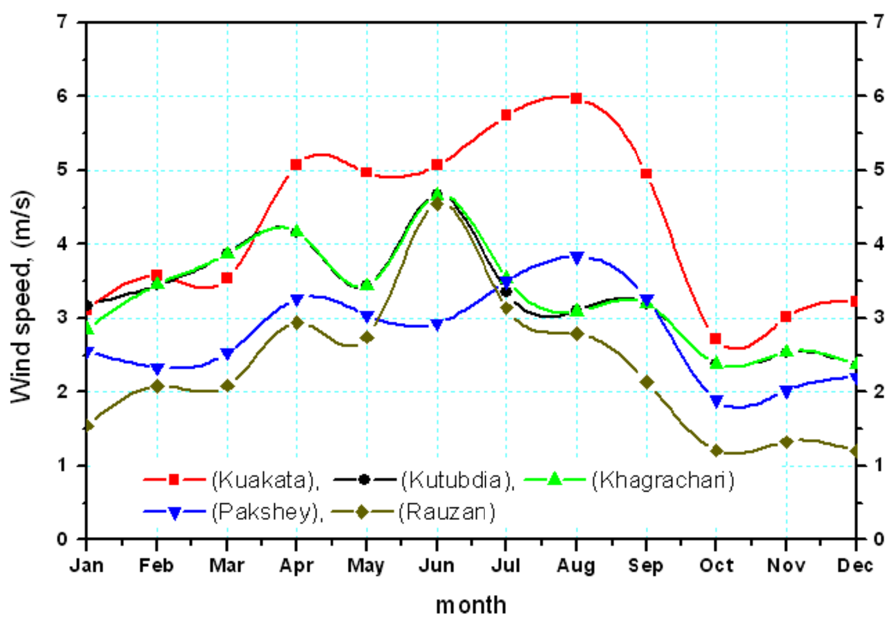


Fig. 4.3: Monthly variation of wind speed for five selected sites.

From the above figure, it has shown the comparison of monthly variation of wind speed for selected sites. Here Kuakata has height wind speed than other sites. The max^{m} velocity is 5.97 m/s at August in Kuakata and min^{m}1.20 m/s at December in Rauzan.

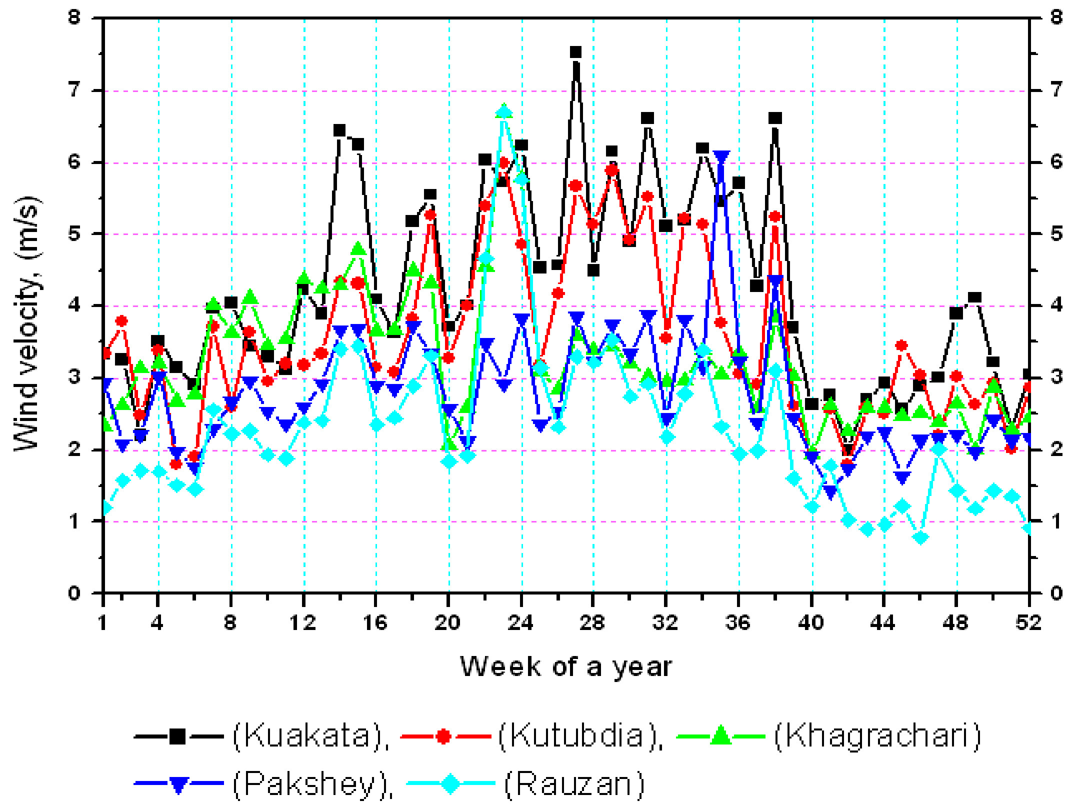


Fig. 4.4: Weekly variation of wind speed.

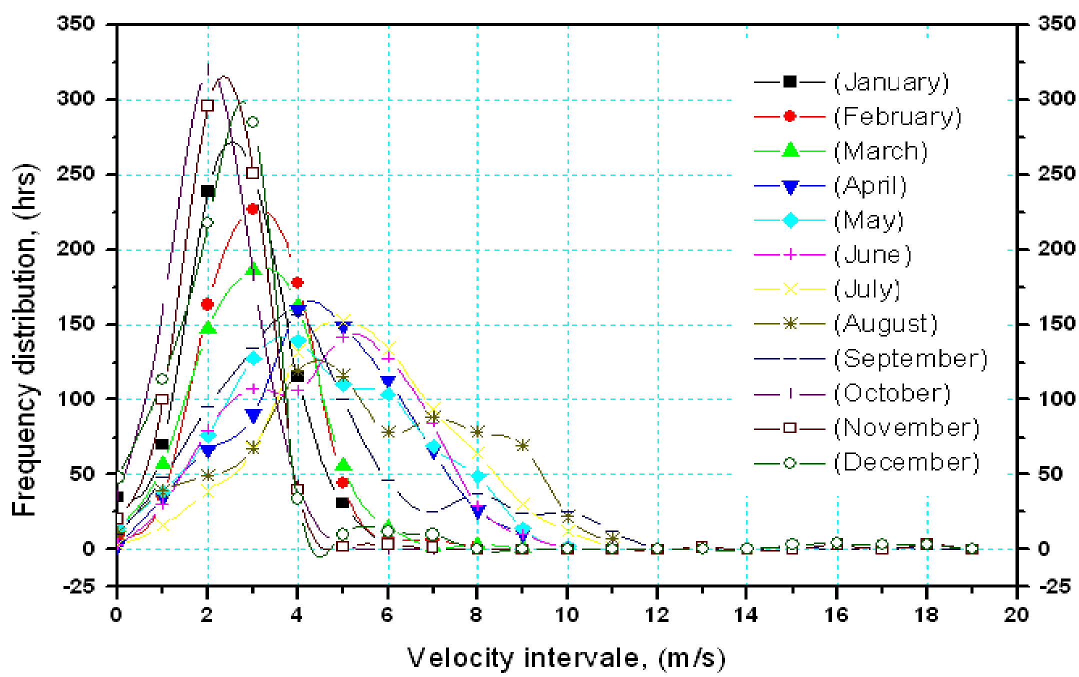


Fig. 4.5: Frequency distribution of wind speed at Kuakata from January to December.

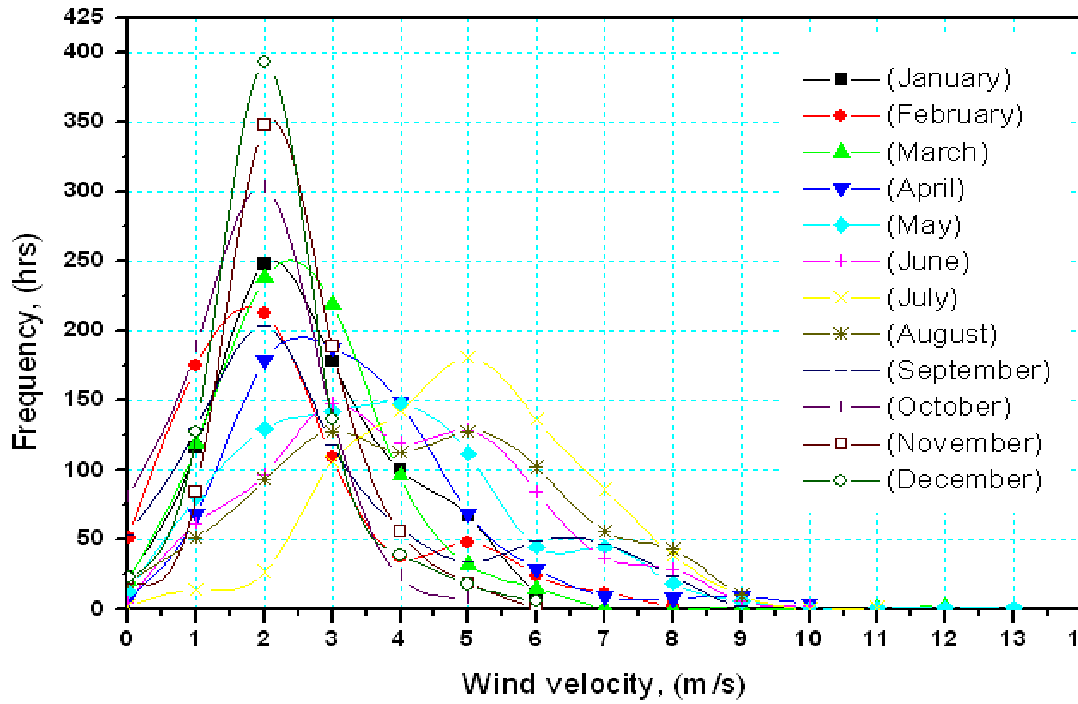


Fig. 4.6: Frequency distribution of wind speed at Kutubdia from January to December.

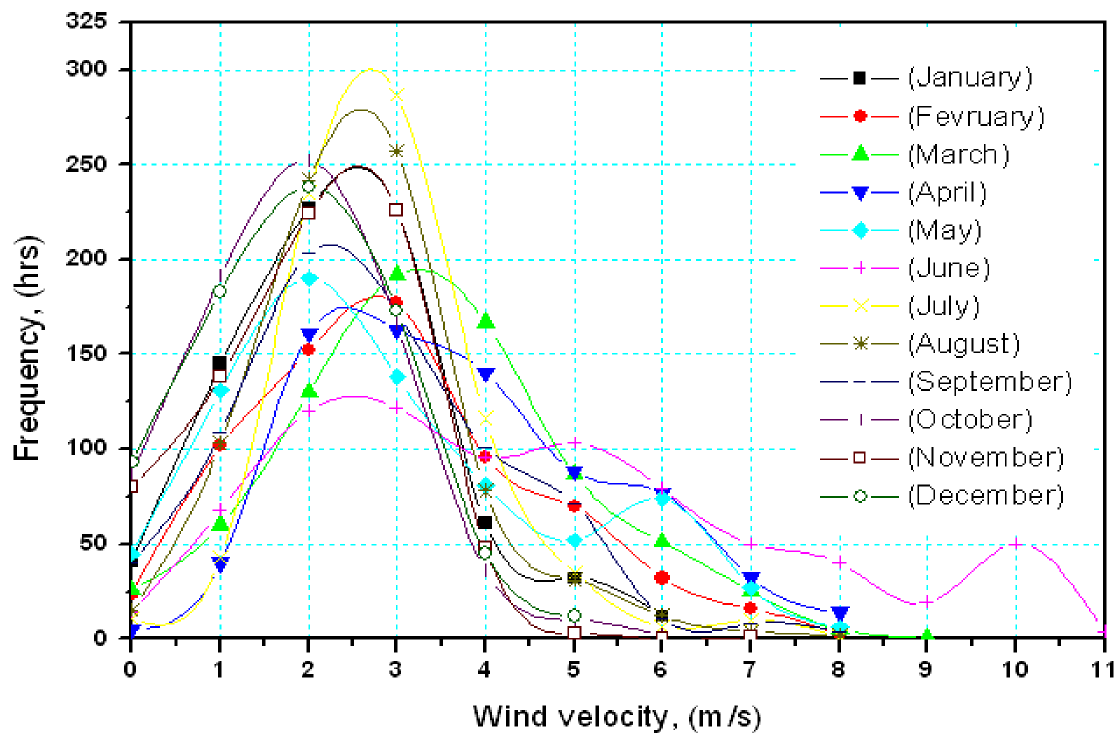


Fig. 4.7: Frequency distribution of wind speed at Khagrachari from January to December.

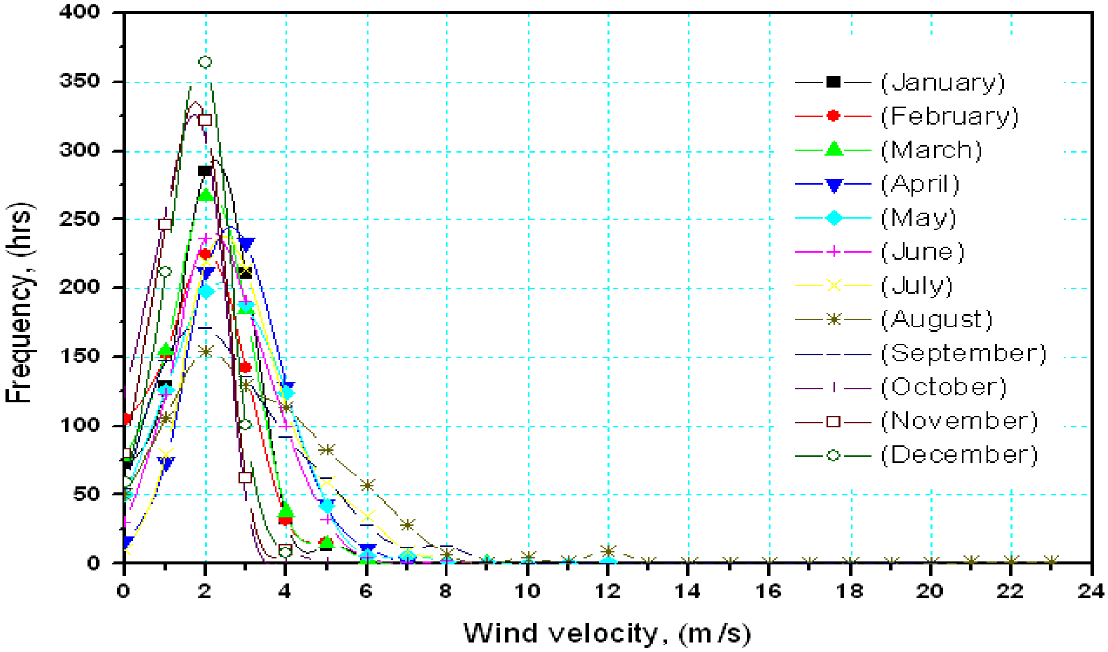


Fig. 4.8: Frequency distribution of wind speed at Pakshey from January to December.

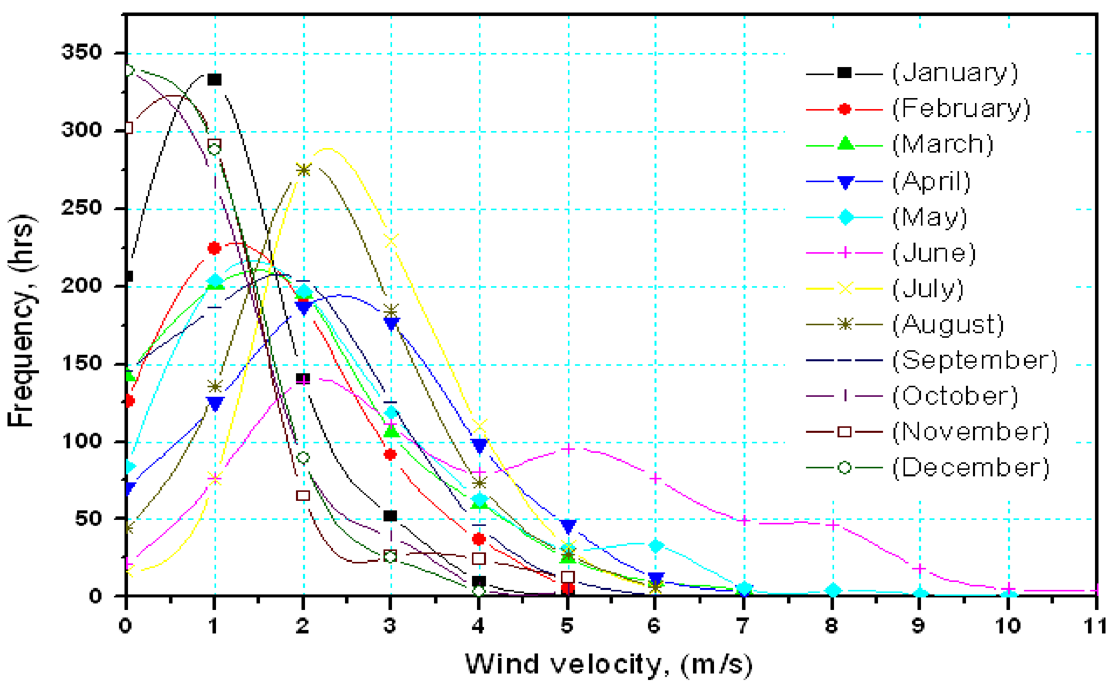


Fig. 4.9: Frequency distribution of wind speed at Rauzan from January to December.

The frequency distribution of each site from January to December has shown in **Fig. 4.5 – 4.9**. Most of the sites the wind velocity 2 to 4 m/s has higher frequency. But in Kuakata and Khagrachari the frequency of wind speed has 5 – 19 m/s from April to September.

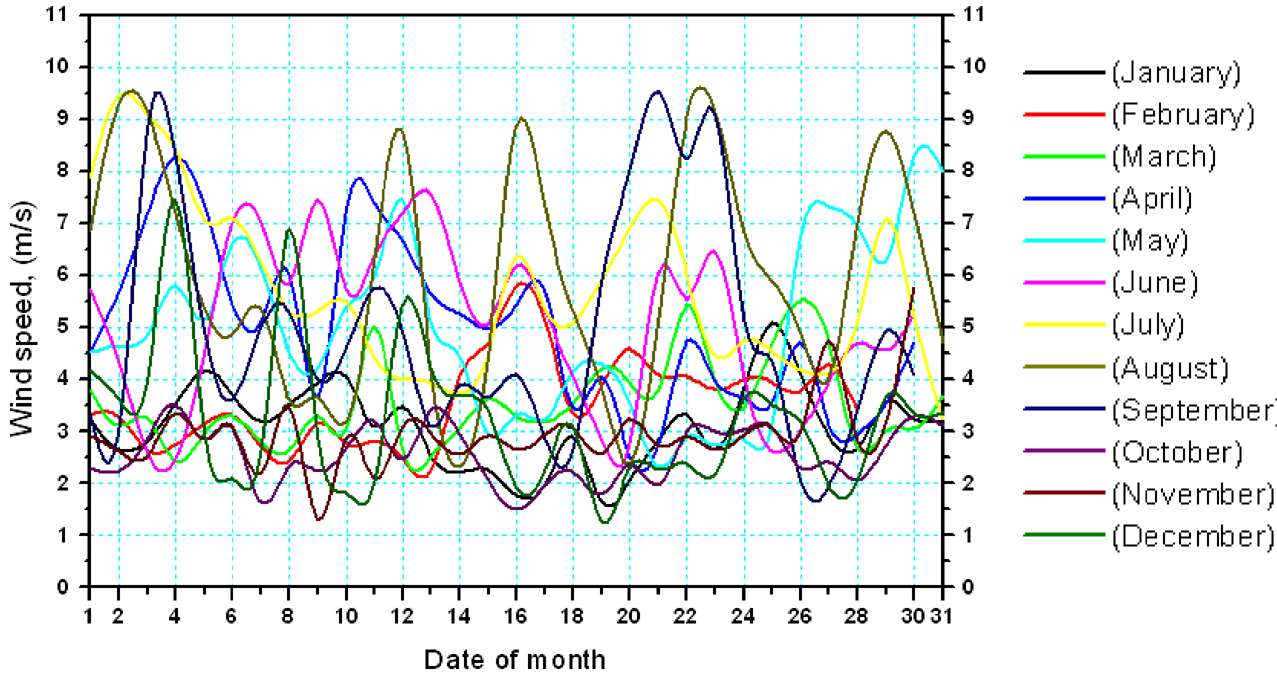


Fig. 4.10: Daily variation of wind speed at Kuakata from January to December.

From the above figure it has been cleared that the wind velocity from April to September has above 5 m/s. The max^{m} speed is about 9.15 m/s at August.

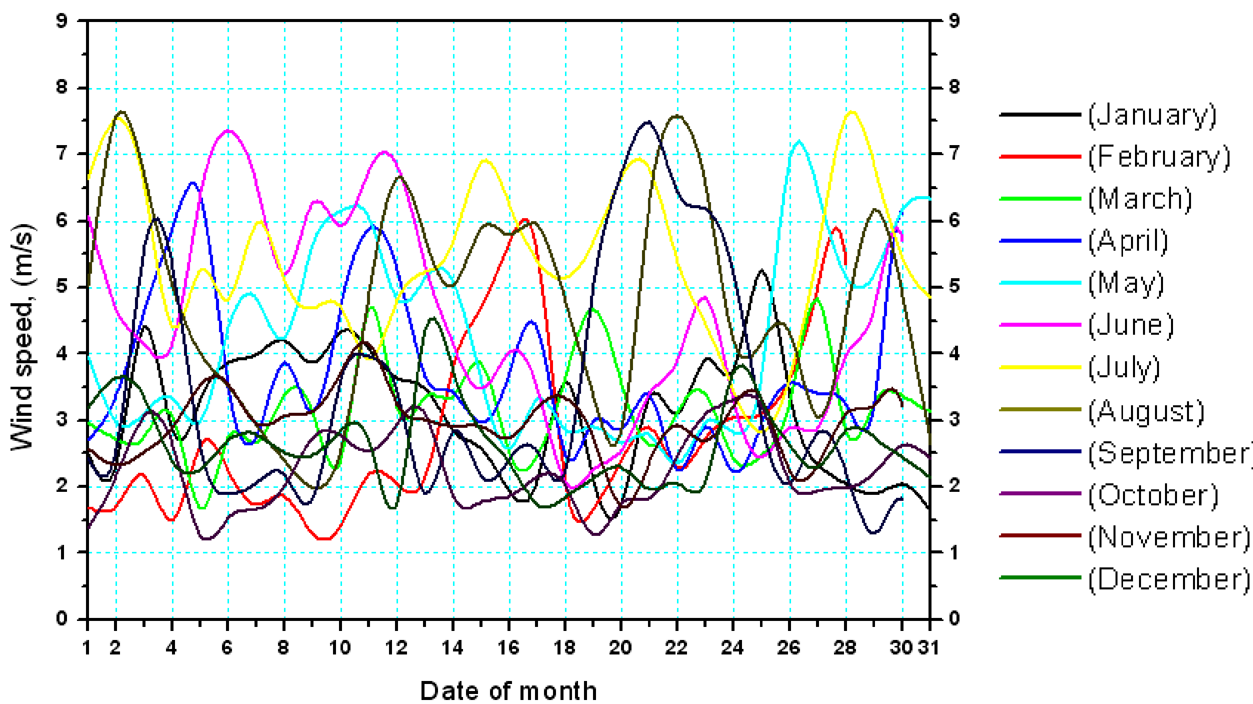


Fig. 4.11: Daily variation of wind speed at Kutubdia from January to December.

From the above figure it can be easily identify the total monthly figure of wind speed at Kutubdia Island.

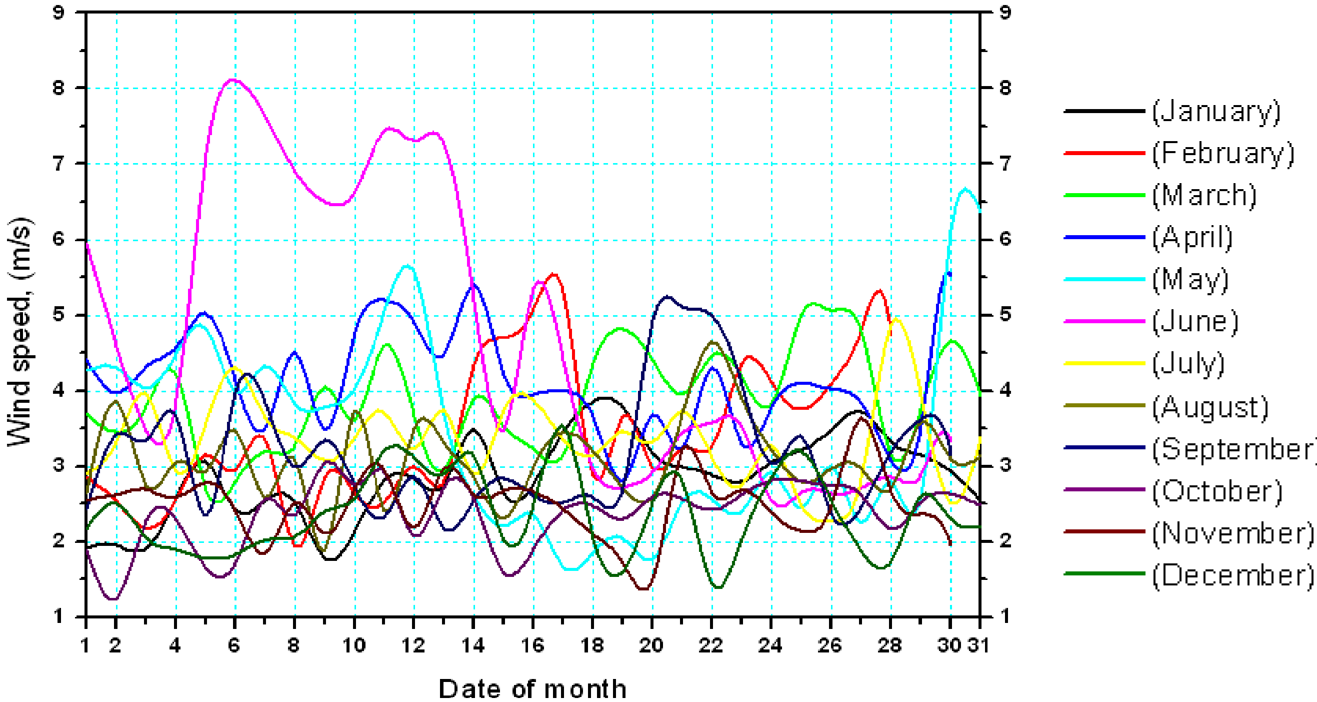


Fig. 4.12: Daily variation of wind speed at Khagrachari from January to December.

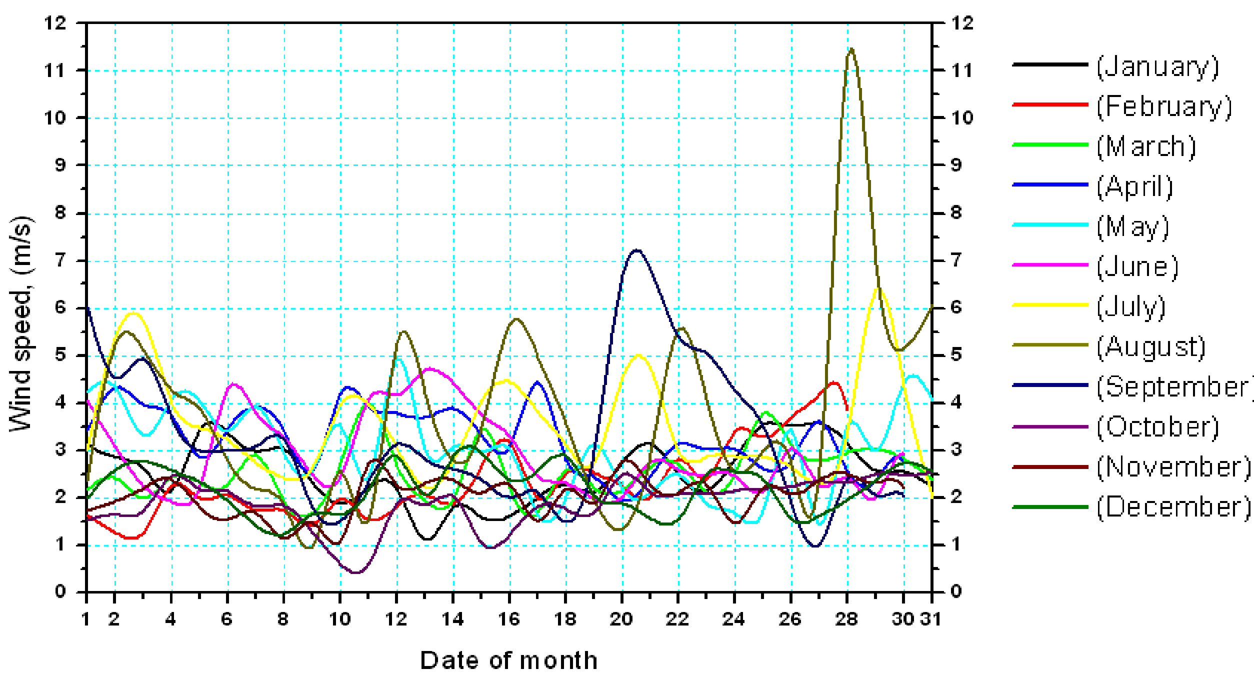


Fig. 4.13: Daily variation of wind speed at Pakshey from January to December.

From **Fig. 4.12** at Khagrachari June 4^{th} to 14^{th} this 10 days wind velocity was about 7 m/s which is higher than other month. On the other hand from **Fig.4.13** at Pakshey 27^{th} to 30^{th} wind velocity was so high and the max^{m} wind speed was 11.5 m/s at August.

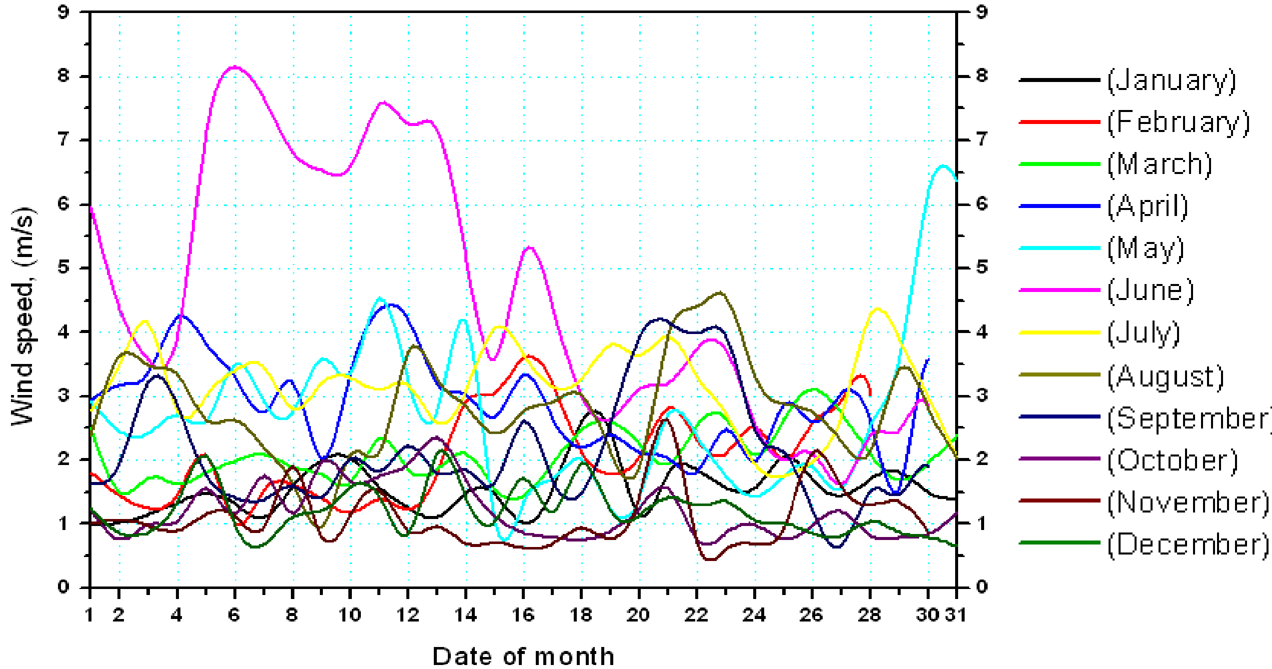


Fig. 4.14: Daily variation of wind speed at Rauzan from January to December.

At Rauzan the wind characteristics is as same as Khagrachari at June 4th to 14th because Rauzan is situated at Khagrachari but different hilly location. From **Fig. 4.10 to 4.15** it has been cleared that the wind speed at April to September for each location was higher than other six months. So, for more clear information the hourly mean wind speed for each location has been analyzed only April to September which has given below-

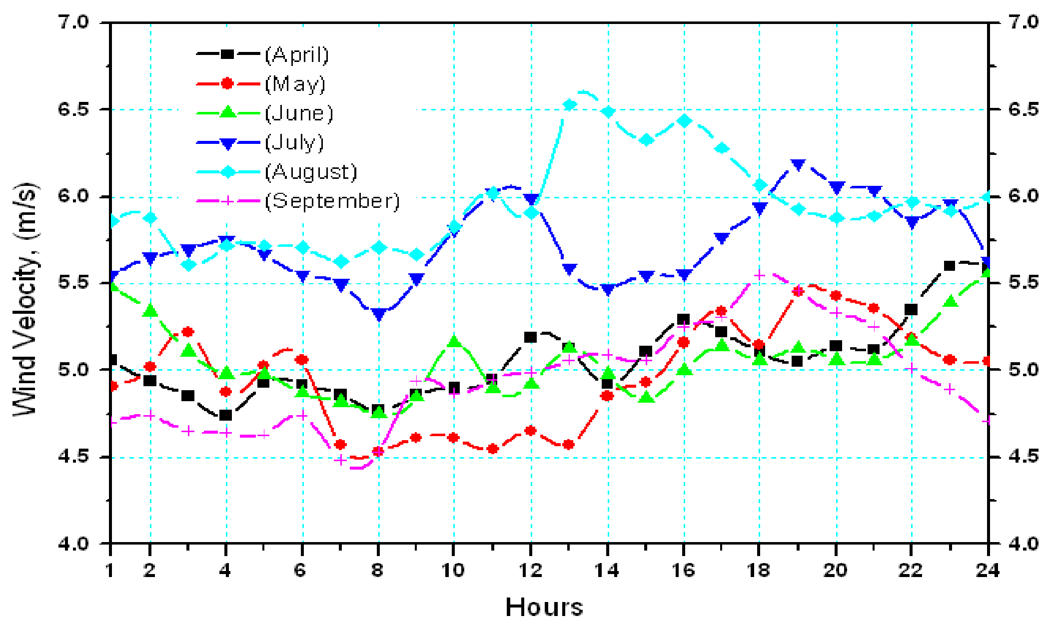


Fig. 4.15: Hourly mean wind speed at Kuakata from April to September.

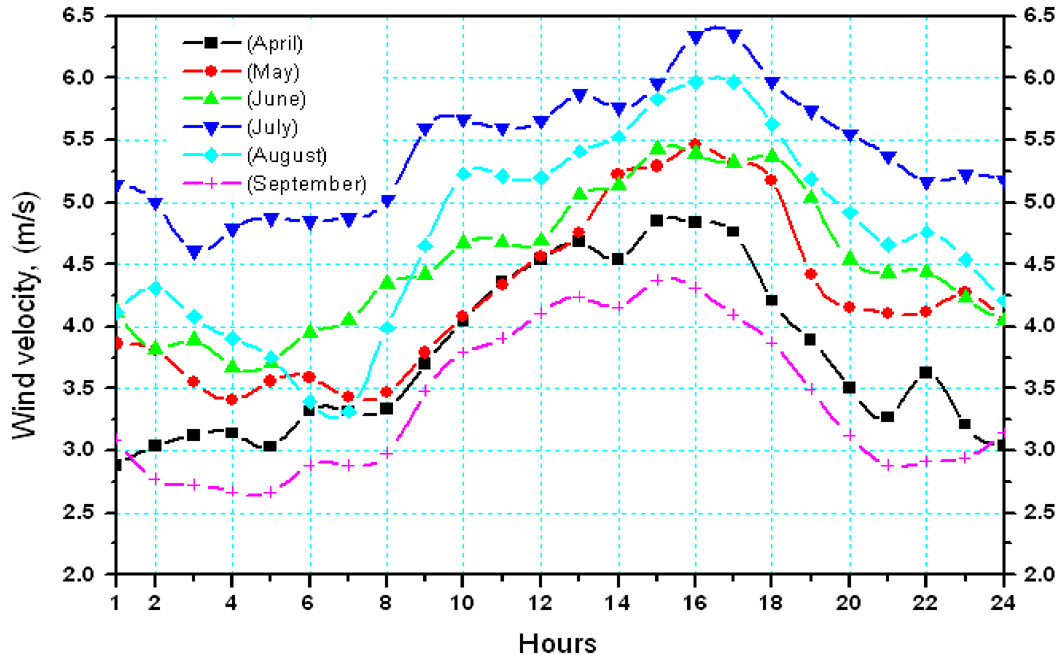


Fig. 4.16: Hourly mean wind speed at Kutubdia from April to September.

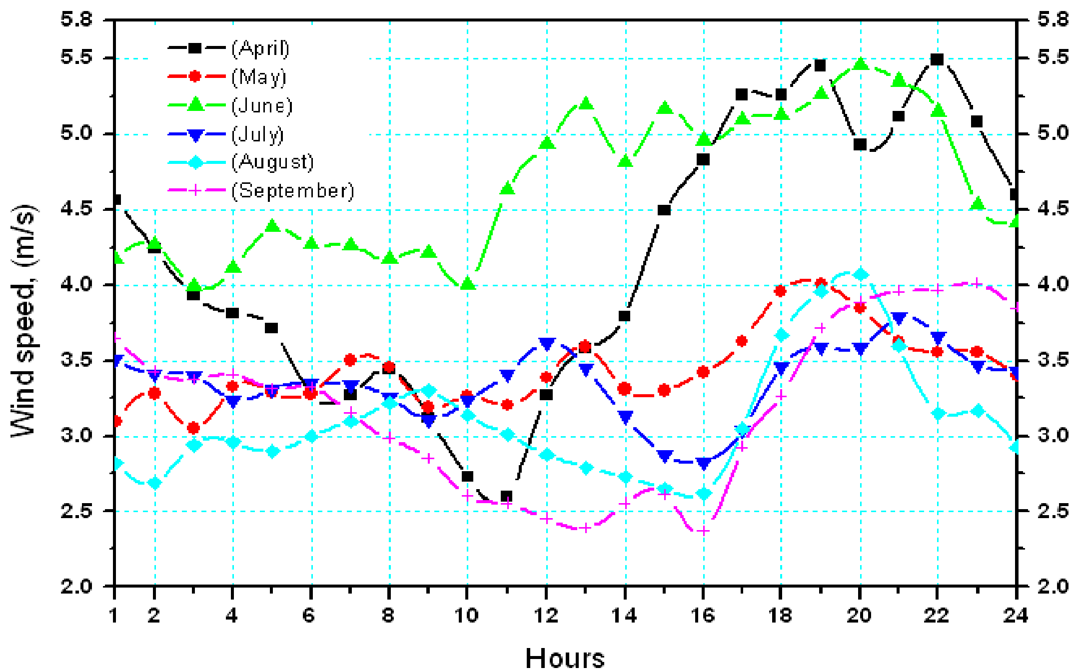


Fig. 4.17: Hourly mean wind speed at Khagrachari from April to September.

The **Fig. 4.15**, **Fig. 4.16 and Fig. 4.17** represent the mean hourly wind speed at Kuakata, Kutubdia and Khagrachari respectively. For clearly observe hourly mean wind speed only considered April to September data and other six month data has low wind speed.

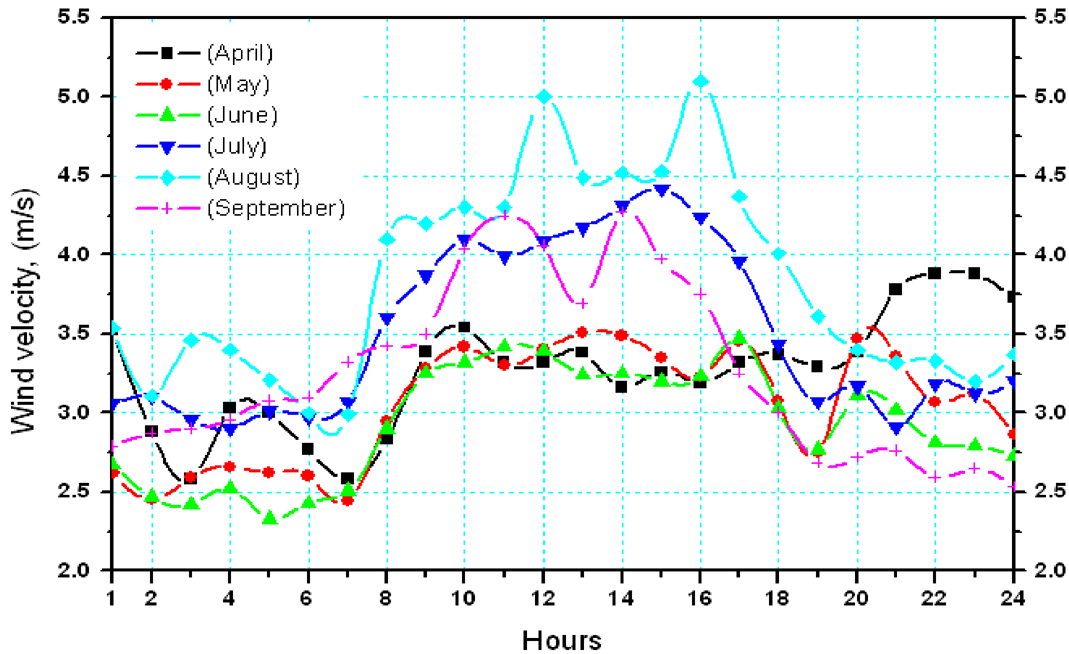


Fig. 4.18: Hourly mean wind speed at Pakshey from April to September.

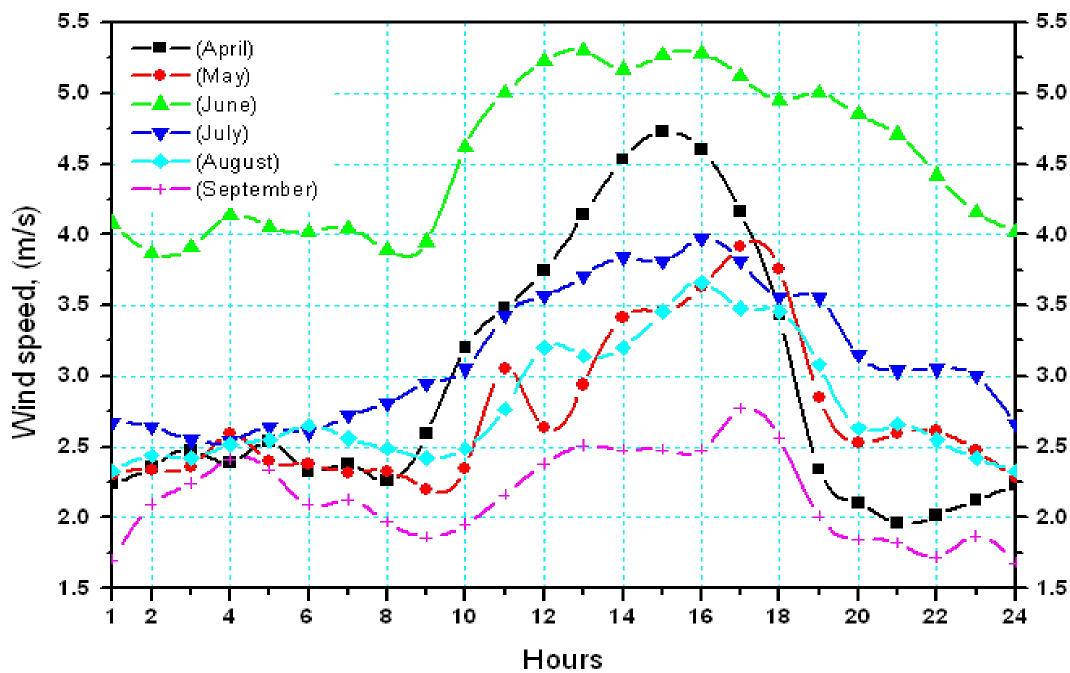


Fig. 4.19: Hourly mean wind speed at Rauzan from April to September.

For hourly mean wind speed 1st hour means 12:00 to 1:00 AM and 24th hour means 11:00 to 12:00 PM. So, from the **Fig. 4.15** to **Fig. 4.19**, it has been cleared that at day time wind speed was higher than the night time. But in Kuakata **Fig. 4.15** low fluctuation of wind speed at day and night time. So, Kuakata is the best site for power generation.

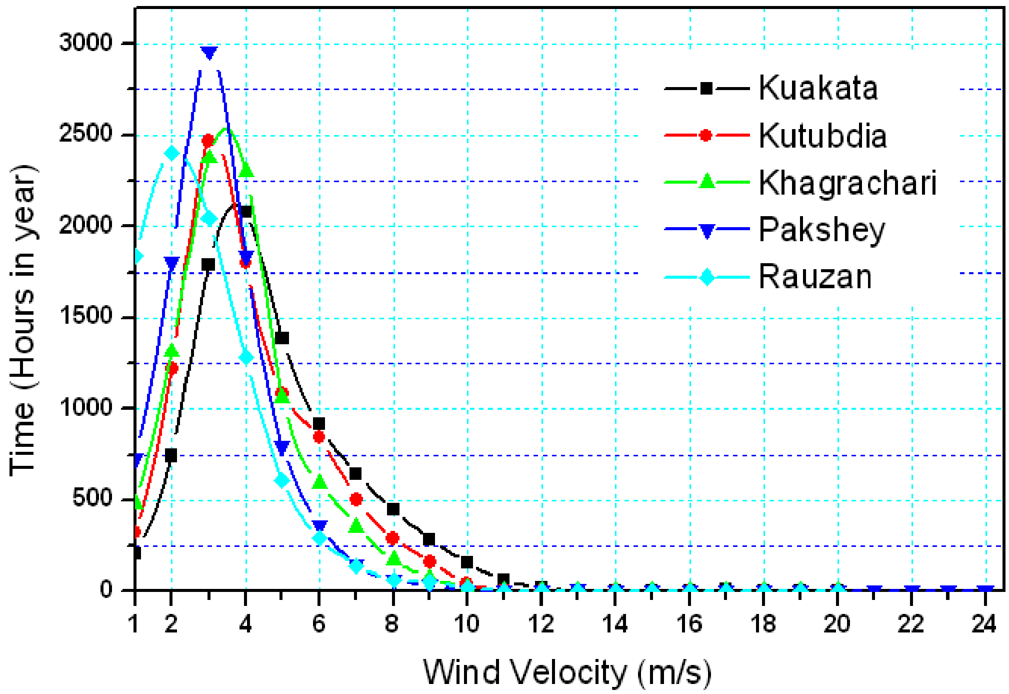


Fig. 4.20: Velocity Duration Curve for Kuakata, Kutubdia, Khagrachari, Pakshey and Rauzan.

One can find a good idea about a site, if he studies wind duration curve of that site. In the above **Fig. 4.20** shows a wind duration curve for five wind sites. From the above figures it has been cleared that the each point on this curve shows the number of hours in a year for which time either the corresponding velocity or higher velocity occurs. It also cleared from the above figure that Kuakata have higher wind velocity than other sites. In this site have 68.7% wind velocity 4 m/s or above and 45% wind velocity 5 m/s or above throughout the whole year. In the case of other sites, the wind velocity variation from 1 to 4 m/s has higher numbers of hours throughout the year.

The wind duration curve for five wind sites are given in the same figure, so that one can easily visualize which site is the best and the most promising one.

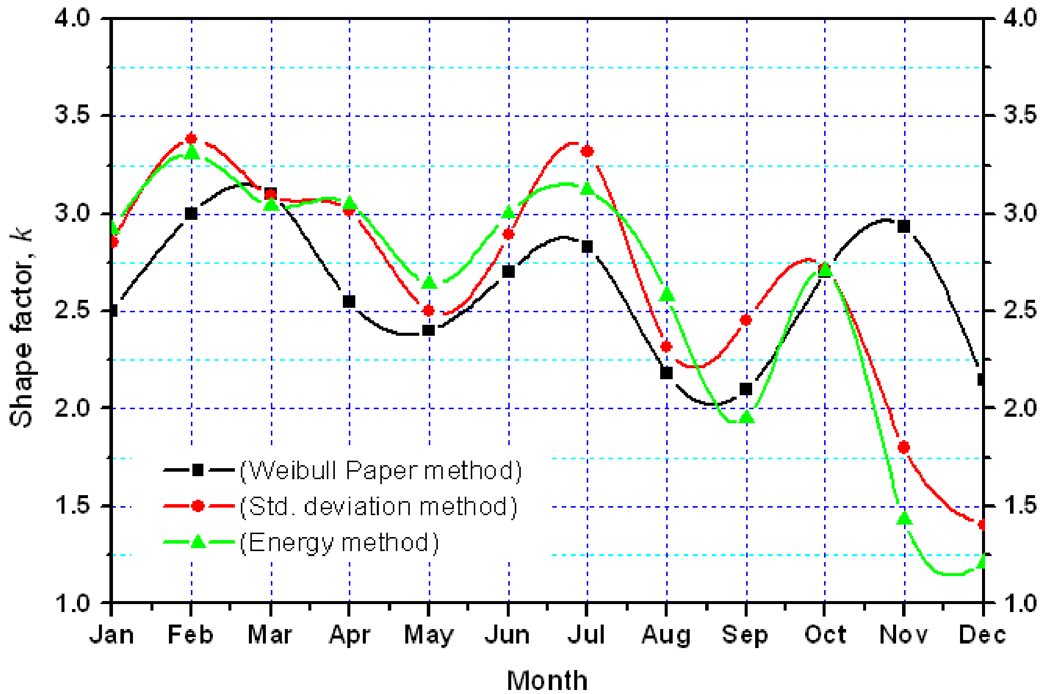


Fig. 4.21: Monthly variation of Weibull Shape factor (*k*) at Kuakata.

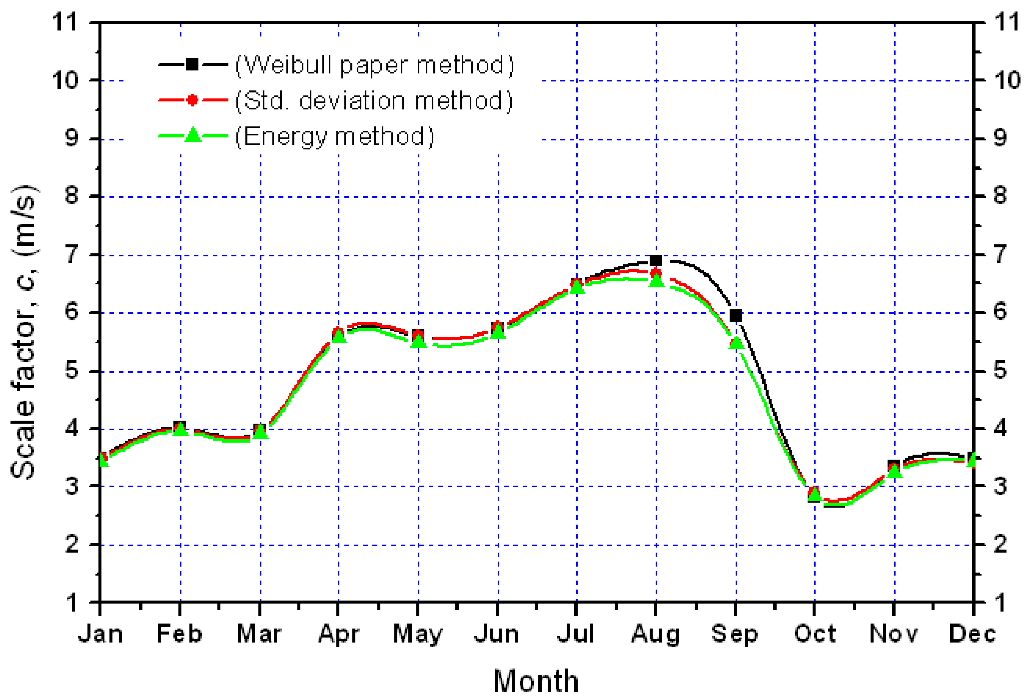


Fig. 4.22: Monthly variation of Weibull Scale factor (*c*) at Kuakata.

From the **Fig. 4.21** Weibull shape factor has been plotted and analyzed. It has been shown that in almost every month except November and December the value of *k* is greater than two i.e. Weibull functions follow very close to the Raleigh function (*k*=2) for the selected sites. The Weibull scale factor *c* remains between 2.83 to 6.90 m/s in **Fig. 4.22**.

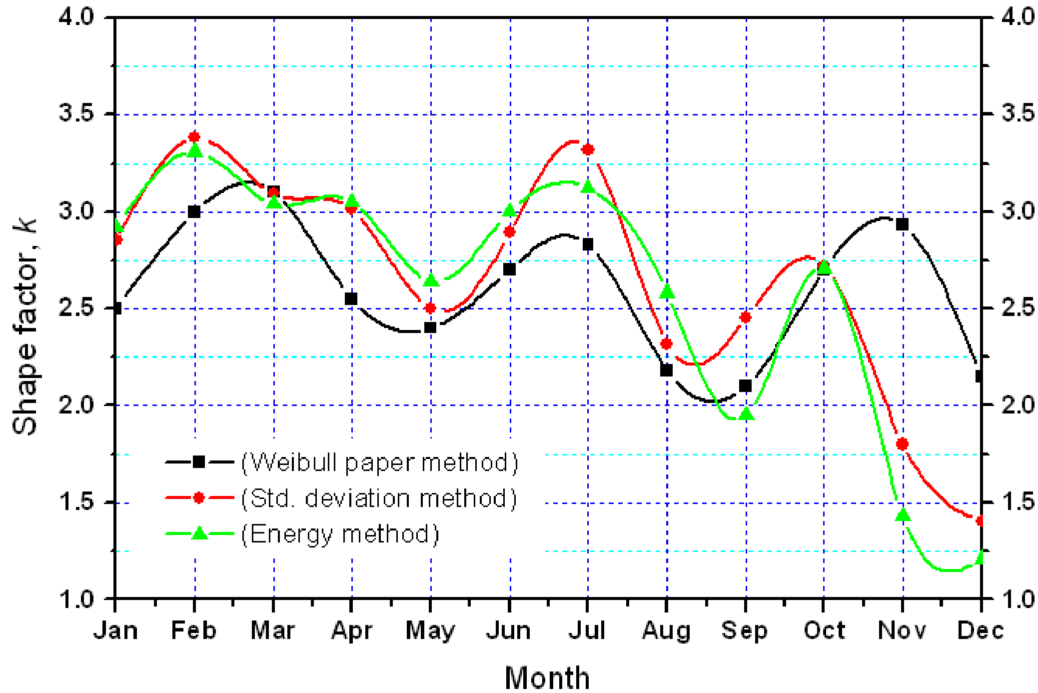


Fig. 4.23: Monthly variation of Weibull Shape factor (*k*) at Kutubdia.

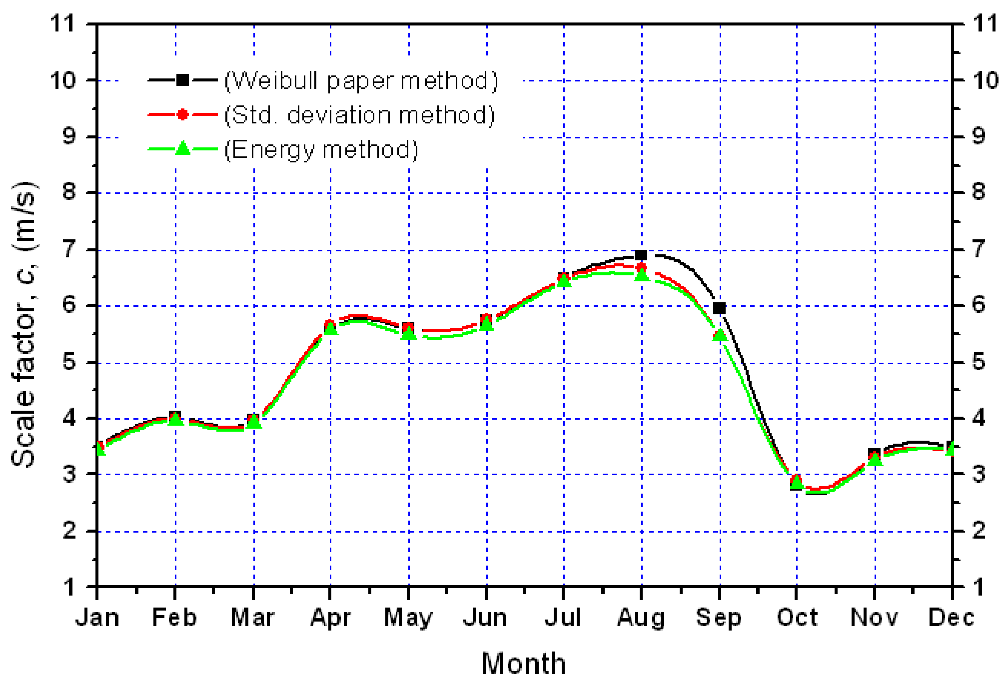


Fig. 4.24: Monthly variation of Weibull Scale factor (*c*) at Kutubdia.

The shape factor (*k*) and scale factor (*c*) were determined for each month. It has been found that the value of *k* remains in between 1.4 to 3.38 and that of *c* remains between 2.83 to 6.90. The most of the Weibull functions follow very close to the Raleigh function (*k*=2) for the selected sites.

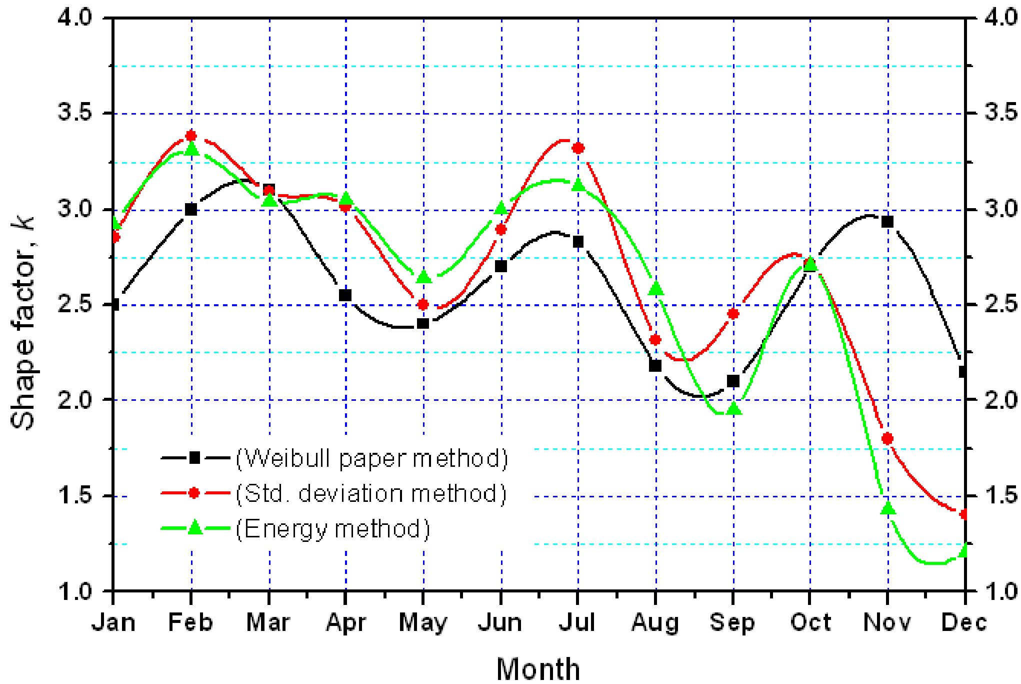


Fig. 4.25: Monthly variation of Weibull Shape factor (*k*) at Khagrachari.

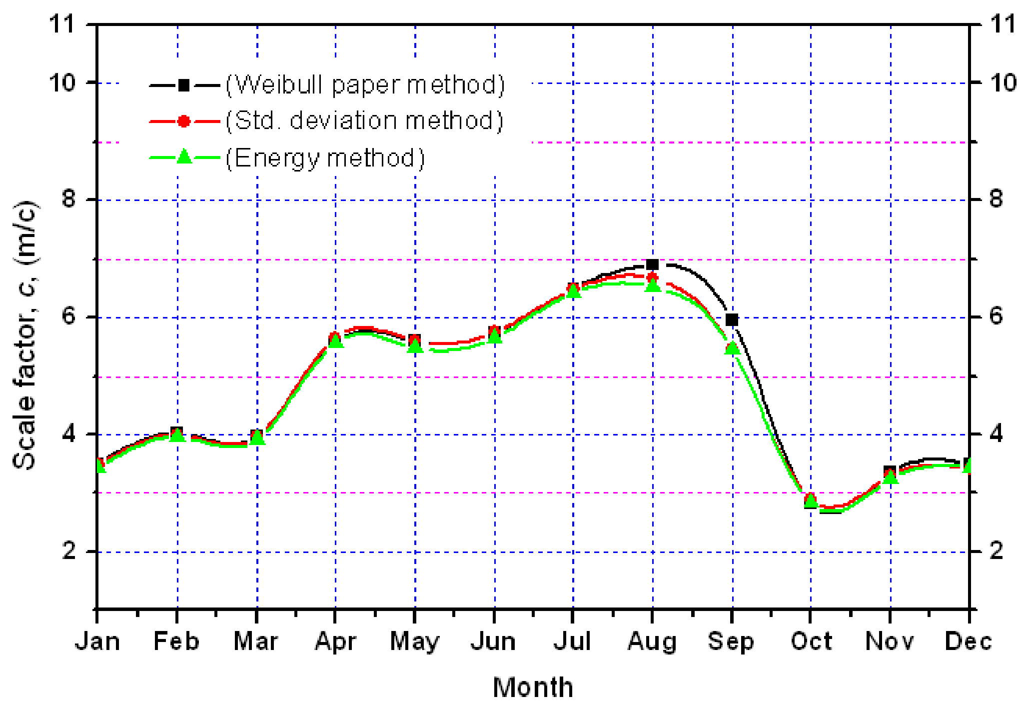


Fig. 4.26: Monthly variation of Weibull Scale factor (*c*) at Khagrachari.

The comparison of Weibull shape factor (*k*) and scale factor (*c*) by three methods which has shown in **Fig. 4.25 - 4.26** for Khagrachari. Here November and December shape factor has been lower than 2 by standard deviation method and energy method.

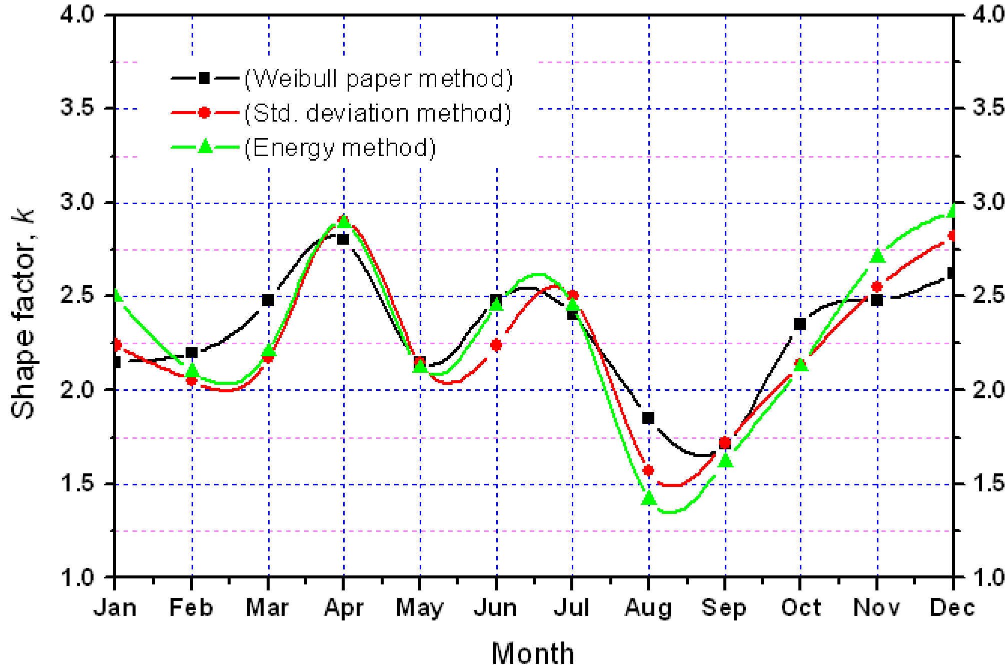


Fig. 4.27: Monthly variation of Weibull Shape factor (*k*) at Pakshey.

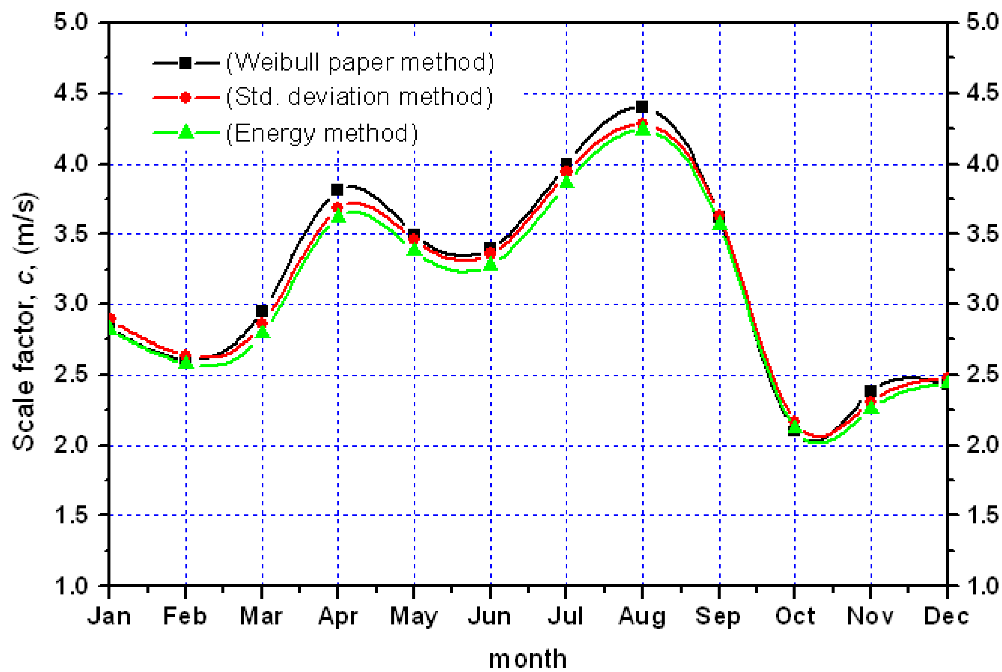


Fig. 4.28: Monthly variation of Weibull Scale factor (*c*) at Pakshey.

The comparison of Weibull shape factor (*k*) and scale factor (*c*) by three methods has shown in **Fig. 4.27 - 4.28** for Pakshey. Here August and September shape factor has been lower than 2 by three methods. It has been found that the value of *k* remains in between 1.42 to 2.95 and that of *c* remains between 2.10 to 4.40.

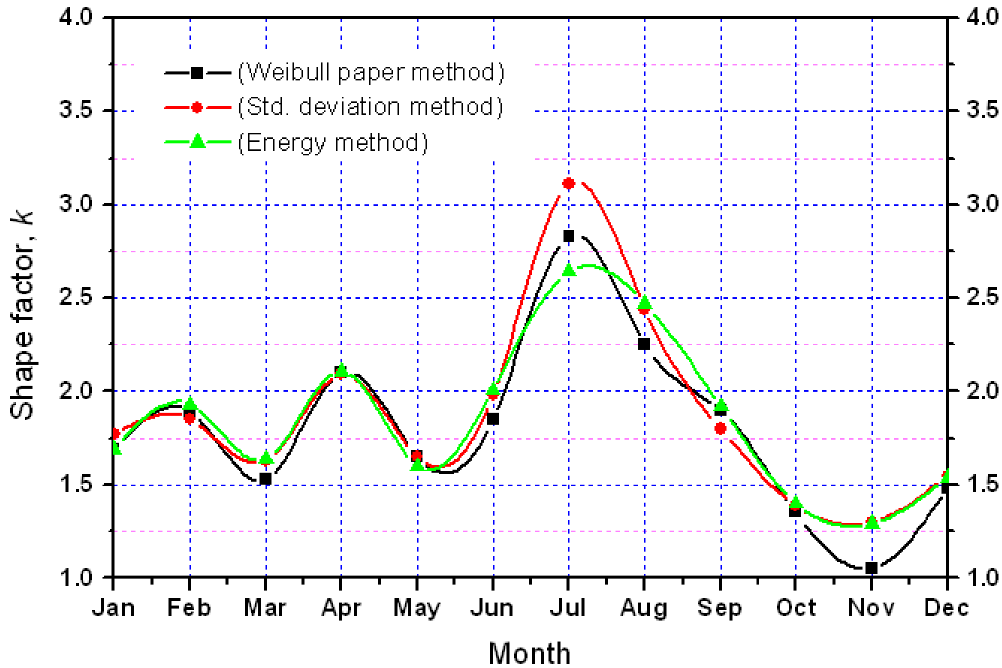


Fig. 4.29: Monthly variation of Weibull Shape factor (*k*) at Rauzan.

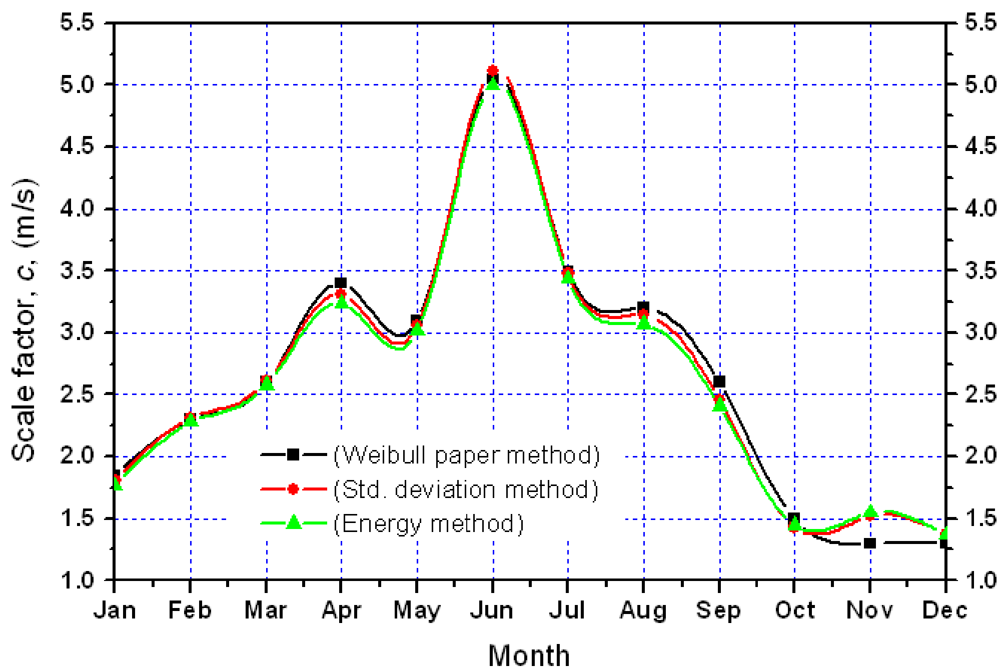


Fig. 4.30: Monthly variation of Weibull Scale factor (*c*) at Rauzan.

Here October to December shape factor has been lower than 1.5 by three methods. It has been found that the value of *k* remains in between 1.05 to 2.47 and that of *c* remains between 2.30 to 5.11.

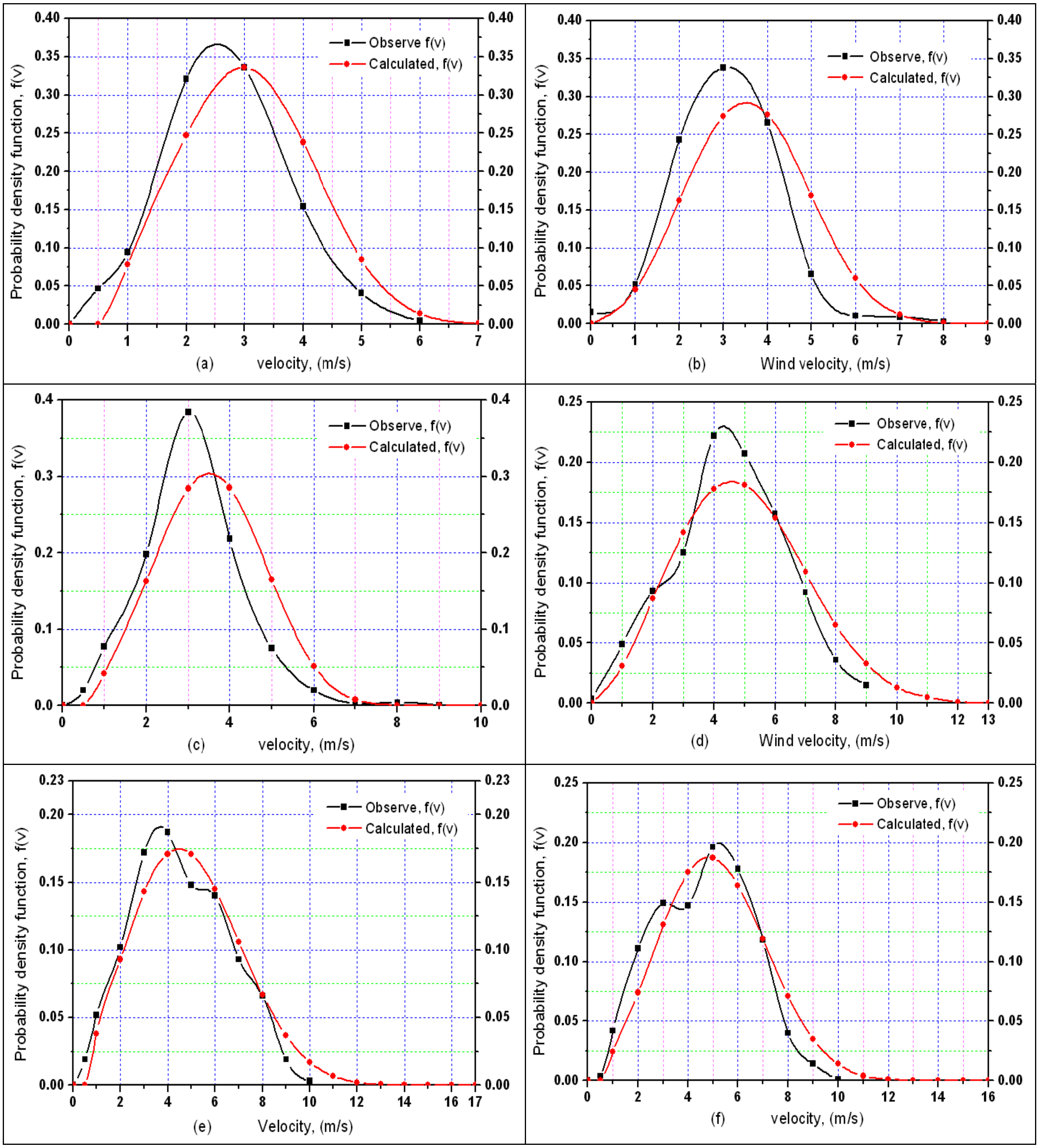


Fig. 4.31: Weibull probability density function **f(v)** for Kuakata at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull probability density function f(v) for Kuakata from January to June and rest of the month i.e. July to December has shown in **Fig. 4.32**.

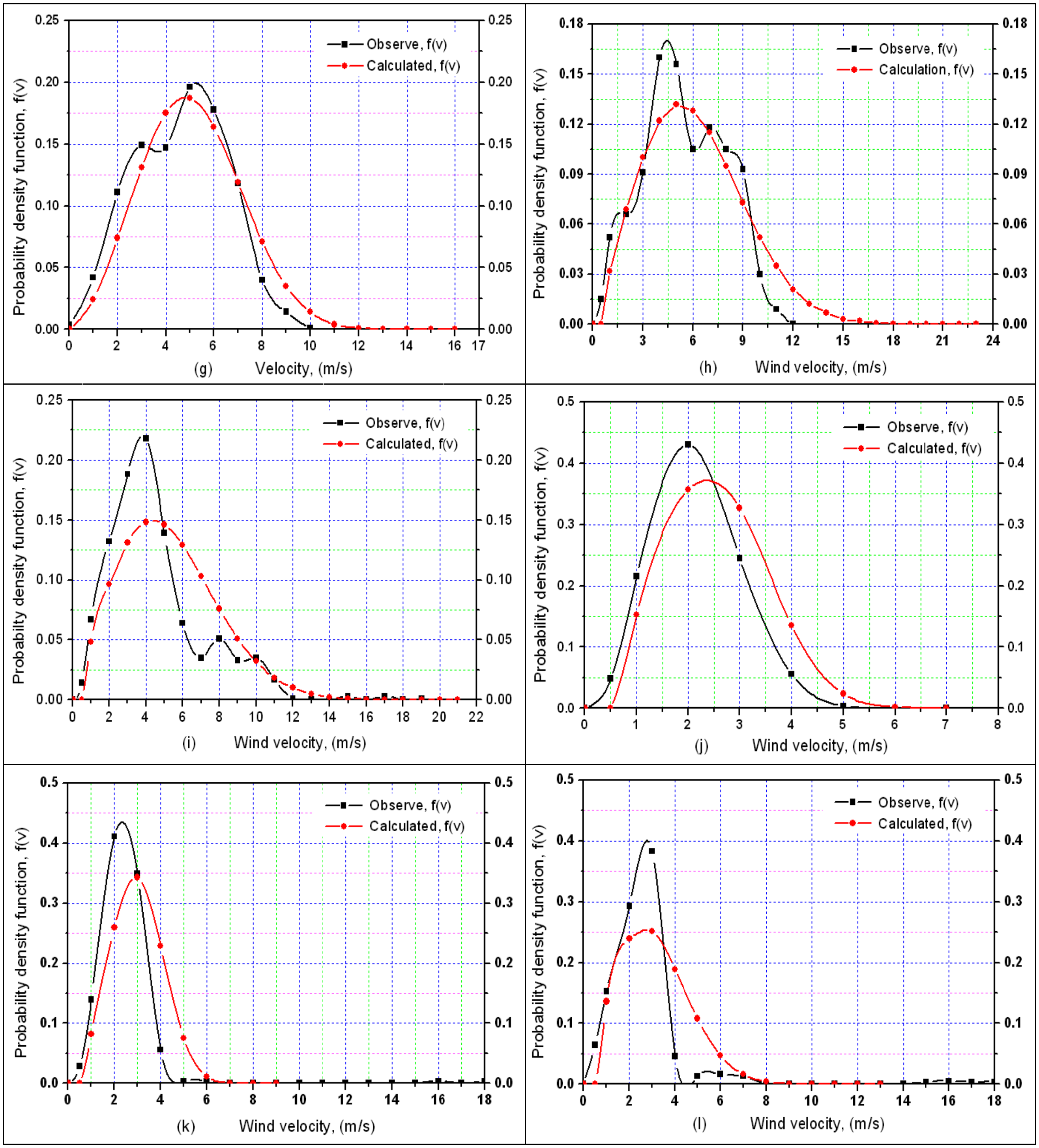


Fig. 4.32: Weibull probability density function **f(v)** for Kuakata at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

From the above **Fig. 4.31 – 4.32**, all the figures of Weibull probability density function for Kuakata, it has been found that the calculated and observed data roughly variation of wind speed but their peak is close to each other except April, August and September.

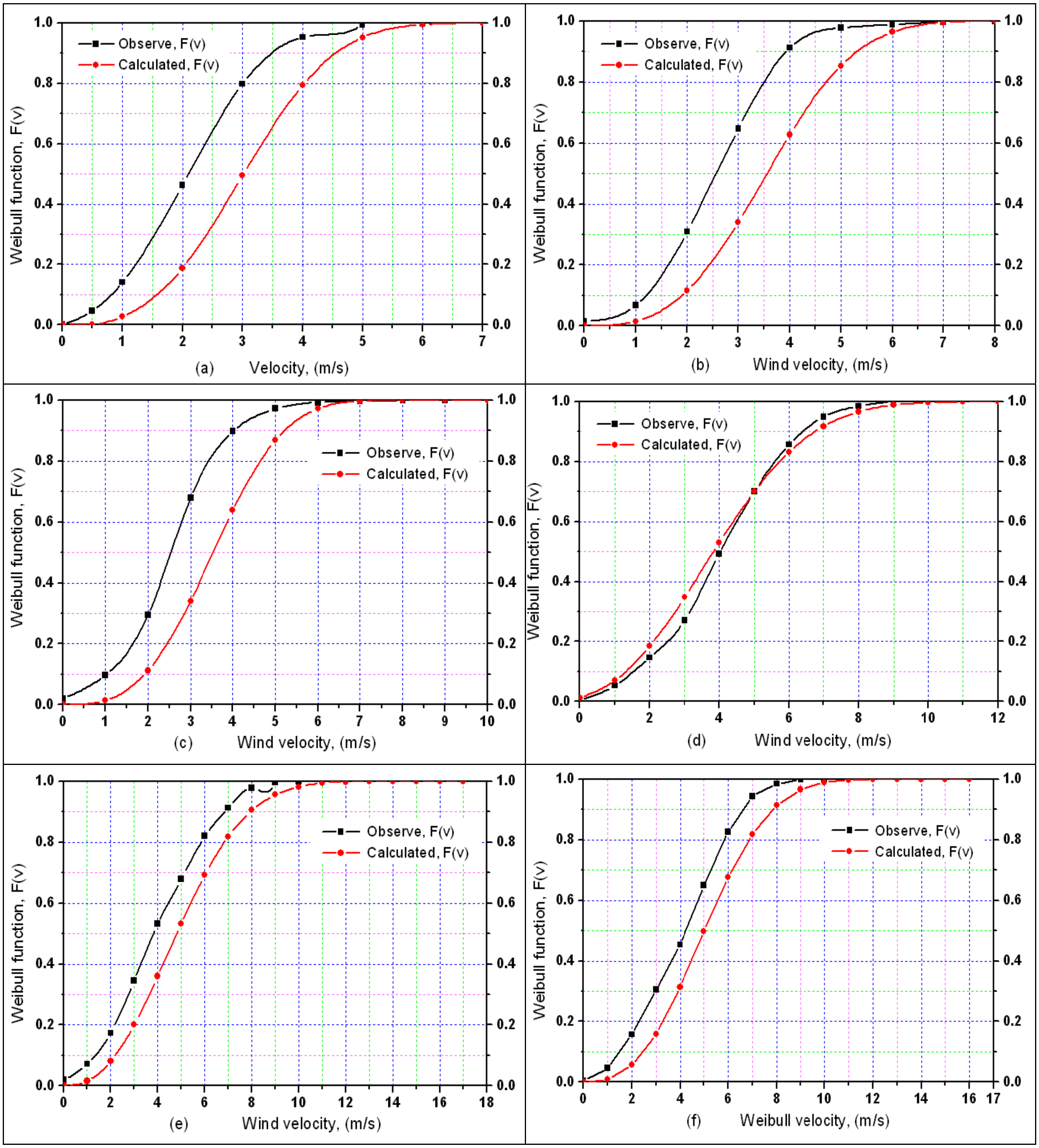


Fig. 4.33: Weibull function **F(v)** for Kuakata at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull function F(v) for Kuakata from January to June and rest of the month i.e. July to December has shown in **Fig. 4.34**.

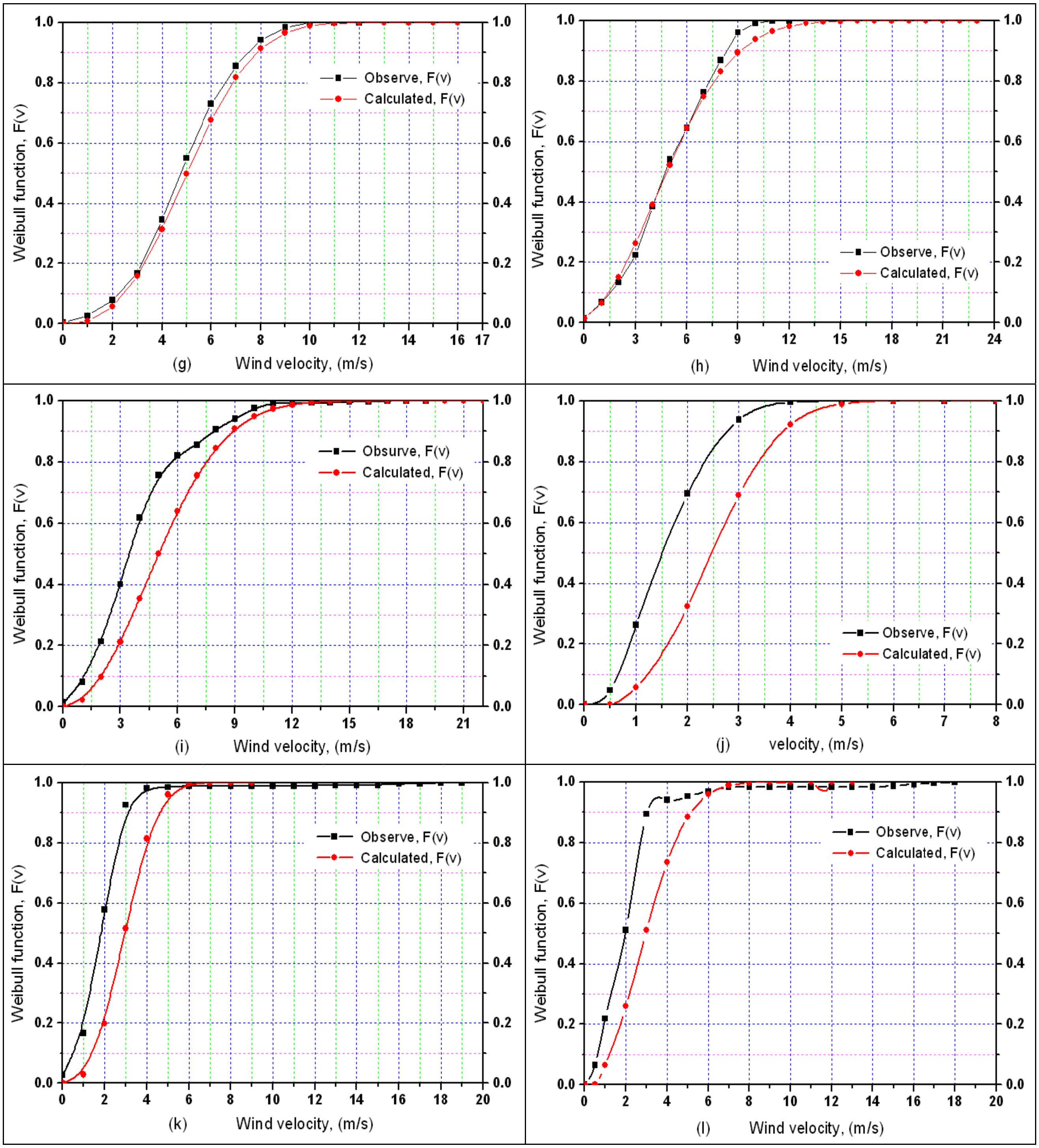


Fig. 4.34: Weibull function **F(v)** for Kuakata at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

In **Fig. 4.33** and **Fig. 4.34**, all the figures for Kuakata has shown that the observed and calculated data are closely fitted with each other except only little variation of January, February and October.

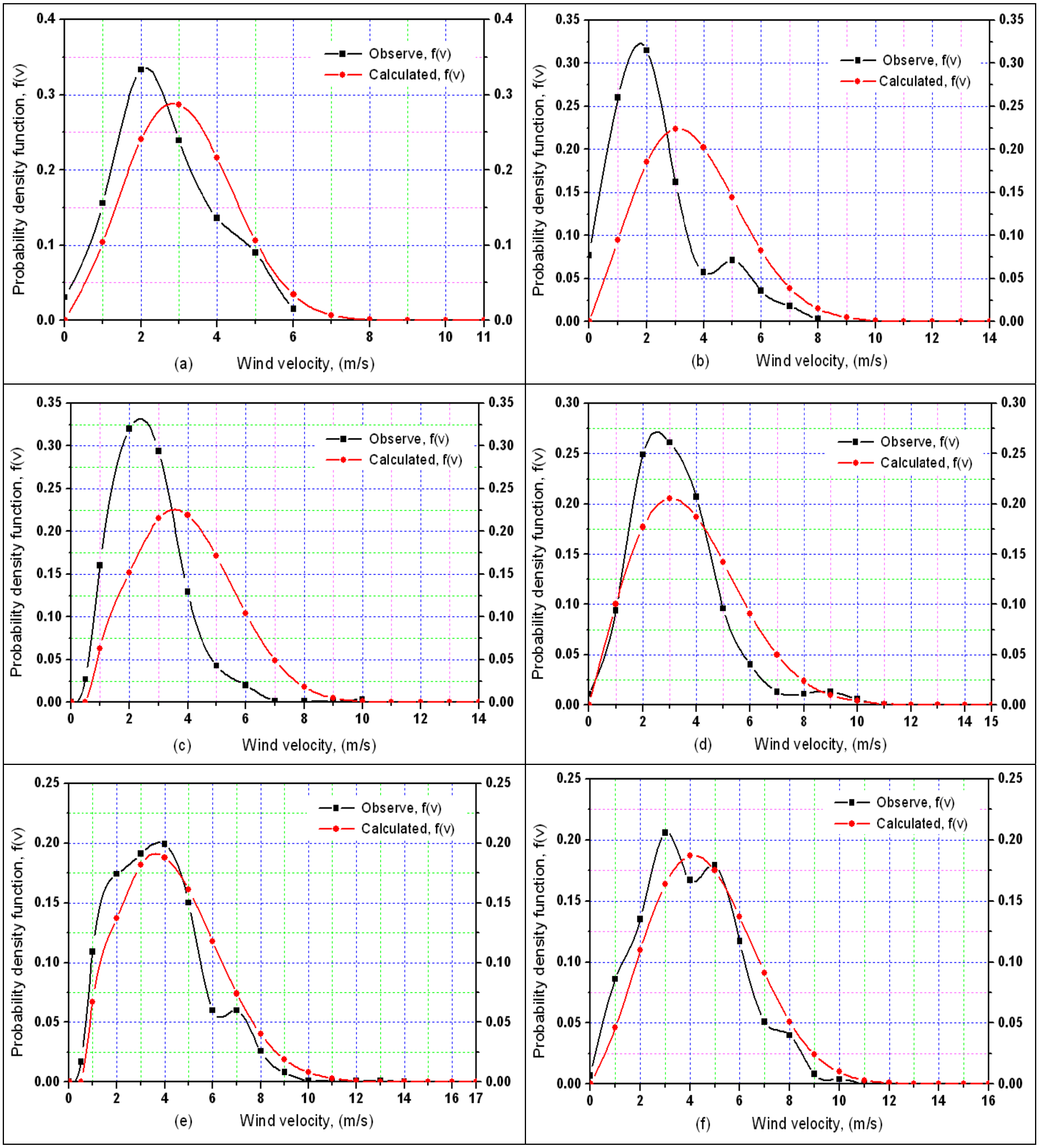


Fig. 4.35: Weibull probability density function **f(v)** for Kutubdia at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull probability density function f(v) for Kutubdia from January to June and rest of the month i.e. July to December has shown in **Fig. 4.36**.

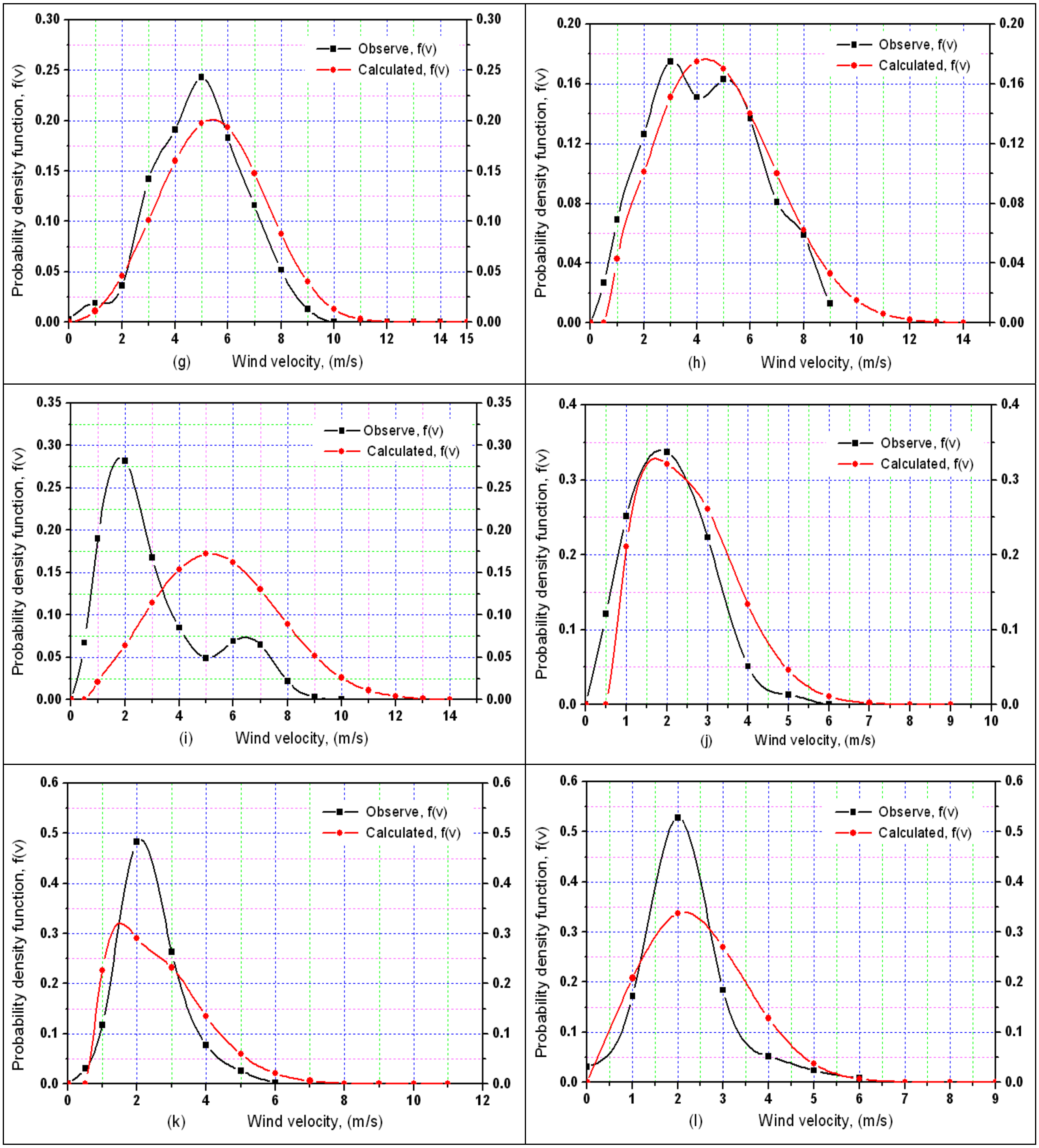


Fig. 4.36: Weibull probability density function **f(v)** for Kutubdia at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

From all the figures of above **Fig. 4.35 – 4.36**, it has been found that the calculated and observed data roughly variation of wind speed but their peak is close to each other except February, March, September, November and December.

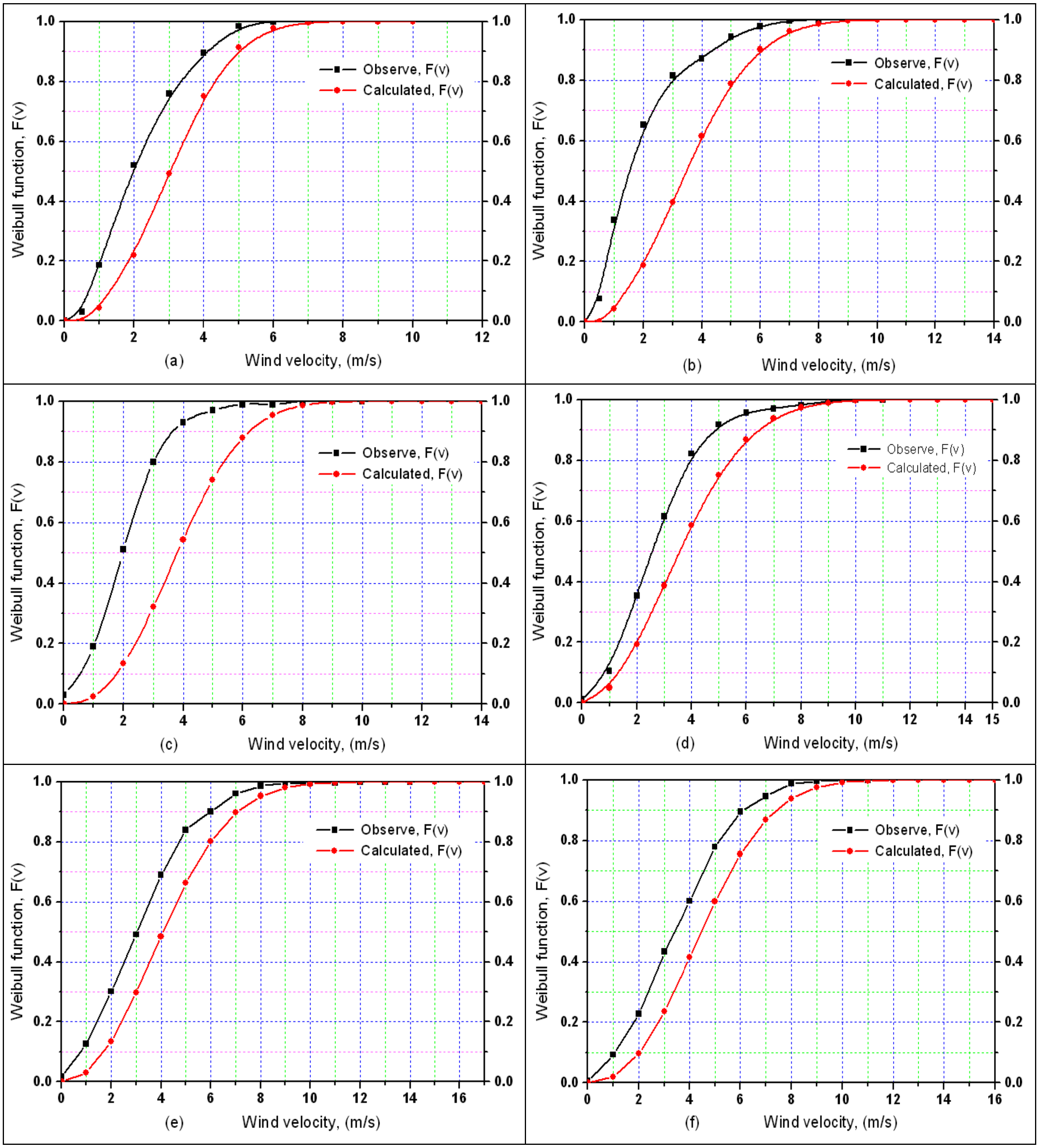


Fig. 4.37: Weibull function **F(v)** for Kutubdia at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull function F(v) for Kutubdia from January to June and rest of the month i.e. July to December has shown in **Fig. 4.38**.

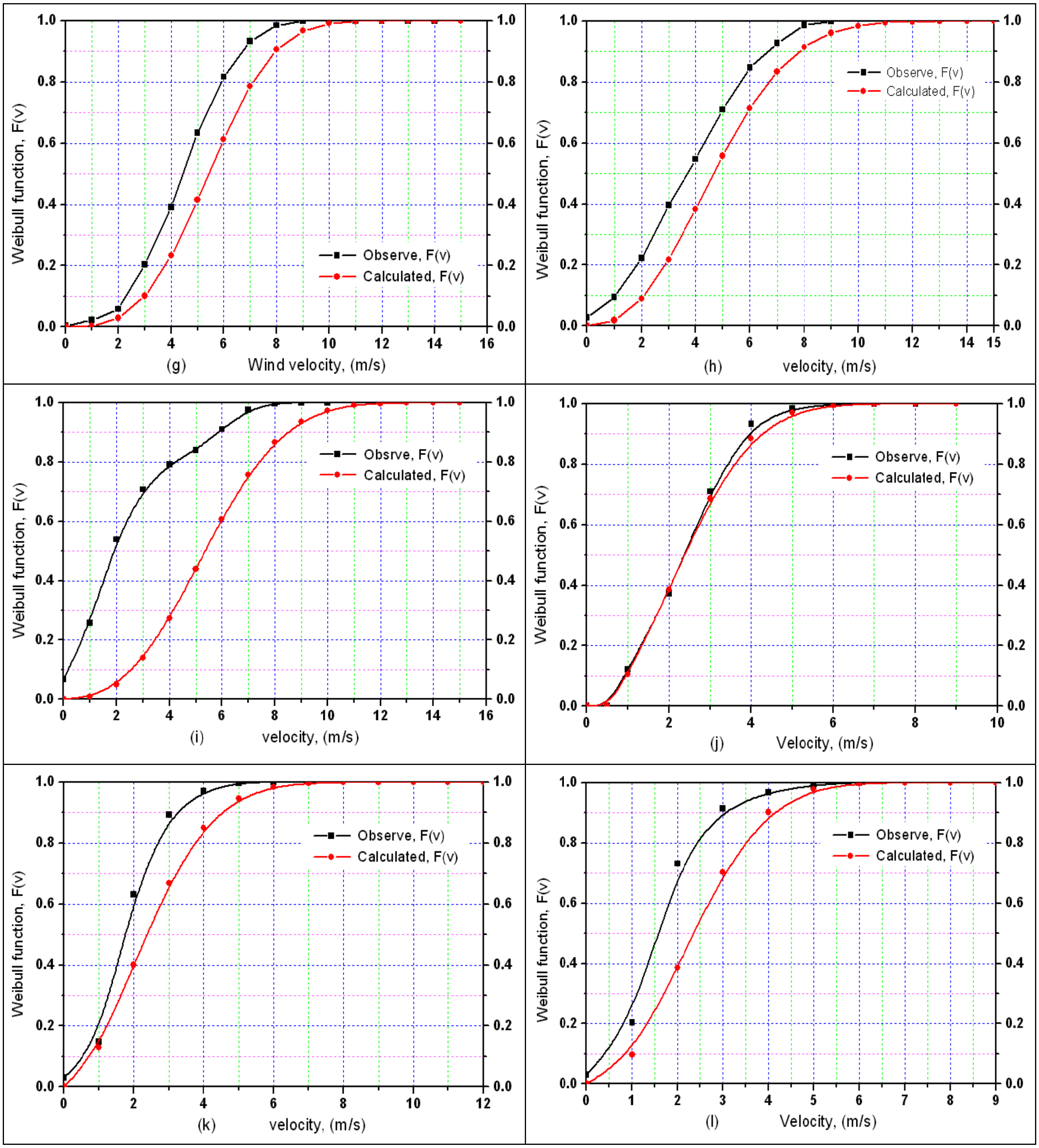


Fig. 4.38: Weibull function **F(v)** for Kutubdia at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

In **Fig. 4.37** and **Fig. 4.38**, all the figures for Kutubdia has shown that the observed and calculated data are closely fitted with each other except only little variation of February, March and September.

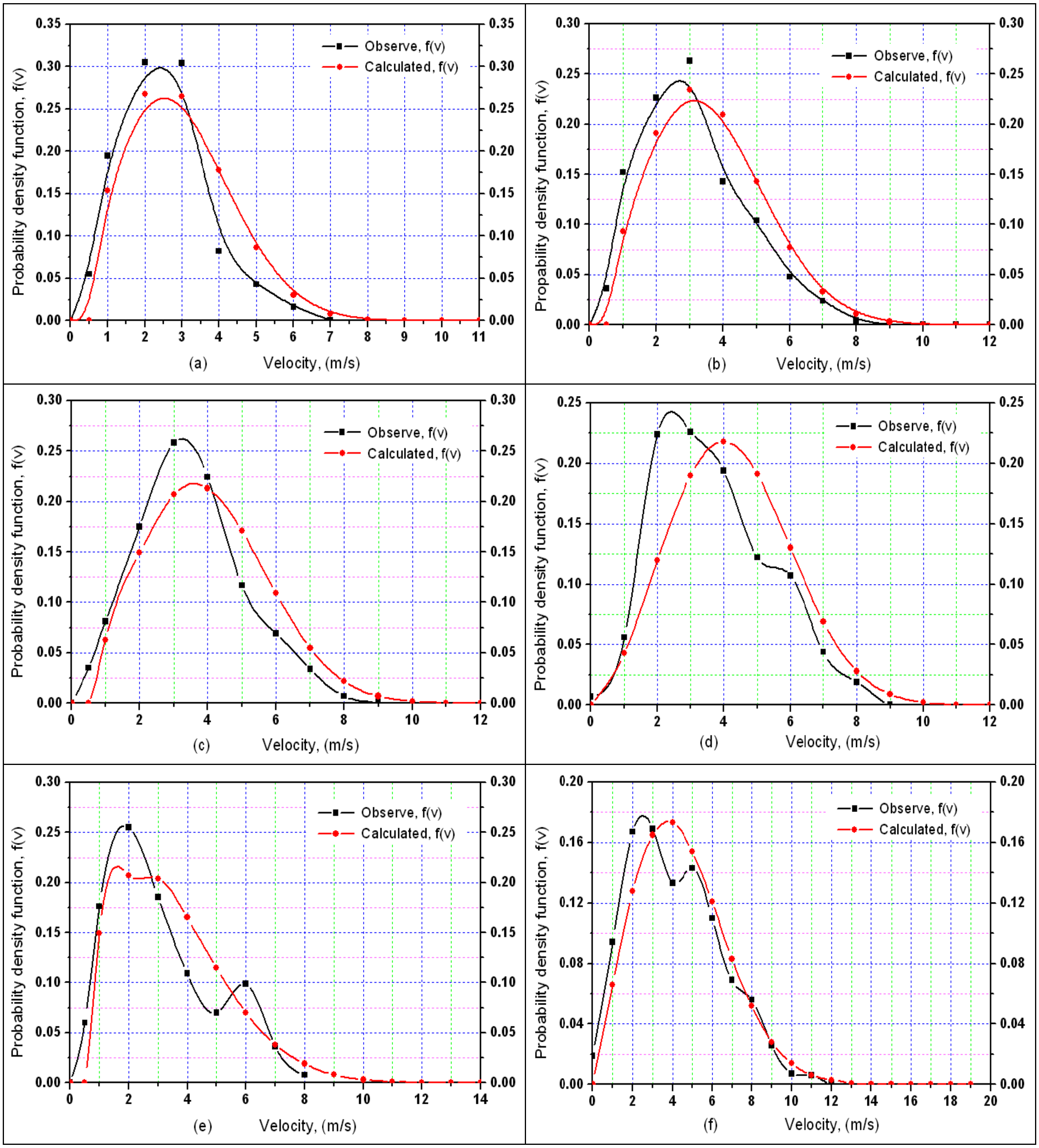


Fig. 4.39: Weibull probability density function **f(v)** for Khagrachari at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull probability density function f(v) for Khagrachari from January to June and rest of the month i.e. July to December has shown in **Fig. 4.40**.

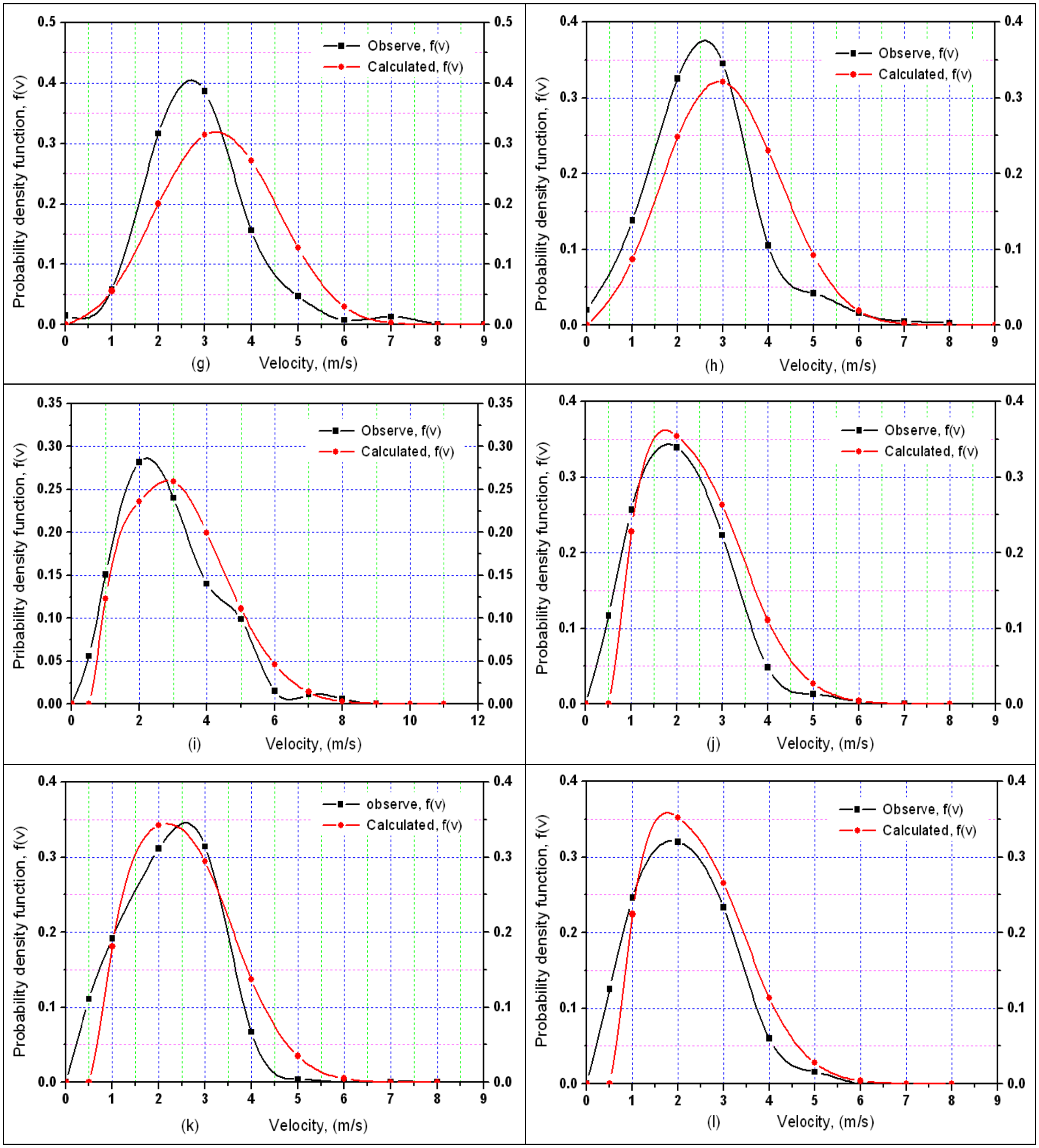


Fig. 4.40: Weibull probability density function **f(v)** for Khagrachari at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

From all the figures of above **Fig. 4.39 – 4.40**, it is found that the calculated and observed data roughly variation of wind speed but their peak is close to each other except April, May and July.

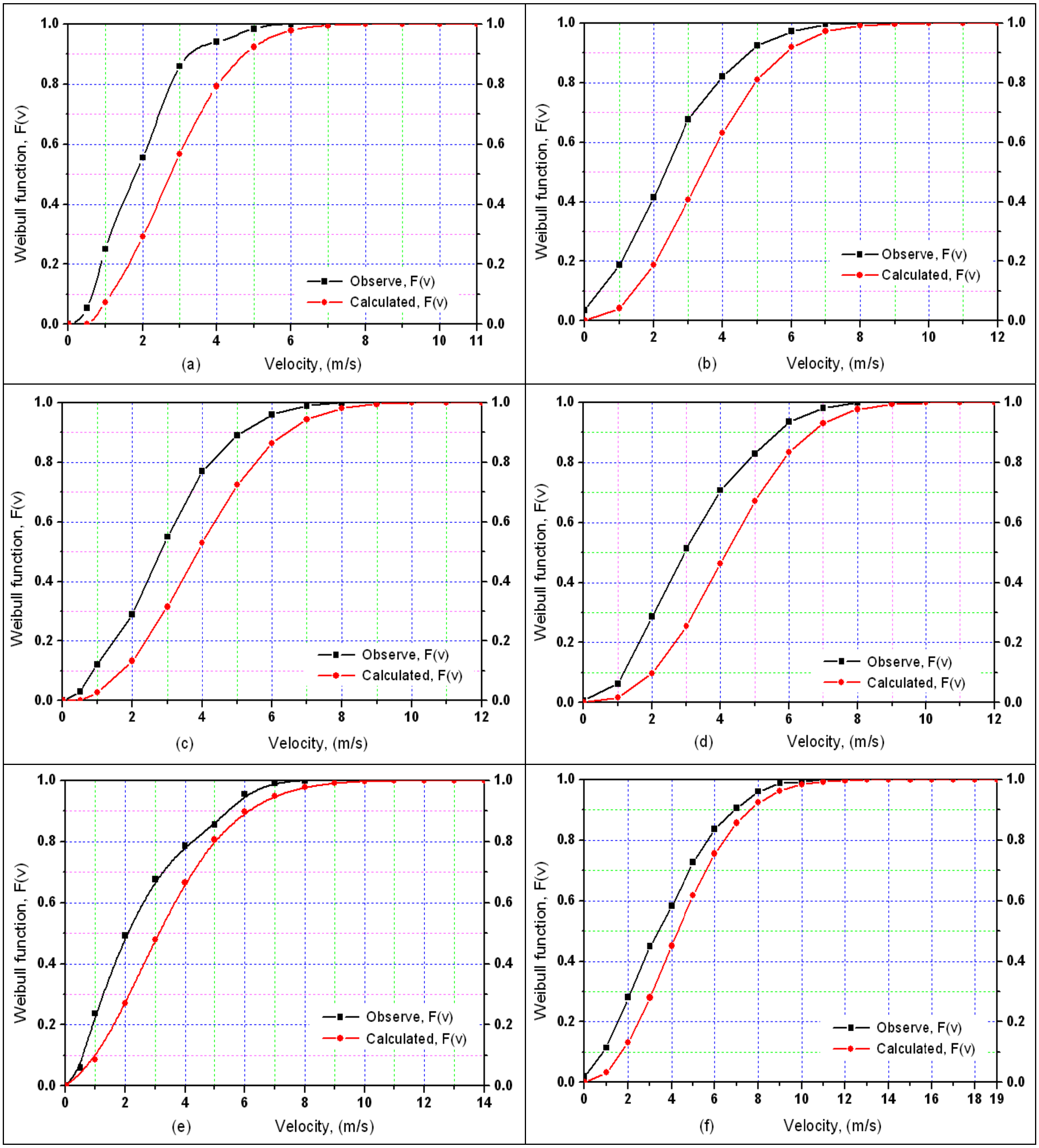


Fig. 4.41: Weibull function **F(v)** for Khagrachari at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull function F(v) for Khagrachari from January to June and rest of the month i.e. July to December has shown in **Fig. 4.42**.

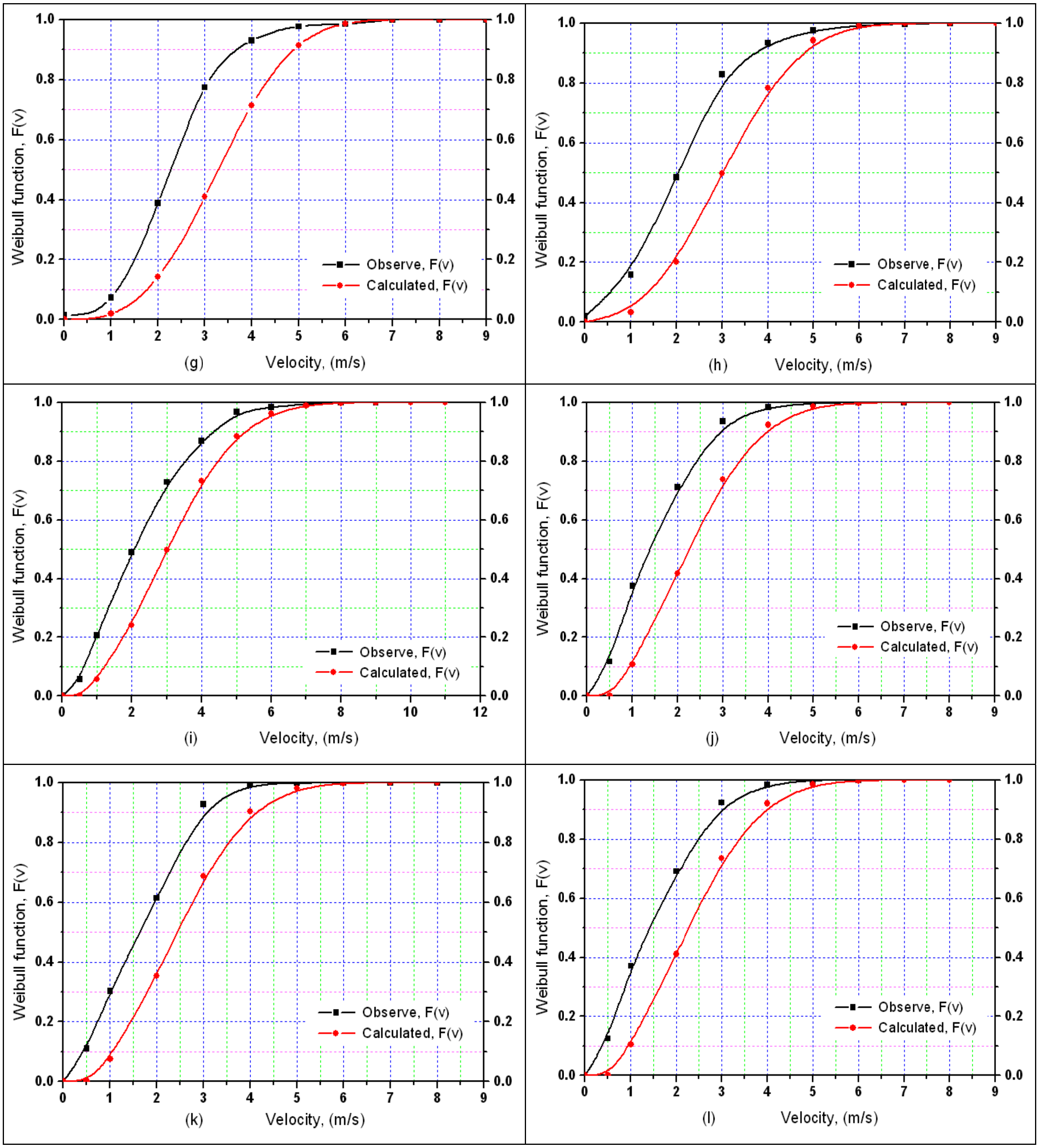


Fig. 4.42: Weibull function **F(v)** for Khagrachari at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

In **Fig. 4.41** and **Fig. 4.42**, all the figures for Khagrachari has shown that the observed and calculated data are closely fitted with each other except only little variation of July and August.

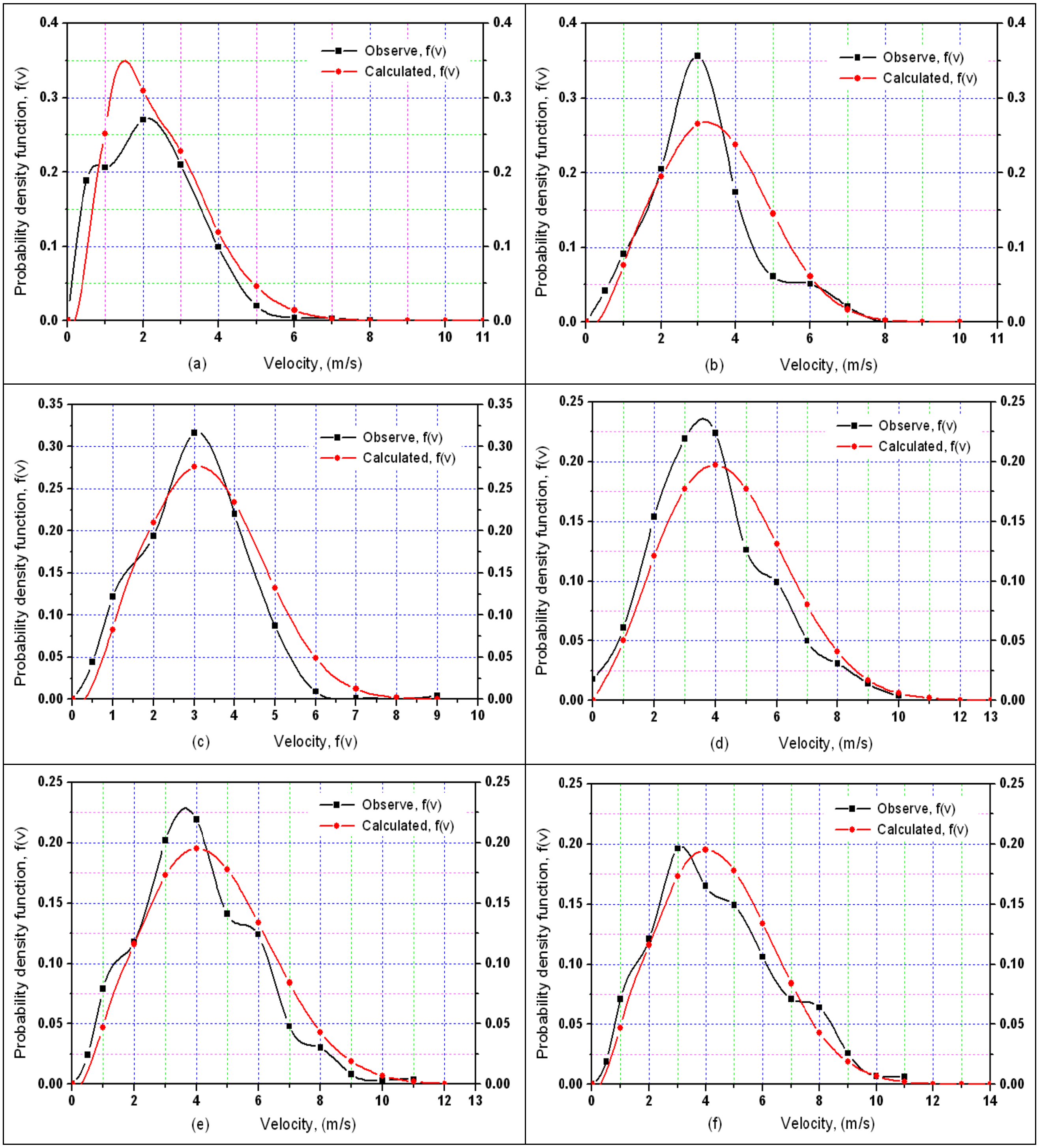


Fig. 4.43: Weibull probability density function **f(v)** for Sitakunda at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull probability density function f(v) for Sitakunda from January to June and rest of the month i.e. July to December has shown in **Fig. 4.44**.

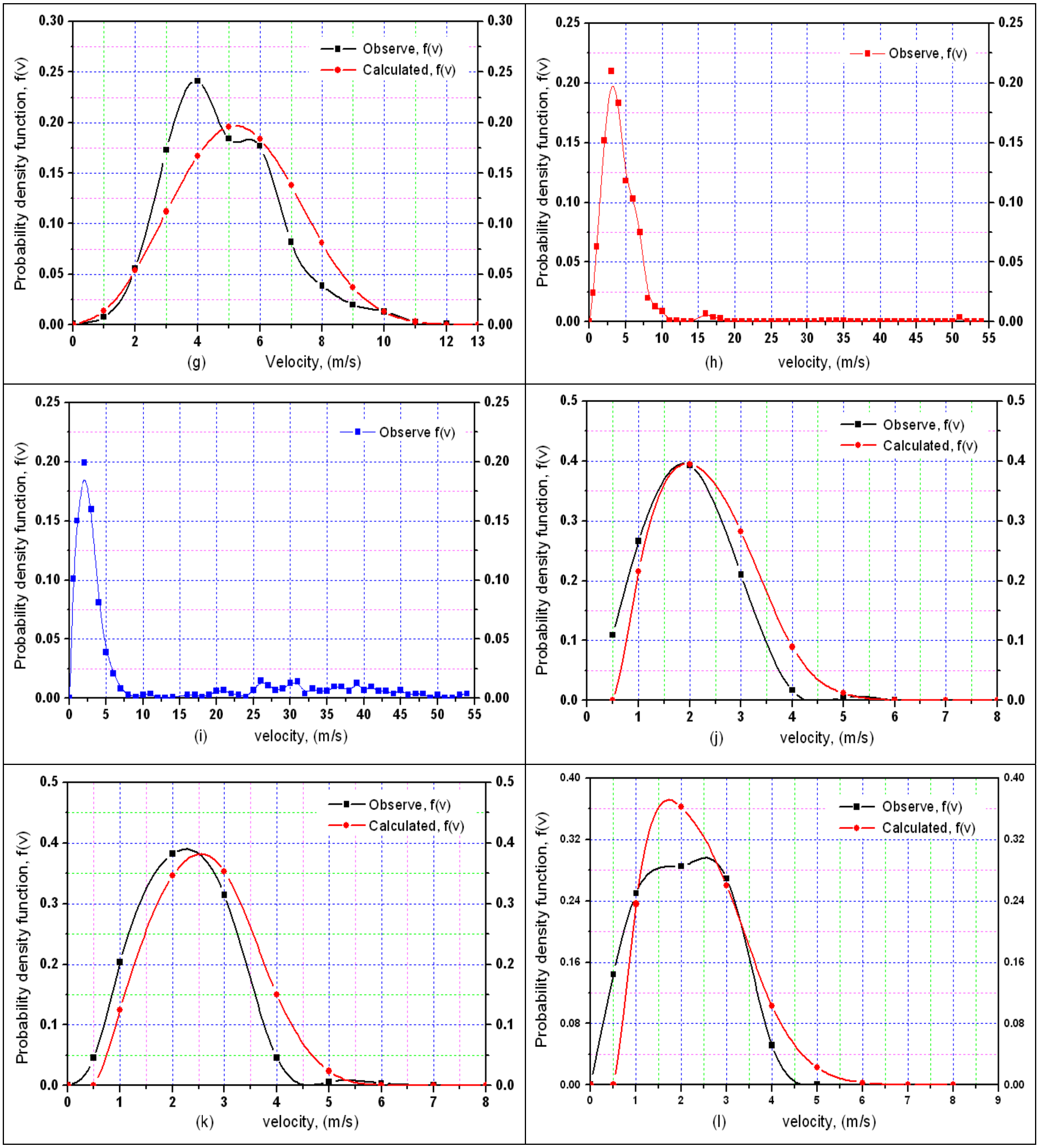


Fig. 4.44: Weibull probability density function **f(v)** for Sitakunda at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

From all the figures of above **Fig. 4.43 – 4.44**, it has been found that the both data roughly variation of wind speed but their peak has closed to each other except January, February and July. Although the value of *k* is out of range so calculated data has not found at August and September. So, single line has drowned for August and September.

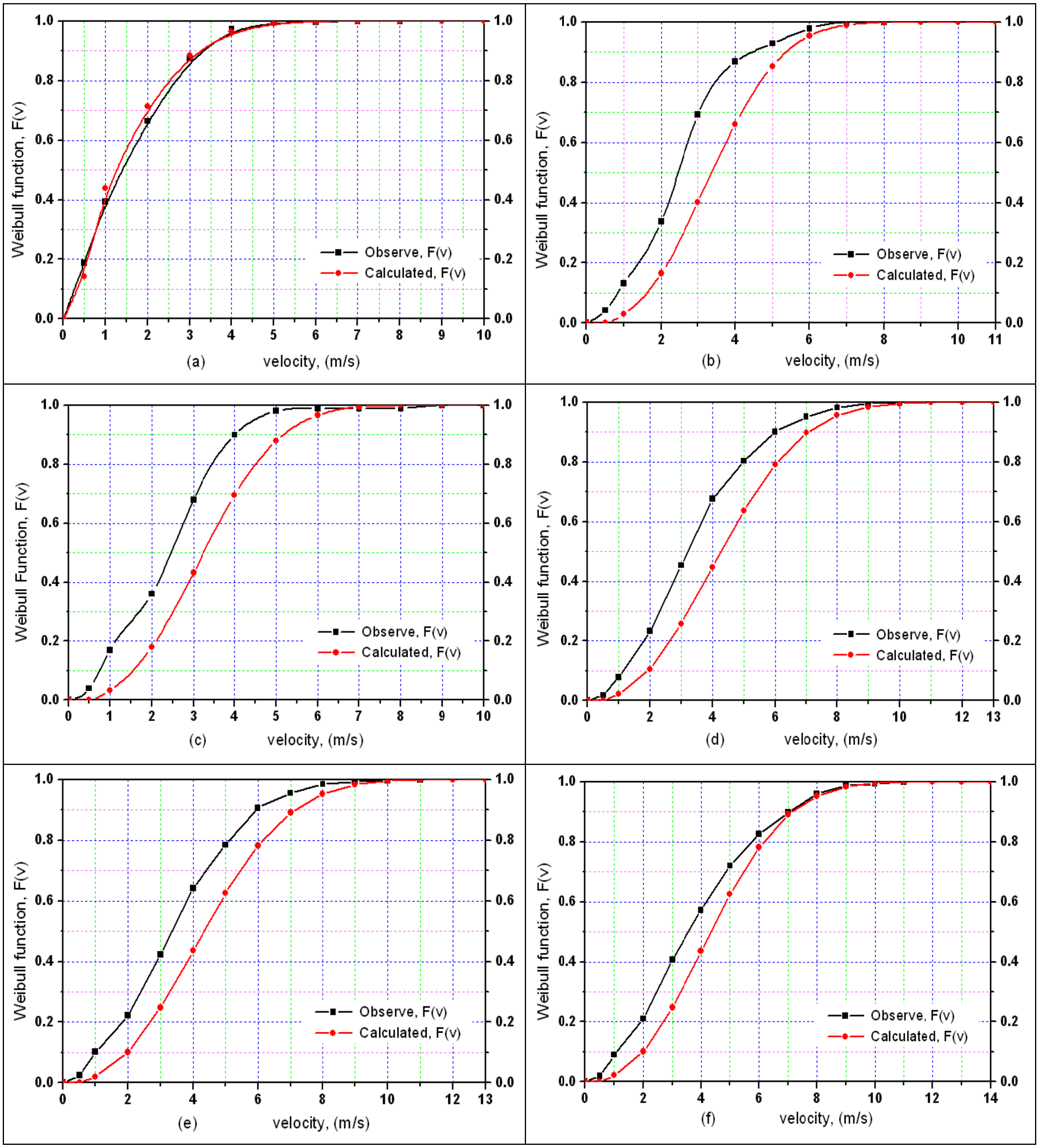


Fig. 4.45: Weibull function **F(v)** for Sitakunda at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull function F(v) for Sitakunda from January to June and rest of the month i.e. July to December has shown in **Fig. 4.46**.

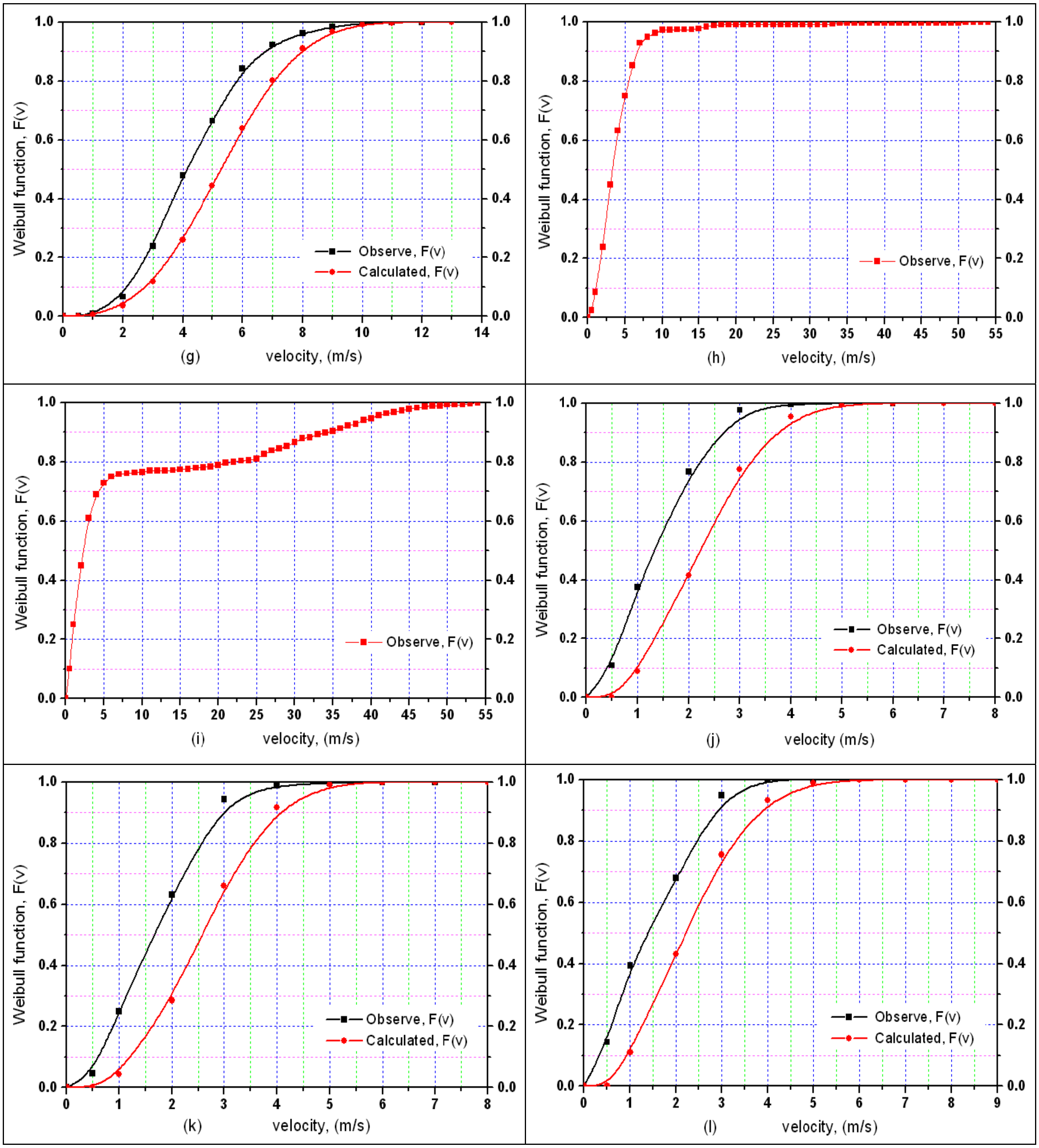


Fig. 4.46: Weibull function **F(v)** for Sitakunda at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

In **Fig. 4.45** and **Fig. 4.46**, all the figures for Sitakunda has shown that the observed and calculated data are closely fitted with each other except only little variation of August and September because the value of *k* was out of rage. So, calculated data has not found.

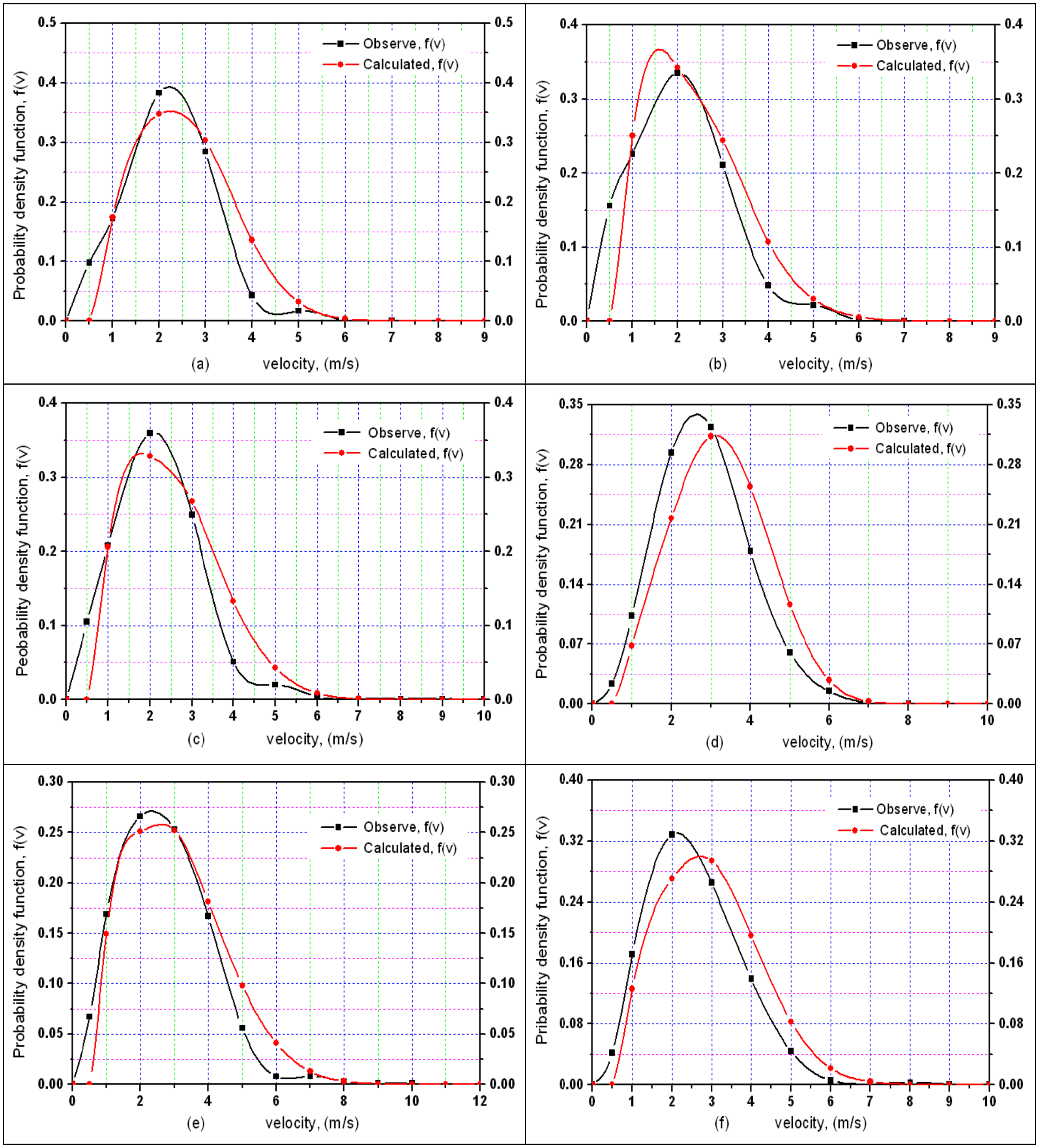


Fig. 4.47: Weibull probability density function **f(v)** for Pakshey at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull probability density function f(v) for Pakshey from January to June and rest of the month i.e. July to December has shown in **Fig. 4.48**.

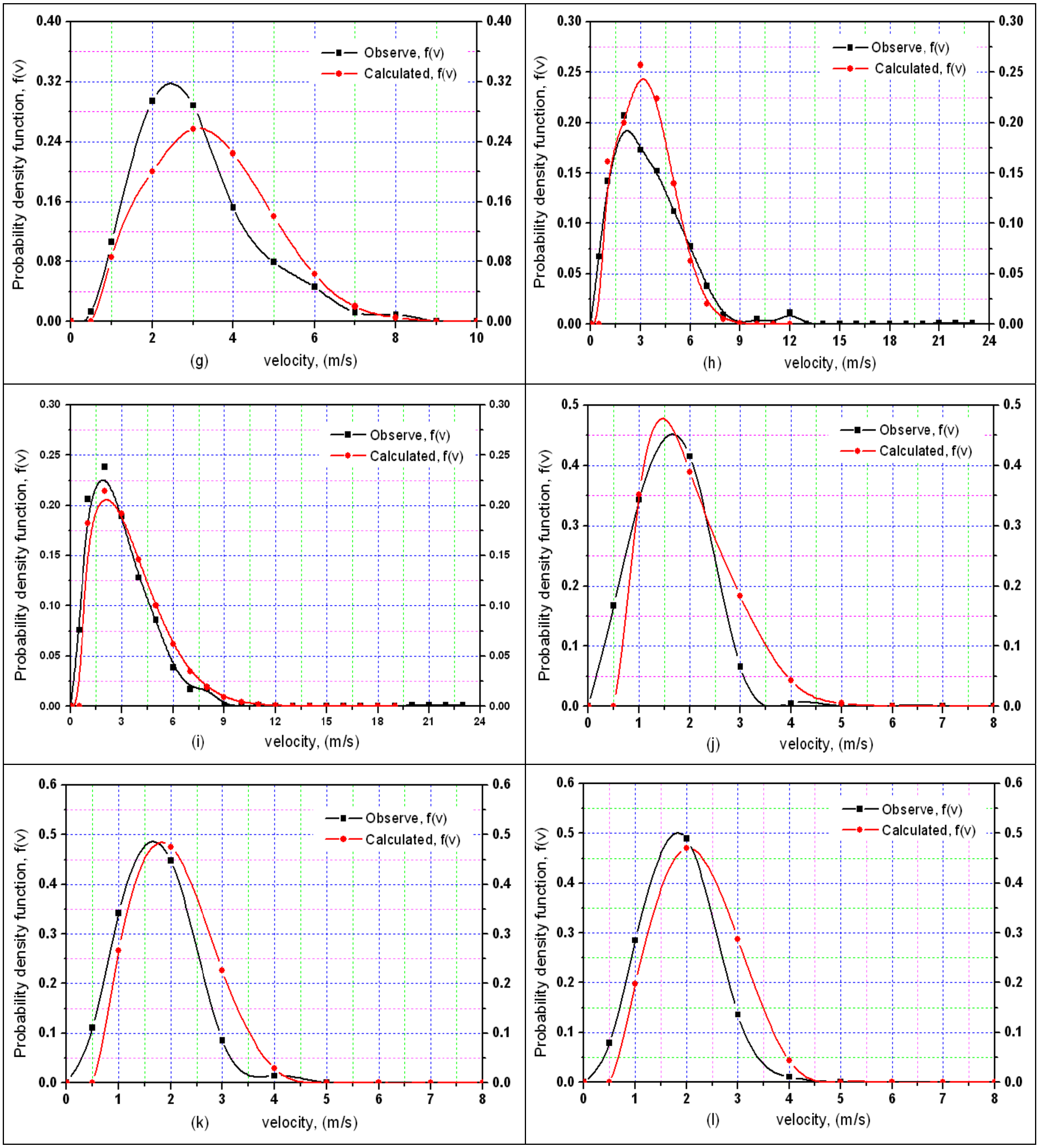


Fig. 4.48: Weibull probability density function **f(v)** for Pakshey at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

From all the figures of above **Fig. 4.47 – 4.48**, it has been found that the calculated and observed data roughly variation of wind speed but their peaks has closed to each other except February, July and August.

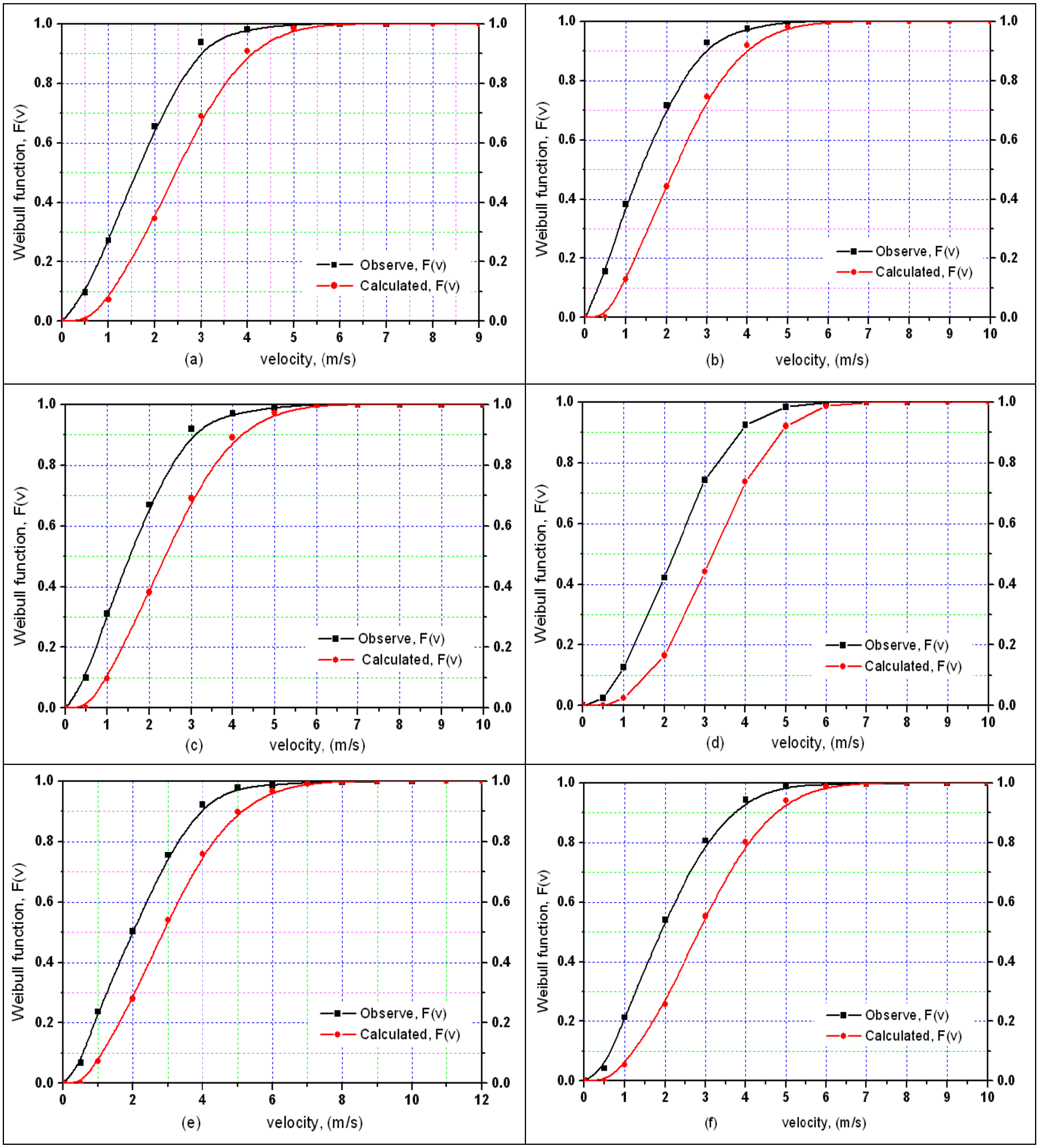


Fig. 4.49: Weibull function **F(v)** for Pakshey at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull function F(v) for Pakshey from January to June and rest of the months i.e. July to December has shown in **Fig. 4.50**.

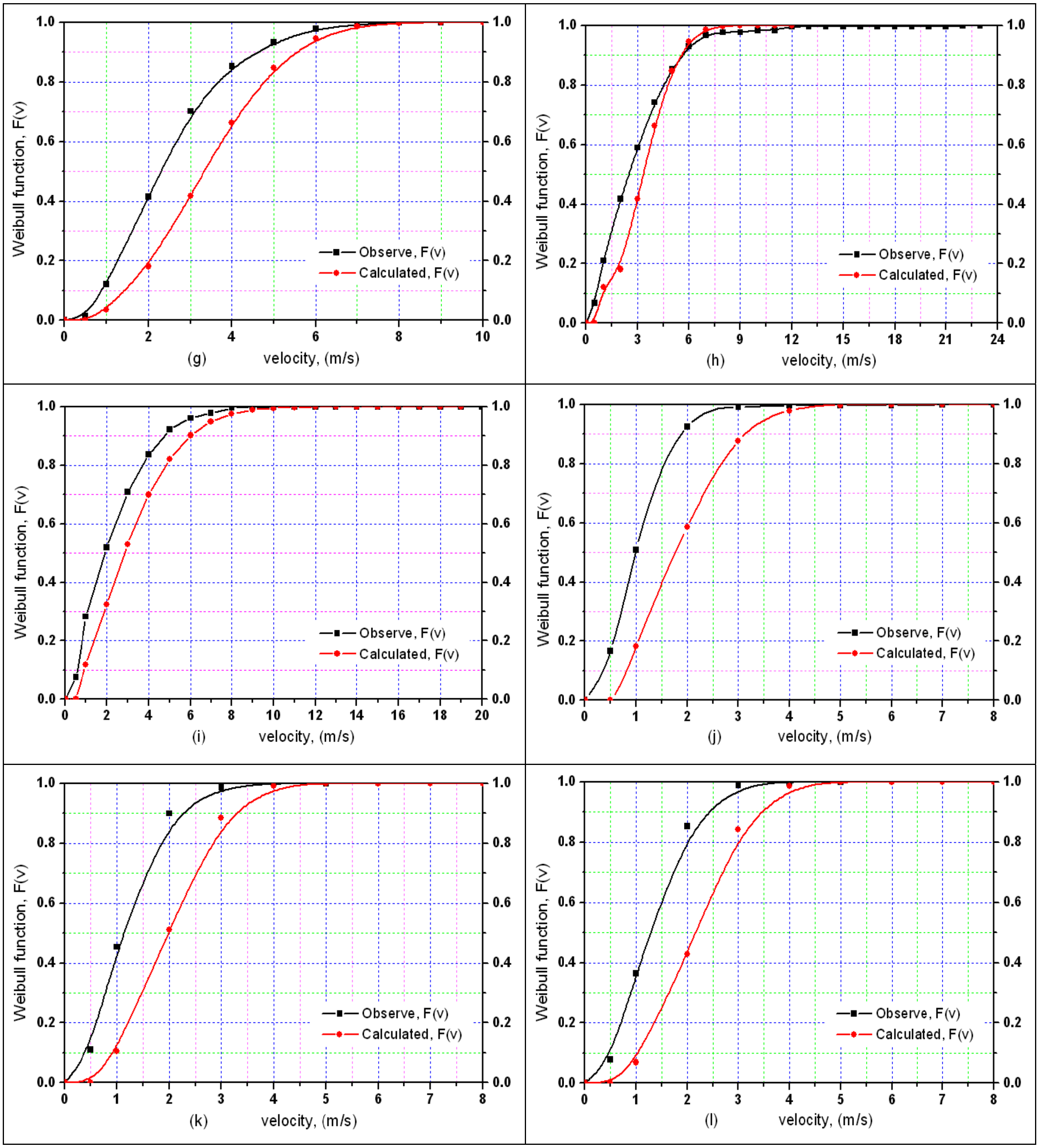


Fig. 4.50: Weibull function **F(v)** for Pakshey at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

Here the entire figures of **Fig. 4.49 – 50**, for Pakshey, it has been observed that both calculated and observed data were fitted with each other except only little variation of each other. The data is more closely fitted on August.

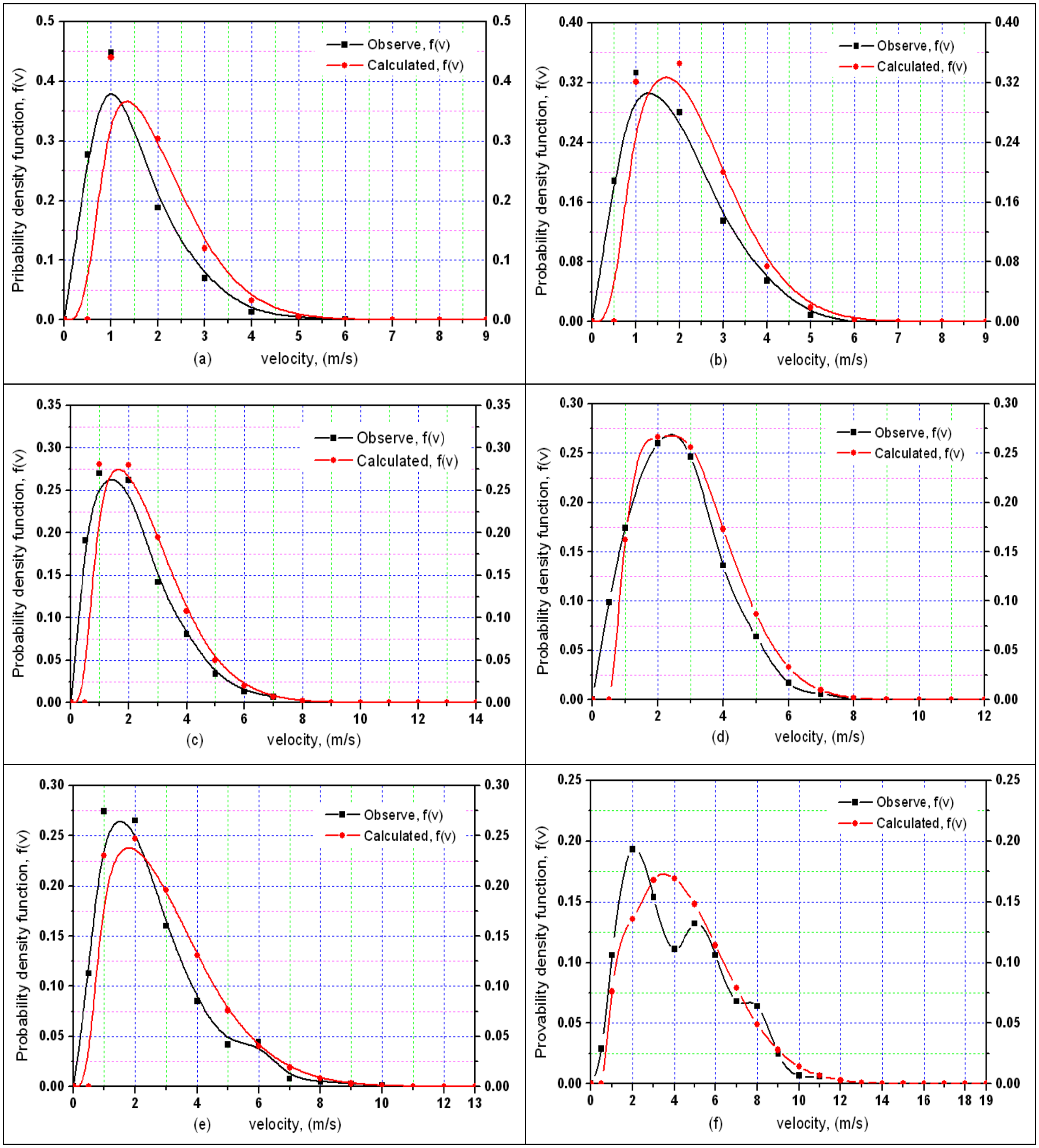


Fig. 4.51: Weibull probability density function **f(v)** for Rauzan at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull probability density function f(v) for Rauzan from January to June and rest of the month i.e. July to December has shown in **Fig. 4.52**.

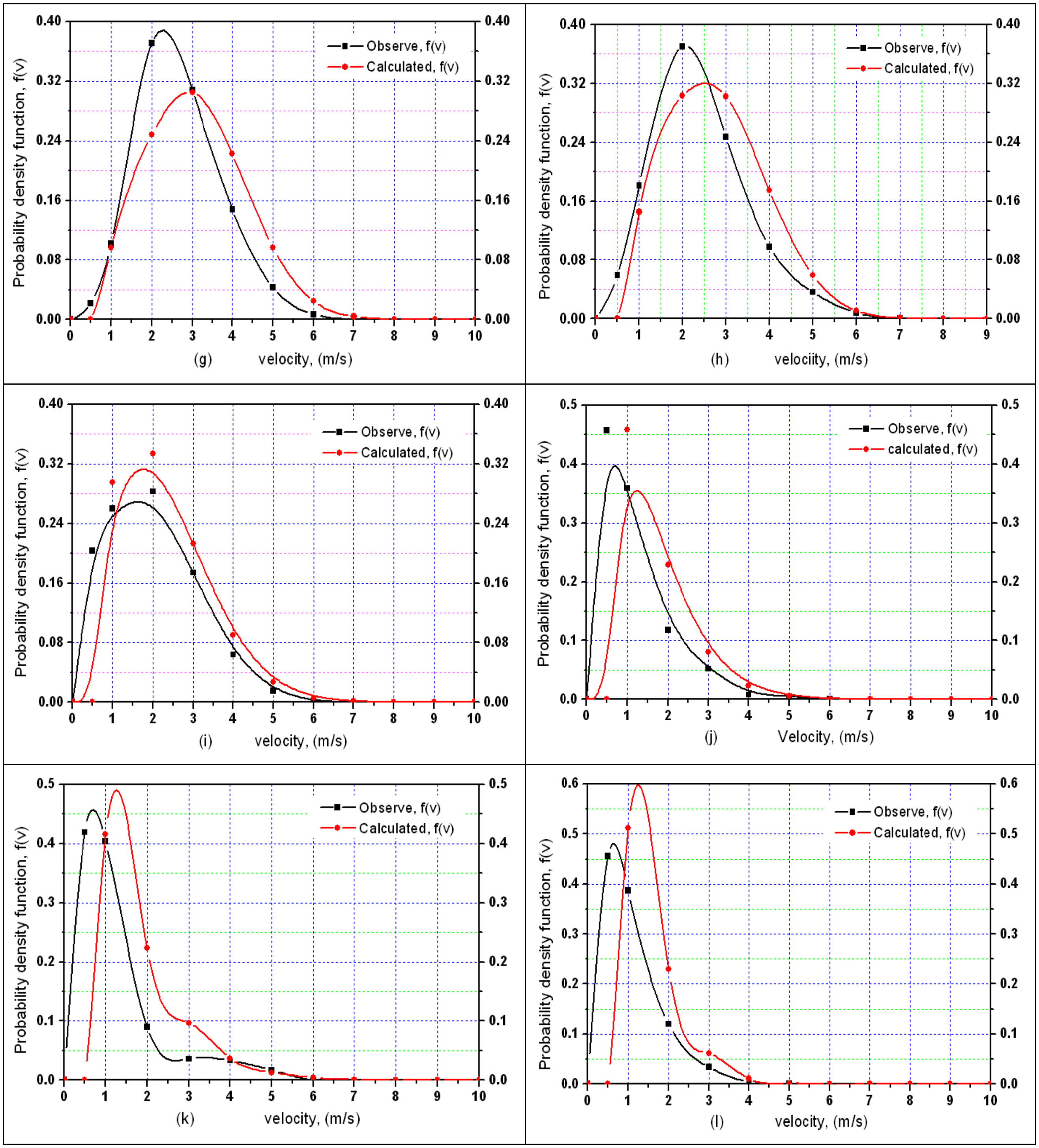


Fig. 4.52: Weibull probability density function **f(v)** for Pakshey at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

From all the figures of above **Fig. 4.51 – 4.52**, it is found that the calculated and observed data roughly variation of wind speed but their peaks has closed to each other except June, July and December.

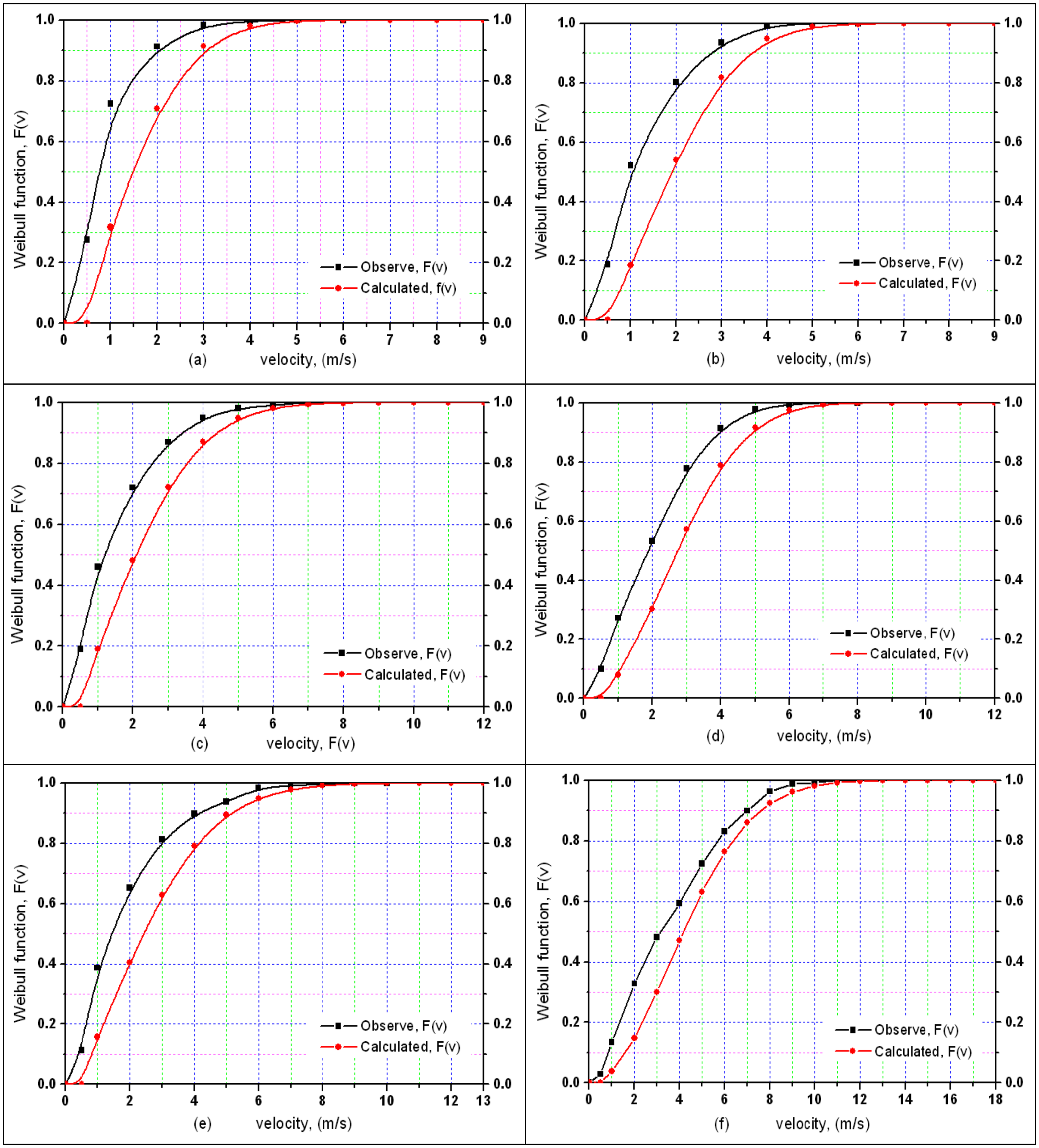


Fig. 4.53: Weibull function **F(v)** for Rauzan at (a) January, (b) February, (c) March, (d) April, (e) May, (f) June.

The above figure shows the Weibull function F(v) for Rauzan from January to June and rest of the month i.e. July to December has shown in **Fig. 4.54**.

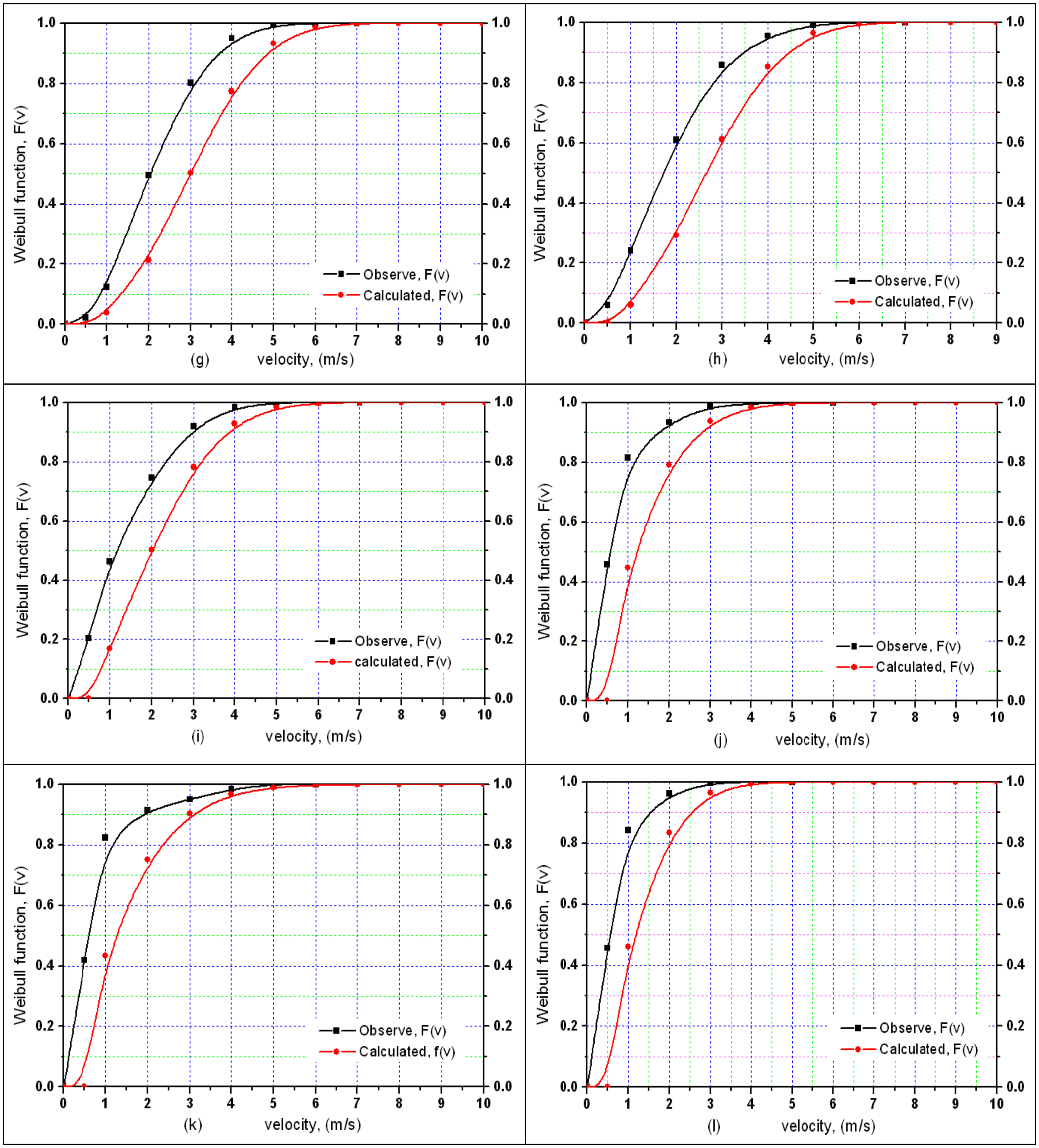


Fig. 4.54: Weibull function **F(v)** for Rauzan at (g) July, (h) August, (i) September, (j) October, (k) November, (l) December.

Here the entire figures of **Fig. 4.53 – 54**, for Rauzan, it has been observed that both calculated and observed data were fitted with each other except only little variation of each other. The data has more closely fitted on June.

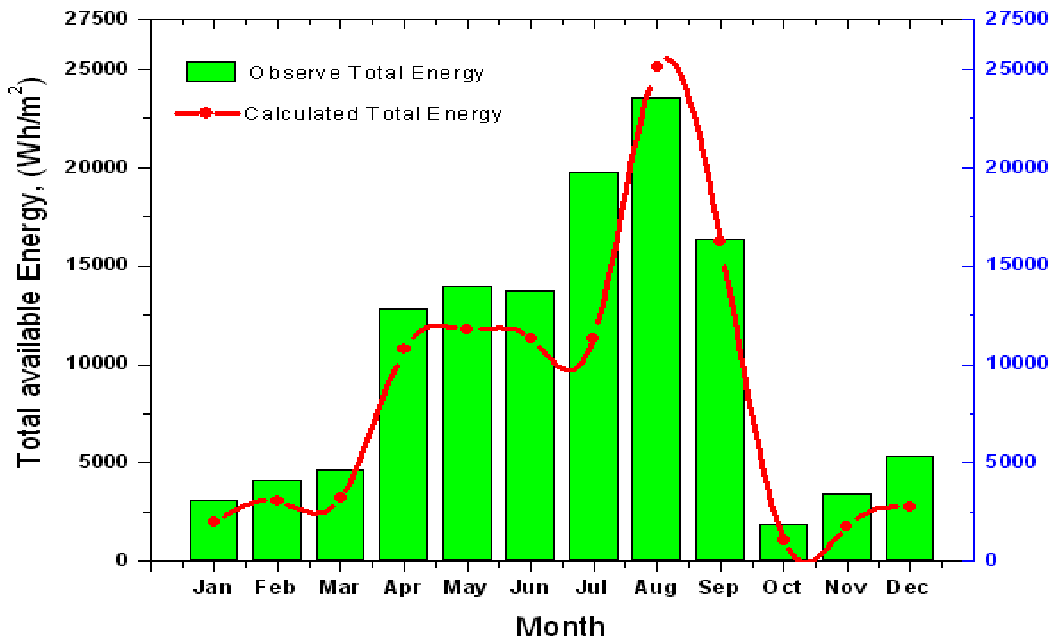


Fig. 4.55: Monthly variation of mean available energy in the wind in Kuakata.

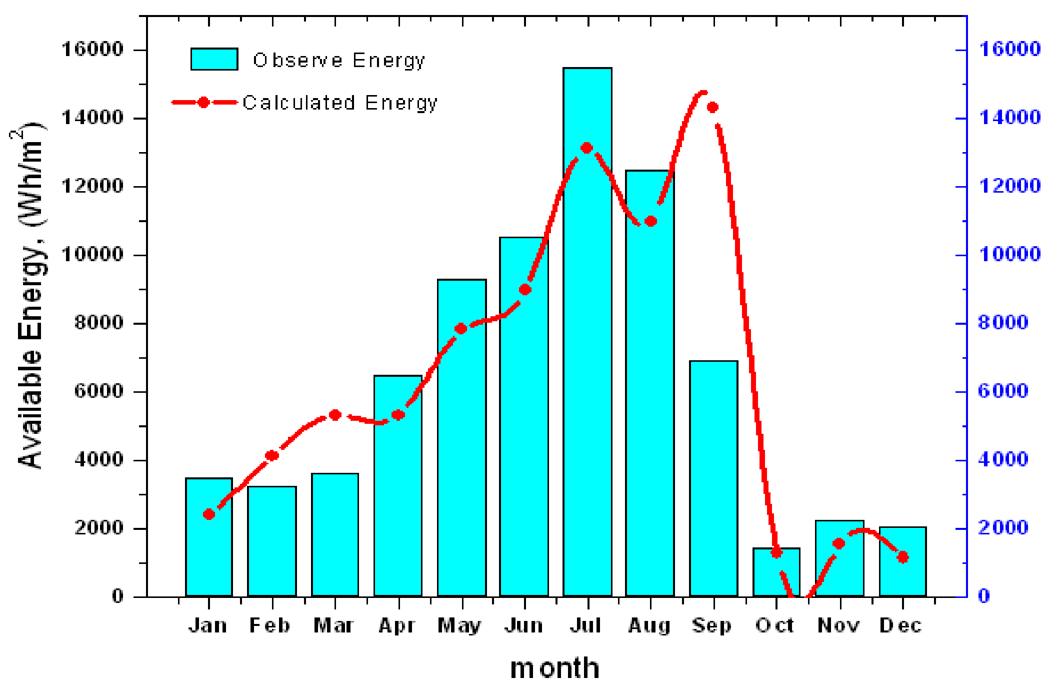


Fig. 4.56: Monthly variation of mean available energy in the wind in Kutubdia.

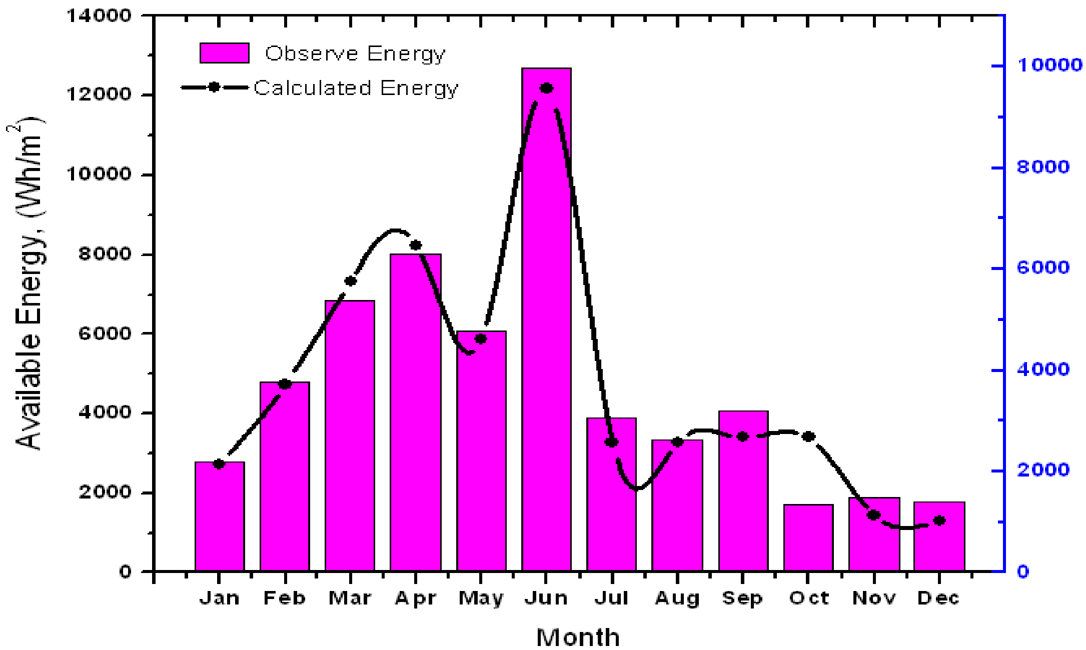


Fig. 4.57: Monthly variation of mean available energy in the wind in Khagrachari.

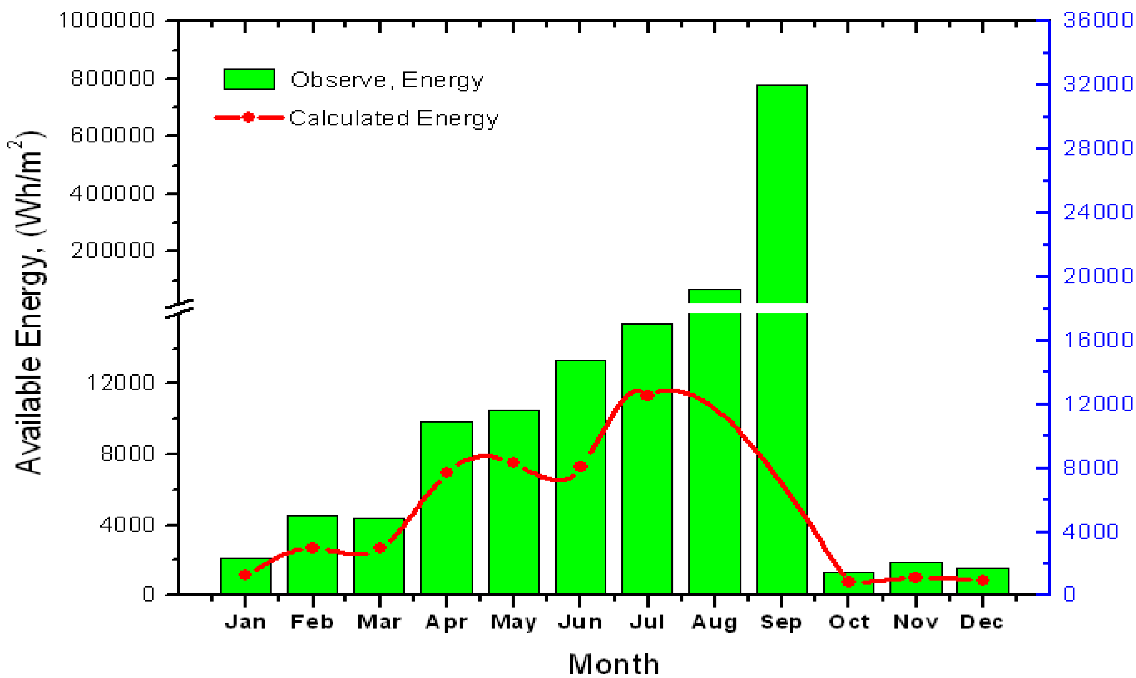


Fig. 4.58: Monthly variation of mean available energy in the wind in Sitakunda.

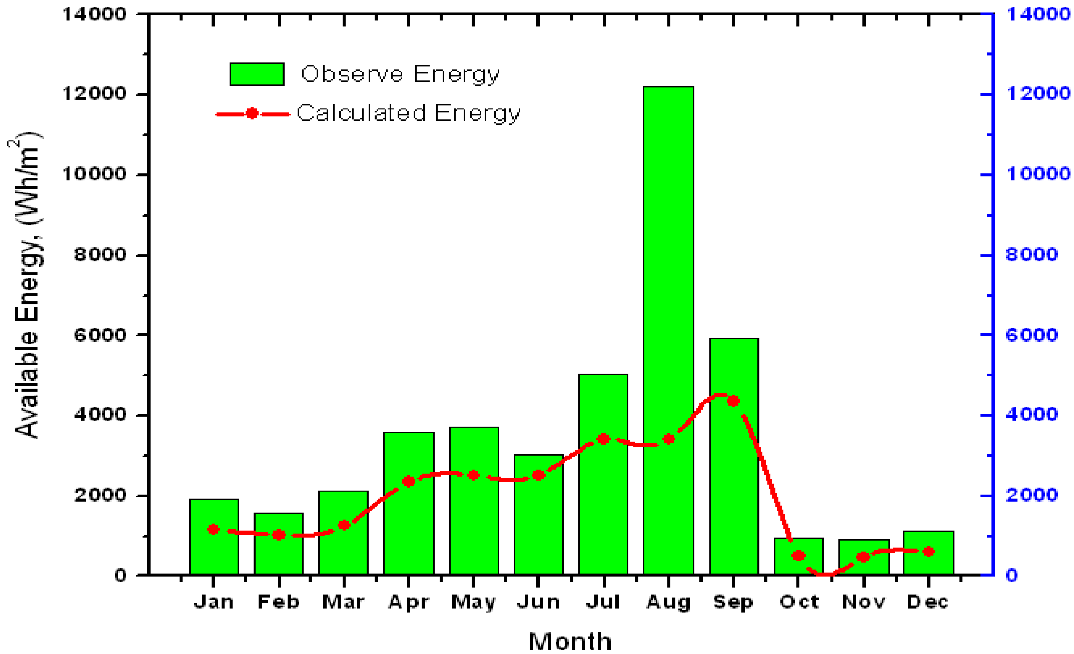


Fig. 4.59: Monthly variation of mean available energy in the wind in Pakshey.

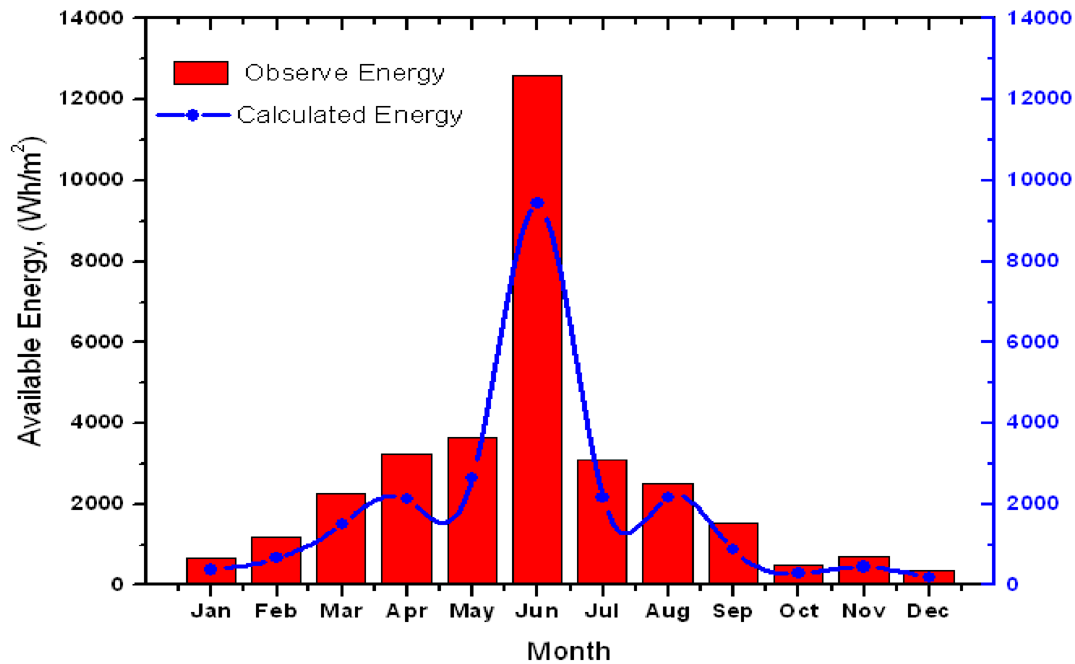


Fig. 4.60: Monthly variation of mean available energy in the wind in Rauzan.

PART – II

SITE SELECTION
&
WIND TURBINE DESIGN

Chapter 5

SITE SELECTION AND DESIGN PARAMETERS

5.1 Introduction, 5.2 Effect of height on wind velocity, 5.3 Determination of wind energy, 5.4 Selection of wind site, 5.5Site visit (Existing wind power plant in Kutubdia), 5.6 Electricity generation achievement by wind.

5.1 INTRODUCTION:

The selection of the site is the most important decision in the development of an offshore (**Offshore** may mean either situated at sea rather than on land, or situated in a different country) wind farm. It is best accomplished through a short-listing process that draws together all known information on the site options, with selection decisions driven by health and safety, feasibility, economics and programmed taking account of information on consenting issues, grid connection and other technical issues. Electricity can be generated in many ways. In each case, a fuel is used to turn a turbine, which drives a generator, which feeds the grid. The turbines are designed to suit the particular fuel characteristics. Wind generated electricity is no different. The wind is the fuel, which drives the turbine, which generates electricity. But unlike fossil fuels it is free and clean. As the wind industry has become better established, the central place of engineering has become overshadowed by other issues, but this is a tribute to the success of engineers and their turbines. Wind must be treated with great respect. The wind speed on a site has a very powerful effect on the economics of a wind farm and wind provides both the fuel to generate electricity and, potentially, loads that can destroy the turbines. This part describes how it can be quantified, harnessed and put to work in an economic and predictable manner. The long and short-term behavior of the wind is described. The latter can be successfully forecasted to allow wind energy to participate in electricity markets. The enormous offshore wind resource offers great potential, but with major engineering challenges, especially regarding reliability, installation and access. Wind is big and wind is heavy. These two factors introduce unique considerations to the construction of a wind farm that differ from the construction of other power generation facilities. Big and heavy will contribute to the determination of an appropriate site, will determine the schedule for constructing the wind farm, and will contribute additional costs to transportation, site preparation, construction, and commissioning.

5.2 EFFECT OF HEIGHT ON WIND VELOCITY:

Wind Velocity Changes with height. The rate of increase of velocity with height depends upon the roughness of the terrain. Usually, the terrain may be divided into three types. This can be seen from **Fig. 5.1**.

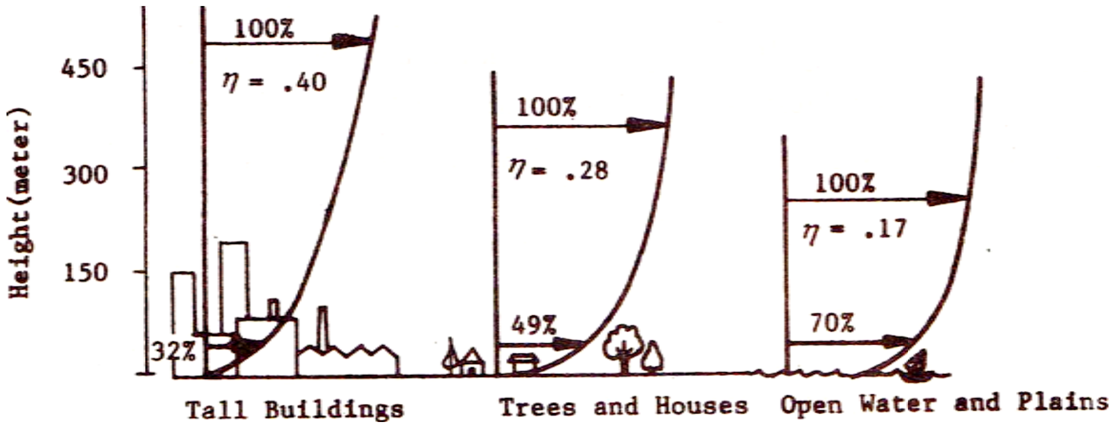


Fig. 5.1: Effect of Roughness on Wind speed.

The wind speed changes with height and the available wind data at different sites are normally measured at different levels. So it is necessary to know the wind speed at wind turbine hub height. The wind power law has been recognized as a useful tool to transfer the anemometer data recorded at certain levels to the desired hub center.

$$\frac{V}{V_0} = \left(\frac{z}{z_0}\right)^{\eta} \tag{5.1}$$

Where V and V_0 are the average speed at z m and at the reference height z_0 = 10m above the ground respectively and the parameter η is the wind speed power law coefficient. The value of the coefficient varies from less than 0.10 to 0.40 depending on the nature of terrain. The maximum value of the coefficient is unity. A value of 0.17 for η may be used, in general, although this is applicable for the open terrain only. The value of η = 0.28 may be chosen for the terrain with trees and houses like the suburb area. But for the city of tall buildings the value of η should be considered as 0.40. At the summits of steep hills to more than 0.25 in sheltered locations. The typical value of 0.14 for low roughness surface [45-47], which is termed the one-seventh power law, is used in this study. If the average wind speed at a particular height is known, the average wind speed at any height can be determined from this law as required for wind machine.

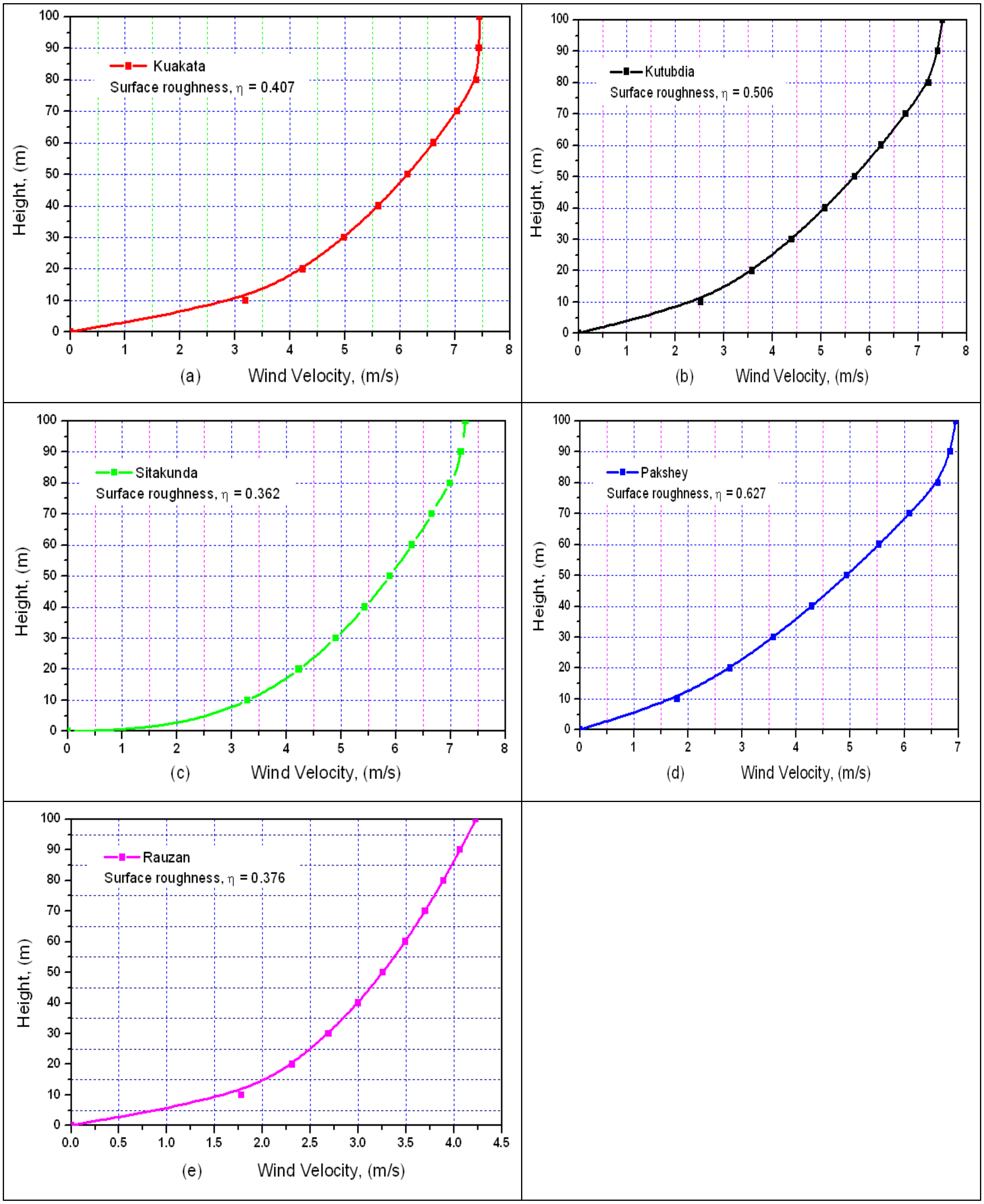


Fig. 5.2: Velocity profile / effect of roughness on wind velocity at (a) Kuakata, (b) Kutubdia, (c) Sitakunda, (d) Pakshey and (e) Rauzan.

From the **Fig. 5.2** shown that the velocity profile or effect of surface roughness on wind velocity at Kuakata, Kutubdia, Sitakunda, Pakshey and Rauzan respectively accept Khagrachari. In Khagrachari, the wind velocity at 10 m height was too low. In the same zone Rauzan wind velocity at 20m height was lower than Khagrachari but the 10 m height wind velocity was lower at Khagrachari than Rauzan. For these reason the surface roughness factor at Khagrachari becomes greater than 1.00. This factor always less than 1.00 but for Khagrachari the factor was greater than 1.00 because of hilly site. So, in this thesis work avoided the site only for drawing velocity profile. It has been clearly discuss that Kutubdia velocity profile is sharper than Kuakata because Kukubdia is an Island. Another observation is that most of the sites the free steam wind velocity started 100 m and above except Rauzan. But in most cases the surface roughness factor becomes higher than 0.28. It may be chosen for the terrain with trees and houses like the suburb area.

5.3 DETERMINATION OF WIND ENERGY:

The available power of a region can be determined from the multiplication of volumetric flow rate and kinetic energy per unit volume i.e.

$$\text{Power,} \quad P = (AV) * \left(\frac{\rho V^2}{2}\right) = \frac{1}{2}\rho A V^3 \quad \text{Watt} \tag{5.4}$$

Where, A, ρ and V are respectively the area, air density and wind velocity. Energy density per unit area can be determined from the power density per unit area times the number of hours per year that the corresponding wind speeds occurs.

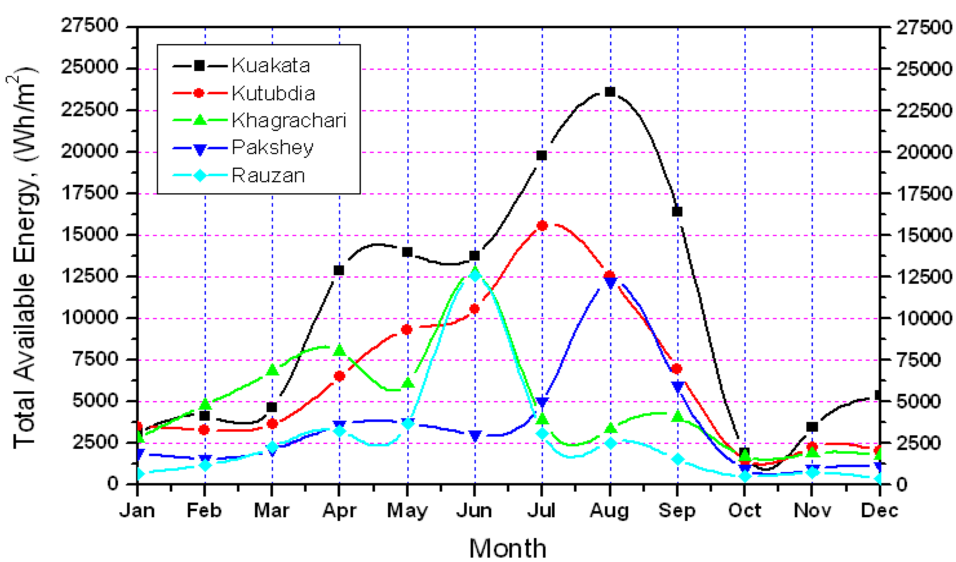


Fig. 5.3: Calculation of total power available for five wind sites.

From the above figure, it has been clear that Kuakata has more available power than other sites. The available power varies between about 2 Kwh/m^2 to 24 Kwh/m^2 for Kuakata. The maximum power was found in August of about 24 Kwhr/m^2 and minimum 1.99 Kwhr/m^2 at October. But in April to September the power above 12.5 Kwhr/m^2. So, these six month is more effective for power generation. The second selected site is Kutubdia where already have a 1000 KW wind battery hybrid power plant.

5.4 SELECTION OF WIND SITE

In selecting a suitable site for the installation of a wind machine the following points have to be considered very carefully. Be reselecting a site, it is necessary to study diurnal, monthly variation of wind speeds, velocity frequency curve, wind duration curve, wind rose etc. of that site obtained from wind data of at least one year period. However, if the meteorological data are available of the region, they can also be studied to observe the long term effect. Since the wind slows down near the ground making a boundary layer which depends on the terrain conditions, so it has to be studied well before selecting the site. Due to the presence of a building in the wind, wake will be generated both at the upstream and downstream sides of the building. During installation of a turbine, it has to be done in such a way that wake region can be avoided; otherwise the output power of the turbine will be relatively lower and the vibration of the machine will be enhanced. The cross-section of the flow over a small building showing wake region can be seen in **Fig. 5.18**.

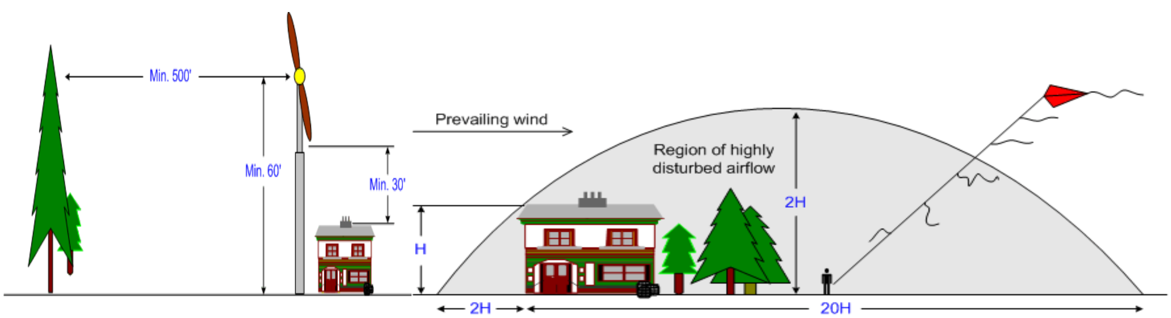


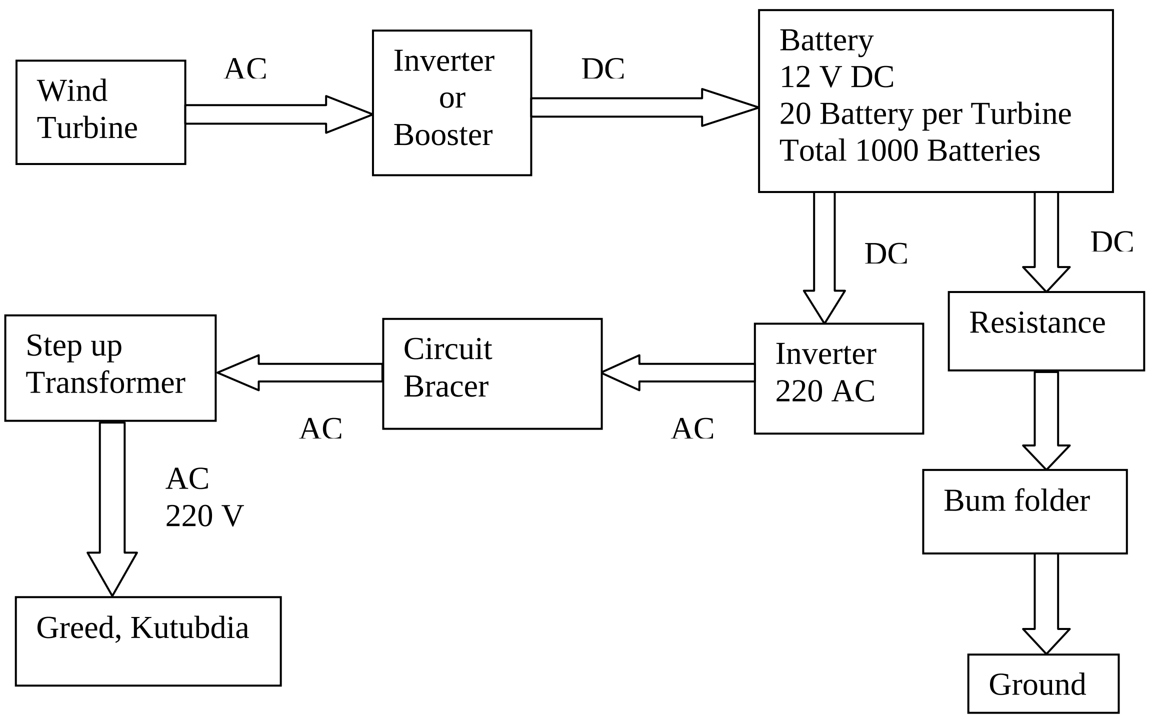
Fig. 5.4: Turbine height in trees and house and wake region over it.

To go beyond the rule of thumb, the airflow over any blunt obstruction, including a tree, tends to create a “bubble” of turbulent air of twice the height of the obstacle, extending 20 times the height of the obstacle behind it. So, your 30 feet high house disturbs the air up to 600 feet away. That tree line with 100 feet trees disturbs the air up to 200 feet high at a distance of 1000 feet away. The quick-and-dirty rule of thumb for turbine height is a minimum of 10 meters (30 feet) plus the length of a turbine blade above the tallest obstacle like trees, house etc. There actually is a cheap way to visually find out at what height turbulent air ends, and smooth, laminar airflow begins. Just fly a kite at your proposed wind turbine location on a windy day, preferably when the wind is coming from the prevailing direction. To visualize airflow, use tape-streamers tied to the kite's string every 15 feet or so.

5.5 SITE VISIT (EXISTING WIND POWER PLANT IN KUTUBDIA)

The author himself and his supervisor Prof. Dr. Mahabubul Alam and Engr. Murtuza, dept. of sustainable rural energy (SRE), LGED visited the existing wind power project in Kutubdia. The aim of the visit was to observe the running project, feasibility study, problems and the local people reactions etc. The outcomes of the visit has given below -

Flow Diagram for 1000 KW Capacity Wind Battery Hybrid Power Plant, Kutubdia



The Wind Battery Hybrid Power Plant at Kutubdia contains the following equipment and materials. Foreign/Imported Materials:

- 50 Nos. 20KW capacity wind turbines
- 50 Nos. Converters-cum-controllers
- 150 Nos. of Blades
- 8 Nos. Boosters-cum-chargers
- 8 Nos. 150KW Capacity Inverters
- 1 No. of Synchronization and Paralleling Panel

Local Materials: To keep the total project costs as low as possible, we have tried our best to maximize the utilization of the local equipment and materials. In the WBHPP at Kutubdia, the following local materials are used.

- 1000 Nos. of 12VDC, 200AH Batteries
- 1 No. Central Control Panel Board
- 2 Nos. 600KVA, 0.4KV/11KV Transformers
- 1 No. of 11KV Grid Sub-Station
- 10 km of 11 KV Transmission Line

5.6 ELECTRICITY GENERATION ACHIEVEMENTS BY WIND

The WBHPP has been running well for more than one and half years. They were supplying 0.60 to 0.80 MWH electrical energy every day at 11KV. The WBHPP supplied more than 240 MWh electrical energy to the consumers of the Kutubdia Upazilla Sadar. This is to be mentioned here that this is the only Renewable Energy Project in Bangladesh supplying green power at 11KV voltage levels successfully and regularly.

Fig. 5.5: 1000 KW Capacity Wind Battery hybrid Power Plant in Kutubdia.

This project was implemented under Bangladesh Power Development Board (BPDB) on 2007 and running March, 2008. This is the first grid quality, 11 KV, largest and successful renewable energy project in Bangladesh. Wind Power plants have plant factors from 27% to 30% and with these plant factors they are technically feasible and commercially viable. The wind flow is very weak in the Winter Season and good during the Summer Season. During morning hours up to 10 O-Clock, the wind is very weak or zero. From 10:00 AM, wind starts to blow and at about 12:00 Noon, the wind is good for electricity generation. Summer winds are better for electricity generation that the winter winds. The electricity generation from this 1MW capacity power is 0 to 400KW during winter season (November to February) and 0 to 800KW in the Monsoon Season (March to October) depending on the available wind speeds. Sometimes, the wind is very good but sometimes it is zero. So, this cannot supply 1MW electricity all the times of a day and 365 days of a year. This plant was started to supply wind electricity for 3 hours during day times and 3 to 4 hours during night times.

During the visit it has been found that some problems exist in the WBHPP. It have some problem in design the turbine blades, necessary distance was not maintain between one turbine to another and the turbine base construction was not good. When wind blows some turbine tower was vibrating. Although the wind power plant have been supported different natural climates like Aila, Narges, Seedor etc and damage different parts it. It was necessary to consider gusty wind characteristics in design the plant which has been discuss in **Chapter – 3**. Another demerit of the plant is 1000 pcs 12 V DC rechargeable batteries. The plant is unable to supply power without charge of its battery though wind velocity is available.

The visiting team also taken in consideration the customer's reactions both they were got the facilities electricity from wind and unaffiliated people. The facilitate people gives different massage about the power but everyone told that "the voltage and power of the electricity from the wind was very good than existing diesel generator and they got more light from the wind power". The team also concern with Kutubdia diesel power plant, under Bangladesh Power Development Board (BPDB). They also told us that the wind power supplied up to 240 KW power continuous 5-6 hours per day. When wind power plant supply the power then the diesel power plant was shut down.

The team recommended that the Kutubia is another prospective wind site for electricity generation. If the wind power project will extended by proper designing then all of the Kutubdia people will get the power facility.

Chapter 6

DESIGN OF HORIZONTAL AXIS WIND TURBINE

6.1 INTRODUCTION:

A **wind turbine** converts the energy of wind into kinetic energy. If the mechanical energy is used directly by machinery, such as pumping water, cutting lumber or grinding stones, the machine is called a windmill. If the mechanical energy is instead converted to electricity, the machine is called a **wind generator**, **wind turbine**, **wind power unit (WPU)**, **wind energy converter (WEC)**, or **aero-generator**. There are two types of wind turbine, first one is horizontal axis wind turbine and second one is vertical axis wind turbine. Wind turbine designs are utilized to create wind turbines that exploit wind energy [18, 53]. The design of a horizontal axis wind turbine in which lift forces on airfoils are the driving forces is described in this chapter. The design of a wind rotor consists of two steps [18]:

- The choice of basic parameters such as the number of blades B, the radius of the rotor R, the type of airfoil and the design tip speed ratio λ_d.
- The calculations of the blade twist angle β_T and the chord C at a number of positions along the blade, in order to produce maximum power at a given tip speed ratio by each section of the blade.

The design procedures are described in the following sections

6.2 SELECTION OF DESIGN TIP SPEED RATIO AND NUMBER OF BLADES:

In wind turbine designs, the question arises as to how many blades should be used. In general, as the number of blades increases, the manufacturing cost also increase.

Increasing the number of blades results improve performance and lower torque variations due to wind shear. Furthermore, power output increases but with diminishing return. The choice of λ_d and B is more or less related. For the lower design tip speed ratios a higher number of blades are chosen. This is done because the influence of B on power coefficient C_p is larger at lower tip speed ratio. For higher design tip speed ratio lower number of blades is chosen. Because, higher number of blades for a high design tip speed ratio will lead to very small and thin blades, which results in manufacturing problems. Type of load also limits the choice of the design tip speed ratio. If it is a piston pump or some other slow running load, that in most cases will require a high starting torque, the design speed of the rotor will usually be chosen low. If the load is running fast like a generator or a centrifugal pump, then a high design speed will be selected. The following **Table - 6.1** may be used as the guideline [55, 56].

Table -6.1: Choice of the Design Tip Speed Ratio and Selection of Number of Blades [41].

Design tip speed ratio, λ_d	Number of blades, B
1	6-20
2	4-12
3	3-6
4	2-4
5-8	2-3
8-15	1-2

The ratio between the speed of the wind and the speed of the blade tips is called Tip speed ratio. High efficiency 3-blade-turbines have tip speed ratio of 6 to 7.

To obtain the optimum configuration the blade is divided into a number of radial stations. Four formulas [18, 53] will be used to describe the information about β_T and C:

Local design speed: $$\lambda_r = \lambda_d \frac{r}{R} \qquad 6.1$$

Where, r is the local speed ratio and R is the rotor radius and $\lambda_d = R\Omega/V_\alpha$ is the tip speed ratio at the design point.

Relation for flow angle, $$\lambda_r = \frac{\sin\phi(2\cos\phi - 1)}{(1-\cos\phi)(2\cos\phi + 1)} \qquad 6.2$$

$$\text{or,}\quad \phi = \frac{2}{3}\tan^{-1}\frac{1}{\lambda_r} \qquad 6.3$$

Where, ϕ is the angle of relative velocity

Twist angle: $\beta_T = \phi - \alpha$ 6.4

Where, α is the angle of attack

Chord: $$C = \frac{8\pi r(1-\cos\phi)}{BC_{l_d}} \qquad 6.5$$

Here C_{l_d} is the design lift coefficient.

The blade starting torque can be calculated by [18],

$$Q_{S_t} = \frac{1}{2}\rho V_\alpha{}^2 B\int_r^R C(r)C_l[90^0 - \beta_T(r)]rdr \qquad 6.6$$

Here, ρ and V_α are the air density and undistributed wind velocity respectively. The rotor configuration is determined using the assumption of zero drag and without any tip loss. Each radial element is optimized independently by continuously varying the chord and twist angle to obtain a maximum energy extraction.

6.3 SELECTION OF AIRFOIL:

Power coefficient of the wind turbine is affected by drag coefficient C_d and lift coefficient C_l values of the airfoil sections. For a fast running load a high design tip speed ratio is selected and airfoils with a low C_d/C_l, ratio is preferred. But for wind turbines having lower design tip speed ratios the use of more blades compensates the power loss due to drag. So, airfoils having higher C_d/C_l, ratio are selected to reduce the manufacturing costs.

Drag affects the expected power coefficient via the C_d/C_l, ratio. This will influence the size and, even more, the speed ratio of the design. Promising airfoils have minimum C_d/C_l ratio ranges 0.1- 0.01 and the NACA airfoil has the lowest values **(Appendix- G).** A large C_d/C_l , ratio restricts the design tip speed ratio. At lower tip speed ratios the use of more blades compensates the power loss due to drag. In this collection of maximum power coefficients it is seen that for a range of design speeds $1 \le \lambda_d \le 10$ the maximum theoretically attainable power coefficients lie between $0.35 \le (C_P)_{max} \le 0.50$. Due to deviations, however, of the ideal geometry and hub losses for example, these maximums will lie between 0.3 and 0.4. This result shows that the choice of the design tip speed ratio hardly affects the power output.

For different types of airfoils the sensitivity for surface roughness are also different. Using airfoil data of NACA standard roughness in the calculation of wind turbine performance, results losses in peak value of the order of 10- 15% in comparison with the peak value obtained with usual airfoil data for a smooth surface.

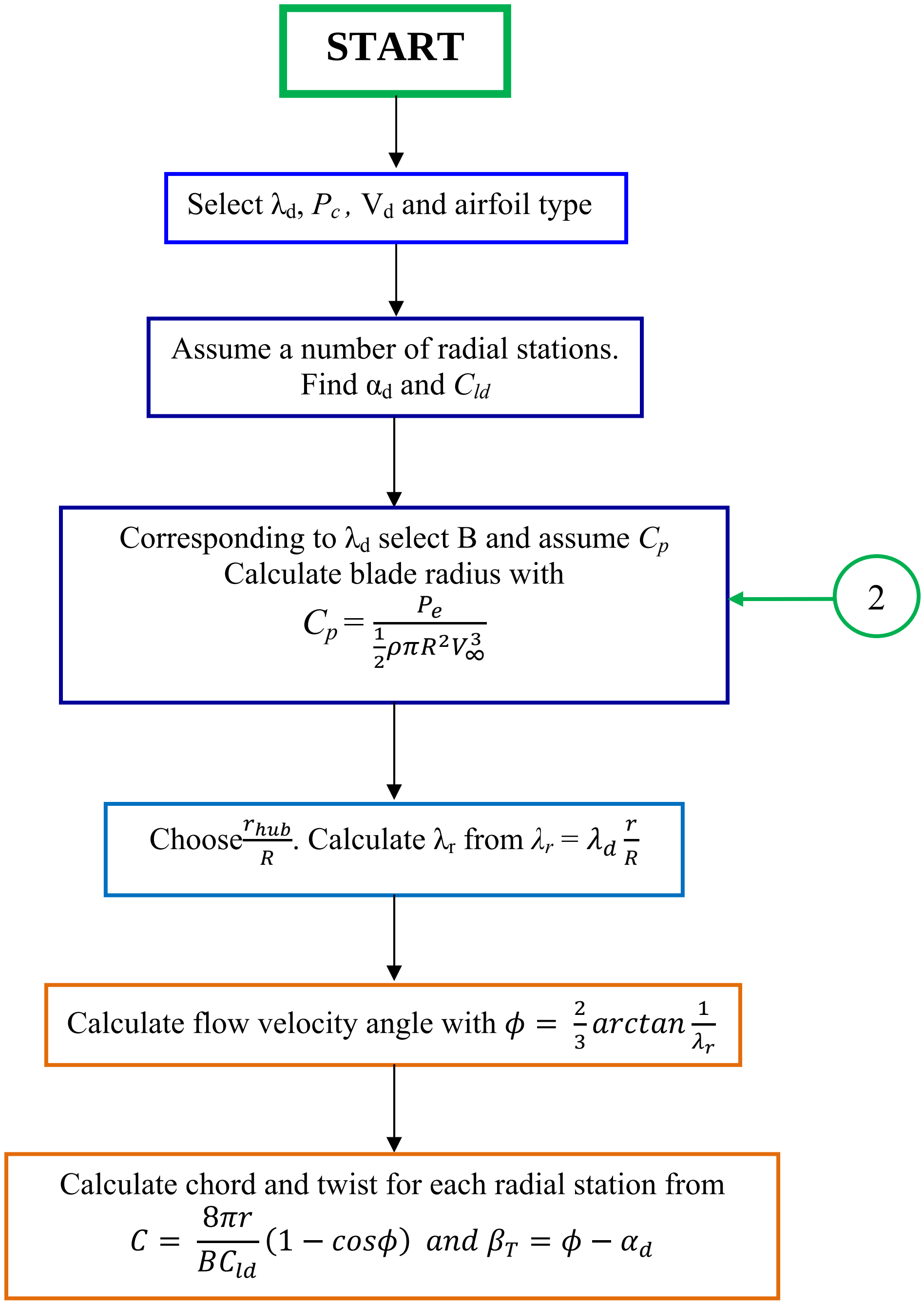
6.4 DESIGN PROCEDURE:

For calculating the blade geometry the following data must be available beforehand:
Design tip speed ratio, λ_d
Amount of power to be extracted, P_e
Design wind velocity, V_d
Type of airfoil section:

1) Assume a certain number of radial stations for which the chord and blade twist are to be assumed.
2) Draw a tangent from the origin to C_l /C_d graph of airfoil section to locate the minimum value of C_d/C_l, are to be drawn. Corresponding to this value find the design angle of attack α_d and design lift coefficient C_{l_d} . This is explained in **Appendix-G**.
3) Number of blades B corresponding to the design tip speed ratio λ_d is to be selected.
4) A reasonable value of C_p, is to be taken. Estimation of the value of C_p has been explained in **Appendix G**.
5) Calculation of blade radius is done from the equation, $C_P = \frac{P_e}{\frac{1}{2}\rho\pi R^2 V_\alpha{}^3}$
6) A fixed value of hub and tip radius ratio, r_{hub} /R is chosen.
7) Calculation of λ_r for each radial station using the equation, $\lambda_r = \lambda_d, r/R$.
8) Determination of ϕ by using the equation $\phi = \frac{2}{3}\tan^{-1}\frac{1}{\lambda_r}$.
9) Find the value of chord for each radial station using the equation, $C = \frac{8\pi r(1-\cos\phi)}{BC_{l_d}}$ is to be found.
10) The value of blade twist is to be calculated using the relation, $\beta_T = \phi - \alpha_d$.

6.5 FLOW DIAGRAM FOR DESIGN PROCEDURE

The design procedure has been provided below in the flow diagram



6.6 SELECTION OF DESIGN PARAMETERS:

The kinetic energy and the wind force are proportional to the square of the wind velocity. However, it is interesting to note that the wind power is proportional to the cube of the wind velocity. If the wind speed increases by two times, the production of power increases by eight times. The expression for determination of the power can be written as-

$$P = \tfrac{1}{2} C_p \, e \, \rho A V^3_{\infty} \tag{6.7}$$

Obviously, for generation of particular amount of power, if the site of high wind velocity can be chosen, the size of the turbine will be lower significantly.

As swept area $A = \pi/4 \, D^2$, the power is directly proportional to the square of the rotor size D according to above equation. It is interesting to note that, the power coefficient is again a great factor in regard to production of power. A well-designed wind turbine can extract about 70 % of power produced by an ideal wind turbine whose rotor efficiency is 59.3 % (Betz's limit). Thus, a well-designed wind turbine can attain maximum power coefficient of 0.7x59.3 = 41.5 %. If the losses of power due to the gear box, chain drive or belt drive, generator or pumping are taken into consideration, the overall efficiency i.e. $C_p \, e$ becomes approximately 30 percent [18, 54].

In **Chapter – 2**, Section 2.4, Table – 2.2 shows that at Kuakata monthly average wind speed varies from 2.57 to 5.97 m/s. So, the designed wind velocity is 5.5 m/s. Maximum power available has shown in Chapter – 5, Section 5.8, Fig. 5.3. From these figure it has been clear that the turbine extracting minimum 800 W for cut in speed 5.5 m/s and maximum 23.9 KW for cut off speed 15 m/s.

Although many factors enter in consideration of the Wind Energy Conversion System (WECS), a rule is that a site with an average wind speed of above 5 m/s will be cost effective with modern wind turbines. So, it can be seen that wind speed in Kuakata is suitable for extracting wind energy for water pumping and electricity generation. In coastal region of Bangladesh there is a normal wind trend of high magnitude were found during the month of April and September during the data collection period.

For the design purpose, let us consider the airfoil section of NACA 4418 which is generally used for horizontal axis wind turbine blades [25].

For the design of a horizontal axis wind turbine, it is important to find out the value of design lift and design angle of attack from graphs that correspond to a minimum value of C_d / C_l ratio. To carry out the iteration procedure for the blade configuration, estimation of design power coefficient is also important. Determination of these parameters has been discussed in the following section.

6.6.1: Determination of Minimum C_d / C_l Ratio.

For airfoil section NACA 44XX, ratio of minimum drag coefficient (C_d) to lift coefficient (C_l) equal to $(C_d/C_l)_{min}$ = 0.01 which has been shown in **Appendix-G**. This parameter is very important to find out the value of design lift and design angle of attack from graphs.

6.6.2: Determination of Design Lift coefficient and Angle of Attack.

From the Appendix-H, **Figure G -1** represents the lift and drag coefficient of the airfoil section NACA 4418 for different Reynolds number. In our selected site the value of is $R_e = 3 \times 10^6$. In the C_d / C_l graph corresponding to the selected R_e a tangent is drawn through $C_d = C_l = 0$. From the point where the tangent touches the curve indicates the minimum C_d / C_l ratio. This ratio determines the maximum power coefficients that can be reached, particularly at high tip speed ratios. From the $C_l - \alpha$ curve corresponding to minimum C_d / C_l ratio the value of lift coefficient and angle of attack are found. The C_l and α values found in the way are known as the design lift coefficient C_{ld} and the design angle of attack, α_d and these are very important parameters in the design process. Again from **Appendix Figure G – 1**, the design lift coefficient, C_{ld} = 1.07 and design angle of attack, $\alpha_d = 7^o$

6.6.3: Selection of Design Tip speed ratio and Number of Blades.

In Appendix-H, for $(C_d/C_l)_{min}$ = 0.01, maximum power coefficient occurs in the range of design tip speeds ratio, $1 \leq \lambda_d \leq 10$.

For the design purposes, let us consider the design tip speed ratio, $\lambda_d = 6$.
On the basis of $\lambda_d = 6$, from **Table – 6.1**, let us consider the number of blades, B = 3.

6.6.4: Determination of Design Power Coefficient.

The power coefficient is affected by the profile drag via the C_d / C_l ratio. The reduction of the maximum power coefficient is proportional to the tip speed ratio and to the C_d / C_l ratio. The curves in Appendix-H, **Figure G – 3** shows for each λ the maximum attainable power coefficient with the number of blades and C_d / C_l ratio as a parameter. In this collection of maximum power coefficients, it is seems that for a range of design tip speed ratio from 1 to 10 and the maximum theoretical attainable power coefficients lie in between 0.30 to 0.50. Considering, $\lambda_d = 6$, B = 3 and $(C_d/C_l)_{min}$ = 0.01, from Appendix **Figure G – 3**, choose maximum power coefficient, $(C_p)_{max} = 0.5$.

For conservative design, $C_p = (C_p)_{max} \times 0.8 = 0.5 \times 0.8 = 0.4$

6.6.5: Calculate of the Blade Radius.

From the Section 7.4 and step 5, calculate the blade radius by the following equation –

$$C_p = \frac{P_e}{\frac{1}{2} \rho \pi R^2 V_\alpha^{\;3}} \qquad (6.8)$$

Rotor Radius, $$R = \sqrt{\frac{2 P_e}{\rho \pi V_\alpha^{\;3} C_p}} \qquad (6.9)$$

Where, air density is 1.22 kg/m^3, power extracted from the wind is approximately 800 W and C_p = 0.4, and designed wind velocity is 5.5 m/s. Now putting the given values, the rotor radius is obtained as 2.50 m is approximately 8 ft. and exactly equal to 250 cm. For design tip speed ratio λ_d = 6, speed of the turbine is N = 126 rpm [calculated by the equation, $\lambda_d = R\omega/V_\alpha$]

6.7 CALCULATION OF TWIST ANGLE AND BLADE CHORD:

In this section, the ideal blade which have divided into 10 cross sections of equal length along the radius and find out some parameters like, local design speed, angle of relative wind velocity, twist angle and blade chord.

Table 6.2: Ideal Blade Sections, Local TSR, Angle of Attack, Blade Setting Angle and Chord

Cross section number	Rotor radius, R	Local design speed, $\lambda_r = \lambda_d \,.\, r/R$	Angle of relative wind velocity, $\varphi = 2/3 \text{ arc tan}(1/\lambda_r)$	Design angle of attack, α_d	Twist angle $\beta_T = \varphi - \alpha_d$	Chord, C
	cm		Degree	degree	degree	cm
1	25	0.6	39.36	7	32.36	44.42
2	50	1.2	26.56	7	19.56	20.65
3	75	1.8	19.38	7	12.38	11.09
4	100	2.4	15.09	7	8.09	6.75
5	125	3	12.3	7	5.3	4.49
6	150	3.6	10.36	7	3.36	3.19
7	175	4.2	8.94	7	1.94	2.38
8	200	4.8	7.86	7	0.86	1.84
9	225	5.4	7	7	0	1.46
10	250	6	7	7	0	1.18

Here, the turbine have a hub for the rotor and the hub has a radius r = 25 cm (10% of R) then the each cross section has a distance r from the rotor center. Local speed ratio 'λ_r', flow angle 'ϕ', blade setting angle 'β_T' and chord 'C' for each sections are calculated by using the equations stated in the Section 6.4, steps 7 to 10. The values are shown in the **Table – 6.2**.

6.8 DEVIATIONS FROM THE IDEAL BLADE FORM:

In the previous section it has been discussed how to calculate the ideal blades form. The chords as well as the blade twist vary in a non-linear manner along the blade. Such blades are usually difficult to manufacture and may not have structural integrity. In order to reduce these problems it is possible to linearize the chords and the twist angles. This results in a small loss of power. If the linearization is done properly the loss becomes only a few percent. In considering such linearization, it must be realized that the outer half of the blades extract about 75% of the power that is extracted by the rotor blades from the wind. Because the blade swept area varies with the square of the radius and the efficiency of the blades is less at smaller radii, where the tip speed ratio λ_r is small. On the other hand, at the tip of the blade the efficiency is low due to the tip losses. For the reasons mentioned above it is advised to linearize the chord C and the blade setting angles β_T, between r = 0.5R and r = 0.9R [53]. The equations for linearized chord and twist can be written in the following way,

$$C = C_1 r + C_2 \quad (6.10)$$

$$\beta_T = C_3 r + C_4 \quad (6.11)$$

Where, C_1, C_2, C_3 and C_4 are the constants. With the value of C and β_T at 0.5R and 0.9R from the ideal blade form the values of C_1, C_2, C_3 and C_4 can be obtained. The ultimate expressions for chord and twist of linearized blade can be written as,

$$C = 2.5(C_{90} - C_{50})\frac{r}{R} + 2.25\,C_{50} - 1.25\,C_{90} \quad (6.12)$$

$$\beta_T = 2.5(\beta_{90} - \beta_{50})\frac{r}{R} + 2.25\beta_{50} - 1.25\beta_{90} \quad (6.13)$$

Where,

C_{50} = chord of the ideal blade form at 0.5R,

C_{90} = chord of the ideal blade form at 0.9R

β_{50} = twist angle of the ideal blade form at 0.5R,

β_{90} = twist angle of the ideal blade form at 0.9R

A further simplification of the blade shape consists of omitting the twist altogether. Introduction of a rotor blade without twist results in a power loss penalty of about 6 to 10% [54]. This might be acceptable for a single production unit but loses its attraction in case of mass production. When the main purpose is the design of a cheap wind turbine, an untwisted blade with a constant chord seems to be a good choice with only limited power losses. Ideal blade form was linearized by using the equations **(6.10)**, **(6.11)**, **(6.12)** and **(6.13)** and shown in below-

Table 6.3: Linearized the Twist Angle and the Blade Chord of the Design Wind Turbine

Cross section number	Rotor radius, R	Local design speed, $\lambda_r = \lambda_d \,.\, r/R$	Angle of relative wind velocity, $\varphi = 2/3$ arc tan$(1/\lambda_r)$	Design angle of attack, α_d	Twist angle $\beta_T = \varphi - \alpha_d$	Chord, C
	cm		degree	degree	degree	cm
1	25	0.6	39.36	7	10.6	7.52
2	50	1.2	26.56	7	9.25	6.79
3	75	1.8	19.38	7	7.90	6.00
4	100	2.4	15.09	7	6.50	5.25
5	125	3	12.3	7	5.30	4.49
6	150	3.6	10.36	7	3.95	3.75
7	175	4.2	8.94	7	2.75	3.00
8	200	4.8	7.86	7	1.27	2.12
9	225	5.4	7	7	0.00	1.46
10	250	6	7	7	0.00	0.702

Figure 6.1 and Figure 6.2 show the distribution of chord and blade twist angles for two types of blades. From these figures it is found that the changes in chords and twist angles are very small at the outer half of the blade. Large variations with the linear chord and twist distributions are found only at the lower radius of the blade.

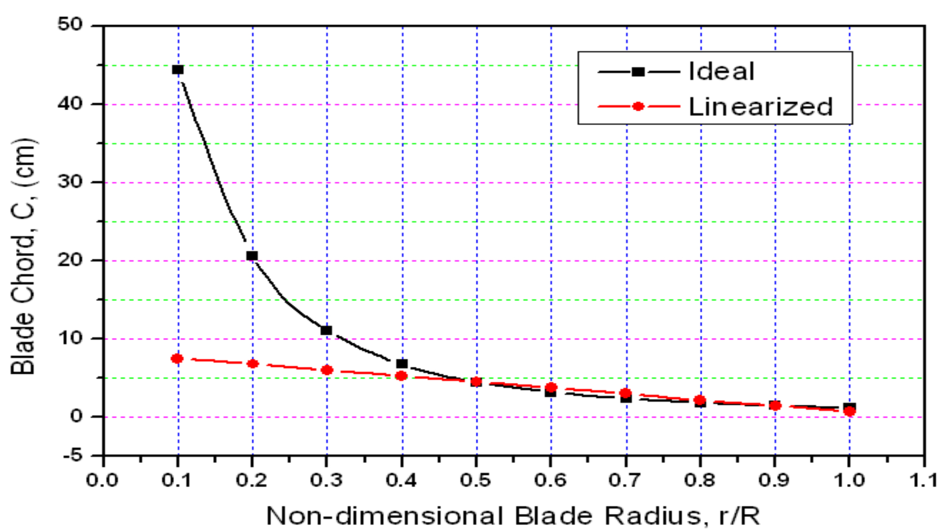


Fig. 6.1: Optimum and Linearized Blade Chord Distribution.

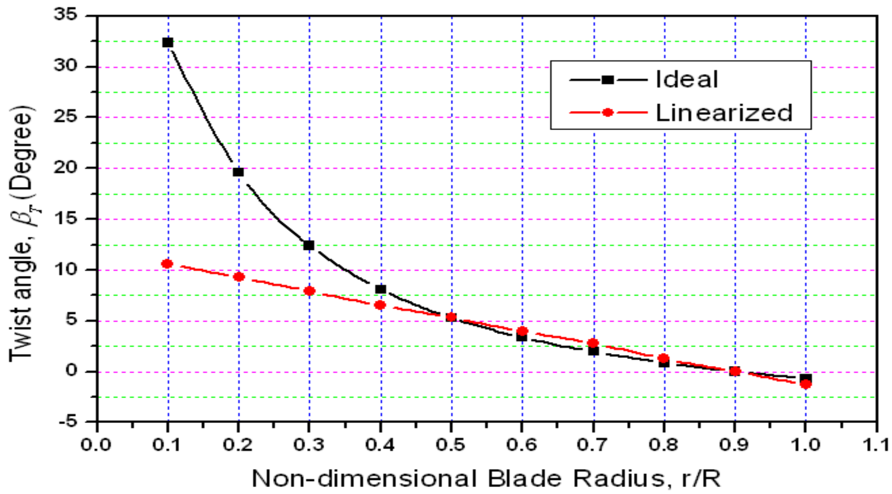


Fig. 6.2: Optimum and Linearized Blade Twist Distribution.

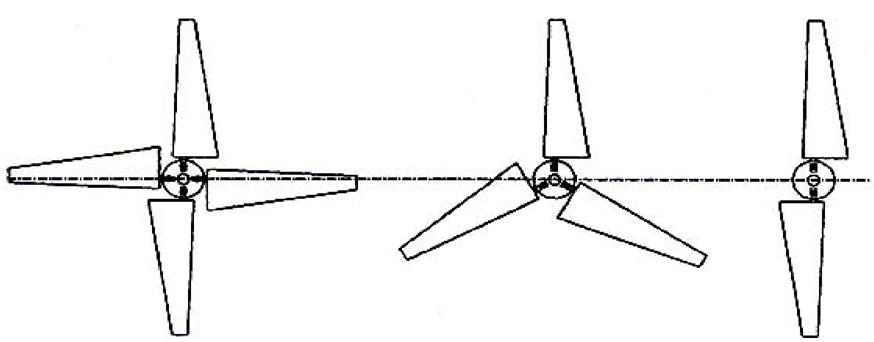
6.9 SOLIDITY:

The physical significance of solidity is solid blockage area. Solidity is generally defined as the function of the circumference of the rotor blocked by the blades. For the horizontal axis wind machine, solidity is defined as –

$$\sigma = \frac{NC}{2\pi R} \tag{6.14}$$

Where, *N* is the number of blades, *C* is the blade chord, *R* is the radius of the rotor

For the multi-bladed turbine the solidity is higher and for the 2 or 3 bladed horizontal axis and Darrieus turbine, the solidity is low. As the solidity increases, the starting torque (the torque at which the turbine starts turning) increases but the RPM and coefficient of performance usually decreases. For the low solidity turbines the RPM and coefficient of performance are higher but the starting torque is lower [58].



Solidity, σ = 0.019 Solidity, σ = 0.014 Solidity, σ = 0.009

Fig. 6.3: Solidity Calculation of the 4, 3 and 2 Bladed wind Turbine

Solidity increases with the increased of number of blades. So, for the selected site the wind turbine has number of blades is 3 and solidity is 0.014 which is between the solidity of 4 and 2 bladed turbines.

Thus, the design values for the model wind turbine are as follows

Blade airfoil type	: NACA 4418
Rotor radius	: 250 cm
Root chord length	: 7.52 cm
Tip chord length	: 0.702 cm
Root twist angle	: 10.60°
Tip twist angle	: 0°
Hub radius	: 25 cm
Number of Blades	: 3
Turbine height	: 1524 cm

6.10 CHOICE OF ROTOR BLADE MATERIAL:

Different blade materials can be used for rotor construction. Some have been tested by Peter Garman [55]:

(i) Solid aluminum alloy;
(ii) Laminated hardwood sheathed with glass fiber reinforced plastic (GRP);
(iii) Steel spar with polyurethane foam filled GRP fairing;
(iv) Untreated hardwood;
(v) Ferro cement (a) untreated, (b) painted, (c) sheathed with Al alloy sheet;
(vi) Steel spar, timber fairing sheathed with Al alloy sheet.

Blade surface finish is critical from the performance point of view and any deterioration causes drastic shaft power reduction. So drag produced by the blade surface friction is very important [55]**.** In this consideration, Aluminum alloy maintains its surface highly finished and hence, high level of performance can be maintained. For this reason, Aluminum alloy is suggested to use for the fabrication of the model.

PART – III

POWER SIMULATION

Chapter 7

DESCRIPTION OF ELECTRONICS CIRCUIT

7.1 INTRODUCTION:

A motor controller is a device or group of devices that serves to govern in some predetermined manner the performance of an electric motor. A motor controller might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and faults [56].

Small motors may have built-in overload devices to automatically open the circuit on overload. Larger motors have a protective overload relay or temperature sensing relay included in the controller and fuses or circuit breaker for over current protection. An automatic motor controller may also include limit switches or other devices to protect the driven machinery. More complex motor controllers may be used to accurately control the speed and torque of the connected motor (or motors) and may be part of closed loop control systems for precise positioning of a driven machine. For example, a numerically controlled lathe will accurately position the cutting tool according to a preprogrammed profile and compensate for varying load conditions and perturbing forces to maintain tool position [56].

7.2 TYPES OF MOTOR CONTROLLER

Motor controllers can be manually, remotely or automatically operated. They may include only the means for starting and stopping the motor or they may include other functions. An electric motor controller can be classified by the type of motor it is to drive such as permanent magnet, servo, series, separately excited, and alternating current [9]. A motor controller is connected to a power source such as a battery pack or power supply, and control circuitry in the form of analog or digital input signals [56].

Equipment uses in the project:

1. Microporcessor, PIC16F877P
2. Microcontroller, PIC16F690-I/P DIP
3. IC , LM 7805
4. IC (4050N, 2Q2222A)
5. IR sensor, IRF540
6. Ultra LED, U57X32
7. Transistor IC, D880
8. Text LCD, YJ-2002A
9. PCB Board
10. Capacitor (10 pF, 330 pF, 10 uF, 15 pF, 470 uF)
11. Resistor (1 KΩ, 1.5 KΩ, 2.2 KΩ, 10 KΩ)
12. Diode 1N4007
13. Battery (DCJ0202)
14. Press Switch, etc.

7.3 DESCRIPTION OF THE MAIN PARTS

7.3.1 Microcontroller Chip:

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input / output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessor used in personal computer or other general purpose applications. Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, and toys. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems [57]. Some microcontrollers may use four-bit words and operate at clock rate frequencies as low as 4 kHz, for low power consumption (milliwatts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nanowatts, making many of them well suited for long lasting battery applications. Other microcontrollers may serve performance-critical roles, where they may need to act more like a digital signal processor (DSP), with higher clock speeds and power consumption [58].

7.3.2 Pin Diagram of the Microcontroller PIC16F877P:

The microcontroller model is PIC18F452 DIP with 40 pins which is used in the project. The pin orientation of the microcontroller has shown below-

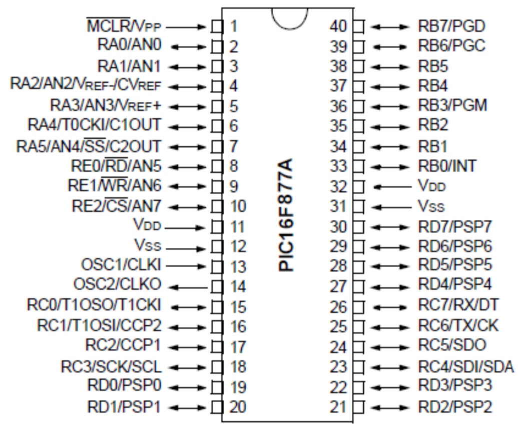


Fig. 7.1: The pin diagram of the microcontroller PIC18F452 DIP.

These devices come in 28-pin and 40/44-pin packages. The 28-pin devices do not have a Parallel Slave Port (PSP) implemented and the number of Analog-to-Digital (A/D) converter input channels is reduced to 5. The following Figure 8.2 is device block diagrams sorted by pin count: 40/44-pin [59].

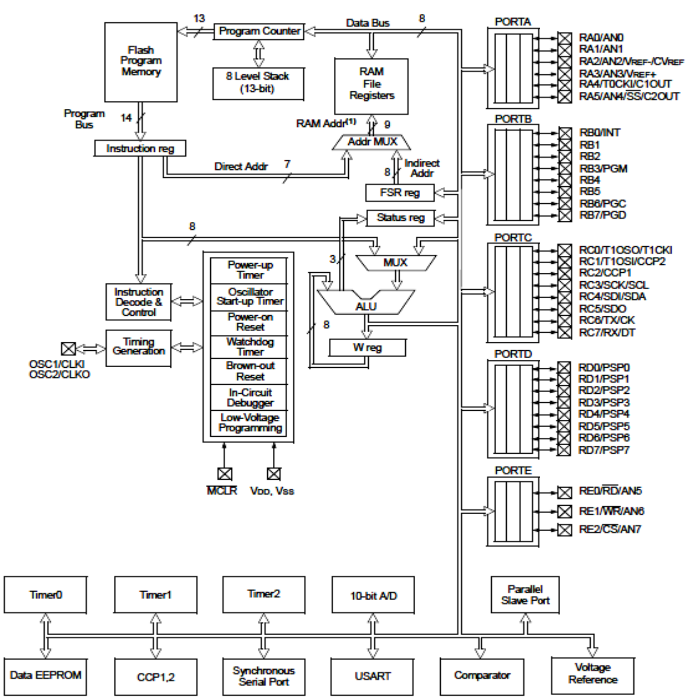


Fig. 7.2: Block diagram for the microcontroller PIC16F877 with 40 pins [59].

Note: (a) Optional multiplexing of CCP2 input/output with RB3 is enabled by selection of configuration bit. (b) The high order bits of the Direct Address for the RAM are from the BSR register (except for the MOVFF instruction). (c) Many of the general purpose I/O pins are multiplexed with one or more peripheral module functions. The multiplexing combinations are device dependent [59].

7.3.3 Pin Diagram of the Microcontroller PIC16F690-I/P DIP:

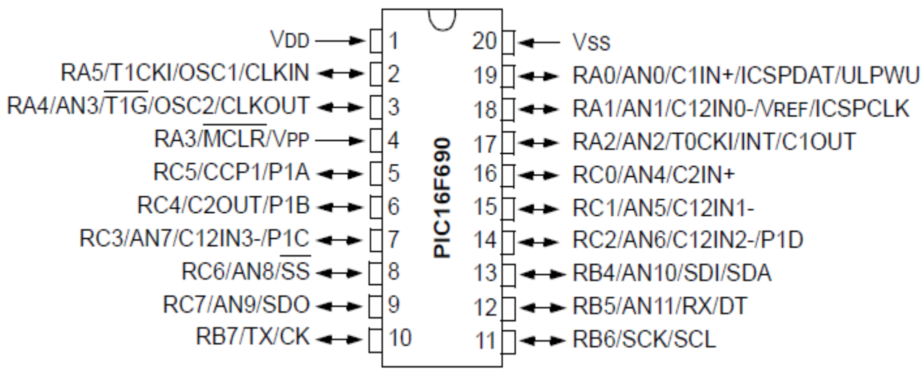


Fig. 7.3: Pin diagram of the microcontroller chip, PIC16F690-I/P DIP [60].

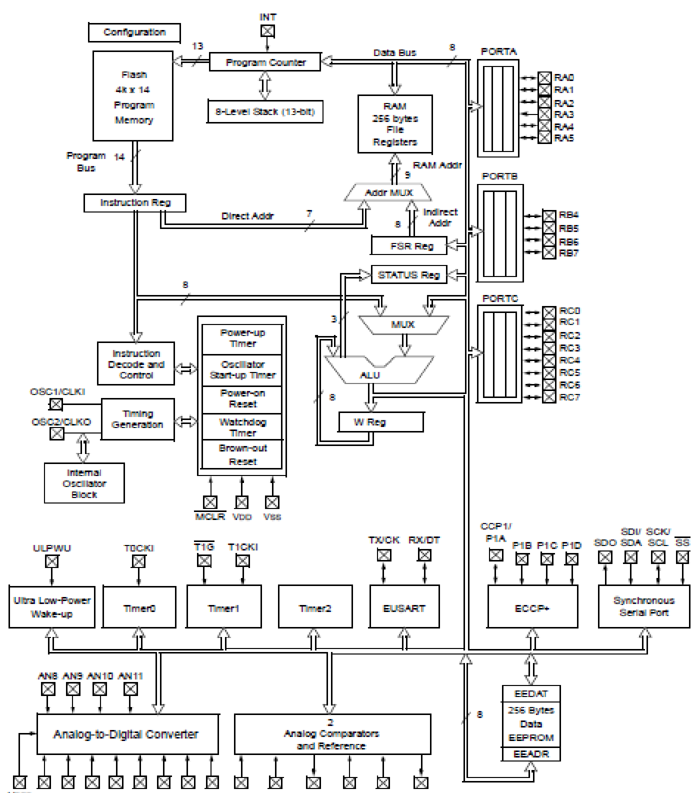
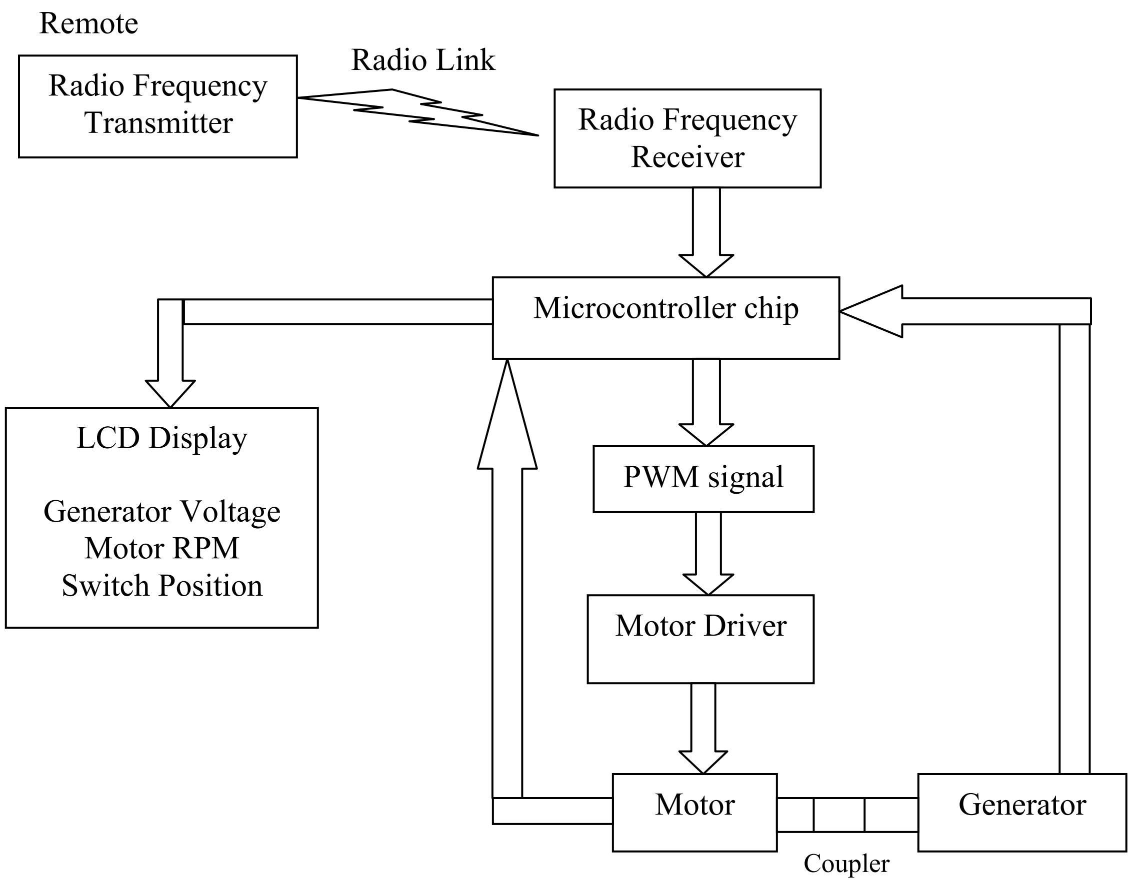


Fig.7.4: Block diagram of the microcontroller chip, PIC16F690-I/P DIP [60].

7.4 BLOCK DIAGRAM OF THE PROJECT

The Block Diagram of the scheme is shown below -



The project was design according to the block diagram mention above. Here, the remote has generate the radio frequency and transmit it through RF transmitter by electromagnetic spectrum. Its frequency is 13.56 MHz because is an industrial standard and the frequency range is 30 KHz to 300 GHz. This radio frequency received by RF receiver and sent to the signal to main microcontroller chip. This microcontroller generate PWM (Pulse-width modulation) signal and sent it to the motor driver. According to this PWM signal, the motor driver supply different voltage to the motor terminal. Finally the motor rotate according to this supply terminal voltage. By different terminal voltage the motor rotate different RPM. The motor has couple to a generator by a coupling shaft. The generator output voltage also sent to the microcontroller. This microcontroller sent this output voltage to the LCD display device and shows the digit in the LCD screen.

7.5 CIRCUIT DIAGRAM

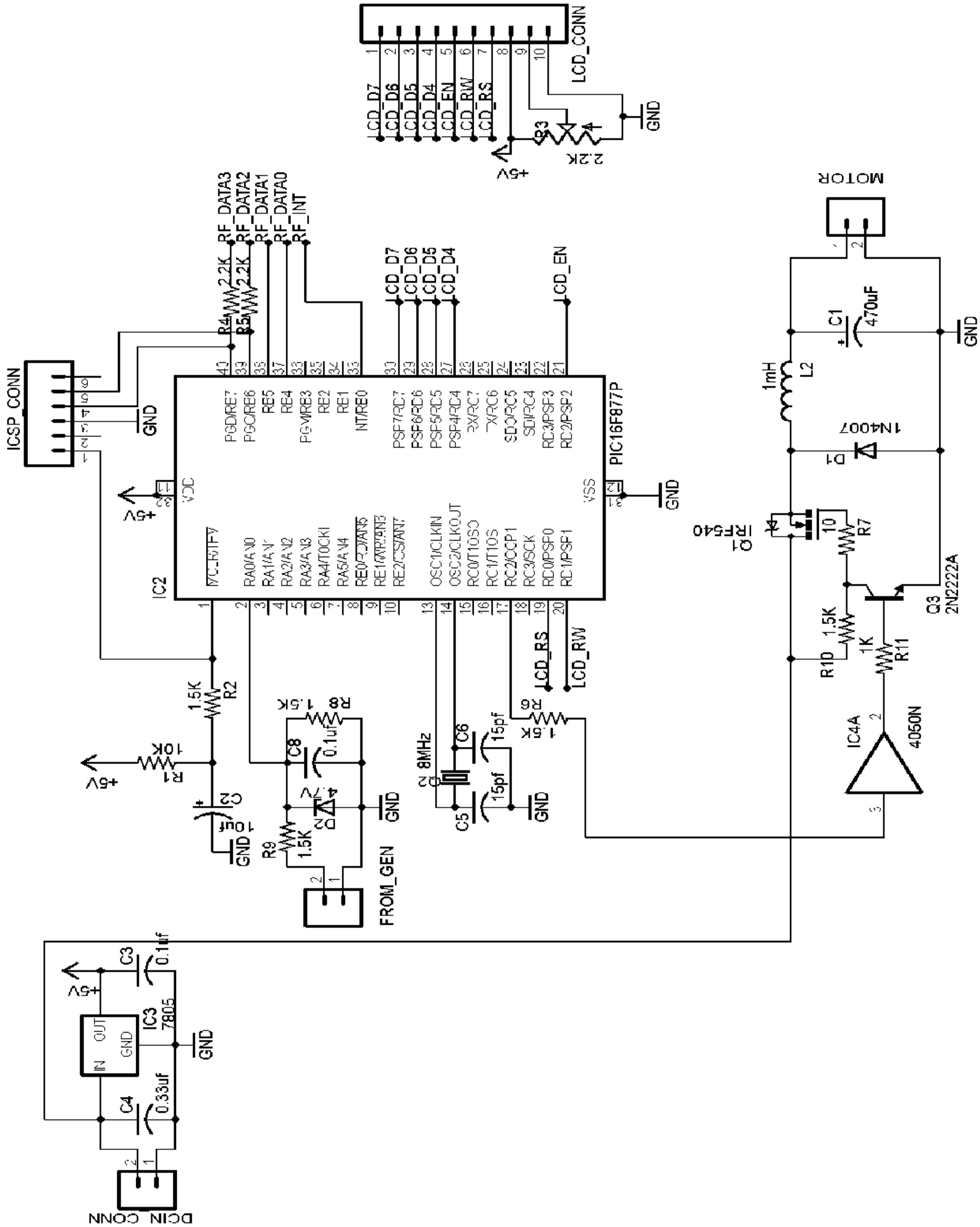


Fig. 7.5: Controller and display circuit diagram for the project.

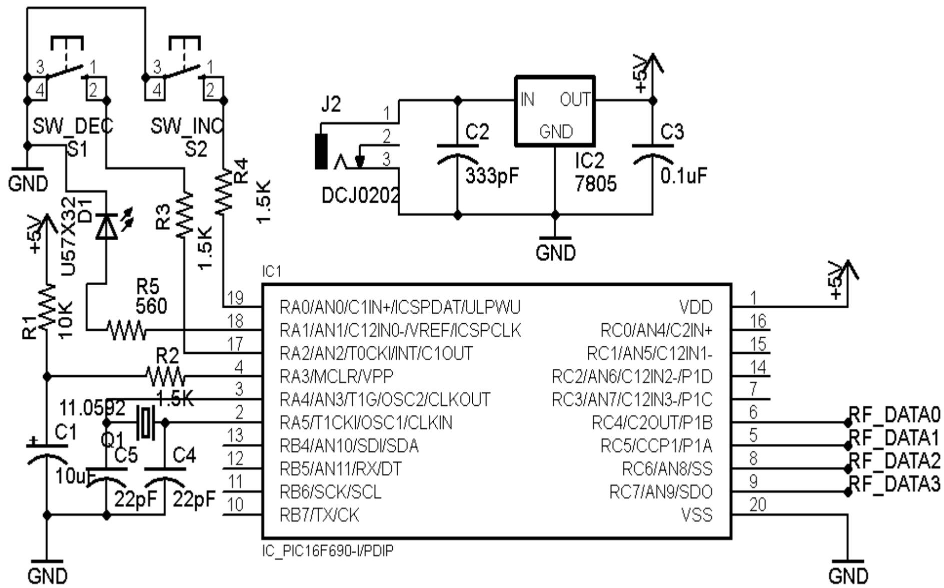


Fig. 7.6: Circuit diagram for the Remote controller.

7.6 PROJECT OVERVIEW

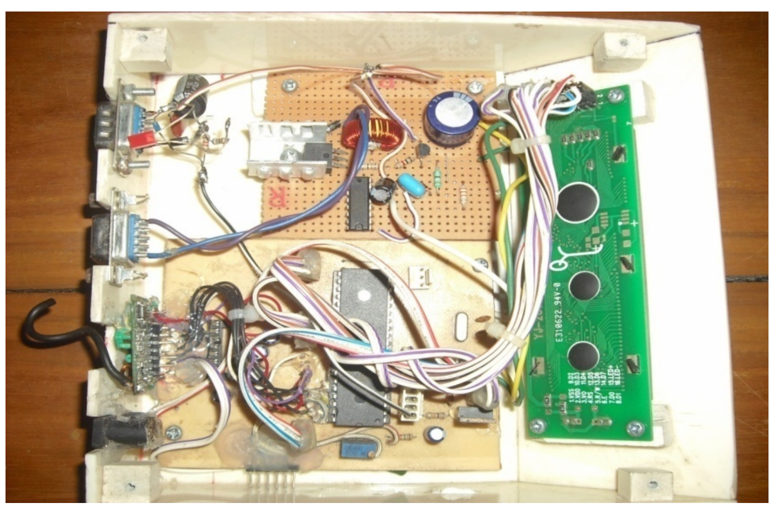


Fig. 7.7: Assemble of controller and display circuit in the project box.

In the front site of the project box, the LCD display device has been assembled for display different characteristics. In the big PCB board with microcontroller chip which contain the total program for the project and controlled the motor in ten steps. The another circuit in the top most right corner of the project box is known as motor drover circuit which drive the motor by receiving signal from the microcontroller. The circuit in the bottom left corner of the box is radio frequency receiver circuit with radio frequency antenna.

Fig. 7.8: Total setup of the project.

7.7 WORKING PROCEDURE

There are two microcontrollers is used for this project one is PIC16F877P in the main controller circuit and another one is PIC16F690-I/P DIP in the remote circuit. First one microcontroller contains the main program and run the program inside the microcontroller. This microcontroller generate PWM signal in its terminal point 18. Other helping circuits are also connected with the microcontroller chip such as motor driver circuit, unipolar triangular wave generator circuit, radio frequency receiver circuit, generator output receive circuit, display circuit etc. At the same in the remote the second microcontroller also connect some circuit such as DC source with biasing circuit, radio frequency transmitter circuit with IR LED, switching and antenna etc. At the starting position the motor rotate at a full load. When the remote switch is on then the program for the radio frequency transmitter rum automatically inside of the microprocessor. There are two multi press switch in the remote, one is for increasing and another is for decreasing. The radio frequency is 13.56 MHz because is an industrial standard and the frequency range is 30 KHz to 300 GHz. If the switch is pressed then the program compare it is > 1 or < 10 and the microcontroller sent a signal to RF transmitter circuit and this circuit transmit a radio signal by it antenna. This signal chance by the RF receiver circuit and this circuit sent a signal to main microcontroller. The program inside the microcontroller checks and compares it and generates a PWM signal corresponding of this signal. The PWM signal frequency is 100 kHz and the operating frequency range is 30-80 kHz. In every steps increase or decrease 5% of the PWM signal frequency. This pulse sent to the motor driver circuit and the circuit sent a certain amount of voltage to the motor terminal and motor run of the voltage. The motor couple to a generator and for different RPM of the motor the generator output voltage is different. The generator output voltage taken by a circuit and sent it to the microcontroller. The microcontroller shows the motor RPM, generator voltage and switch position of that moment in the LCD display. By this procedure the motor was controlled by ten steps.

7.8 DATA RECORD

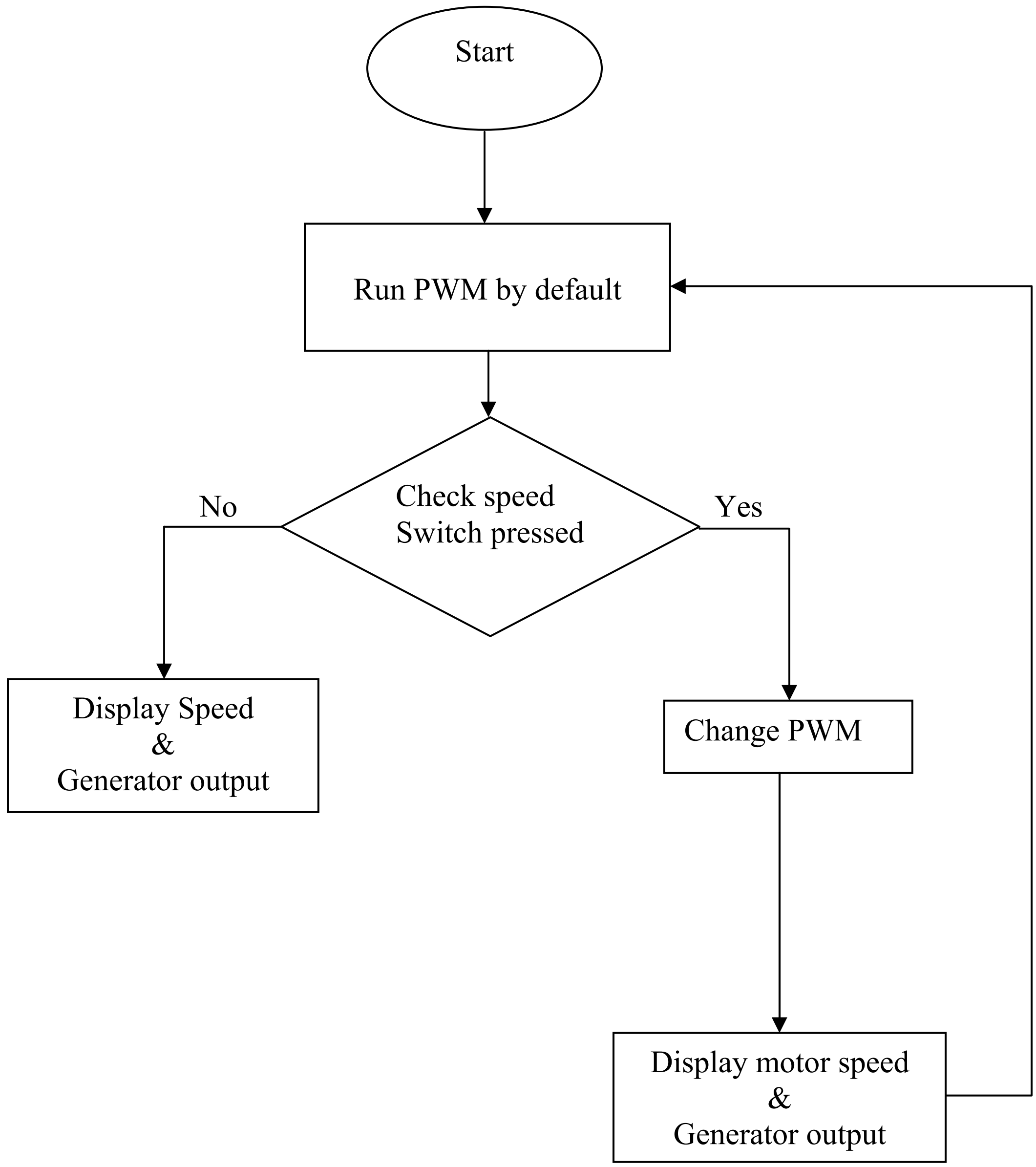
The following simulated data has been recorded -

Table 7.1: Simulated data for the model of power simulation.

Step	Wind velocity	Turbine speed	Turbine power	Correction factor	Motor speed	Generator Voltage	Output Current	Power
	m/s	rpm	KW		rpm	V	A	W
1	5.5	126	0.80	5.85	737	1.42	0.09	0.128
2	6.5	152	1.95	12.96	1970	2.28	0.11	0.25
3	7.5	172	2.99	11.11	1912	2.24	0.12	0.27
4	8.5	195	4.35	9.97	1945	2.26	0.19	0.43
5	9.5	218	6.07	13.72	2992	2.78	0.16	0.44
6	10.5	240.6	8.21	12.53	3015	2.83	0.23	0.65
7	11.5	263.5	10.78	11.96	3155	2.84	0.32	0.91
8	12.5	286.5	13.85	11.44	3278	2.96	0.41	1.21
9	13.5	309.4	17.44	11.17	3456	3.49	0.44	1.53
10	14.5	332.3	21.61	10.99	3652	3.57	0.55	1.96

For the power simulation of the designed turbine by a motor considering some factors has been discussed here. The motor has been controlled in ten steps in the cut in speed and cut off speed range. During the simulation of theoretical designed wind turbine and the model a correction factor has been considered in the program which has shown in the above table. Most of the values of the correction factor are near about 10. So, it can easily say that the model is 1/10 scale of the prototype.

7.9 PROGRAM ALGORITHM FOR THE PROJECT



The program for the project has been done by using programming language C, which has shown in **Appendix – H**.

Chapter 8

DISCUSSIONS

8.1 DISCUSSIONS:

The following discussions are made from the thesis works are given below -

(i) The WBHPP is unable to supply power without charge of its battery though wind velocity is available because it have some problem in design the turbine blades, necessary distance was not maintain between one turbine to another and the turbine base construction was not good. When wind blows some turbine tower was vibrating. Another demerit of the plant is 1000 pcs 12V DC rechargeable batteries.

(ii) The correlation between observed and calculated data was not found for Sitakunda, August and September because in this two month the wind velocities were too irregular. For this reason the value of k and c was out of range. So, the correlation was not found of the couple month.

(iii) For the analysis of wind gust, it has been shown that the wind velocity was about 96 m/s at August in Sitakunda because it was hurricane class wind speed and it may have another cause i.e. fault reading of the measuring instrument.

(iv) The surface roughness factor always less than 1.00 but for Khagrachari the factor was greater than 1.00 because it’s a hilly site. From the data it has been shown that in the same zone at 10m height Khagrachari wind velocity was lower than Rauzan because the 10 m height data for Khagrachari was under wake zone of forest in front of the wind monitoring station.

(v) The motor has been controlled in ten steps by using PWM signal. The generator output voltage increases by increasing the RPM of the motor. But in some steps like step 3, 4 and 6, 7 the RPM and output voltage variation is too little. It has two causes fast of one is in the increasing and decreasing steps only 5% of PWM signal increasing or decreasing of its total operating frequency range (30-80 kHz). After one or two steps the frequency variation is higher than the motor responding. Second one is the generator which has been used in this project is not actual generator coil, it is actually a motor coil. So, in the coil winding flux is not generating properly. These are two major causes for occurring this variation.

Appendix-A

Frequency Distribution for Selected Sites

Table A-1: Frequency distribution of wind speeds in Kuakata, 2006 (Above 20 m height) Bangladesh.

Location	Month / Velocity Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	Total Hours
Kuakata, 2006	**January**	35	70	239	250	115	31	4	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	February	10	35	163	227	178	44	7	6	2	-	-	-	-	-	-	-	-	-	-	-	**672**
	March	15	57	147	286	162	56	15	2	3	1	-	-	-	-	-	-	-	-	-	-	**744**
	April	3	35	67	90	160	149	113	66	26	11	-	-	-	-	-	-	-	-	-	-	**720**
	May	14	39	76	128	139	110	104	69	49	14	2	-	-	-	-	-	-	-	-	-	**744**
	June	3	30	80	107	106	141	128	85	29	10	1	-	-	-	-	-	-	-	-	-	**720**
	July	3	16	39	67	132	152	134	94	64	30	12	1	-	-	-	-	-	-	-	-	**744**
	August	11	39	49	68	119	116	78	88	78	69	22	7	-	-	-	-	-	-	-	-	**744**
	September	10	48	95	135	157	100	46	25	37	24	25	12	1	-	-	2	-	2	-	1	**720**
	October	36	160	320	182	42	3	0	0	0	0	0	1	-	-	-	-	-	-	-	-	**744**
	November	20	100	296	251	40	2	3	1	0	0	0	0	0	1	0	0	3	0	3	0	**720**
	December	48	114	218	285	34	10	12	10	0	0	0	0	0	0	0	3	4	3	3	0	**744**
Total Hours =		**208**	**743**	**1789**	**2076**	**1384**	**914**	**644**	**446**	**288**	**159**	**62**	**21**	**1**	**1**	**0**	**5**	**7**	**5**	**6**	**1**	**8760**

Table A-2: Frequency distribution of wind speeds in Kutubdia, 2006 (Above 20 m height) Bangladesh.

Location	Month / Velocity Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	Total Hours
Kutubdia, 2006	**January**	23	116	248	178	101	67	11	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	February	52	175	212	109	38	48	24	12	2	-	-	-	-	-	-	-	-	-	-	-	**672**
	March	20	119	238	219	96	32	15	1	0	1	0	1	2	-	-	-	-	-	-	-	**744**
	April	8	68	179	188	149	69	29	9	8	9	4	-	-	-	-	-	-	-	-	-	**720**
	May	13	81	130	142	148	112	45	45	19	6	1	1	0	1	-	-	-	-	-	-	**744**
	June	5	62	97	148	120	129	84	37	29	6	3	-	-	-	-	-	-	-	-	-	**720**
	July	2	14	27	106	142	181	136	86	39	10	0	1	-	-	-	-	-	-	-	-	**744**
	August	20	51	93	128	113	128	102	56	43	10	-	-	-	-	-	-	-	-	-	-	**744**
	September	54	130	203	118	59	34	49	47	24	2	-	-	-	-	-	-	-	-	-	-	**720**
	October	81	189	303	139	24	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	November	22	84	348	189	56	19	2	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	December	23	128	393	137	39	18	6	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
Total Hours =		**323**	**1217**	**2471**	**1801**	**1085**	**845**	**503**	**293**	**164**	**44**	**8**	**3**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**8760**

Table A-3: Frequency distribution of wind speeds in Khagrachari, 2006 (Above 20 m height) Bangladesh.

Location	Month \ Velocity Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	Total Hours
Khagrachari, 2006	**January**	41	145	227	226	61	32	12	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	February	24	102	152	177	96	70	32	16	3	-	-	-	-	-	-	-	-	-	-	-	**672**
	March	26	60	130	192	167	87	51	25	5	1	-	-	-	-	-	-	-	-	-	-	**744**
	April	5	40	161	163	140	88	77	32	14	-	-	-	-	-	-	-	-	-	-	-	**720**
	May	45	131	190	138	81	52	74	27	6	-	-	-	-	-	-	-	-	-	-	-	**744**
	June	14	68	120	122	96	103	79	50	40	19	5	4	-	-	-	-	-	-	-	-	**720**
	July	11	43	235	287	116	35	6	10	1	-	-	-	-	-	-	-	-	-	-	-	**744**
	August	15	103	242	257	78	31	12	4	2	-	-	-	-	-	-	-	-	-	-	-	**744**
	September	40	109	203	173	101	71	11	8	4	-	-	-	-	-	-	-	-	-	-	-	**720**
	October	87	191	252	166	36	10	2	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	November	80	138	224	226	48	3	0	1	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	December	93	183	238	173	45	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
Total Hours =		**481**	**1313**	**2374**	**2300**	**1065**	**594**	**356**	**173**	**75**	**20**	**5**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8760**

Table A-4: Frequency distribution of wind speeds in Sitakunda, 2006 (Above 20 m height) Bangladesh.

Location	Month \ Vel ocity Interval	**0-1**	**1-2**	**2-3**	**3-4**	**4-5**	**5-6**	**6-7**	**7-8**	**8-9**	**9-10**	**10-11**	**11-12**	**12-13**	**13-14**	**14-15**	**15-16**	**16-17**	**17-18**	**18-19**	**19-20**	**Total Hours**
Sitakunda, 2006	**January**	140	153	201	156	74	15	3	2	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	February	28	61	138	239	117	41	34	14	-	-	-	-	-	-	-	-	-	-	-	-	**672**
	March	33	91	144	235	164	65	7	1	0	3	1	-	-	-	-	-	-	-	-	-	**744**
	April	13	44	111	158	161	91	71	36	22	10	3	-	-	-	-	-	-	-	-	-	**720**
	May	18	59	88	150	163	105	92	36	22	6	2		3	-	-	-	-	-	-	-	**744**
	June	14	51	87	141	119	107	76	51	46	19	5	4	-	-	-	-	-	-	-	-	**720**
	July	1	6	42	129	179	137	132	61	29	15	10	2	1	-	-	-	-	-	-	-	**744**
	August	18	47	113	156	136	88	77	56	15	10	**7**	1	1	0	0	2	5	3	2	0	-
	September	73	108	143	115	58	28	15	6	2	1	2	3	0	0	1	2	2	2	1	2	-
	October	81	198	292	156	13	4	0	0	0	-	-	-	-	-	-	-	-	-	-	-	**744**
	November	33	146	275	226	33	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	December	107	186	212	200	39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
		559	**1150**	**1846**	**2061**	**1256**	**685**	**510**	**263**	**136**	**64**	**30**	**10**	**5**	**0**	**1**	**4**	**7**	**5**	**3**	**2**	

N.B.: Rest of the data for August and September has shown in the Table A-5.

Table A-5: Frequency distribution of wind speeds in Sitakundu, 2006 (Above 20 m height), Bangladesh.

Location	Month \ Vel Interval	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	29-30	30-31	31-32	32-33	33-34	34-35	35-36	36-37	37-38	38-39	39-40	40-41	41-42	42-43	43-44	44-45	45-46	46-47	47-48	48-49	50-51	51-52	53-54	54-55	**Total**
Sitakundu,2006	January	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	February	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	March	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	April	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	June	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	July	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	August	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	**744**
	September	4	5	3	2	1	5	11	8	5	6	9	10	3	6	4	4	7	7	4	9	5	7	4	4	3	5	2	3	3	2	0	2	3	**720**
	October	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	November	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	December	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Hours =		**4**	**5**	**3**	**2**	**1**	**5**	**11**	**8**	**5**	**6**	**9**	**10**	**4**	**7**	**5**	**5**	**7**	**7**	**4**	**9**	**5**	**7**	**4**	**4**	**3**	**5**	**2**	**3**	**3**	**2**	**3**	**2**	**3**	**8760**

Table A-6: Frequency distribution of wind speeds in Pakshey,2006 (Above 20 m height) Bangladesh.

Location	Month \ Vel ocity Interval	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24	Total Hours
Pakshey, 2006	**January**	73	129	285	211	32	13	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	February	105	152	225	142	32	15	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**672**
	March	78	155	267	185	38	15	3	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	April	17	74	212	233	129	43	11	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	May	50	126	198	188	124	42	6	6	2	1	0	0	1	-	-	-	-	-	-	-	-	-	-	-	**744**
	June	30	123	236	191	100	32	4	1	2	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	July	10	79	219	214	113	59	34	9	7	-	-	-	-	-	-	-	-	-	-					-	**744**
	August	50	106	154	129	113	83	57	28	7	0	4	1	9	0	0	0	0	0	0	0	0	1	1	1	**744**
	September	55	148	171	136	92	62	28	12	13	1	0	1	0	0	0	0	0	0	0	0	1	-	-	-	**720**
	October	124	255	309	49	4	0	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	November	80	246	322	62	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	December	59	212	364	101	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
Total Hours =		**731**	**1805**	**2962**	**1841**	**795**	**364**	**146**	**59**	**33**	**4**	**4**	**2**	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**8760**

Table A-7: Frequency distribution of wind speeds in Rauzan, 2006 (Above 20 m height) Bangladesh.

Location	Vel ocity Interval / Month	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	Total Hours
Rauzan, 2006	**January**	206	333	140	52	10	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	February	126	224	188	91	37	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**672**
	March	142	201	195	106	60	25	10	5	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	April	71	125	187	177	98	46	12	4	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	May	84	204	197	119	63	31	33	6	4	2	1	-	-	-	--	-	-	-	-	-	**744**
	June	21	76	139	111	80	95	76	49	46	18	5	4	-	-	-	-	-	-	-	-	**720**
	July	16	76	276	229	110	32	5	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	August	44	135	275	184	73	27	6	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
	September	146	187	204	125	46	11	1	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	October	340	267	88	39	6	4	0	-	-		-	-	-	-	-	-	-	-	-	-	**744**
	November	302	291	65	26	24	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**720**
	December	339	288	89	25	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**744**
Total Hours =		**1837**	**2407**	**2043**	**1284**	**610**	**292**	**143**	**64**	**50**	**20**	**6**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**8760**

Appendix-B

Mean Monthly at an Hour Speed for Each Location

(All Wind speeds are in m/s)

Table B-1: Monthly Average Wind Speed above 20 m height.

Location	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Kuakata	3.11	3.57	3.54	5.07	4.97	5.1	5.74	5.97	4.95	2.57	3.01	3.22
Kutubdia	3.11	2.80	3.15	3.77	4.24	4.53	5.42	4.74	3.39	2.25	2.85	2.65
Khagrachari	2.85	3.45	3.88	4.16	3.44	4.67	3.36	3.1	3.19	2.38	2.53	2.37
Sitakunda	2.72	3.17	3.36	4.41	4.46	4.8	5.35	5.15	10.1	2.25	2.64	2.32
Pakshey	2.55	2.33	2.53	3.26	3.04	2.93	3.5	3.83	3.26	1.89	2.02	2.2
Rauzan	1.55	2.08	2.09	2.94	2.74	4.55	3.14	2.79	2.14	1.21	1.33	1.2

Table B-2: Monthly Average Wind Speed above 10 m height.

Location	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Kuakata	2.15	2.62	2.65	3.83	3.81	3.82	4.44	4.75	3.81	1.76	2.15	2.55
Kutubdia	1.69	1.79	1.90	2.77	3.30	3.81	4.63	3.95	2.58	1.26	1.39	1.11
Khagrachari	0.63	1.37	1.25	1.67	1.69	3.70	0.95	0.81	0.92	0.45	0.45	0.31
Sitakundu	1.96	2.47	2.64	3.78	3.84	4.26	4.78	4.87	5.97	1.43	1.81	1.66
Pakshey	1.18	1.42	1.59	2.55	2.35	2.29	2.80	2.86	2.34	0.86	0.70	0.71
Rauzan	0.89	1.58	1.37	2.25	2.88	4.00	2.40	2.10	1.51	0.70	0.68	0.67

Table B-3: Weekly Average Wind Speed above 20 m height.

Location	Week																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Kuakata	3.34	3.26	2.21	3.51	3.15	2.91	3.97	4.05	3.44	3.3	3.13	4.23	3.89	6.44	6.24	4.1	3.64	5.18	5.55	3.71	4.01	6.03	5.72	6.23	4.54	4.57
Kutubdia	3.33	3.78	2.48	3.39	1.8	1.91	3.71	2.59	3.64	2.96	3.2	3.18	3.34	4.35	4.31	3.15	3.08	3.84	5.26	3.28	4.00	5.39	5.98	4.86	3.19	4.18
Khagrachari	2.34	2.62	3.24	3.21	2.68	2.77	4.01	3.63	4.111	3.46	3.54	4.379	4.25	4.29	4.78	3.66	3.67	4.49	4.32	2.07	2.59	4.55	6.69	5.78	3.102	2.85
Sitakundu	2.88	3.18	2.35	2.91	1.53	2.17	4.01	3.51	3.86	3.04	3.4	3.63	3.67	5.41	5.4	3.49	3.21	4.48	5.35	3.31	4.21	5.19	6.71	5.74	3.38	3.5
Pakshey	2.93	2.08	2.22	3.03	1.97	1.77	2.3	2.67	2.96	2.54	2.36	2.59	2.92	3.66	3.69	2.89	2.85	3.73	3.33	2.57	2.11	3.48	2.92	3.83	2.37	2.54
Rauzan	1.2	1.58	1.72	1.7	1.52	1.46	2.56	2.23	2.27	1.94	1.89	2.39	2.41	3.41	3.44	2.36	2.45	2.89	3.31	1.84	1.92	4.67	6.7	5.76	3.14	2.32

Table B-4: Weekly Average Wind Speed above 20 m height.

Location	Week																									
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Kuakata	7.53	4.49	6.15	4.9	6.61	5.11	5.2	6.194	5.45	5.71	4.28	6.61	3.7	2.64	2.76	1.99	2.7	2.94	2.57	2.89	3.01	3.9	4.12	3.22	2.25	3.05
Kutubdia	5.66	5.13	5.89	4.91	5.51	3.56	5.22	5.14	3.76	3.06	2.9	5.24	2.62	1.96	2.56	1.81	2.58	2.51	3.44	3.04	2.2	3.02	2.64	2.94	2.01	2.86
Khagrachari	3.59	3.39	3.43	3.21	3.02	2.96	2.97	3.4	3.05	3.35	2.58	3.85	3.03	1.95	2.633	2.26	2.59	2.59	2.48	2.52	2.39	2.64	2.01	2.78	2.28	2.45
Sitakundu	5.59	5.49	6.19	4.54	4.87	3.44	4.81	8.25	3.14	2.58	9.29	28.4	2.43	2.03	2.46	1.99	2.43	2.57	2.87	2.73	2.16	2.93	2.31	2.67	1.68	2.54
Pakshey	3.85	3.24	3.74	3.33	3.88	2.44	3.81	3.16	6.09	3.24	2.39	4.36	2.45	1.92	1.43	1.74	2.19	2.25	1.63	2.14	2.16	2.21	1.98	2.421	2.14	2.17
Rauzan	3.29	3.22	3.53	2.75	2.92	2.19	2.78	3.39	2.33	1.95	1.99	3.11	1.61	1.22	1.79	1.03	0.91	0.97	1.23	0.79	2.01	1.44	1.19	1.44	1.36	0.92

Table B-5: Weekly Average Wind Speed above 10 m height.

Location	Week																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Kuakata	2.27	2.24	1.59	2.46	2.16	2	2.92	3.107	2.62	2.39	2.26	3.21	2.98	4.75	4.67	3.23	2.78	3.89	4.32	2.92	3.144	4.48	4.35	4.36	3.56	3.7
Kutubdia	1.71	2.17	1.41	1.85	0.85	0.86	2.65	1.63	2.43	1.52	1.82	2.16	2.26	3.36	3.3	2.08	2.2	2.8	4.24	2.26	3.18	4.62	5.24	4.14	2.47	3.53
Khagrachari	0.545	0.65	0.519	0.79	0.48	0.42	1.92	1.88	1.86	0.92	0.56	1.73	1.87	1.934	2.54	1.056	0.98	1.84	1.37	0.95	1.481	3.9	6.07	5.34	2.17	0.51
Sitakundu	2.06	2.35	1.71	2.13	0.95	1.39	3.29	2.773	3.132	2.26	2.59	3.02	3.09	4.75	4.8	2.85	2.59	3.99	4.68	2.56	3.556	4.679	6.1	5.3	2.8	2.857
Pakshey	1.29	0.95	1.18	1.4	0.83	0.86	1.41	1.78	1.97	1.598	1.46	1.676	1.94	3.06	3.08	2.08	2.04	3.02	2.58	1.8	1.468	2.86	2.273	3.3	1.68	1.85
Rauzan	0.59	0.7	1.22	0.91	1.18	1	2	1.72	1.71	1.2	1.096	1.65	1.69	2.68	2.69	1.71	1.84	2.2	2.55	2.7	2.96	4.49	6.08	5.322	2.56	1.73

Table B-6: Weekly Average Wind Speed above 10 m height.

Location	Week																									
	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Kuakata	5.84	3.42	4.71	3.69	5.52	4.18	4.16	4.51	4.35	4.43	3.1	5.07	3.05	2.01	2.03	1.36	1.61	2.01	1.81	2.03	2.15	3.02	3.81	2.56	1.57	2.08
Kutubdia	4.66	4.37	5.07	4.31	4.77	2.94	4.32	4.22	2.98	2.15	1.9	4.6	1.91	1.24	1.73	0.9	1.22	1.11	1.99	1.5	0.94	1.36	1.03	1.34	0.77	1.18
Khagrachari	0.96	1.01	1.06	0.89	0.72	0.89	0.74	0.93	0.76	1.49	0.71	0.72	0.84	0.41	0.74	0.45	0.29	0.14	0.27	0.44	0.82	0.32	0.08	0.46	0.31	0.43
Sitakundu	5.08	4.98	5.59	3.94	4.19	2.86	4.2	8.191	3.86	3.2	5.46	14.2	2.06	1.41	1.69	1.15	1.42	1.59	1.87	1.88	1.64	2.04	1.64	1.95	1.23	1.81
Pakshey	3.13	2.63	3.05	2.57	3.08	1.73	3.07	2.48	3.96	2.33	1.51	3.49	1.71	1.17	0.72	0.86	0.68	0.69	0.53	0.55	1.03	0.79	0.53	0.88	0.81	0.63
Rauzan	2.55	2.46	2.81	2.13	2.25	1.52	2.11	2.66	1.6	1.31	1.38	2.44	1.05	0.76	1.22	0.59	0.41	0.35	0.51	0.32	1.33	0.74	0.73	0.79	0.82	0.49

Appendix-C

Hourly Average and Daily Average wind Speed for Each Location

(All speeds are in m/sec)

Table C-1: Hourly average wind Speed at Kutubdia, (January - December), 2006.

Site	Hour	Month											
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Kuutubdia	**1**	3.22	2.06	2.41	2.88	3.86	4.12	5.14	4.12	3.09	2.04	2.8	2.8
	2	2.9	2.34	2.5	3.04	3.81	3.82	5.00	4.31	2.77	2.08	2.8	2.69
	3	2.9	2.4	2.64	3.12	3.55	3.89	4.61	4.08	2.72	2.16	2.8	2.74
	4	2.92	2.44	2.67	3.14	3.41	3.67	4.79	3.9	2.67	2.18	2.71	2.77
	5	2.91	2.43	2.61	3.03	3.56	3.71	4.87	3.75	2.66	2.18	2.63	2.57
	6	3.05	2.37	2.68	3.32	3.59	3.95	4.85	3.4	2.88	2.22	2.67	2.48
	7	3.03	2.5	2.53	3.32	3.43	4.05	4.87	3.32	2.88	2.4	2.78	2.57
	8	2.74	2.6	2.4	3.34	3.47	4.35	5.02	3.99	2.98	1.95	2.65	2.52
	9	2.51	2.54	2.67	3.7	3.79	4.42	5.6	4.65	3.48	1.99	2.45	2.06
	10	2.58	2.6	3.1	4.05	4.08	4.67	5.67	5.23	3.79	1.95	2.62	2.08
	11	3.11	2.82	3.48	4.36	4.33	4.68	5.6	5.21	3.9	2.09	2.78	2.51
	12	3.19	3.31	3.56	4.54	4.56	4.69	5.66	5.2	4.11	2.36	2.87	2.89
	13	3.39	3.57	3.49	4.68	4.76	5.06	5.87	5.41	4.24	2.58	3.09	3.05
	14	3.57	3.56	3.79	4.54	5.22	5.14	5.76	5.53	4.16	2.73	3.21	3.02
	15	3.56	3.53	4.15	4.85	5.29	5.43	5.96	5.83	4.37	2.7	3.37	2.92
	16	3.53	3.61	4.27	4.84	5.46	5.39	6.34	5.97	4.31	2.58	3.31	3.04
	17	3.36	3.46	4.2	4.76	5.32	5.32	6.35	5.97	4.09	2.57	3.31	2.96
	18	3.14	3.4	4.1	4.21	5.18	5.37	5.97	5.63	3.87	2.59	3.11	2.75
	19	3.16	3.07	3.89	3.89	4.42	5.04	5.74	5.19	3.49	2.42	2.89	2.56
	20	3.15	2.84	3.48	3.51	4.16	4.54	5.55	4.92	3.12	2.16	2.74	2.41
	21	3.18	2.7	3.23	3.27	4.11	4.43	5.37	4.66	2.88	2.03	2.73	2.33
	22	3.13	2.48	2.92	3.63	4.12	4.44	5.17	4.76	2.91	1.91	2.65	2.51
	23	3.38	2.45	2.54	3.21	4.27	4.23	5.22	4.54	2.94	2.01	2.7	2.66
	24	3.14	2.24	2.22	3.04	4.05	4.05	5.18	4.21	3.14	2.07	2.71	2.73
Total =		**3.17**	**3.45**	**3.88**	**4.16**	**3.44**	**4.67**	**3.36**	**3.10**	**3.19**	**2.38**	**2.53**	**2.37**

Table C-2: Hourly average wind Speed at Khagrachari, (January - December), 2006.

Site	Hour	month											
		Jan	**Feb**	**Ma**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Khagrachari	**1**	3.51	4.21	4.36	4.56	3.1	4.1	3.5	2.82	3.6	2.9	3.0	2.92
	2	3.24	3.87	4.06	4.24	3.28	4.2	3.4	2.69	3.4	2.8	3.0	2.93
	3	2.99	3.64	3.61	3.93	3.05	3.9	3.4	2.94	3.3	2.6	3.0	3.05
	4	2.97	3.26	3.19	3.81	3.32	4.1	3.2	2.96	3.4	2.5	3.0	3.09
	5	2.94	3.31	3.29	3.71	3.29	4.3	3.3	2.9	3.3	2.5	2.9	3.03
	6	2.86	3.24	3.28	3.28	3.28	4.2	3.3	3	3.3	2.5	2.8	2.82
	7	2.67	3.42	3.37	3.27	3.5	4.2	3.3	3.1	3.1	2.5	2.8	2.8
	8	2.77	3.59	3.3	3.44	3.46	4.1	3.2	3.22	2.9	2.6	2.9	2.75
	9	2.8	3.48	3.09	3.12	3.19	4.2	3.1	3.3	2.8	2.6	3.0	2.83
	10	2.57	2.93	2.62	2.73	3.27	4.0	3.2	3.14	2.6	2.3	2.8	2.88
	11	2.45	2.56	2.48	2.6	3.2	4.6	3.4	3.01	2.5	2.1	2.3	2.67
	12	2.15	2.45	2.5	3.27	3.39	4.9	3.6	2.88	2.4	2.0	1.8	2.31
	13	2.01	2.44	2.63	3.58	3.59	5.1	3.4	2.79	2.3	1.7	1.4	2.02
	14	1.98	2.38	2.88	3.79	3.31	4.8	3.1	2.73	2.5	1.4	1.3	1.83
	15	2.14	2.6	3.39	4.49	3.3	5.1	2.8	2.65	2.6	1.2	1.4	1.6
	16	2.54	2.92	3.91	4.83	3.42	4.9	2.8	2.62	2.3	1.3	1.6	1.54
	17	2.43	3.05	4.22	5.26	3.63	5.0	3.0	3.05	2.9	1.5	1.9	1.41
	18	2.29	3.1	4.61	5.26	3.96	5.1	3.4	3.67	3.2	1.9	1.9	1.42
	19	2.73	3.46	5.25	5.45	4.01	5.2	3.5	3.96	3.7	2.2	2.2	1.34
	20	3.47	3.98	5.43	4.93	3.85	5.4	3.5	4.07	3.8	2.9	2.8	1.7
	21	3.81	4.5	5.88	5.11	3.62	5.3	3.7	3.6	3.9	3.3	2.7	2.2
	22	3.8	4.85	5.42	5.49	3.56	5.1	3.6	3.15	3.9	3.1	2.9	2.48
	23	3.68	5.1	5.3	5.08	3.56	4.5	3.4	3.17	4.0	3.0	2.9	2.61
	24	3.61	4.57	4.75	4.6	3.4	4.4	3.4	2.93	3.8	2.9	3.1	2.75
Total =		**3.11**	**3.57**	**3.54**	**5.07**	**4.97**	**5.1**	**5.7**	**5.97**	**4.95**	**2.57**	**3.01**	**3.22**

Table C-3: Hourly average wind Speed at Sitakunda, (January - December),2006.

Site		month											
	Hour	**Jan**	**Feb**	**Ma**	**Apr**	**May**	**Jun**	**Jul**	**Au**	**Sep**	**Oct**	**Nov**	**Dec**
Sitadunda	**1**	2.73	3.15	3.16	3.85	4.19	4.07	4.69	3.58	11.28	2.09	2.62	2.61
	2	2.8	3.15	3.15	3.62	4.07	4.1	4.47	4.43	9.73	2.36	2.78	2.64
	3	2.74	2.79	2.87	3.92	3.89	4.23	4.54	3.44	11.53	2.09	2.73	2.57
	4	2.78	2.83	2.95	3.71	3.75	4.24	4.4	3.87	10.53	2.11	2.76	2.25
	5	2.91	2.91	2.88	3.7	3.63	4.25	4.32	3.9	10.82	2	2.63	2.01
	6	2.51	2.63	2.78	3.53	3.69	4.29	4.3	4.12	9.28	2.04	2.8	1.97
	7	2.38	2.4	2.72	3.39	3.75	4.2	4.42	3.97	9.78	1.6	2.53	2.09
	8	2.3	2.33	2.52	3.24	3.86	4.27	5.01	5.73	10.29	1.77	1.85	1.65
	9	1.87	2.37	2.25	4.15	4.11	4.8	5.35	7.32	10.05	1.93	1.83	1.3
	10	1.72	2.7	2.8	4.85	4.36	5.28	6.01	6.26	10.19	2.05	2.19	1.97
	11	2.43	3.43	3.45	5.07	4.79	5.5	5.98	7.42	9.49	2.5	2.41	2.65
	12	2.97	3.81	3.95	5.53	5.05	5.57	5.86	6.03	10.94	2.71	2.96	2.77
	13	3.29	4.05	4.26	5.46	5.1	5.52	5.99	5.58	9.65	2.92	3.33	2.95
	14	3.51	4.2	4.49	5.37	5.17	5.39	6	5.71	11.36	2.95	3.34	3.08
	15	3.64	4.24	4.49	5.46	5.14	5.37	6.4	6.03	9.13	2.87	3.38	2.79
	16	3.43	4.2	4.48	5.45	5.09	5.37	6.2	5.46	9.82	2.61	3.01	2.23
	17	3.05	3.78	4.44	5.1	5.07	5.31	6.06	5.86	9.53	2.54	2.57	1.83
	18	2.8	3.51	4.03	4.76	5.15	5.32	5.9	5.33	9.09	2.4	2.35	1.76
	19	2.68	3.13	3.71	4.51	4.71	5.16	5.99	5.45	9.47	2.21	2.47	1.78
	20	2.3	2.83	3.32	4.47	4.71	4.94	5.8	5.75	10.59	2.2	2.51	2.02
	21	2.28	2.88	2.87	4.44	5.11	4.85	5.45	5.42	10.56	1.86	2.54	2.34
	22	2.68	2.88	2.92	4.27	4.72	4.52	5.24	4.37	9.74	2	2.59	2.71
	23	2.81	2.94	2.99	3.95	4.08	4.29	5.15	4.64	9.08	2.13	2.64	2.82
	24	2.78	2.96	3.14	3.81	3.91	4.43	4.89	3.85	8.98	2.18	2.63	2.88
Total =		**2.72**	**3.17**	**3.36**	**4.41**	**4.46**	**4.80**	**5.35**	**5.15**	**10.1**	**2.25**	**2.64**	**2.32**

Table C-4: Hourly average wind Speed at Pakshey, (January - December),2006.

Site		month											
	Hour	**Jan**	**Feb**	**Ma**	**Apr**	**May**	**Jun**	**Jul**	**Au**	**Sep**	**Oct**	**Nov**	**Dec**
Pakshey	**1**	2.7	2.16	2.45	3.52	2.62	2.67	3.06	3.54	2.79	1.83	2.05	2.41
	2	2.71	2.23	2.32	2.88	2.45	2.47	3.1	3.11	2.87	1.83	2.03	2.44
	3	2.68	2.4	2.27	2.58	2.59	2.42	2.96	3.46	2.9	1.8	2.06	2.38
	4	2.6	2.29	2.32	3.03	2.66	2.52	2.9	3.4	2.96	1.89	2.16	2.36
	5	2.47	2.35	2.18	3	2.62	2.33	3.01	3.21	3.08	1.88	2.04	2.24
	6	2.33	2.36	2.15	2.77	2.6	2.43	2.97	3	3.1	1.8	1.89	2.23
	7	2.43	2.33	2.08	2.58	2.44	2.51	3.07	2.99	3.32	1.68	1.89	1.94
	8	2.35	2.13	1.96	2.83	2.95	2.9	3.6	4.1	3.42	1.65	1.73	2
	9	2.11	1.85	1.89	3.39	3.28	3.25	3.87	4.2	3.5	1.53	1.7	1.8
	10	2.52	1.85	2.47	3.54	3.42	3.32	4.1	4.3	4.04	1.64	1.93	1.68
	11	2.95	2.16	2.7	3.32	3.3	3.42	3.99	4.3	4.25	2.03	2.3	1.84
	12	2.76	2.41	2.86	3.32	3.4	3.39	4.09	5	4.06	2.06	2.38	2.11
	13	2.91	2.54	3.18	3.38	3.51	3.24	4.17	4.49	3.69	2.18	2.32	2.48
	14	3.06	2.89	3.32	3.16	3.49	3.25	4.31	4.52	4.27	2.26	2.5	2.47
	15	3.05	3.05	3.3	3.26	3.35	3.2	4.42	4.53	3.97	2.29	2.54	2.59
	16	2.81	2.95	2.95	3.19	3.23	3.23	4.24	5.1	3.75	2.23	2.33	2.36
	17	2.26	2.44	2.82	3.32	3.45	3.47	3.96	4.37	3.25	1.87	1.86	1.87
	18	1.93	1.98	2.46	3.37	3.08	3.03	3.43	4.01	3	1.85	1.75	1.93
	19	2.23	2.22	2.45	3.29	2.75	2.77	3.07	3.61	2.68	1.92	1.75	2.09
	20	2.41	2.44	2.59	3.38	3.47	3.11	3.17	3.4	2.72	1.75	1.85	2.19
	21	2.47	2.33	2.78	3.78	3.36	3.02	2.91	3.32	2.76	1.73	1.84	2.12
	22	2.44	2.28	2.39	3.88	3.07	2.81	3.18	3.33	2.59	1.95	1.87	2.3
	23	2.49	2.21	2.46	3.88	3.12	2.79	3.12	3.2	2.65	1.84	1.82	2.39
	24	2.54	2.14	2.44	3.73	2.86	2.73	3.2	3.37	2.53	1.81	1.93	2.45
Total =		**2.55**	**2.33**	**2.53**	**3.26**	**3.04**	**2.93**	**3.50**	**3.83**	**3.26**	**1.89**	**2.02**	**2.20**

Table C-5: Hourly average wind Speed at Rauzan, (January - December),2006.

Site		month											
	Hour	**Jan**	**Feb**	**Ma**	**Apr**	**May**	**Jun**	**Jul**	**Au**	**Sep**	**Oct**	**Nov**	**Dec**
Rauzan	**1**	1.45	1.78	1.62	2.24	2.31	4.08	2.67	2.33	1.7	1.15	1.32	1.35
	2	1.52	2.07	1.84	2.36	2.34	3.87	2.64	2.44	2.09	1.31	1.16	1.48
	3	1.49	2.2	1.71	2.48	2.36	3.91	2.55	2.42	2.24	1.39	1.31	1.32
	4	1.22	2	1.76	2.39	2.59	4.14	2.54	2.52	2.41	1.31	1.42	0.97
	5	1.23	2.23	1.7	2.54	2.4	4.05	2.64	2.55	2.34	1.32	1.57	0.93
	6	1.22	2.34	1.61	2.33	2.38	4.02	2.6	2.65	2.09	1.17	1.57	0.89
	7	1.26	2.3	1.68	2.38	2.32	4.04	2.72	2.56	2.12	1.02	1.46	0.77
	8	1.21	1.83	1.36	2.26	2.33	3.89	2.81	2.49	1.97	1.02	1.35	0.87
	9	0.85	1.65	1.19	2.59	2.2	3.95	2.95	2.42	1.86	1.05	1.23	0.83
	10	1.18	1.64	1.79	3.2	2.35	4.62	3.05	2.49	1.95	1.24	0.99	0.73
	11	1.49	2.02	2.24	3.48	3.05	5	3.43	2.77	2.16	1.24	1.21	1.03
	12	1.83	2.19	2.79	3.75	2.63	5.23	3.57	3.2	2.38	1.23	1.2	1.16
	13	1.99	2.44	3.07	4.14	2.94	5.3	3.71	3.14	2.51	1.1	1.32	1.49
	14	2.17	2.73	3.42	4.53	3.42	5.17	3.84	3.2	2.48	1.22	1.39	1.59
	15	2.28	2.97	3.59	4.73	3.46	5.27	3.81	3.46	2.48	1.47	1.56	1.71
	16	2.32	3.01	3.6	4.6	3.63	5.28	3.97	3.66	2.48	1.68	1.69	1.58
	17	1.92	2.76	3.27	4.16	3.92	5.12	3.81	3.48	2.77	1.65	1.68	1.51
	18	1.54	2.09	2.38	3.43	3.76	4.95	3.56	3.46	2.56	1.46	1.37	1.36
	19	1.32	1.62	1.84	2.34	2.85	5	3.55	3.08	2.01	1.12	1.05	1.23
	20	1.24	1.44	1.75	2.1	2.53	4.85	3.15	2.63	1.84	1	1.12	1.02
	21	1.37	1.41	1.51	1.96	2.59	4.71	3.04	2.66	1.82	0.94	1.12	0.92
	22	1.72	1.63	1.5	2.02	2.61	4.42	3.05	2.55	1.72	0.98	1.32	1.06
	23	1.77	1.65	1.48	2.12	2.48	4.16	3	2.42	1.87	0.9	1.17	1.54
	24	1.77	1.92	1.46	2.23	2.28	4.02	2.66	2.33	1.68	0.99	1.45	1.45
Total =		**1.55**	**2.08**	**2.09**	**2.94**	**2.74**	**4.55**	**3.14**	**2.79**	**2.14**	**1.21**	**1.33**	**1.20**

Daily Average wind speed (m/s)

Table C-6: Daily average wind Speed at Kuakata, (January - December),2006.

Location	Date	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Kuakata,2006	**1**	3.27	3.33	3.80	4.50	4.52	5.73	7.89	6.84	3.36	2.30	2.93	4.17
	2	2.64	3.28	3.11	5.69	4.63	4.34	9.45	9.29	3.06	2.23	2.61	3.62
	3	2.84	2.63	3.24	7.21	4.87	2.58	9.08	9.13	8.87	2.88	2.54	4.04
	4	3.54	2.75	2.44	8.26	5.78	2.48	8.41	7.19	8.31	3.51	3.34	7.45
	5	4.16	3.16	2.98	7.31	5.15	4.55	7.07	5.35	4.88	2.85	2.87	2.91
	6	3.71	3.31	3.29	5.46	6.61	7.01	7.09	4.87	3.61	3.06	3.10	2.08
	7	3.19	2.72	2.81	5.12	6.12	7.02	6.27	5.35	5.00	1.64	2.20	2.63
	8	3.51	2.44	2.64	6.02	4.53	5.85	5.31	3.61	5.30	2.34	3.49	6.89
	9	3.95	3.16	3.29	3.66	4.23	7.45	5.32	3.66	4.01	2.24	1.31	2.86
	10	4.02	2.76	3.09	7.33	5.42	5.71	5.48	3.22	4.64	2.70	2.90	1.81
	11	3.09	2.81	5.01	7.39	5.99	6.38	4.41	6.33	5.74	3.18	2.11	2.05
	12	3.47	2.47	2.64	6.65	7.45	7.22	4.01	8.75	4.89	2.47	3.09	5.46
	13	2.54	2.25	2.52	5.65	5.11	7.55	3.93	4.17	3.09	3.41	2.98	4.25
	14	2.22	4.06	3.07	5.26	4.45	5.89	3.73	2.34	3.88	2.96	2.56	3.67
	15	2.25	4.72	3.62	4.97	2.94	5.08	4.51	4.52	3.66	2.07	2.93	3.39
	16	1.78	5.79	3.30	5.45	3.33	6.18	6.35	8.89	4.08	1.50	2.65	1.93
	17	1.99	5.13	3.19	5.69	3.23	5.33	5.35	7.34	2.87	1.98	2.95	2.26
	18	2.90	3.35	3.54	3.47	4.15	4.06	5.09	5.32	2.64	2.22	3.06	3.09
	19	1.65	3.89	4.21	4.05	4.29	2.84	5.94	3.81	5.91	1.80	2.58	1.26
	20	2.07	4.58	3.94	2.52	3.55	2.77	6.90	2.40	8.02	2.36	3.24	2.31
	21	2.85	4.08	3.81	2.78	2.32	6.07	7.44	5.17	9.52	1.99	2.72	2.27
	22	3.32	4.06	5.44	4.73	2.91	5.54	6.01	9.05	8.22	3.02	2.91	2.39
	23	2.66	3.81	3.99	3.98	2.74	6.45	4.46	9.15	9.09	2.99	2.64	2.18
	24	3.86	4.01	3.49	3.64	2.84	4.03	4.75	6.82	5.13	3.04	2.95	3.64
	25	5.08	3.94	4.68	3.57	3.15	2.61	4.54	5.89	4.35	3.07	3.05	3.51
	26	4.08	3.79	5.52	4.69	6.78	3.03	4.18	4.87	2.04	2.29	3.01	3.17
	27	2.91	4.29	4.70	3.11	7.32	3.97	4.13	4.04	1.97	2.42	4.75	1.96
	28	2.67	3.41	2.69	2.95	6.97	4.69	5.11	7.00	3.41	2.06	2.84	2.06
	29	3.55		3.02	3.55	6.31	4.56	7.09	8.77	4.93	2.75	3.22	3.67
	30	3.25		3.06	4.71	8.28	5.26	5.21	7.19	4.09	3.29	5.76	3.36
	31	3.22		3.69		8.01		3.23	4.72		3.12		3.37
Total Average		**3.11**	**3.57**	**3.54**	**5.07**	**4.97**	**5.1**	**5.74**	**5.97**	**4.95**	**2.57**	**3.01**	**3.22**

Table C-7: Daily average wind Speed at Kutubdia, (January - December),2006.

Location	Date	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Kutubdia,2006	1	2.52	1.7	2.97	2.7	3.97	6.09	6.63	5.01	2.44	1.39	2.58	3.18
	2	2.36	1.71	2.71	3.38	2.97	4.67	7.54	7.58	2.57	2.17	2.33	3.64
	3	4.42	2.16	2.76	4.67	3.11	4.14	6.49	6.66	5.63	3.07	2.53	3.33
	4	2.83	1.5	3.05	5.91	3.32	4.18	4.41	5.01	5.29	2.63	2.9	2.38
	5	3.32	2.63	1.67	6.36	2.99	6.42	5.27	4	2.57	1.25	3.54	2.27
	6	3.87	2.24	2.74	3.5	4.4	7.35	4.82	3.51	1.88	1.53	3.54	2.7
	7	3.99	1.73	2.67	2.76	4.82	6.54	5.97	2.92	2.06	1.66	2.94	2.78
	8	4.2	1.85	3.39	3.87	4.24	5.2	5.1	2.39	2.17	2.02	3.06	2.52
	9	3.87	1.29	3.12	3.13	5.64	6.27	4.69	1.99	1.82	2.73	3.13	2.48
	10	4.34	1.42	2.41	4.73	6.15	5.93	4.7	2.57	3.62	2.76	3.73	2.85
	11	4.07	2.19	4.69	5.89	6.04	6.76	3.91	4.92	3.96	2.54	4.15	2.68
	12	3.63	2.04	3.19	5.27	4.82	6.83	4.81	6.64	3.43	2.95	3.24	1.75
	13	3.48	2.15	3.35	3.66	5.14	5.33	5.23	5.74	1.9	3.09	3	4.37
	14	2.84	3.84	3.37	3.41	5.07	4.13	5.71	5.03	2.83	1.85	2.9	3.72
	15	2.57	4.72	3.85	2.96	3.57	3.47	6.89	5.9	2.15	1.77	2.9	2.83
	16	1.93	5.69	2.5	3.73	2.58	4.03	6.24	5.79	2.43	1.86	2.73	2.36
	17	2.1	5.51	2.47	4.38	3.32	3.48	5.4	5.94	2.53	2.15	3.2	1.73
	18	3.59	2.03	3.66	2.47	2.85	2.06	5.14	4.77	2.27	2.02	3.33	1.84
	19	2.08	1.68	4.67	2.99	2.91	2.27	5.7	3.35	5.06	1.27	2.72	2.13
	20	1.75	2.4	3.54	2.87	2.67	2.56	6.67	2.88	6.73	1.75	1.7	2.29
	21	3.36	2.89	2.62	3.38	2.77	3.41	6.77	6.33	7.48	1.83	2.39	1.96
	22	3.1	2.29	3.13	2.25	2.35	3.92	5.38	7.58	6.42	2.47	2.92	2.05
	23	3.92	2.73	3.38	2.9	2.97	4.84	4.45	6.53	6.18	3.09	2.69	2.1
	24	3.77	3.03	2.43	2.22	2.81	3.29	3.44	4.2	5.2	3.31	3.22	3.73
	25	5.26	3.09	2.48	2.97	3.73	2.45	2.82	4.19	2.95	3.21	3.33	3.29
	26	3.34	3.64	3.3	3.56	6.95	2.89	3.68	4.3	2.06	2.05	2.22	2.62
	27	2.33	5.04	4.81	3.39	6.42	2.9	5.59	3.04	2.82	1.94	2.34	2.3
	28	2.04	5.34	2.83	3.24	5.16	3.98	7.58	4.57	2.21	1.99	3.09	2.85
	29	1.89		3.27	3.28	5.2	4.7	6.82	6.18	1.29	2.22	3.24	2.74
	30	2.04		3.37	6.11	6.18	5.7	5.44	4.87	1.81	2.63	3.21	2.45
	31	1.64		3.12		6.32		4.84	2.65		2.42		2.14
Total Average		**3.11**	**2.8**	**3.15**	**3.73**	**4.24**	**4.53**	**5.42**	**4.47**	**3.39**	**2.25**	**2.96**	**2.65**

Table C-8: Daily average wind Speed at Khagrachari, (January - December),2006.

Location	Date	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Khagrachari,2006	1	1.92	2.85	3.69	4.42	4.27	5.95	2.89	2.65	2.43	1.89	2.55	2.18
	2	1.95	2.54	3.45	3.97	4.3	4.59	3.33	3.85	3.42	1.25	2.63	2.5
	3	1.91	2.18	3.79	4.32	4.04	3.47	3.95	2.74	3.34	2.28	2.69	2.05
	4	2.59	2.57	4.21	4.58	4.5	3.89	2.93	3.06	3.65	2.28	2.59	1.89
	5	3.05	3.15	2.68	5.02	4.81	7.15	3.58	2.94	2.34	1.65	2.78	1.78
	6	2.42	2.95	2.8	4.14	3.99	8.11	4.31	3.47	3.98	1.72	2.41	1.83
	7	2.55	3.35	3.19	3.51	4.33	7.63	3.64	2.59	3.84	2.57	1.85	2.02
	8	2.51	1.93	3.28	4.5	3.82	6.9	3.37	3.08	2.99	2.35	2.52	2.07
	9	1.78	2.85	4.05	3.48	3.78	6.5	3.08	1.89	3.34	3.05	2.11	2.4
	10	2.15	2.63	3.62	4.77	4.04	6.64	3.39	3.74	2.73	2.75	2.71	2.59
	11	2.81	2.53	4.6	5.21	5.05	7.45	3.71	2.41	2.33	2.92	2.95	3.21
	12	2.83	2.99	3.67	4.9	5.57	7.31	3.24	3.51	2.86	2.07	2.19	3.12
	13	2.76	2.81	2.95	4.49	3.68	7.27	3.73	3.3	2.17	2.73	2.97	2.9
	14	3.48	4.34	3.89	5.4	2.6	5.19	2.89	2.85	2.55	2.56	2.62	3.13
	15	2.64	4.7	3.53	4.21	2.2	3.49	3.74	2.31	2.84	1.59	2.68	2.02
	16	2.77	5.08	3.22	3.95	2.35	5.36	3.87	3	2.61	1.91	2.66	2.5
	17	3.46	5.3	3.16	4	1.66	4.41	3.35	3.45	2.52	2.42	2.43	3.52
	18	3.86	2.87	4.37	3.65	1.86	2.96	3.15	3.2	2.59	2.47	2.1	2.04
	19	3.78	3.66	4.82	2.81	2.04	2.72	3.46	2.7	2.72	2.3	1.72	1.61
	20	3.17	2.98	4.4	3.68	1.78	2.93	3.32	2.6	4.94	2.6	1.51	2.52
	21	2.99	3.25	3.96	3.24	2.53	3.44	3.73	3.69	5.11	2.57	3.22	2.79
	22	2.88	3.26	4.46	4.31	2.56	3.58	3.11	4.64	5	2.42	2.65	1.44
	23	2.8	4.37	4.18	3.29	2.41	3.52	2.76	3.89	4.07	2.63	2.69	2.04
	24	3.06	4.11	3.83	3.78	2.91	2.54	3.26	3.21	3.03	2.81	2.38	2.86
	25	3.21	3.75	5.01	4.1	2.45	2.66	2.47	2.79	3.39	2.8	2.14	3.2
	26	3.49	4.1	5.06	4.02	3	2.64	2.27	2.97	2.37	2.74	2.48	2.55
	27	3.72	4.8	4.8	3.84	2.26	2.71	2.83	2.97	2.46	2.62	3.64	1.88
	28	3.32	4.74	3.14	3.08	2.79	2.86	4.88	2.71	3.19	2.17	2.66	1.74
	29	3.15		3.76	3.55	2.6	2.89	3.94	3.58	3.63	2.53	2.36	2.61
	30	2.93		4.66	5.51	6.12	3.33	2.51	3.1	3.16	2.63	1.96	2.3
	31	2.54		3.94		6.36		3.39	3.14		2.48		2.2
Total Average		**2.85**	**3.45**	**3.88**	**4.16**	**3.44**	**4.67**	**3.36**	**3.1**	**3.19**	**2.38**	**2.53**	**2.37**

Table C-9: Daily average wind Speed at Sitakunda, (January - December),2006.

Location	Date	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Sitakunda,2006	1	2.29	1.24	3.62	3.98	4.67	5.94	4.82	3.44	1.83	1.23	2.41	2.96
	2	2.24	1.45	2.6	4.39	3.65	4.24	6.29	6.13	1.63	1.78	2.4	3
	3	2.19	1.68	2.87	5.48	3.76	3.62	7.37	6.05	1.87	2.07	2.72	2.77
	4	3.27	1.39	2.76	7.32	4.31	4.08	4.74	5.52	2.67	2.39	2.9	1.78
	5	3.65	2.92	1.96	7.36	3.99	7.2	5.93	4.51	3.93	1.93	3.31	1.96
	6	3.27	2.77	2.26	4.44	5.28	8.16	5.46	3.2	2.7	2.34	3.05	2
	7	3.25	1.55	2.44	4.22	4.33	7.71	5.22	4.07	1.62	2.45	2.46	3.03
	8	3.15	1.62	3.07	4.67	4.32	6.67	4.11	2.59	2.4	2.03	2.75	2.21
	9	3.35	1.7	3.56	3.27	5.65	6.56	4.8	2.31	2.83	2.5	1.91	2.43
	10	3.67	2.14	2.87	5.9	6.15	6.61	5.44	2.34	4	2.42	2.94	2.07
	11	3.27	2.5	5.14	7.13	6.64	7.65	5.09	3.21	3.19	2.07	3.69	3.08
	12	3.49	2.55	3.56	6.55	5.68	7.27	5.12	6.38	2.32	2.94	2.81	2.35
	13	3.33	2.07	3.41	4.61	4.68	7.02	5.62	5.48	2.18	3.48	2.67	3.22
	14	1.98	4.06	4.05	4.36	4.48	5.07	5.2	4.84	3.6	1.8	2.7	3.54
	15	1.84	4.73	2.97	4.1	3.21	3.65	7.16	4.26	10.6	1.91	2.67	2.7
	16	1.34	6.21	2.43	4.81	3.59	5.19	6.03	5.22	39.2	1.66	2.35	1.71
	17	2.06	5.69	3.48	4.59	2.91	4.35	5.31	5.51	31.4	2	2.74	2.13
	18	4.16	2.74	3.9	2.91	2.68	2.98	5.75	4.98	31.6	2.13	3.18	1.91
	19	2.83	2.69	4.72	2.82	3.05	2.62	5.81	3.35	32.5	2.15	2.24	1.64
	20	1.44	2.97	4.1	3.15	3.24	3.14	7.59	3.24	35.5	2.07	1.86	1.8
	21	2.8	3.95	2.11	3.24	3.23	3.18	7.59	6.25	31.5	1.99	2.26	1.2
	22	2.77	3.5	4.26	2.94	2.71	3.85	5.44	8.32	29.3	2.18	2.67	1.11
	23	3.64	3.83	3.96	2.95	3.01	4.49	4.44	7.91	7.3	3.02	2.34	2
	24	3.46	4.07	2.56	2.09	2.63	3.36	3.79	6.44	4.22	3.16	2.78	3.67
	25	3.91	3.57	3.69	3.35	3.29	2.14	3.92	11.8	2.95	2.66	3.2	3.26
	26	2.99	4.34	4.45	3.92	7.08	3.34	2.91	13.8	1.49	2.31	2.22	1.82
	27	2.23	5.55	4.8	3.61	7.55	2.78	4.31	4.14	2.03	1.91	2.45	1.2
	28	1.38	5.27	3.32	3.5	5.83	3.94	6.24	5.09	1.8	1.75	2.8	2.09
	29	1.78		3.26	3.05	4.74	3.38	6.16	3.56	2.04	2.22	3	3.03
	30	2		2.75	5.72	5.63	4.14	4.75	2.77	2.5	2.69	3.58	2.7
	31	1.16		3.15		6.36		3.65	2.94		2.62		1.44
Total Average		**2.72**	**3.17**	**3.36**	**4.41**	**4.46**	**4.8**	**5.35**	**5.15**	**10.1**	**2.25**	**2.64**	**2.32**

Table C-10: Daily average wind Speed at Pakshey, (January - December),2006.

Location	Date	Month											
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Pakshey,2006	**1**	3.12	1.65	2.17	3.39	4.22	4.04	3	2.34	6.05	1.51	1.74	1.99
	2	2.85	1.27	2.41	4.32	4.33	3.07	5.37	5.23	4.53	1.64	1.92	2.59
	3	2.61	1.27	1.99	3.96	3.31	2.24	5.72	5.11	4.92	1.73	2.21	2.76
	4	2.16	2.26	2.43	3.72	4.09	1.9	4	4.27	3.67	2.47	2.38	2.57
	5	3.44	1.98	2.31	2.84	4.03	2.25	3.47	3.87	2.98	2.18	1.79	2.33
	6	3.36	2.05	2.29	3.46	3.41	4.3	3.22	2.77	3	2.13	1.54	1.92
	7	2.97	1.73	2.89	3.91	3.93	3.78	2.74	2.18	3.09	1.81	1.67	1.41
	8	3.02	1.73	1.91	3.39	2.92	3.26	2.41	1.84	3.22	1.83	1.14	1.23
	9	2.32	1.42	1.68	2.57	2.59	2.48	2.63	0.97	1.79	1.27	1.47	1.64
	10	1.87	1.97	2.74	4.2	3.52	2.46	3.97	2.55	1.51	0.59	1.09	1.65
	11	2.22	1.53	3.99	3.93	2.42	4.08	3.97	1.53	2.34	0.6	2.71	2.17
	12	2.18	1.82	2.67	3.77	4.94	4.16	3.06	5.26	3.13	1.88	2.26	2.87
	13	1.11	2.07	1.94	3.69	3.01	4.68	2.22	4.21	2.81	1.84	2.31	2.06
	14	1.81	1.87	1.99	3.88	3.08	4.41	2.78	2.78	2.59	2.02	2.36	2.89
	15	1.59	2.67	3.46	3.31	2.95	3.74	4.04	3.5	2.37	1.04	2.1	2.94
	16	1.62	3.16	2.19	3.1	3.01	3.28	4.44	5.67	2	1.23	2.27	2.37
	17	2.01	1.98	1.69	4.43	1.63	2.45	3.8	4.97	2.11	1.81	1.5	2.58
	18	2.27	2.51	2.59	2.8	2.01	2.3	3.11	3.55	1.48	1.76	2.18	2.88
	19	2.12	2.52	2.21	2.44	3.13	1.97	2.74	1.97	2.98	1.69	1.89	2.04
	20	2.76	2.24	2.16	1.93	2.18	2.03	4.54	1.35	6.7	2.5	2.77	1.87
	21	3.13	2.03	2.65	2.46	2.1	2.76	4.73	2.93	6.81	2.1	2.26	1.56
	22	2.48	2.81	2.69	3.13	2.49	2.59	2.97	5.55	5.39	2.07	2.1	1.55
	23	2.15	2.4	2.12	3.02	1.87	2.48	2.86	4.07	5.04	2.07	2.27	2.5
	24	2.82	3.4	2.51	3.02	1.68	2.45	2.86	2.54	4.27	2.14	1.47	2.54
	25	3.54	3.27	3.77	2.62	1.73	2.15	2.85	2.99	3.51	2.18	2.21	2.39
	26	3.51	3.7	3.1	2.8	3.42	3.04	2.63	2.7	1.87	2.24	2.07	1.55
	27	3.57	4.18	2.77	3.61	1.43	2.27	2.28	2.64	1.02	2.34	2.38	1.62
	28	3.14	3.83	2.96	2.54	3.52	2.42	3.42	11.3	2.41	2.31	2.5	1.95
	29	2.57		3.02	2.38	2.98	2.01	6.39	6.92	2.04	2.5	2.31	2.38
	30	2.54		2.81	2.73	4.44	2.89	4.35	5.15	2.02	2.47	2.19	2.73
	31	2.21		2.38		4.05		1.98	6.07		2.53		2.54
Total Average		**2.55**	**2.33**	**2.53**	**3.26**	**3.04**	**2.93**	**3.5**	**3.83**	**3.26**	**1.89**	**2.02**	**2.2**

Table C-11: Daily average wind Speed at Rauzan, (January - December),2006.

Location	Date	Month											
		January	February	March	April	May	June	July	August	September	October	November	December
Rauzan,2006	**1**	0.98	1.81	2.5	2.93	2.93	5.97	2.78	2.38	1.63	1.23	1	1.24
	2	1.02	1.44	1.5	3.17	2.45	4.37	3.5	3.64	1.96	0.76	1.06	0.86
	3	1.16	1.24	1.72	3.38	2.43	3.56	4.12	3.47	3.24	0.99	0.97	0.88
	4	1.34	1.48	1.63	4.25	2.71	4	2.75	3.33	2.83	1.06	0.9	1.37
	5	1.47	2.06	1.81	3.81	2.63	7.15	3.02	2.63	1.76	1.55	1.16	2.06
	6	1.31	1.01	1.99	3.29	3.5	8.15	3.4	2.63	1.41	1.16	1.11	0.97
	7	1.11	1.54	2.09	2.75	2.9	7.65	3.44	2.18	1.38	1.75	0.96	0.69
	8	1.6	1.61	1.89	3.2	2.77	6.8	2.8	1.61	1.6	1.17	1.89	1.12
	9	2	1.4	1.77	2.03	3.58	6.53	3.21	0.97	1.42	1.97	0.79	1.21
	10	2.03	1.18	1.66	3.39	3.37	6.61	3.28	2.09	2.03	1.66	1.16	1.58
	11	1.57	1.39	2.34	4.36	4.53	7.57	3.11	2.14	1.83	1.76	1.52	1.42
	12	1.25	1.23	1.85	4.19	3.22	7.26	3.16	3.7	2.23	1.95	0.89	0.85
	13	1.11	1.81	1.86	3.18	2.79	7.15	2.58	3.26	1.79	2.35	0.96	2.11
	14	1.5	2.92	2.1	3.01	4.15	5.11	3.11	2.83	1.84	1.67	0.69	1.39
	15	1.46	3.05	1.54	2.69	1.03	3.59	4.07	2.41	1.65	1.12	0.71	1.04
	16	1.01	3.61	1.45	3.33	1.35	5.26	3.64	2.77	2.61	0.86	0.62	1.72
	17	1.56	3.18	1.96	2.65	1.72	4.38	3.14	2.91	1.67	0.79	0.7	1.19
	18	2.61	2.12	2.48	2.2	2	2.99	3.28	3.01	1.5	0.75	0.94	1.95
	19	2.44	1.78	2.6	2.39	1.22	2.65	3.8	2.12	2.6	0.9	0.77	1.2
	20	1.13	2.07	2.25	2.11	1.42	3.12	3.64	1.92	3.94	1.25	1.46	1.14
	21	1.8	2.81	1.94	2.03	2.72	3.21	3.93	3.97	4.16	1.55	2.62	1.42
	22	1.84	2.31	2.56	1.82	2.37	3.75	3.3	4.41	3.98	0.75	0.7	1.29
	23	1.57	2.12	2.64	2.48	1.74	3.71	2.71	4.54	3.92	0.87	0.62	1.35
	24	1.57	2.52	2.08	1.99	1.43	2.55	1.93	3.3	2.46	0.98	0.68	1.05
	25	2.06	2.01	2.66	2.88	1.76	2.01	1.75	2.87	2.11	0.76	0.97	1.01
	26	1.69	2.6	3.1	2.59	1.88	2.1	1.98	2.74	1.2	0.98	2.12	0.85
	27	1.44	2.94	2.72	3.05	1.56	1.62	2.72	2.28	0.67	1.19	1.58	0.82
	28	1.71	3.02	2.08	2.58	2.55	2.4	4.29	2.16	1.52	0.82	1.3	1.04
	29	1.81		1.69	1.58	3.63	2.48	3.88	3.43	1.46	0.79	1.34	0.87
	30	1.49		1.97	3.57	6.24	2.84	2.97	2.79	1.88	0.85	0.85	0.79
	31	1.38		2.39		6.37		2.02	2.03		1.19		0.65
Total Average		**1.55**	**2.08**	**2.09**	**2.94**	**2.74**	**4.55**	**3.14**	**2.79**	**2.14**	**1.21**	**1.33**	**1.2**

Appendix – D

Data Analysis of Each Location

Table D-1: Data analysis of wind speed January, 2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, " E" (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	35	744	0.047	35	0.047043	709	0.952957	0.5	0.4375
1-2	70	744	0.094	105	0.141129	674	0.858871	1.5	23.625
2-3	239	744	0.321	344	0.4623656	505	0.53763	2.5	373.4375
3-4	250	744	0.336	594	0.7983871	494	0.201613	3.5	1071.875
4-5	115	744	0.154	709	0.952957	629	0.0470	4.5	1047.938
5-6	31	744	0.041	740	0.9946237	713	0.0054	5.5	515.7625
6-7	4	744	0.005	744	1	740	0.0000	6.5	109.85
Total,	**744**								**3142.925**

Table D-2: Calculated Data for Kuakata, January, ***k* =2.92, *c* = 3.42**

Velocity, m/s	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency, hrs	Cumulative velocity Frequency, hrs	Velocity Duration	Mean Velocity, m/s	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.078	0.027	0.973	58.2935	20.2414	723.75	0.5	0.728669
2	0.247	0.188	0.812	184.04	140.178	603.82	1.5	62.11361
3	0.336	0.494	0.506	249.716	367.862	376.13	2.5	390.1819
4	0.238	0.794	0.206	176.753	590.756	153.24	3.5	757.828
5	0.085	0.952	0.048	63.5511	708.102	35.898	4.5	579.1094
6	0.014	0.994	0.006	10.7073	739.738	4.2619	5.5	178.1428
7	0.001	1	3E-04	0.76499	743.774	0.2264	6.5	21.00862
							Total Energy =	**1989.113**

Table D-3: Data analysis of wind speed February,2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	10	672	0.014881	10	0.014881	662	0.9851	0.5	0.125
1-2	35	672	0.052083	45	0.066964	637	0.933	1.5	11.8125
2-3	163	672	0.24256	208	0.309524	509	0.690	2.5	254.6875
3-4	227	672	0.337798	435	0.647321	445	0.352	3.5	973.2625
4-5	178	672	0.264881	613	0.912202	494	0.0878	4.5	1622.025
5-6	44	672	0.065476	657	0.977679	628	0.0223	5.5	732.05
6-7	7	672	0.010417	664	0.988095	665	0.0119	6.5	192.2375
7-8	6	672	0.008929	670	0.997024	666	0.0030	7.5	253.125
8-9	2	672	0.002976	672	1	670	0.0000	8.5	122.825
Total	**672**								**4162.15**

Table D-4: Calculated Data for Kuakata, February, ***k* =3.00, *c* = 4.02**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.045	0.015	0.985	30.558	10.2649	661.735	0.5	0.381977
2	0.163	0.116	0.884	109.75	77.8601	594.14	1.5	37.03954
3	0.274	0.34	0.66	184.31	228.522	443.478	2.5	287.9903
4	0.276	0.627	0.373	185.39	421.086	250.914	3.5	794.8621
5	0.169	0.854	0.146	113.27	573.885	98.1149	4.5	1032.181
6	0.06	0.964	0.036	40.192	647.823	24.1765	5.5	668.6936
7	0.012	0.995	0.005	7.7451	668.577	3.42286	6.5	212.7005
8	0.001	1	4E-04	0.7503	671.746	0.25387	7.5	31.65328
9	5E-05	1	1E-05	0.0336	671.991	0.00899	8.5	2.066027
							Total Energy =	**3067.568**

Table D-5: Data analysis of wind speed March, 2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	15	744	0.02	15	0.02	729	0.9798	0.5	0.1875
1-2	57	744	0.077	72	0.097	687	0.9032	1.5	19.2375
2-3	147	744	0.198	219	0.294	597	0.70565	2.5	229.6875
3-4	286	744	0.384	505	0.679	458	0.3212	3.5	1226.225
4-5	162	744	0.218	667	0.897	582	0.1035	4.5	1476.225
5-6	56	744	0.075	723	0.972	688	0.0282	5.5	931.7
6-7	15	744	0.02	738	0.992	729	0.0081	6.5	411.9375
7-8	2	744	0.003	740	0.995	742	0.0054	7.5	84.375
8-9	3	744	0.004	743	0.999	741	0.0013	8.5	184.2375
9-10	1	744	0.001	744	1	743	0.0000	9.5	85.7375
Total	**744**								**4649.55**

Table D-6: Calculated Data for Kuakata, March, ***k* =3.00, *c* = 4.02**

Velocity	Calculated, f(v)	Calculated F(v) =1-$e^{-(\frac{v}{c})^k}$	Calculated S(v)= $e^{-(\frac{v}{c})^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.042	0.014	0.986	31.427	10.208	733.792	0.5	0.392832
2	0.163	0.112	0.888	121.34	83.1113	660.889	1.5	40.95334
3	0.284	0.341	0.659	211.08	253.36	490.64	2.5	329.8084
4	0.285	0.638	0.362	212.09	474.551	269.449	3.5	909.3511
5	0.165	0.868	0.132	123.08	646.137	97.8628	4.5	1121.544
6	0.052	0.972	0.028	38.647	723.046	20.9543	5.5	642.9883
7	0.008	0.997	0.003	5.9971	741.648	2.3524	6.5	164.6954
8	6E-04	1	2E-04	0.4147	743.877	0.1229	7.5	17.49577
9	2E-05	1	4E-06	0.0114	743.997	0.00265	8.5	0.702574
10	2E-07	1	3E-08	0.0001	744	2.1E-05	9.5	0.009616
							Total Energy =	**3227.942**

Table D-7: Observed data; Data analysis of wind speed April, 2006 at Kuakata.

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	3	720	0.004	3	0.004	717	0.9958	0.5	0.0375
1-2	35	720	0.049	38	0.053	685	0.9472	1.5	11.8125
2-3	67	720	0.093	105	0.146	653	0.85417	2.5	104.6875
3-4	90	720	0.125	195	0.271	630	0.7292	3.5	385.875
4-5	160	720	0.222	355	0.493	560	0.5069	4.5	1458
5-6	149	720	0.207	504	0.7	571	0.3000	5.5	2478.9875
6-7	113	720	0.157	617	0.857	607	0.1431	6.5	3103.2625
7-8	66	720	0.092	683	0.949	654	0.0514	7.5	2784.375
8-9	26	720	0.036	709	0.985	694	0.0153	8.5	1596.725
9-10	11	720	0.015	720	1	709	0.0000	9.5	943.1125
Total	**720**								**12866.875**

Table D-8: Calculated Data for Kuakata, April, ***k* =2.55, *c* = 5.58**

Velocity	Calculated, f(v)	Calculated F(v) =1-$e^{-(\frac{v}{c})^k}$	Calculated S(v)= $e^{-(\frac{v}{c})^k}$	velocity Frequency	Cumulativ e velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.031	0.012	0.988	22.622	8.92707	711.073	0.5	0.282779
2	0.087	0.07	0.93	62.348	50.7309	669.269	1.5	21.04234
3	0.142	0.186	0.814	102.39	133.728	586.272	2.5	159.9854
4	0.178	0.348	0.652	128.03	250.646	469.354	3.5	548.9348
5	0.181	0.53	0.47	130.34	381.892	338.108	4.5	1187.735
6	0.154	0.7	0.3	110.54	503.851	216.149	5.5	1839.069
7	0.109	0.832	0.168	78.638	598.91	121.09	6.5	2159.597
8	0.065	0.918	0.082	46.93	661.246	58.754	7.5	1979.857
9	0.033	0.966	0.034	23.414	695.578	24.4219	8.5	1437.919
10	0.013	0.988	0.012	9.7152	711.393	8.60655	9.5	832.9577
11	0.005	0.996	0.004	3.3319	717.454	2.54629	10.5	385.7074
12	0.001	0.999	9E-04	0.9382	719.373	0.62651	11.5	142.683
13	3E-04	1	2E-04	0.2154	720	0.12704	12.5	42.06459
							Total Energy =	**10749.83**

Table D-9: Observed data; Data analysis of wind speed May,2006 at Kuakata.

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	$T-h_i$	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	14	744	0.019	14	0.019	730	0.9812	0.5	0.175
1-2	39	744	0.052	53	0.071	705	0.9288	1.5	13.1625
2-3	76	744	0.102	129	0.173	668	0.82661	2.5	118.75
3-4	128	744	0.172	257	0.345	616	0.6546	3.5	548.8
4-5	139	744	0.187	396	0.532	605	0.4677	4.5	1266.6375
5-6	110	744	0.148	506	0.68	634	0.3199	5.5	1830.125
6-7	104	744	0.14	610	0.82	640	0.1801	6.5	2856.1
7-8	69	744	0.093	679	0.913	675	0.0874	7.5	2910.9375
8-9	49	744	0.066	728	0.978	695	0.0215	8.5	3009.2125
9-10	14	744	0.019	742	0.997	730	0.0027	9.5	1200.325
10-11	2	744	0.003	744	1	742	0.0000	10.5	231.525
Total	**744**								**13985.75**

Table D-10: Calculated Data for Kuakata, May, ***k* =2.40, *c* = 5.60**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^{k}}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^{k}}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.038	0.016	0.984	28.131	11.8154	732.185	0.5	0.351634
2	0.093	0.081	0.919	69.323	60.2803	683.72	1.5	23.39666
3	0.143	0.2	0.8	106.41	149.062	594.938	2.5	166.273
4	0.171	0.36	0.64	127.45	267.683	476.317	3.5	546.4425
5	0.171	0.533	0.467	127	396.704	347.296	4.5	1157.326
6	0.145	0.693	0.307	107.91	515.403	228.597	5.5	1795.272
7	0.106	0.819	0.181	78.946	609.217	134.783	6.5	2168.058
8	0.067	0.905	0.095	49.915	673.313	70.6874	7.5	2105.774
9	0.037	0.956	0.044	27.283	711.236	32.7642	8.5	1675.546
10	0.017	0.982	0.018	12.876	730.658	13.3418	9.5	1103.943
11	0.007	0.994	0.006	5.2345	739.254	4.74642	10.5	605.9594
12	0.002	0.998	0.002	1.828	742.533	1.46747	11.5	278.0196
13	7E-04	0.999	5E-04	0.5467	743.608	0.39234	12.5	106.7759
14	2E-04	1	1E-04	0.1396	743.91	0.09028	13.5	34.33481
15	4E-05	1	2E-05	0.0303	743.982	0.0178	14.5	9.238328
16	7E-06	1	4E-06	0.0056	743.997	0.00299	15.5	2.077442
17	1E-06	1	6E-07	0.0009	744	0.00043	16.5	0.3898
							Total Energy =	**11779.18**

Table D-11: Data analysis of wind speed June, 2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	3	720	0.004	3	0.004	717	0.9958	0.5	0.0375
1-2	30	720	0.042	33	0.046	690	0.9542	1.5	10.125
2-3	80	720	0.111	113	0.157	640	0.84306	2.5	125
3-4	107	720	0.149	220	0.306	613	0.6944	3.5	458.7625
4-5	106	720	0.147	326	0.453	614	0.5472	4.5	965.925
5-6	141	720	0.196	467	0.649	579	0.3514	5.5	2345.8875
6-7	128	720	0.178	595	0.826	592	0.1736	6.5	3515.2
7-8	85	720	0.118	680	0.944	635	0.0556	7.5	3585.9375
8-9	29	720	0.04	709	0.985	691	0.0153	8.5	1780.9625
9-10	10	720	0.014	719	0.999	710	0.0014	9.5	857.375
10-11	1	720	0.001	720	1	719	0.0000	10.5	115.7625
Total	**720**								**13760.975**

Table D-12: Calculated Data for Kuakata, June, ***k* =2.70, *c* = 5.74**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	E=0.1V^3h_i
1	0.024	0.009	0.991	17.209	6.40225	713.598	0.5	0.215112
2	0.074	0.056	0.944	53.233	40.5984	679.402	1.5	17.96606
3	0.131	0.159	0.841	94.496	114.651	605.349	2.5	147.65
4	0.175	0.314	0.686	125.7	226.208	493.792	3.5	538.9537
5	0.187	0.498	0.502	134.49	358.468	361.532	4.5	1225.56
6	0.164	0.676	0.324	118.31	486.731	233.269	5.5	1968.359
7	0.119	0.819	0.181	85.933	589.626	130.374	6.5	2359.93
8	0.071	0.914	0.086	51.355	657.909	62.0912	7.5	2166.547
9	0.035	0.966	0.034	25.065	695.194	24.8061	8.5	1539.324
10	0.014	0.989	0.011	9.8973	711.811	8.18873	9.5	848.5723
11	0.004	0.997	0.003	3.1284	717.799	2.20117	10.5	362.1523
12	0.001	0.999	7E-04	0.7828	719.525	0.47502	11.5	119.0467
13	2E-04	1	1E-04	0.1533	719.919	0.08117	12.5	29.93227
14	3E-05	1	2E-05	0.0232	719.989	0.01084	13.5	5.709542
15	4E-06	1	2E-06	0.0027	719.999	0.00112	14.5	0.818831
16	3E-07	1	1E-07	0.0002	720	8.7E-05	15.5	0.087453
							Total Energy =	**11330.82**

Table D-13: Data analysis of wind speed July, 2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	$T-h_i$	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	3	744	0.004	3	0.004	741	0.996	0.5	0.0375
1-2	16	744	0.022	19	0.026	728	0.9745	1.5	5.4
2-3	39	744	0.052	58	0.078	705	0.92204	2.5	60.9375
3-4	67	744	0.09	125	0.168	677	0.832	3.5	287.2625
4-5	132	744	0.177	257	0.345	612	0.6546	4.5	1202.85
5-6	152	744	0.204	409	0.55	592	0.4503	5.5	2528.9
6-7	134	744	0.18	543	0.73	610	0.2702	6.5	3679.975
7-8	94	744	0.126	637	0.856	650	0.1438	7.5	3965.625
8-9	64	744	0.086	701	0.942	680	0.0578	8.5	3930.4
9-10	30	744	0.04	731	0.983	714	0.0175	9.5	2572.125
10-11	12	744	0.016	743	0.999	732	0.0013	10.5	1389.15
11-12	1	744	0.001	744	1	743	0.0000	11.5	152.0875
12-13	0	744	0	744	1	744	0.0000	12.5	0
Total	**744**								**19774.75**

Table D-14: Calculated Data for Kuakata, July, ***k* =2.83, *c* = 6.50**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	E=$0.1V^3h_i$
1	0.024	0.009	0.991	17.209	6.40225	713.598	0.5	0.215112
2	0.074	0.056	0.944	53.233	40.5984	679.402	1.5	17.96606
3	0.131	0.159	0.841	94.496	114.651	605.349	2.5	147.65
4	0.175	0.314	0.686	125.7	226.208	493.792	3.5	538.9537
5	0.187	0.498	0.502	134.49	358.468	361.532	4.5	1225.56
6	0.164	0.676	0.324	118.31	486.731	233.269	5.5	1968.359
7	0.119	0.819	0.181	85.933	589.626	130.374	6.5	2359.93
8	0.071	0.914	0.086	51.355	657.909	62.0912	7.5	2166.547
9	0.035	0.966	0.034	25.065	695.194	24.8061	8.5	1539.324
10	0.014	0.989	0.011	9.8973	711.811	8.18873	9.5	848.5723
11	0.004	0.997	0.003	3.1284	717.799	2.20117	10.5	362.1523
12	0.001	0.999	7E-04	0.7828	719.525	0.47502	11.5	119.0467
13	2E-04	1	1E-04	0.1533	719.919	0.08117	12.5	29.93227
14	3E-05	1	2E-05	0.0232	719.989	0.01084	13.5	5.709542
15	4E-06	1	2E-06	0.0027	719.999	0.00112	14.5	0.818831
16	3E-07	1	1E-07	0.0002	720	8.7E-05	15.5	0.087453
							Total Energy =	**11330.82**

Table D-15: Data analysis of wind speed August, 2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	$T-h_i$	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	11	744	0.015	11	0.015	733	0.9852	0.5	0.1375
1-2	39	744	0.052	50	0.067	705	0.9328	1.5	13.1625
2-3	49	744	0.066	99	0.133	695	0.86694	2.5	76.5625
3-4	68	744	0.091	167	0.224	676	0.7755	3.5	291.55
4-5	119	744	0.16	286	0.384	625	0.6156	4.5	1084.3875
5-6	116	744	0.156	402	0.54	628	0.4597	5.5	1929.95
6-7	78	744	0.105	480	0.645	666	0.3548	6.5	2142.075
7-8	88	744	0.118	568	0.763	656	0.2366	7.5	3712.5
8-9	78	744	0.105	646	0.868	666	0.1317	8.5	4790.175
9-10	69	744	0.093	715	0.961	675	0.0390	9.5	5915.8875
10-11	22	744	0.03	737	0.991	722	0.0094	10.5	2546.775
11-12	7	744	0.009	744	1	737	0.0000	11.5	1064.6125
12-13	0	744	0	744	1	744	0.0000	12.5	0
Total	**744**								**23567.775**

Table D-16: Calculated Data for Kuakata, August, ***k* =2.18, *c* = 6.90**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.032	0.015	0.985	23.708	10.9563	733.044	0.5	0.29635
2	0.069	0.065	0.935	50.975	48.3738	695.626	1.5	17.20404
3	0.1	0.15	0.85	74.761	111.725	632.275	2.5	116.8139
4	0.122	0.263	0.737	91.088	195.388	548.612	3.5	390.5404
5	0.132	0.391	0.609	97.931	290.716	453.284	4.5	892.3963
6	0.128	0.522	0.478	95.351	388.088	355.912	5.5	1586.406
7	0.115	0.644	0.356	85.196	478.882	265.118	6.5	2339.705
8	0.095	0.749	0.251	70.377	556.924	187.076	7.5	2969.018
9	0.073	0.832	0.168	53.985	619.118	124.882	8.5	3315.351
10	0.052	0.894	0.106	38.56	665.228	78.7724	9.5	3306.055
11	0.035	0.937	0.063	25.69	697.101	46.899	10.5	2973.996
12	0.021	0.965	0.035	15.982	717.671	26.3291	11.5	2430.686
13	0.012	0.981	0.019	9.2898	730.075	13.9248	12.5	1814.413
14	0.007	0.991	0.009	5.0471	737.068	6.93173	13.5	1241.766
15	0.003	0.996	0.004	2.5633	740.755	3.24523	14.5	781.4528
16	0.002	0.998	0.002	1.217	742.572	1.42779	15.5	453.1976
17	7E-04	0.999	8E-04	0.5401	743.41	0.58991	16.5	242.6235
18	3E-04	1	3E-04	0.224	743.771	0.22872	17.5	120.0628
19	1E-04	1	1E-04	0.0868	743.917	0.08317	18.5	54.97358
20	4E-05	1	4E-05	0.0314	743.972	0.02834	19.5	23.30817
21	1E-05	1	1E-05	0.0106	743.991	0.00905	20.5	9.156513
22	5E-06	1	4E-06	0.0034	743.997	0.0027	21.5	3.334381
23	1E-06	1	1E-06	0.001	743.999	0.00076	22.5	1.125922
24	4E-07	1	3E-07	0.0003	744	0.0002	23.5	0.352624
Total Energy =								**25084.23**

Table D-17: Data analysis of wind speed September, 2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i$/T	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	10	720	0.014	10	0.014	710	0.9861	0.5	0.125
1-2	48	720	0.067	58	0.081	672	0.9194	1.5	16.2
2-3	95	720	0.132	153	0.213	625	0.78750	2.5	148.4375
3-4	135	720	0.188	288	0.4	585	0.6	3.5	578.8125
4-5	157	720	0.218	445	0.618	563	0.3819	4.5	1430.6625
5-6	100	720	0.139	545	0.757	620	0.2431	5.5	1663.75
6-7	46	720	0.064	591	0.821	674	0.1792	6.5	1263.275
7-8	25	720	0.035	616	0.856	695	0.1444	7.5	1054.6875
8-9	37	720	0.051	653	0.907	683	0.0931	8.5	2272.2625
9-10	24	720	0.033	677	0.94	696	0.0597	9.5	2057.7
10-11	25	720	0.035	702	0.975	695	0.0250	10.5	2894.0625
11-12	12	720	0.017	714	0.992	708	0.0083	11.5	1825.05
12-13	1	720	0.001	715	0.993	719	0.0069	12.5	195.3125
13-14	0	720	0	715	0.993	720	0.0069	13.5	0
14-15	0	720	0	715	0.993	720	0.0069	14.5	0
15-16	2	720	0.003	717	0.996	718	0.0042	15.5	390.625
16-17	0	720	0	717	0.996	720	0.0042	16.5	0
17-18	2	720	0.003	719	0.999	718	0.0014	17.5	390.625
18-19	0	720	0	719	0.999	720	0.0014	18.5	0
19-20	1	720	0.001	720	1	719	0.0000	19.5	195.3125
Total	**720**								**16376.9**

Table D-18: Calculated Data for Kuakata, September, ***k* =2.10, *c* = 5.95**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	E=0.1V^3h_i
1	0.048	0.023	0.977	36.061	17.3766	726.623	0.5	0.450768
2	0.096	0.096	0.904	71.522	71.6862	672.314	1.5	24.13862
3	0.131	0.211	0.789	97.508	157.221	586.779	2.5	152.3566
4	0.148	0.352	0.648	109.88	262.122	481.878	3.5	471.1299
5	0.146	0.5	0.5	108.34	372.312	371.688	4.5	987.2256
6	0.129	0.639	0.361	95.781	475.107	268.893	5.5	1593.555
7	0.103	0.755	0.245	76.907	561.768	182.232	6.5	2112.059
8	0.076	0.845	0.155	56.494	628.423	115.577	7.5	2383.356
9	0.051	0.908	0.092	38.136	675.461	68.5386	8.5	2342.029
10	0.032	0.949	0.051	23.725	706.028	37.9722	9.5	2034.088
11	0.018	0.974	0.026	13.627	724.36	19.6404	10.5	1577.552
12	0.01	0.987	0.013	7.2366	734.522	9.47771	11.5	1100.601
13	0.005	0.994	0.006	3.5558	739.736	4.26443	12.5	694.4849
14	0.002	0.998	0.002	1.6175	742.212	1.78805	13.5	397.9746
15	9E-04	0.999	9E-04	0.6815	743.302	0.69828	14.5	207.7629
16	4E-04	1	3E-04	0.266	743.746	0.25386	15.5	99.05107
17	1E-04	1	1E-04	0.0962	743.914	0.08588	16.5	43.2079
18	4E-05	1	4E-05	0.0322	743.973	0.02702	17.5	17.27203
19	1E-05	1	1E-05	0.01	743.992	0.0079	18.5	6.334783
20	4E-06	1	3E-06	0.0029	743.998	0.00215	19.5	2.133815
21	1E-06	1	7E-07	0.0008	743.999	0.00054	20.5	0.660642
22	3E-07	1	2E-07	0.0002	744	0.00013	21.5	0.188122
							Total Energy =	**16247.61**

Table D-19: Observed data: Data analysis of wind speed October,2006 at Kuakata

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i$/T	T-h_i	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	36	744	0.048	36	0.048	708	0.95161	0.5	0.45
1-2	160	744	0.215	196	0.263	584	0.73656	1.5	54
2-3	320	744	0.43	516	0.694	424	0.30645	2.5	500
3-4	182	744	0.245	698	0.938	562	0.06183	3.5	780.325
4-5	42	744	0.056	740	0.995	702	0.0054	4.5	382.725
5-6	3	744	0.004	743	0.999	741	0.0013	5.5	49.9125
6-7	0	744	0	743	0.999	744	0.0013	6.5	0
11-12	1	744	0.001	744	1	743	0.0000	11.5	152.0875
12-13	0	744	0	744	1	744	0.0000	12.5	0
Total	**744**								**1919.5**

Table D-20: Calculated Data for Kuakata, October, ***k* =2.70, *c* = 2.83**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.153	0.058	0.942	114.01	43.5237	700.476	0.5	1.425095
2	0.357	0.324	0.676	265.92	241.127	502.873	1.5	89.74771
3	0.327	0.69	0.31	243.13	513.223	230.777	2.5	379.8916
4	0.135	0.922	0.078	100.28	685.633	58.3666	3.5	429.9428
5	0.024	0.99	0.01	17.871	736.882	7.1182	4.5	162.8535
6	0.002	1	5E-04	1.2662	743.63	0.36992	5.5	21.0667
7	4E-05	1	1E-05	0.0324	743.993	0.00729	6.5	0.890867
8	4E-07	1	7E-08	0.0003	744	4.9E-05	7.5	0.011497
							Total Energy =	**1085.83**

Table D-21: Data analysis of wind speed November,2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	$T-h_i$	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	20	720	0.028	20	0.028	700	0.97222	0.5	0.25
1-2	100	720	0.139	120	0.167	620	0.83333	1.5	33.75
2-3	296	720	0.411	416	0.578	424	0.42222	2.5	462.5
3-4	251	720	0.349	667	0.926	469	0.07361	3.5	1076.1625
4-5	40	720	0.056	707	0.982	680	0.0181	4.5	364.5
5-6	2	720	0.003	709	0.985	718	0.0153	5.5	33.275
6-7	3	720	0.004	712	0.989	717	0.0111	6.5	82.3875
7-8	1	720	0.001	713	0.99	719	0.0097	7.5	42.1875
8-9	0	720	0	713	0.99	720	0.0097	8.5	0
9-10	0	720	0	713	0.99	720	0.0097	9.5	0
10-11	0	720	0	713	0.99	720	0.0097	10.5	0
11-12	0	720	0	713	0.99	720	0.0097	11.5	0
12-13	0	720	0	713	0.99	720	0.0097	12.5	0
13-14	1	720	0.001	714	0.992	719	0.0083	13.5	195.3125
14-15	0	720	0	714	0.992	720	0.0083	14.5	0
15-16	0	720	0	714	0.992	720	0.0083	15.5	0
16-17	3	720	0.004	717	0.996	717	0.0042	16.5	585.9375
17-18	0	720	0	717	0.996	720	0.0042	17.5	0
18-19	3	720	0.004	720	1	717	0.0000	18.5	585.9375
19-20	0	720	0	720	1	720	0.0000	19.5	0
Total	**720**								**3462.2**

Table D-22: Calculated Data for Kuakata, November, ***k* =2.93, *c* = 3.35**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^{k}}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^{k}}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	E=0.1V^3h_i
1	0.082	0.029	0.971	59.326	20.5438	699.456	0.5	0.741578
2	0.259	0.198	0.802	186.64	142.542	577.458	1.5	62.98952
3	0.343	0.515	0.485	246.8	370.847	349.153	2.5	385.6253
4	0.229	0.814	0.186	165.04	585.99	134.01	3.5	707.6261
5	0.075	0.961	0.039	53.799	691.603	28.3971	4.5	490.2416
6	0.011	0.996	0.004	7.802	717.103	2.89659	5.5	129.8057
7	6E-04	1	2E-04	0.4506	719.876	0.12425	6.5	12.37501
8	1E-05	1	3E-06	0.0092	719.998	0.00196	7.5	0.388217
9	8E-08	1	1E-08	6E-05	720	1E-05	8.5	0.003609
							Total Energy =	**1789.797**

Table D-23: Data analysis of wind speed December,2006 at Kuakata.

Observed data:

Velocity Interval, V	Frequency, h_i	Total Time, T	Relative Frequency, f(v)	Cumulative Frequency, F(v)	Relative Cumulative Frequency, F(V)	Velocity Duration	Relative Velocity Duration	Average velocity	Energy, (Wh/m^2)
m/s	hrs	hrs	h_i/T	$\sum h_i$	$\sum h_i/T$	$T-h_i$	1-F(v)	m/s	$E=0.1V^3h_i$
0-1	48	744	0.065	48	0.065	696	0.9355	0.5	0.6
1-2	114	744	0.153	162	0.218	630	0.7823	1.5	38.475
2-3	218	744	0.293	380	0.511	526	0.48925	2.5	340.625
3-4	285	744	0.383	665	0.894	459	0.1062	3.5	1221.9375
4-5	34	744	0.046	699	0.94	710	0.0605	4.5	309.825
5-6	10	744	0.013	709	0.953	734	0.0470	5.5	166.375
6-7	12	744	0.016	721	0.969	732	0.0309	6.5	329.55
7-8	10	744	0.013	731	0.983	734	0.0175	7.5	421.875
8-9	0	744	0	731	0.983	744	0.0175	8.5	0
9-10	0	744	0	731	0.983	744	0.0175	9.5	0
10-11	0	744	0	731	0.983	744	0.0175	10.5	0
11-12	0	744	0	731	0.983	744	0.0175	11.5	0
12-13	0	744	0	731	0.983	744	0.0175	12.5	0
13-14	0	744	0	731	0.983	744	0.0175	13.5	0
14-15	0	744	0	731	0.983	744	0.0175	14.5	0
15-16	3	744	0.004	734	0.987	741	0.0134	15.5	585.9375
16-17	4	744	0.005	738	0.992	740	0.0081	16.5	781.25
17-18	3	744	0.004	741	0.996	741	0.0040	17.5	585.9375
18-19	3	744	0.004	744	1	741	0.0000	18.5	585.9375
19-20	0	744	0	744	1	744	0.0000	19.5	0
Total	**744**								**5368.325**

Table D-24: Calculated Data for Kuakata, December, ***k* =2.15, *c* = 3.50**

Velocity	Calculated, f(v)= $\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^k}$	Calculated F(v) =1-$e^{-\left(\frac{v}{c}\right)^k}$	Calculated S(v)= $e^{-\left(\frac{v}{c}\right)^k}$	velocity Frequency	Cumulative velocity Frequency	Velocity Duration	Mean Velocity	Energy (Wh/m^2)
V	f(v)	F(V)	S(v)	h_i=f(v)xH	F(v)xH	S(v)xH	V	$E=0.1V^3h_i$
1	0.136	0.065	0.935	101.13	48.6654	695.335	0.5	1.264143
2	0.239	0.259	0.741	177.85	192.963	551.037	1.5	60.02483
3	0.251	0.512	0.488	186.71	381.095	362.905	2.5	291.7388
4	0.189	0.736	0.264	140.58	547.73	196.27	3.5	602.7264
5	0.108	0.884	0.116	79.994	657.593	86.4067	4.5	728.9412
6	0.047	0.959	0.041	35.105	713.253	30.7472	5.5	584.0625
7	0.016	0.988	0.012	11.984	735.209	8.7913	6.5	329.1155
8	0.004	0.997	0.003	3.1938	741.991	2.00938	7.5	134.7383
9	9E-04	1	5E-04	0.6652	743.635	0.36547	8.5	40.84937
10	1E-04	1	7E-05	0.1082	743.947	0.05268	9.5	9.279664
11	2E-05	1	8E-06	0.0137	743.994	0.006	10.5	1.591282
12	2E-06	1	7E-07	0.0014	743.999	0.00054	11.5	0.206953
13	1E-07	1	5E-08	0.0001	744	3.8E-05	12.5	0.020473
							Total Energy =	**2784.559**

In this appendix, shown both observed and calculated data only for Kuakata, but others five sites like Kutubdia, Khagrachari, Sitakunda, Pakshey and Rauzan has been calculated by the same procedure. Other sites data has not shown in this appendix but the graphs have been shown in the chapter – 4.

Table D-25: Total Available Energy in the Wind for Each Location.

Site name	Total Available Energy in the Wind, (Wh/m^2)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kuakata	3142.93	4162.15	4649.55	12866.9	13985.8	13761	19774.7	23567.8	16376.9	1919.5	3462.2	5368.33
Kutubdia	3527.27	3291.35	3645.6	6516.63	9330.06	10557.3	15538	12532.7	6944.83	1486	2264.05	2064.58
Khagrachari	2790.93	4808.58	6864.23	8028.23	6076.35	12728.5	3899.78	3362.63	4083.08	1720.38	1896.05	1786.25
Sitakunda	2126.95	4533.93	4446.98	9871.33	10522.7	13357	15453.9	73593.2	781781	1377.95	1898	1608.25
Pakshey	1929.78	1581.63	2131.23	3590.63	3729.53	3033.8	5041.13	12220.9	5943.7	948.025	944.1	1146.98
Rauzan	697.7	1198.08	2277.03	3250.8	3670.05	12593	3111.03	2543.9	1549.28	520.3	733.375	375.025

Appendix-E

Table E-1: Value of *k* and *c* for Kuakata, Kutubdia and Khagrachari

Sites		Weibull paper		Std. deviation		Energy	
	Month	*k*	*c*	*k*	*c*	*k*	*c*
Kuakata	January	2.50	3.51	2.85	3.48	2.92	3.42
	February	3.00	4.02	3.38	3.99	3.31	3.96
	March	3.10	3.98	3.09	3.98	3.04	3.92
	April	2.55	5.58	3.01	5.65	3.05	5.56
	May	2.40	5.60	2.50	5.60	2.64	5.48
	June	2.70	5.74	2.89	5.75	3.00	5.66
	July	2.83	6.50	3.32	6.48	3.12	6.42
	August	2.18	6.90	2.32	6.67	2.58	6.52
	September	2.10	5.95	2.45	5.46	1.95	5.46
	October	2.70	2.83	2.72	2.89	2.71	2.83
	November	2.93	3.35	1.80	3.30	1.43	3.24
	December	2.15	3.50	1.40	3.41	1.21	3.44
	Month	***k***	***c***	***k***	***c***	***k***	***c***
Kutubdia	January	2.50	3.51	2.85	3.48	2.92	3.42
	February	3.00	4.02	3.38	3.99	3.31	3.96
	March	3.10	3.98	3.09	3.98	3.04	3.92
	April	2.55	5.58	3.01	5.65	3.05	5.56
	May	2.40	5.60	2.50	5.60	2.64	5.48
	June	2.70	5.74	2.89	5.75	3.00	5.66
	July	2.83	6.50	3.32	6.48	3.12	6.42
	August	2.18	6.90	2.32	6.67	2.58	6.52
	September	2.10	5.95	2.45	5.46	1.95	5.46
	October	2.70	2.83	2.72	2.89	2.71	2.83
	November	2.93	3.35	1.80	3.30	1.43	3.24
	December	2.15	3.50	1.40	3.41	1.21	3.44
	Month	***k***	***c***	***k***	***c***	***k***	***c***
Khagrachari	January	2.50	3.51	2.85	3.48	2.92	3.42
	February	3.00	4.02	3.38	3.99	3.31	3.96
	March	3.10	3.98	3.09	3.98	3.04	3.92
	April	2.55	5.58	3.01	5.65	3.05	5.56
	May	2.40	5.60	2.50	5.60	2.64	5.48
	June	2.70	5.74	2.89	5.75	3.00	5.66
	July	2.83	6.50	3.32	6.48	3.12	6.42
	August	2.18	6.90	2.32	6.67	2.58	6.52
	September	2.10	5.95	2.45	5.46	1.95	5.46
	October	2.70	2.83	2.72	2.89	2.71	2.83
	November	2.93	3.35	1.80	3.30	1.43	3.24
	December	2.15	3.50	1.40	3.41	1.21	3.44

Table E-2: Value of *k* and *c* for Sitakunda, Pakshey and Rauzan.

Sites		Weibull paper method		Std. deviation method		Energy method	
	Month	***k***	***c***	***k***	***c***	***k***	***c***
Sitakunda	January	2.05	2.80	1.81	2.72	1.91	2.67
	February	2.60	4.00	2.5	3.97	2.58	3.88
	March	2.45	3.60	2.55	3.82	2.58	3.74
	April	2.10	4.97	2.40	4.98	2.40	4.97
	May	1.90	5.03	2.41	5.04	2.42	5.04
	June	2.00	5.43	2.32	5.43	2.28	5.43
	July	2.20	6.02	3.19	4.88	3.00	5.97
	August	1.95	5.66	2.09	3.47	> Range	> Range
	September	1.32	10.83	1.10	2.23	> Range	> Range
	October	1.90	2.56	2.19	2.57	2.52	2.56
	November	2.75	3.00	2.85	2.97	2.89	2.92
	December	2.00	2.60	2.14	2.64	2.26	2.58
	Month	***k***	***c***	***k***	***c***	***k***	***c***
Pakshey	January	2.15	2.83	2.24	2.89	2.50	2.82
	February	2.20	2.61	2.05	2.64	2.10	2.58
	March	2.48	2.95	2.17	2.86	2.21	2.79
	April	2.80	3.81	2.90	3.68	2.89	3.62
	May	2.15	3.50	2.15	3.46	2.12	3.38
	June	2.48	3.40	2.24	3.36	2.45	3.28
	July	2.40	4.00	2.50	3.94	2.45	3.86
	August	1.85	4.40	1.57	4.28	1.42	4.24
	September	1.71	3.62	1.72	3.63	1.62	3.57
	October	2.35	2.10	2.14	2.17	2.13	2.12
	November	2.48	2.38	2.55	2.31	2.71	2.26
	December	2.62	2.43	2.82	2.48	2.95	2.44
	Month	***k***	***c***	***k***	***c***	***k***	***c***
Rauzan	January	1.69	1.85	1.77	1.81	1.69	1.77
	February	1.89	2.30	1.85	2.32	1.93	2.28
	March	1.53	2.60	1.63	2.61	1.64	2.58
	April	2.10	3.40	2.09	3.31	2.11	3.24
	May	1.65	3.10	1.65	3.06	1.60	3.02
	June	1.85	5.05	1.98	5.11	2.01	5.00
	July	2.83	3.50	3.11	3.48	2.64	3.44
	August	2.25	3.20	2.44	3.14	2.47	3.07
	September	1.90	2.60	1.80	2.46	1.92	2.41
	October	1.35	1.50	1.39	1.43	1.40	1.45
	November	1.05	1.30	1.30	1.52	1.29	1.55
	December	1.48	1.30	1.55	1.38	1.54	1.37

THEORY OF WEIBULL DISTRIBUTION

For more than half a century the Weibull distribution has attracted the attention of statisticians working on theory and methods as well as various fields of statistics. Hundreds or even thousands of papers have been written on this distribution and the research is ongoing. Together with the normal, exponential distributions, the Weibull distribution is without any doubt, the most popular model in statistics [8]. It is of utmost interest to theory orientated statisticians because of its great number of special features and to practitioners because of its ability to fit to data from various fields, ranging from life data to weather data or observations made in economics and business administration, in health, in physical and social science, in hydrology, in biology or in the engineering sciences [8]

E 1.1 PROBABILITY DENSITY FUNCTION:

The probability density function means the relative frequency of wind speeds for the site. Therefore, the shape of wind speeds distribution can be guessed when it is plotted. The equation of Weibull Density Function [8] is given by,

$$f(v) = \frac{dF(v)}{dv} = \left[\frac{k}{c}\right]\left[\frac{v}{c}\right]^{k-1} \times e^{-\left(\frac{v}{c}\right)^k} \qquad \text{(E.1)}$$

E 1.2 CUMULATIVE DISTRIBUTION FUNCTION:

Cumulative distribution function is the integration of Weibull Density Function. It is the cumulative of relative frequency of each velocity interval.
The equation of Weibull Function [6] is given by,

$$F(v) = \int_0^v f(v')d(v') \quad \text{or} \quad F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \qquad \text{(E.2)}$$

E 1.3 VELOCITY DURATION FUNCTION:

The velocity duration curve directly shows the length individual wind velocity. The more length means the higher the duration of that wind speed. From this curve we can get how much time the turbine will be on running condition when the cut-in speed (The lowest wind speed at which a wind turbine begins producing usable power.) is identified from Weibull Function. The equation is given below [8]-

$$S(v) = e^{-\left(\frac{v}{c}\right)^k} \quad \text{(E.3)}$$

The velocity duration, S(v) is the period of time during which the wind speed is available greater than that specific wind speed. The shape of the duration curve follows a negative exponential function. Studying the shape of this duration curve an idea is obtained about the wind regime for that site. The more horizontal shape means longer duration period of that specific wind speed.

E 1.4 LULL PERIOD:

The lull period is the times during which the turbine or windmill will not be on operating condition. This is very low velocity classes. It is normally fall under the speed that is not sufficient to produce output of the turbine. It is generally called unproductive time of wind speeds. There are several distributions, which are used for analysis; the statistical observed wind data. They are:

a) Rayleigh distribution,
b) Chi-squared distribution,
c) Normal distribution,
d) Binomial distribution,
e) Poisson distribution and
f) Weibull distribution.

All these distributions are used to determine the probability of occurrence. The nature of occurrence affects the shape of the probability curve and cumulative curve, in case of wind regime, probability nature mostly fits to Weibull Function. This function has much flexibility. Depending on the 'k' value it falls under

k =l	: Exponential
k = 1.5-3	: Logarithmic Normal Distribution
k = 2.0	: Rayleigh (very close to normal) Distribution
k = 3.1-3.6	: Again Logarithmic Normal Distribution
k >3.6	: Normal Distribution

E 1.5 THE WEIBULL DISTRIBUTION:

The Weibull distribution is characterized by two parameters: the shape parameter k (dimensionless) and the scale parameter c (m/s.) The cumulative distribution function [8] is given by

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad \text{(E.4)}$$

And the Weibull density (provability density) function by [8],

$$f(v) = \frac{dF(v)}{dv} = \left[\frac{k}{c}\right]\left[\frac{v}{c}\right]^{k-1} \times e^{-\left(\frac{v}{c}\right)^k} \quad \text{(E.5)}$$

With an expression of Gamma function, Γ(x) the average wind speed can be expressed as a function of *c* and *k* or vice versa and c is a function of wind speed, v (m/s) and *k*.
The integral found cannot be solved however, but it can be reduced to a standard integral, the so-called gamma function [8].

$$\Gamma(x) = \int_0^{\alpha} y^{x-1} \times e^{-y} dy \quad \text{(E.6)}$$

With y= $(v/c)^k$ and v/c = y^{x-1}
One obtains x=1+1/k and after a few manipulation,

$$\overline{V} = C \times \Gamma(1 + \frac{1}{k}) = 0.8525 + 0.0135k + e^{-[2.0+3.0(K-1)]} \quad \text{(E.7)}$$

This formula can easily be handled by pocket calculators in energy output calculations. The accuracy of the approximation is within 0.5% for $1.6 < k < 3.5$.

E 1.6 METHODS FOR CALCULATING WEIBULL PARAMETERS:

Since the hourly time-series wind speed data may always be enormous, it is desirable to have only a few key parameters, which can illuminate the characteristics of a wide range of wind speed data. There are several methods by which Weibull shape factor, *k* and Weibull scale factor, *c* can be determined. Three popular methods for calculating Weibull Parameters are: a) Weibull paper method. b) Standard - deviation analysis. c) Energy pattern factor analysis.

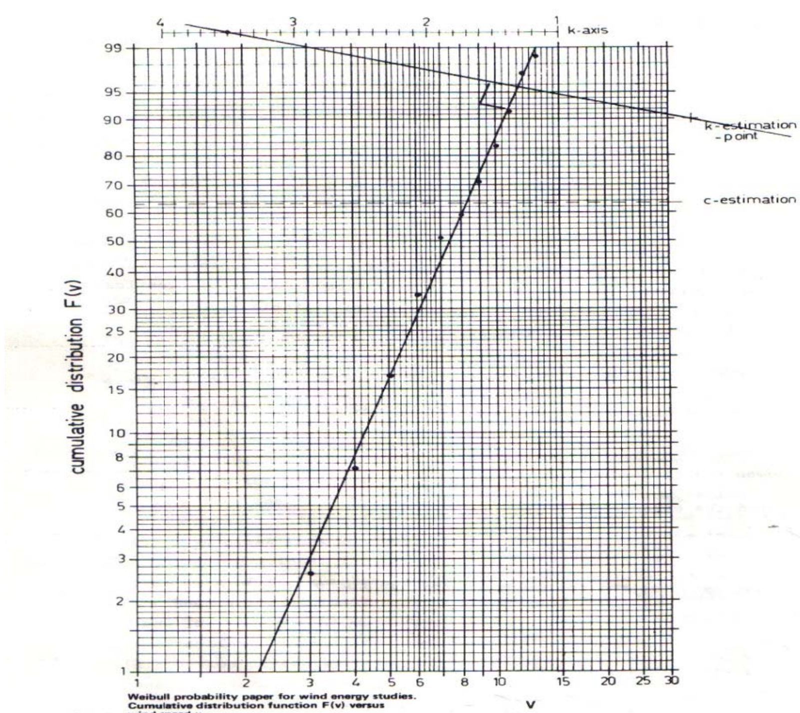
E 1.7.a WEIBULL PAPER METHOD:

In principle it would be possible to construct the dimensionless velocity frequency curve or the cumulative distribution, to draw these curves and to "guess" the Weibull factor from their position. Comparing curves is a rather awkward business; however, it is preferred to transform them into straight lines for comparison purposes. The so-called, Weibull paper is constructed in such a way that the cumulative Weibull distribution becomes a straight line, with the shape factor k as its slope, as shown **Fig E.1** in the next page. Expression (E.4) can be rewritten as:

$$\{1 - F(v)\}^{-1} = e^{(v/c)^k} \quad \text{(E.8)}$$

$\ln [1-F(v)]^{-1} = k \ln V - k \ln c$ [Taking logarithm in both side]

The horizontal axis of the Weibull paper now becomes in V while at the vertical axis in $\ln(1 - F(v))^{-1}$ is placed. The result is a straight line with slope *k* or V = *c* one finds: $F(c) = 1 - e^{-1} = 0.632$ and this gives an estimation for the value of c, by drawing a horizontal line at F (v) = 0.632. The intersection point with the Weibull line gives the value of c. The practical procedure to find the Weibull shape factor from a given set of data starts with establishing the cumulative distribution of the data. The procedures now consist of plotting the percentages of the cumulative, distribution as a function of the upper boundaries of their respective intervals on the Weibull paper. The result will be a number of dots lying more or less on a straight line. In case the line is straight, the distribution perfectly fits to the Weibull distribution. In many cases, however, the line will be slightly bent. Then the linearization should be focused on the wind speed interval that is most interesting for over wind energy applications, i.e. between 0.7 V and 2 V.



Appendix Fig. E.1: Cumulative distribution Vs wind speed graph

The value of k is found by measuring the slope of the line just drawn. In the Fig E.1, draw a second line through the '+' marked "k-estimation point", and a perpendicular to the Weibull line. The intersection of this second line with the linear k-axis on top of the paper gives the desired k-value. The c-value, if required, is simply the intersection of the Weibull line with the-dotted line, marked "c-estimation". Preferably this procedure should be applied not to the data of one month only, but to those of a number of months or years.

E 1.7.b STANDARD-DEVIATION ANALYSIS METHOD:

By determining the mean wind speed V_{mean} and standard deviation σ of wind data *k* and *c* can be obtained by solving the following equations [27].

$$\sigma = \sqrt{[\int_{0}^{\alpha}(v-\bar{v})\oint(v)dv]} \tag{E.9}$$

And the expression for f (v),

$$f(v) = \frac{dF(v)}{dv} = (\frac{k}{c})(\frac{v}{c})^{k-1} \times e^{-(\frac{v}{c})^{k}} \tag{E.10}$$

One can find next expression for σ [26],

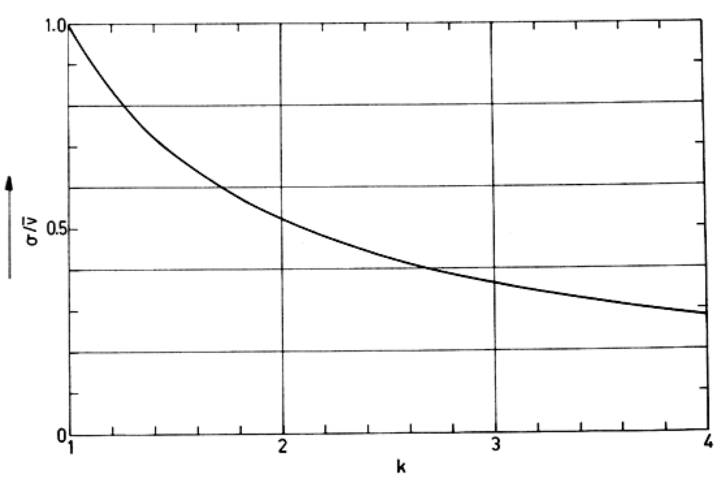
$$\sigma = c\sqrt{\left[\Gamma\left(1+\frac{2}{k}\right)-\Gamma^{2}\left(1+\frac{1}{k}\right)\right]} \tag{E.11}$$

Or with $\bar{v} = c \times \Gamma\left(1+\frac{1}{k}\right)$ (E.12)

$$\frac{\sigma}{v} = \frac{\sqrt{\left[\Gamma\left(1+\frac{2}{k}\right)-\Gamma^{2}\left(1+\frac{1}{k}\right)\right]}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{E.13}$$

The standard deviation of the distribution is calculated with,

$$\sigma^{2} = \frac{\sum (V_n)^2 - \frac{\left(\sum V_n\right)^2}{N}}{N-1} \tag{E.14}$$



Appendix Fig. E.2: The relative standard deviation of a Weibull distribution as a function of Weibull shape factor, *k*. [8]

Table E- 3: For scale factor (*c*) corresponding to shape factor (*k*).

k	$\frac{\bar{v}}{c} = \Gamma\left(1 + \frac{1}{k}\right)$	$\Gamma^k\left(1 + \frac{1}{k}\right)$
1	1	1
1.25	0.931384	0.914978
1.5	0.902745	0.857724
1.6	0.896574	0.839727
1.7	0.892244	0.823802
1.8	0.889287	0.809609
1.9	0.887363	0.796880
2.0	0.886227	0.785398(π/4)
2.1	0.885694	0.774989
2.2	0.885625	0.765507
2.3	0.885915	0.756835
2.4	0.886482	0.748873
2.5	0.887264	0.741535
3.0	0.892979	0.712073
3.5	0.899747	0.690910
4.0	0.906402	0.674970

The importance of Weibull shape factor k is that when $k = 1.00$ represents an exponential distribution [11]. If the value of k varies between 1.5 to 3 represent the logarithmic normal distribution. When $k = 2$, represent Rayleigh distribution and when Weibull shape factor of about 3.25 or above represents an approximately normal distribution [14, 32]. The Table – 1 is the standard table where the values of the gamma function as used in the velocity distribution function. By this table the value of c varies corresponding to the value of k which varies from 1 to max^{m} 4. So, the max^{m} value of c depends on $k = 4$ and max^{m} monthly mean velocity of that wind site.

E 1.7.c ENERGY PATTERN FACTOR ANALYSIS:

The energy pattern factor k_E is defined by Golding [32] as,

$$k_E = \frac{\text{Total amount of power available in the wind}}{\text{Power calculated by cubing the mean wind speed}} \qquad \text{(E.15)}$$

Realizing that the power density of the wind is given by [32],

$$\frac{P(v)}{A} = \frac{1}{3}\rho V^3 \quad [\text{W/m}^2] \qquad \text{(E.16)}$$

Then the total amount of energy available in the wind in a period T [32] is equal to

$$\frac{E}{A} = T\int_{0}^{\alpha} \frac{1}{2}\rho v^3 f(v)dv \quad [\mathrm{J/m^2}] \tag{E.17}$$

Whereas the energy [32] is calculated by cubing the mean wind speed is equal to

$$\frac{E}{A} = \frac{1}{2}\rho V^3 T \tag{E.18}$$

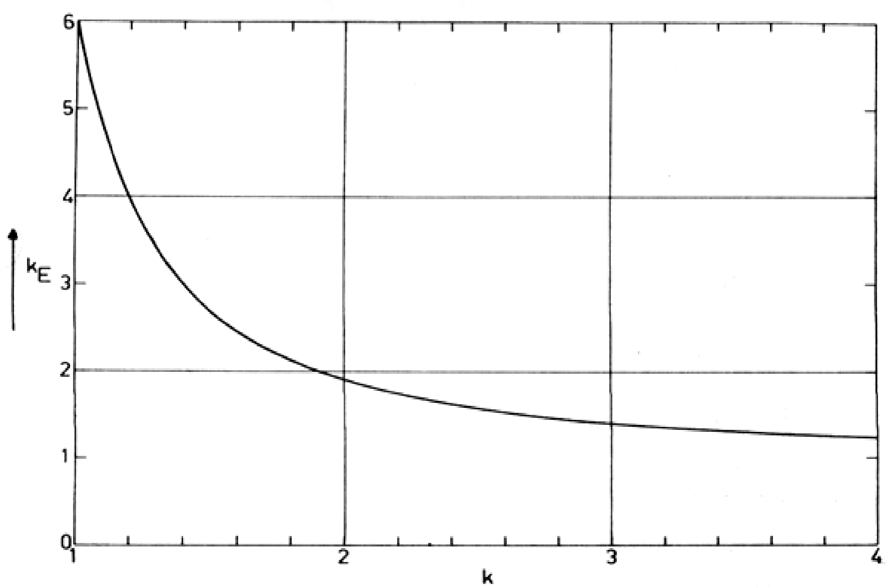
Using Weibull provability density function f(v) in (E.15) results,

$$k_E = \frac{\Gamma(1+\frac{3}{k})}{\Gamma^3(1+\frac{1}{k})} \tag{E.19}$$

The energy pattern factor of a given set of N hourly data V_n can be determined with [32]

$$k_E = \frac{\frac{1}{N}\sum_{n=1}^{N}(V_n)^3}{\left(\frac{1}{N}\sum_{n=1}^{N}V_n\right)^3} \tag{E.20}$$

Using the above expression the Weibull shape parameter k is easily found by following figure.



Appendix Fig. E.3: The energy pattern factor of a Weibull wind speed distribution as a function of the Weibull shape factor, *k*.

Appendix – F

Wind class and Ranging data

Table F–1: Wind of medium intensity, **Sitakundu, September**

Wind of medium intensity (8.0 - 10.7)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
8.41	1.543	12.98	9.17	14.88	1.42
8.97	1.543	13.84	9.17	15.74	1.51
9.75	1.543	15.04	9.17	16.94	1.64
10.42	1.543	16.08	9.17	17.98	1.75
8.62	1.543	13.3	9.17	15.2	1.45
8.82	1.543	13.61	9.17	15.51	1.48

Table F–2: Strong wind, **Sitakundu, September**

Strong Wind (10.8 - 13.8)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
13.13	1.543	20.26	12.11	21.86	1.67
12.93	1.543	19.95	12.11	21.55	1.65
11.32	1.543	17.47	12.11	19.07	1.44
11.06	1.543	17.07	12.11	18.67	1.41

Table F–3: Very Strong wind, **Sitakundu, September**

Very Strong Wind (13.9 - 17.1)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
14.97	1.543	23.1	16.12	24.4	1.43
16.9	1.543	26.08	16.12	27.38	1.62
15.88	1.543	24.5	16.12	25.8	1.52
16.32	1.543	25.18	16.12	26.48	1.56
15.68	1.543	24.19	16.12	25.49	1.5
16.99	1.543	26.22	16.12	27.52	1.63

Table F–4: Gale, **Sitakundu, September**

Gale (17.2 - 20.7)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) Vg	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
19.05	1.543	29.39	19.41	31.39	1.51
20.32	1.543	31.35	19.41	33.35	1.62
17.77	1.543	27.42	19.41	29.42	1.41
19.15	1.543	29.55	19.41	31.55	1.52
20.67	1.543	31.89	19.41	33.89	1.64
20.06	1.543	30.95	19.41	32.95	1.59
18.76	1.543	28.95	19.41	30.95	1.49
18.69	1.543	28.84	19.41	30.84	1.49
20.18	1.543	31.14	19.41	33.14	1.6

Table F–5: Strom, **Sitakundu, September**

Storm (20.8 - 24.4)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
22.69	1.543	35.01	23.09	36.81	1.52
21.78	1.543	33.61	23.09	35.41	1.46
22.95	1.543	35.41	23.09	37.21	1.53
21.36	1.543	32.96	23.09	34.76	1.43
24.14	1.543	37.25	23.09	39.05	1.61
23.33	1.543	36	23.09	37.8	1.56
24.23	1.543	37.39	23.09	39.19	1.62
24.23	1.543	37.39	23.09	39.19	1.62

Table F–6: Violent Strom, **Sitakundu, September**

Violent Storm (24.5 - 28.4)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
26.62	1.543	41.07	26.79	43.57	1.53
27.75	1.543	42.82	26.79	45.32	1.6
26.78	1.543	41.32	26.79	43.82	1.54
28.37	1.543	43.77	26.79	46.27	1.63
28.33	1.543	43.71	26.79	46.21	1.63
27.99	1.543	43.19	26.79	45.69	1.61
27.02	1.543	41.69	26.79	44.19	1.56
27.39	1.543	42.26	26.79	44.76	1.58
26.08	1.543	40.24	26.79	42.74	1.5
26.08	1.543	40.24	26.79	42.74	1.5
28.23	1.543	43.56	26.79	46.06	1.63
27.55	1.543	42.51	26.79	45.01	1.59
24.91	1.543	38.44	26.79	40.94	1.43
25.41	1.543	39.21	26.79	41.71	1.46
27.58	1.543	42.56	26.79	45.06	1.59
24.97	1.543	38.53	26.79	41.03	1.44
27.16	1.543	41.91	26.79	44.41	1.56
27.66	1.543	42.68	26.79	45.18	1.59
26.28	1.543	40.55	26.79	43.05	1.51
24.53	1.543	37.85	26.79	40.35	1.41
25.65	1.543	39.58	26.79	42.08	1.48
28.41	1.543	43.84	26.79	46.34	1.64
25.38	1.543	39.16	26.79	41.66	1.46
26.89	1.543	41.49	26.79	43.99	1.55

Table F–7: Violent Strom -I, **Sitakundu, September**

Violent Storm - I (28.5 - 33.99)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
29.64	1.543	45.73	31.25	49.83	1.46
30.65	1.543	47.29	31.25	51.39	1.51
27.39	1.543	42.26	31.25	46.36	1.35
29.92	1.543	46.17	31.25	50.27	1.48
29.75	1.543	45.9	31.25	50	1.47
29.5	1.543	45.52	31.25	49.62	1.46
31.54	1.543	48.67	31.25	52.77	1.56
29.55	1.543	45.6	31.25	49.7	1.46
31.25	1.543	48.22	31.25	52.32	1.54
32.38	1.543	49.96	31.25	54.06	1.6
28.64	1.543	44.19	31.25	48.29	1.41
32.57	1.543	50.26	31.25	54.36	1.61
31.9	1.543	49.22	31.25	53.32	1.58
30.8	1.543	47.52	31.25	51.62	1.52
28.65	1.543	44.21	31.25	48.31	1.41
32.39	1.543	49.98	31.25	54.08	1.6
31.45	1.543	48.53	31.25	52.63	1.55
29.43	1.543	45.41	31.25	49.51	1.45
30.55	1.543	47.14	31.25	51.24	1.51
29.04	1.543	44.81	31.25	48.91	1.43
33.37	1.543	51.49	31.25	55.59	1.65
33.78	1.543	52.12	31.25	56.22	1.67
33.9	1.543	52.31	31.25	56.41	1.67
33.84	1.543	52.22	31.25	56.32	1.67
33.7	1.543	52	31.25	56.1	1.66
33.62	1.543	51.88	31.25	55.98	1.66
32.64	1.543	50.36	31.25	54.46	1.61
33.2	1.543	51.23	31.25	55.33	1.64

Table F–8: Hurrican, **Sitakundu, September**

Hurricane (> 34.00)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
37.94	1.543	58.54	41.65	80.34	1.41
34.47	1.543	53.19	41.65	74.99	1.28
39.68	1.543	61.23	41.65	83.03	1.47
34.63	1.543	53.43	41.65	75.23	1.28
36.77	1.543	56.74	41.65	78.54	1.36
35.97	1.543	55.5	41.65	77.3	1.33
36.15	1.543	55.78	41.65	77.58	1.34
35.09	1.543	54.14	41.65	75.94	1.3
34.18	1.543	52.74	41.65	74.54	1.27
35.96	1.543	55.49	41.65	77.29	1.33
37.54	1.543	57.92	41.65	79.72	1.39
37	1.543	57.09	41.65	78.89	1.37
36.7	1.543	56.63	41.65	78.43	1.36
33.46	1.543	51.63	41.65	73.43	1.24
37.57	1.543	57.97	41.65	79.77	1.39
37.16	1.543	57.34	41.65	79.14	1.38
38.05	1.543	58.71	41.65	80.51	1.41
34.02	1.543	52.49	41.65	74.29	1.26
36.31	1.543	56.03	41.65	77.83	1.35
35.27	1.543	54.42	41.65	76.22	1.31
34.35	1.543	53	41.65	74.8	1.27
35.08	1.543	54.13	41.65	75.93	1.3
34.1	1.543	52.62	41.65	74.42	1.26
36.09	1.543	55.69	41.65	77.49	1.34
36.08	1.543	55.67	41.65	77.47	1.34
34.94	1.543	53.91	41.65	75.71	1.29
36.27	1.543	55.96	41.65	77.76	1.34
35.5	1.543	54.78	41.65	76.58	1.32
41.82	1.543	64.53	41.65	86.33	1.55
39.71	1.543	61.27	41.65	83.07	1.47
46.98	1.543	72.49	41.65	94.29	1.74
37.93	1.543	58.53	41.65	80.33	1.41

39.79	1.543	61.4	41.65	83.2	1.47
38.69	1.543	59.7	41.65	81.5	1.43
37.45	1.543	57.79	41.65	79.59	1.39
40.6	1.543	62.65	41.65	84.45	1.5
40.96	1.543	63.2	41.65	85	1.52
38.6	1.543	59.56	41.65	81.36	1.43
41.98	1.543	64.78	41.65	86.58	1.56
43.93	1.543	67.78	41.65	89.58	1.63
40.25	1.543	62.11	41.65	83.91	1.49
40.12	1.543	61.91	41.65	83.71	1.49
42.43	1.543	65.47	41.65	87.27	1.57
45.24	1.543	69.81	41.65	91.61	1.68
45.64	1.543	70.42	41.65	92.22	1.69
40.15	1.543	61.95	41.65	83.75	1.49
38.06	1.543	58.73	41.65	80.53	1.41
37.4	1.543	57.71	41.65	79.51	1.39
39.2	1.543	60.49	41.65	82.29	1.45
41.67	1.543	64.3	41.65	86.1	1.54
46.96	1.543	72.46	41.65	94.26	1.74
42.25	1.543	65.19	41.65	86.99	1.57
45.29	1.543	69.88	41.65	91.68	1.68
43.42	1.543	67	41.65	88.8	1.61
45.68	1.543	70.48	41.65	92.28	1.69
42.92	1.543	66.23	41.65	88.03	1.59
42.48	1.543	65.55	41.65	87.35	1.57
45.72	1.543	70.55	41.65	92.35	1.69
44.08	1.543	68.02	41.65	89.82	1.63
44.92	1.543	69.31	41.65	91.11	1.66
42.6	1.543	65.73	41.65	87.53	1.58
44.17	1.543	68.15	41.65	89.95	1.64
47.26	1.543	72.92	41.65	94.72	1.75
51.46	1.543	79.4	41.65	101.2	1.91
55.14	1.543	85.08	41.65	106.88	2.04
49.32	1.543	76.1	41.65	97.9	1.83
49.09	1.543	75.75	41.65	97.55	1.82
49.15	1.543	75.84	41.65	97.64	1.82
48.37	1.543	74.63	41.65	96.43	1.79
47.52	1.543	73.32	41.65	95.12	1.76
47.73	1.543	73.65	41.65	95.45	1.77

56.25	1.543	86.79	41.65	108.59	2.08
48.61	1.543	75.01	41.65	96.81	1.8
52.74	1.543	81.38	41.65	103.18	1.95
51.26	1.543	79.09	41.65	100.89	1.9
48.61	1.543	75.01	41.65	96.81	1.8
55.36	1.543	85.42	41.65	107.22	2.05
47.17	1.543	72.78	41.65	94.58	1.75
54.8	1.543	84.56	41.65	106.36	2.03
54.98	1.543	84.83	41.65	106.63	2.04
47.56	1.543	73.39	41.65	95.19	1.76
49.86	1.543	76.93	41.65	98.73	1.85
50.53	1.543	77.97	41.65	99.77	1.87

Table F–9: Wind of medium intensity, **Sitakundu, August.**

Wind of medium intensity (8.0 - 10.7)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
9.88	1.543	15.24	9.09	17.24	1.68
8.99	1.543	13.87	9.09	15.87	1.53
10.31	1.543	15.91	9.09	17.91	1.75
8.36	1.543	12.9	9.09	14.9	1.42
8.15	1.543	12.58	9.09	14.58	1.38
8.6	1.543	13.27	9.09	15.27	1.46
8.27	1.543	12.76	9.09	14.76	1.4
10.27	1.543	15.85	9.09	17.85	1.74
9.64	1.543	14.87	9.09	16.87	1.64
8.65	1.543	13.35	9.09	15.35	1.47
9.35	1.543	14.43	9.09	16.43	1.59
8.11	1.543	12.51	9.09	14.51	1.38
8.34	1.543	12.87	9.09	14.87	1.42
9.88	1.543	15.24	9.09	17.24	1.68
9.89	1.543	15.26	9.09	17.26	1.68
8.03	1.543	12.39	9.09	14.39	1.36
8.05	1.543	12.42	9.09	14.42	1.37
8.83	1.543	13.62	9.09	15.62	1.5
8.38	1.543	12.93	9.09	14.93	1.42
8.21	1.543	12.67	9.09	14.67	1.39
9.57	1.543	14.77	9.09	16.77	1.62
9.62	1.543	14.84	9.09	16.84	1.63
9.98	1.543	15.4	9.09	17.4	1.69
10.21	1.543	15.75	9.09	17.75	1.73
8.41	1.543	12.98	9.09	14.98	1.43
8.08	1.543	12.47	9.09	14.47	1.37
9.91	1.543	15.29	9.09	17.29	1.68
10.37	1.543	16	9.09	18	1.76
9.31	1.543	14.37	9.09	16.37	1.58
9.5	2.543	24.16	9.09	26.16	2.66
8.76	3.543	31.04	9.09	33.04	3.41

Table F–10: Strong wind, **Sitakundu, August.**

Strong Wind (10.8 - 13.8)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
11.34	1.543	17.5	11.78	17.9	1.49
12.06	1.543	18.61	11.78	19.01	1.58
11.93	1.543	18.41	11.78	18.81	1.56

Table F–11: Very Strong wind, **Sitakundu, August.**

Very Strong Wind (13.9 - 17.1)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
16.02	1.543	24.72	16.46	25.42	1.5
16.06	1.543	24.78	16.46	25.48	1.51
16.71	1.543	25.78	16.46	26.48	1.57
16.17	1.543	24.95	16.46	25.65	1.52
16.9	1.543	26.08	16.46	26.78	1.58
16.9	1.543	26.08	16.46	26.78	1.58

Table F–12: Gale, **Sitakundu, August.**

Gale (17.2 - 20.7)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
19.73	1.543	30.44	18.63	32.14	1.63
19.49	1.543	30.07	18.63	31.77	1.61
18.37	1.543	28.34	18.63	30.04	1.52
18.39	1.543	28.38	18.63	30.08	1.52
18.06	1.543	27.87	18.63	29.57	1.5
17.44	1.543	26.91	18.63	28.61	1.44
17.99	1.543	27.76	18.63	29.46	1.49
19.6	1.543	30.24	18.63	31.94	1.62

Table F-13: Violent Storm –I , Sitakunda, August.

Violent Storm - I (28.5 - 33.99)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
31.76	1.543	49.01	32.81	50.61	1.49
33.85	1.543	52.23	32.81	53.83	1.59

Table F-14: Hurrican , Sitakunda, August.

Hurricane (> 34.00)	Gust Factor K_g	Measured gust, $G = AG$	Maximal hourly mean speed, $\overline{V_{max}} = AV$	Modelled gust (Using Equ.-9) V_g	Ratio, $R = G/\overline{V_{max}}$
m/sec		m/sec	m/sec	m/sec	
36.45	1.543	56.24	63.6	109.74	0.88
50.99	1.543	78.68	63.6	132.18	1.24
98.25	1.543	151.6	63.6	205.1	2.38
68.7	1.543	106	63.6	159.5	1.67

Table F – 15: Monthly variation of gust speed on August and September.

	August	September		August	September
Date	V_g (m/s)	V_g (m/s)	Date	V_g (m/s)	V_g (m/s)
1	5.31	2.82	16	8.05	58.45
2	9.46	2.52	17	8.50	48.42
3	9.34	2.89	18	7.68	48.79
4	8.51	4.12	19	5.17	50.21
5	6.96	6.06	20	5.00	54.78
6	4.93	4.17	21	9.50	48.59
7	6.27	2.50	22	12.84	45.13
8	4.00	3.70	23	12.21	11.26
9	3.57	4.30	24	9.94	6.51
10	3.61	6.17	25	18.21	4.55
11	4.96	4.92	26	21.24	2.30
12	9.85	3.58	27	6.39	3.13
13	8.45	3.36	28	7.85	2.78
14	7.47	5.37	29	5.49	3.15
15	6.57	16.28	30	4.28	3.86
			31	4.54	

Appendix – G

Determination of Wind Turbine Design Factors

Table G – 1: Determination of minimum C_d/C_l ratio.

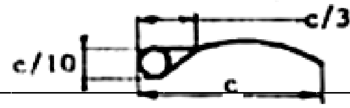
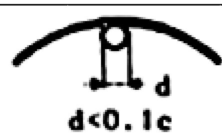
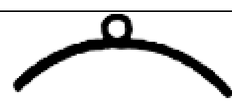
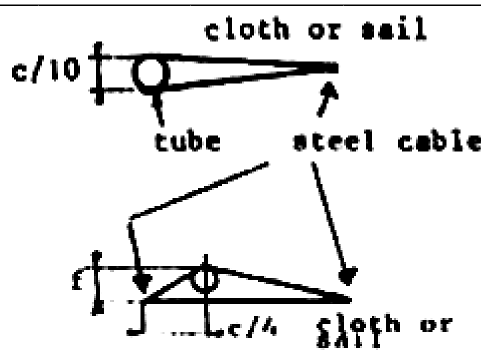
Airfoil name	Geometrical description	$(C_d/C_l)_{min}$	α^o	C_l
Sail and pole		0.1	5	0.8
Flat steel plate		0.1	4	0.4
Arched steel plate	 f/c = 0.07	0.02	4	0.9
	f/c = 0.10	0.02	3	1.25
Arched steel plate with tube on concave side	 f/c = 0.07	0.05	5	0.9
	f/c = 0.10	0.05	4	1.1
Arched steel plate with tube on convex side	 f/c = 0.10	0.2	14	1.25
Sail wing		0.05	2	1.0
Sail trouser		0.1	4	0.1
NACA 4412		0.01	4	0.8
NACA 23015		0.01	4	0.8

Figure G –1: Determination of Design Lift Coefficient and Design Angle of Attack [18].

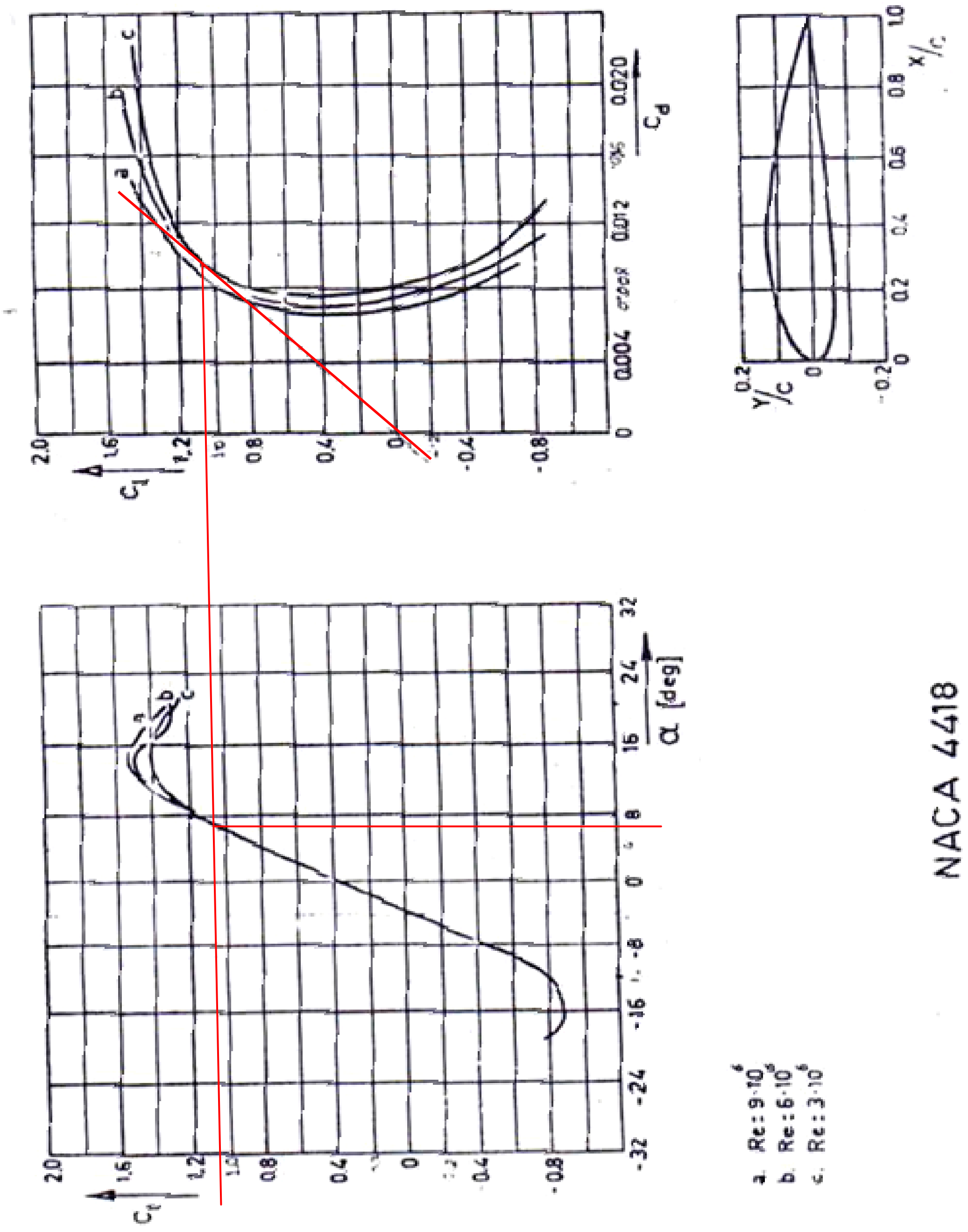


Figure G – 2: Determination of Maximum Power Coefficient [18].

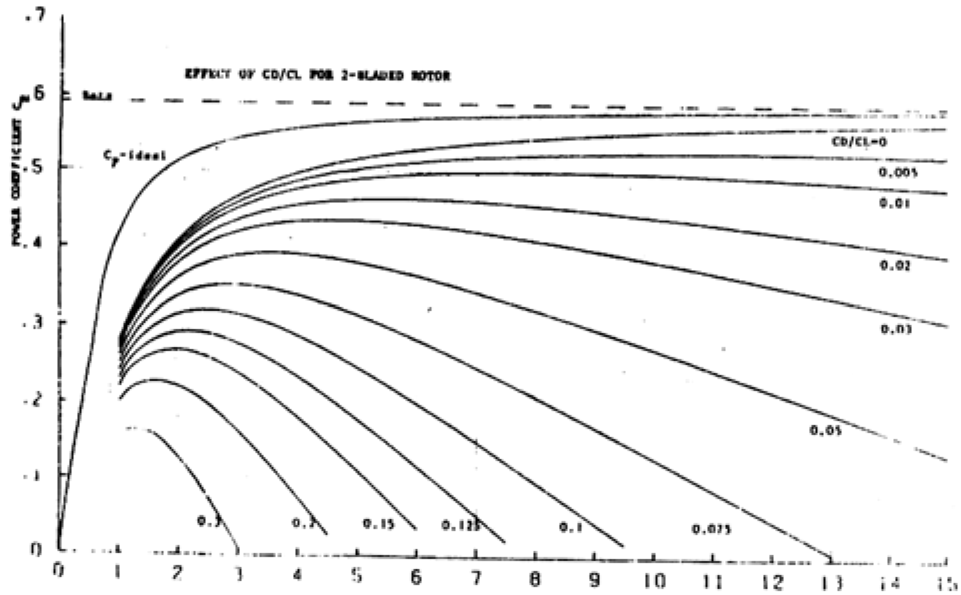


Figure for 2 bladed Rotor [18].

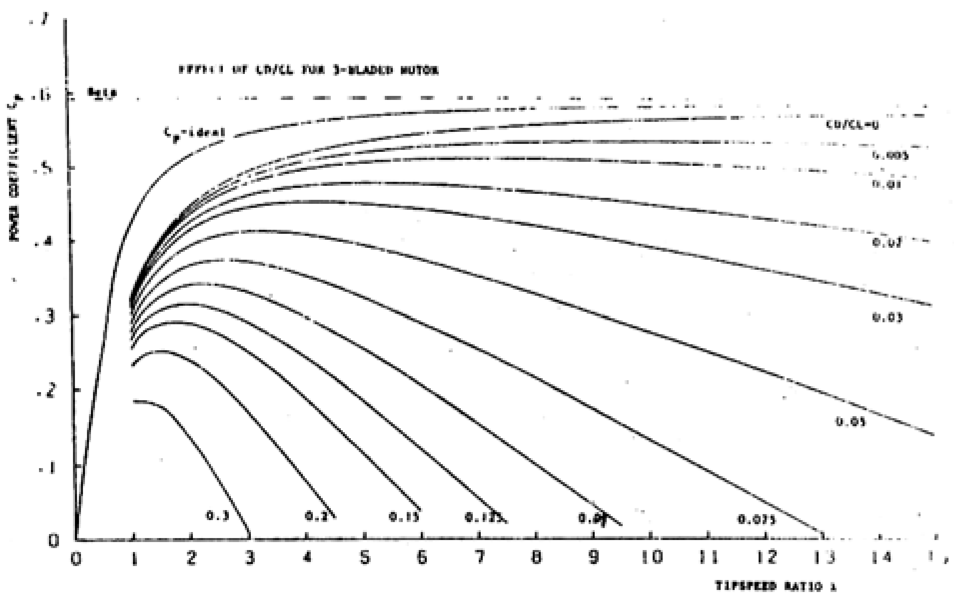
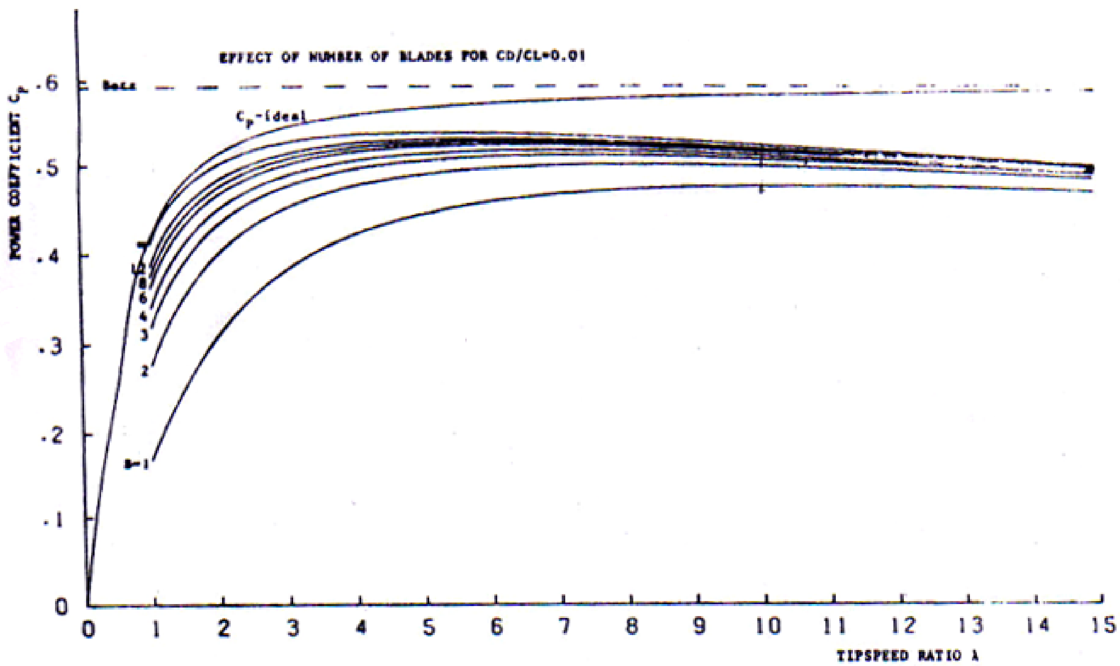
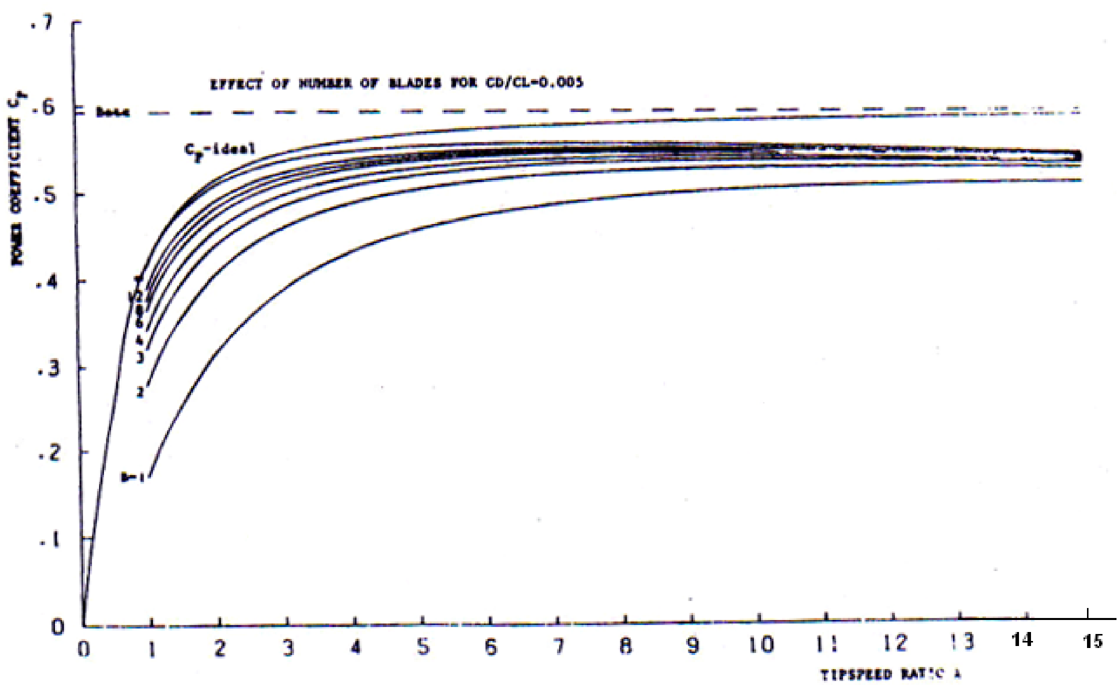


Figure for 3 bladed Rotor [18].

Figure G – 3: Determination of Design Power Coefficient [18].





Appendix – H

Program for the project of power simulation

```
//Program for motor speed control

sbit LCD_RS at RD0_bit;
sbit LCD_RW at RD1_bit;
sbit LCD_EN at RD2_bit;
sbit LCD_D7 at RD7_bit;
sbit LCD_D6 at RD6_bit;
sbit LCD_D5 at RD5_bit;
sbit LCD_D4 at RD4_bit;

// Pin direction

sbit LCD_RS_Direction at TRISD0_bit;
sbit LCD_RW_Direction at TRISD1_bit;
sbit LCD_EN_Direction at TRISD2_bit;
sbit LCD_D7_Direction at TRISD7_bit;
sbit LCD_D6_Direction at TRISD6_bit;
sbit LCD_D5_Direction at TRISD5_bit;
sbit LCD_D4_Direction at TRISD4_bit;

#define _CPU_FREQ 8000000
#define ENABLE_OUTPUT_DRIVER 0
#define DISABLE_OUTPUT_DRIVER 1

unsigned int dutyVal;
unsigned short RF_DATA_ARRIVED=0,rfData=1;
void InitSinglePWM(unsigned long pwmFreq,unsigned short dutyPercent) {
   TRISC.F2 = DISABLE_OUTPUT_DRIVER;
   PR2 = (unsigned short) ceil((_CPU_FREQ / (pwmFreq * 4 * 4)) - 1) ;
   dutyVal = (unsigned int) ceil(((4 * dutyPercent) / 100) * (PR2 + 1));
   CCP1CON =  ((dutyVal & 0x0003) << 4) | 0x0C;
   CCPR1L = (unsigned short) (dutyVal >> 2);

   PIR1.TMR2IF=0;
   T2CON = (1 << TMR2ON) | 0x01;
   while(!PIR1.TMR2IF);
   TRISC.F2 = ENABLE_OUTPUT_DRIVER;
}
void ChangeDutyCycle(unsigned short dutyPercent) {
```

```
    dutyVal = (unsigned int) ceil(((4 * dutyPercent) / 100) * (PR2 + 1));
    CCP1CON = ((dutyVal & 0x0003) << 4) | 0x0C;
    CCPR1L = (unsigned short) (dutyVal >> 2);
}
void InitADC() {
    ADCON1 |= (1 << ADFM) | (1 << ADCS2) | 0x0E; // 0x0E only for PA0=Analog
    ADCON0 = 0x80;
    ADCON0 |= 1 << ADON;
    delay_us(50);
}
unsigned int GetChannelZeroVal() {
        ADCON0 |= 1 << GO_DONE;
        while(ADCON0.GO_DONE);
        return ((ADRESH << 8) | ADRESL);
}
void interrupt() {
    if(INTCON.INTF==1) {
      rfData = PORTB >> 4;
      INTCON.INTF = 0;
      RF_DATA_ARRIVED=1;
    }
}
void main() {
    unsigned double genVolt,motorRpm;
    unsigned char txt[15];
    unsigned short i;
    TRISB = 0xF1;
    PORTB = 0x04;
    LCD_RW=0;
    LCD_RW_Direction=0;
    Lcd_Init();
    Lcd_Cmd(_LCD_CURSOR_OFF);
    InitADC();
    InitSinglePWM(10000,5);
    OPTION_REG = 1 << INTEDG;
    INTCON |= 1 << INTE;
    INTCON |= (1 << GIE) | (1 << PEIE);

    while(1) {
          genVolt=GetChannelZeroVal() * 5;
          genVolt= genVolt / 1023;
          motorRpm = (genVolt /((11-rfData) * 1.2)) * genVolt * 450 * (11-rfData);
          FloatToStr(genVolt,txt);
          i=0;
```

```
        while(txt[i++]!='.');
        txt[i+2]='\0';
        Lcd_Out(1,1,txt);
        Lcd_Out(1,6,"Volt");
        FloatToStr(motorRpm,txt);
        i=0;
        while(txt[i++]!='.');
        i+=2;
        while(i<9) txt[i++] = ' ';
        txt[9]='\0';
        Lcd_Out(2,1,txt);
        Lcd_Out(2,10,"RPM");
        Lcd_Out(1,15,"SW>");
        ByteToStr(11-rfData,txt);
        Lcd_Out(1,18,txt);
        if(RF_DATA_ARRIVED==1) {
          ChangeDutyCycle(5 + (rfData * 7));
          RF_DATA_ARRIVED = 0;
        }
        delay_ms(500)
    }
}
```

//Program for Radio frequency Transmitter

```
sbit SW_INC at PORTA.B0;
sbit SW_INC_Direction at TRISA.B0;
sbit TX_LED at PORTA.B1;
sbit TX_LED_Direction at TRISA.B1;
sbit SW_DEC at PORTA.B2;
sbit SW_DEC_Direction at TRISA.B2;
unsigned short txData=0;

void main() {
    ANSEL = 0x00;
    ANSELH = 0x00;
    TRISC = 0x00;
    SW_INC_Direction = 1;
    SW_DEC_Direction = 1;
    TX_LED_Direction = 0;
    PORTC = 0x00;
    TX_LED =  0;
    delay_ms(500);
```

```
    while(1) {
        if(SW_INC == 0) {
          if(txData < 10) txData++;
          TX_LED = 1;
          PORTC = txData << 4;
          delay_ms(150);
          PORTC = 0x00;
          delay_ms(150);
          TX_LED = 0;
        }
        if(SW_DEC == 0) {
          if(txData > 1) txData--;
          TX_LED = 1;
          PORTC = txData << 4;
          delay_ms(150);
          PORTC = 0x00;
          delay_ms(150);
          TX_LED = 0;

        }
    }
}
```

Chapter 10

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