A study on wind turbine and power plant of Bangladesh

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We hereby declare that, this thesis has been done by us under the supervision of **Fahmida Hossain Tithi**, Assistant Professor , Department of EEE Daffodil International University . We also declare that neither this thesis nor any part of this thesis has been submitted elsewhere for award of any degree or diploma.

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LIST OF ABBREVIATIONS

VAWT	Vertical Axis Wind Turbines
HAWT	Horizontal Axis Wind Turbines
BPDB	Bangladesh power development Board
LGED	Local Government Engineering Department
BRAC	Bangladesh Rural Advancement Committee
REP	Renewable Energy Programmer
RET	Renewable Energy Technology
TSR	Tip speed ratio
DG	Distributed generation

BCSIR	Bangladesh Council of Scientific and Industrial Research
IFRD	The International Foundation for Research and Development
WBHPP	Wind Battery Hybrid Power Project
SCR	Converter circuit elements
DFIG	Doubly fed induction generators

LIST OF SYMBOLS

D	Rotor diameter
P	The power of the wind measured in W (Watt)
ρ (rho)	Air Density
V	The velocity of the wind measured in m/s (meters per second).
r	The radius of the rotor measured in m (meters).
C_p	Power coefficient
l	length
A	swept area
ω_m	The mechanical angular velocity
v	wind velocity
R	The maximum radius of the rotating turbine in, m
b	Interference factor
W	Kinetic power

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ABSTRACT

The policy has set up targets for developing renewable energy resources to meet 5% of the total power demand by 2015 and 10% by 2020. For this purpose Bangladesh Power Development Board (BPDB) has installed 50 small wind turbines (the first wind firm in Bangladesh) each having 20 kW capacities, totaling one mega-watt wind battery hydride power plant in Kutubdia Island, in the southern region. The feasibility study of wind power and physical investigation were made on the wind firm. Wind energy is rapidly growing. In 2006 the installed generating capacity in the world increased by 25%, a growth rate which has more or less been sustained during the last decade. And there is no reason to believe that this growth will slow significantly in the coming years. For example, the United Kingdom's goal for installed wind turbines by 2020 is 33 GW up from 2 GW in 2006, an average annual growth rate of 22% over that period. More than half of all turbines are installed in Europe, but United States, India and lately China are also rapidly growing markets. The cradle of modern wind energy was set by innovative blacksmiths in rural Denmark. Now the wind provides more than 20% of the electrical power in Denmark, the industry has professionalized and has close ties with public research at universities. This focus issue is concerned with research in wind energy.

CHAPTER 1

INTRODUCTION OF MODERN WIND TURBINE

1.1 Introduction of Modern Wind Turbine

A wind turbine, as described in this Paper, is a machine which converts the power in the wind into electricity. This is in contrast to a ‘windmill’, which is a machine which converts the wind’s power into mechanical power. As electricity generators, wind turbines are connected to some electrical network. These systems include battery-charging tour, personal range power systems, separated or isle systems, and huge application plants. With regards to complete figures, the most frequently found wind generators are actually quite small – on the order of 10kw or less. With regards to complete producing potential, the generators that make up the majority of the potential are, in common, rather huge – in the range of 1.5 to 5MW. These larger turbines are used primarily in large utility grids, at first mostly in Europe and the United States and more recently in China and India. A typical modern wind turbine, in a wind farm configuration, connected to a utility network, is illustrated. The turbine shown is a General Electric 1.5MWand this manufacturer had delivered over 10 000 units of this model at the time of writing of this text. To understand how wind turbines are used, it is useful to briefly consider some of the fundamental facts underlying their operation.

Fig: 1.1 Modern utility-scale wind turbine. Reproduced by permission of General Electricity

In modern wind turbines, the actual conversion process uses the basic aerodynamic force of lift to produce a net positive torque on a rotating shaft, resulting first in the production of mechanical power and then in its transformation to electricity in a generator. Wind turbines, unlike most other generators, can produce energy only in response to the resource that is immediately available. It is not possible to store the wind and use it at a later time. The output of a wind turbine is thus inherently fluctuating and non dispatch able. (The most one can do is to limit production below what the wind could produce. Any system to which a wind turbine is connected must, in some way, take this variability into account. In smaller networks, there may be energy storage, backup generators, and some specialized control systems. A further fact is that the wind is not transportable: it can only be converted where it is blowing. Historically, a product such as ground wheat was made at the windmill and then transported to its point of use. Today, the possibility of conveying electrical energy via power lines compensates to some extent for wind's inability to be transported. In the future, hydrogen-based energy systems may add to this possibility. [1]

1.2 Types of Modern Wind Turbine

Wind turbines can be divided according to their construction technology into two macro-families:

1. Vertical Axis Wind Turbines – VAWT
2. Horizontal Axis Wind Turbines – HAWT

VAWT turbines, which constitute 1% of the turbines used at present, are divided into:

1. Savonius turbines.
2. Darrieus turbines.
3. hybrid turbines, Darrieus -Savonius type.

Whereas HAWT turbines, which constitutes 99% of the turbines used at present, are divided into:

1. Upwind turbines
2. Downwind turbines.[2]

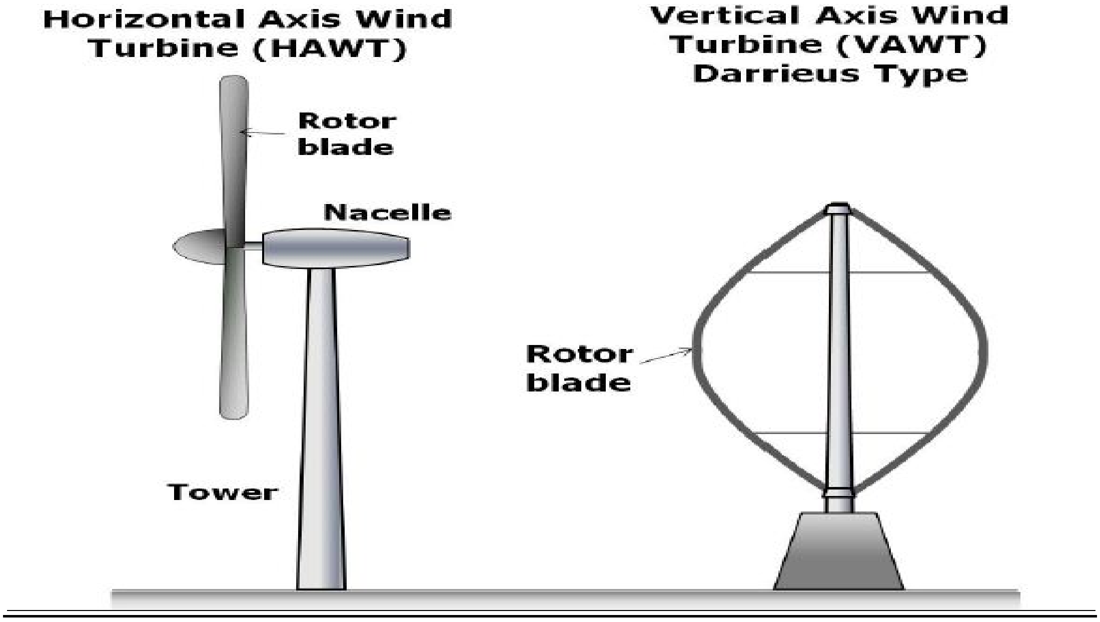

Fig: 1.2 Horizontal and vertical axis wind turbine

Horizontal Axis Wind Turbines (HAWT):

Horizontal axis wind turbines, also shortened to HAWT, are the common style that most of us think of when we think of a wind turbine. A HAWT has a similar design to a windmill, it has blades that look like a propeller that spin on the horizontal axis.

Fig:1.3 Horizontal axis wind turbines (3 bladed wind turbine by vestas, a Danish company that make large wind turbine, from 0.85MW to 3MW.)

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator. Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount.

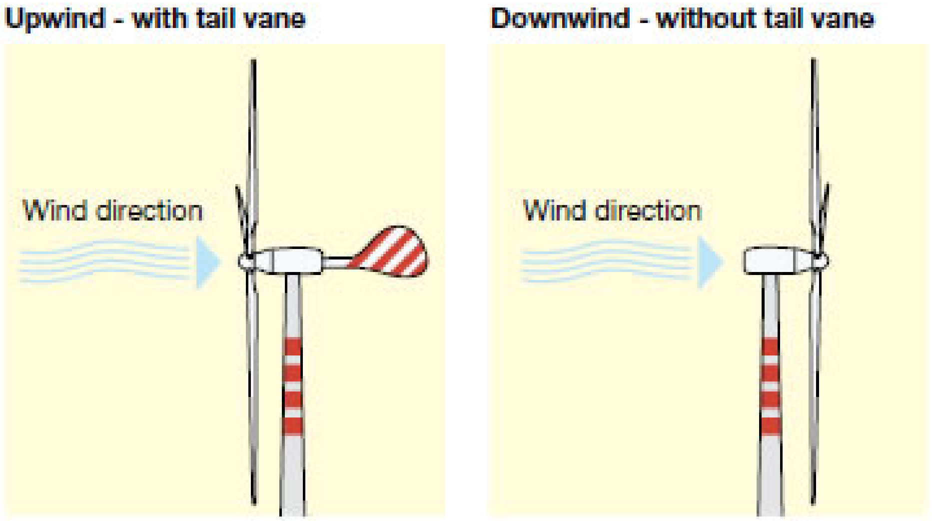

Fig: 1.4 : Upwind and down wind tail vane.

Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind. Additionally, in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines. [2]

Modern HAWTs usually feature rotors that resemble aircraft propellers, which operate on similar aerodynamic principles, i.e., the air flow over the airfoil shaped blades creates a lifting force that turns the rotor. The nacelle of a HAWT houses a gearbox and generator. HAWTS can be placed on towers to take advantage of higher winds farther from the ground.

The capture area of a HAWT, the area over which the sweeping blades can “capture” the wind, is given by

$$A = \pi \frac{\frac{D}{2}}{2}$$

where D is the rotor diameter. However, this capture area must face directly into the wind, to maximize power generation, so HAWTS require a means for alignment (yawing mechanism) so that the entire nacelle can rotate into the wind.On smaller wind turbines (like the Lokata shown in Figure), a tail vane provides a “passive” yaw control. In large, grid-connected turbines, yaw control is active, with wind direction sensors and motors that rotate the nacelle.[3]

Fig:1.5 (Lokota, a small 900W wind turbine by Aeromaga Chinese company)

1.3 Advantage and Disadvantage of Wind Turbine:

HAWT advantages

1. The tall tower base allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up the wind speed can increase by 20% and the power output by 34%.

2. High efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation. In contrast, all vertical axis wind turbines, and most proposed airborne wind turbine designs, involve various types of reciprocating actions, requiring airfoil surfaces to backtrack against the wind for part of the cycle. Backtracking against the wind leads to inherently lower efficiency.

HAWT disadvantages

1. Massive tower construction is required to support the heavy blades, gearbox, and generator.

2. Components of a horizontal axis wind turbine (gearbox, rotor shaft and brake assembly) being lifted into position.

3. Their height makes them obtrusively visible across large areas, disrupting the appearance of the landscape and sometimes creating local opposition.

4. HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

5. HAWTs generally require a braking or yawing device in high winds to stop the turbine from spinning and destroying or damaging itself. [4]

Cyclic stresses and vibration

When the turbine turns to face the wind, the rotating blades act like a gyroscope. As it pivots, gyroscopic precession tries to twist the turbine into a forward or backward somersault. For each blade on a wind generator's turbine, force is at a minimum when the blade is horizontal and at a maximum when the blade is vertical. This cyclic twisting can quickly fatigue and crack the blade roots, hub and axle of the turbines. [4]

Vertical Axis wind Turbine (VAWT)

Darrieus Wind turbine with classic tropsokein or egg-beater shaped rotor. This one features a 30 meter high rotor.

The 5 bladed H-TYPE or Gyromill wind turbine is variation of the Darrieus-type wind turbine.

Fig: 1.6 : Darrieus and Gvromill wind turbine

Vertical axis wind turbines, as shortened to VAWTs, have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds. With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT generally creates drag when rotating into the wind. It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop.

The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence. [2]

Vertical axis wind turbines-Savonius type:

It is the simplest model of turbines and it consists of two (or four) vertical sheets, without airfoil, and curved to form a semi circumference . It is also called “drag turbine”, since the motive torque is based on the difference in resistance (friction) offered against the wind by the vertical surfaces symmetrically arranged with respect to the axis.

Fig:1.7 Vertical axis wind turbines-Savonius

The main characteristics of Savonious turbine are

- “slow” turbine
- low efficiency value
- suitability for low values of wind speed and within a limited range
- necessity of adequate speed control to keep the efficiency within acceptable values
- necessity of a mechanical break for stopping the Turbine
- necessity of a robust structure to withstand extreme winds (the high exposed surface of the blades
- suitable for small power applications only
- low noise [2]

Vertical axis wind turbines – Darrieus type:

They are vertical axis “lift-type” wind turbines since the surfaces presented to the wind have an airfoil able to generate a distribution of the pressure on the blade and therefore an available torque at the rotation axis. In comparison with the “drag-type” Savonius turbines, Darrieus type (and lift-type turbines) offer higher efficiency since they reduce the losses due to friction. However, Darrieus-type turbines cannot start autonomously since, independently of the wind speed, the start-up torque is null: as a consequence this type of turbine needs an auxiliary device. For the combined type Darrieus-Savonius the starting torque is represented by the Savonius turbine coaxial and internal to the Darrieus turbine. [2]

Fig:1.8 Vertical axis wind turbines – Darrieus type

The main characteristics of the Darrieus-type turbine are

- "fast" turbine

- reduced efficiency in comparison with horizontal Axis turbines, also because a great part of the

Blade surface rotates very close to the axis at a low Speed

- Adaptability to variations in the direction of the Wind

- effective for winds with an important vertical component of speed (sites on slopes or installation on the roof of the buildings "corner effect")

- suitable for low values of wind speed and for a limited range

- necessity of an adequate speed control to keep the efficiency within acceptable value

- Impossibility of reducing the aerodynamic surface in case of speed exceeding the rated one because of the fixed blades

- necessity of a mechanical break for stopping the turbine

- necessity of a structure not extremely robust to withstand extreme winds (given the smaller surface of the blades exposed to the wind in comparison with Savonius turbines)

- suitable for large power applications

- low noise and with vibrations limited to the foundations, therefore suitable to be installed on buildings

- able to operate also under turbulent wind conditions

- gearbox and electric generator may be positioned at ground level [2]

VAWT advantages

1. No yaw mechanisms is needed.

2. A VAWT can be located nearer the ground, making it easier to maintain the moving parts.

3. VAWTs have lower wind startup speeds than the typical the HAWTs.

4. VAWTs may be built at locations where taller structures are prohibited.

5. VAWTs situated close to the ground can take advantage of locations where rooftops, mesas, hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT disadvantages

1. Most VAWTs have a average decreased efficiency from a common HAWT, mainly because of the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.
2. Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.
3. Because VAWTs are not commonly deployed due mainly to the serious disadvantages mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.[4]

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1.4 Operation principle of wind turbines

Wind turbines or aero generators transform the kinetic energy of the wind into electrical energy with no use of fuel and passing through the phase of conversion into mechanical rotation energy carried out by the blades. Turbines can be divided into "lift" machines and "drag" machines according to which force is generated by the wind and exploited as "motive force". To understand the operation principle of a wind turbine, reference is to be made to the most widespread turbines, that is the "lift" ones. In the "lift" turbines, with respect to the "drag" type, the wind flows on both blade surfaces, which have different profiles, thus creating at the upper surface a depression area with respect to the pressure on the lower surface.

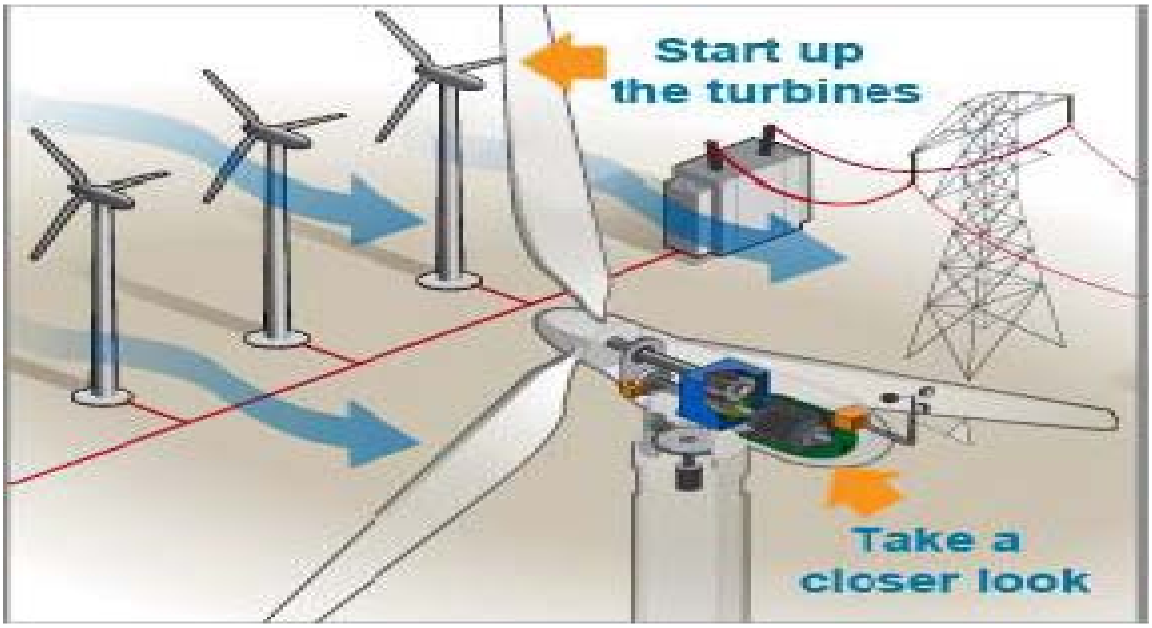


Fig:1.9 Working principle of wind turbine

Lift force on the wings of an airplane can lift it from the ground and support it in flight, whereas in a wind turbine, since the blades are bound to the ground, it determines the rotation about the hub axis. At the same time a drag force is generated, which is opposed to the motion and is perpendicular to the lift force. In the turbines correctly designed, the ratio lift-drag is high in the field of normal operation. An aerogenerator requires a minimum wind velocity (cutin speed) of 3-5 m/s and delivers the nameplate capacity at a wind velocity of 12- m/s. At high speeds, usually exceeding 25 m/s (cut-off speed) the turbine is blocked by the braking system for safety reasons. The block can be carried out by means of real mechanical brakes which slow down the rotor or, for variable pitch blades, "hiding" the blades from the wind, by putting them in the so-called "flag" position. [5]

The main advantages of the wind plants can be summarized as:

- distributed generation
- effective conversion of the wind energy into electrical energy (59% theoretical efficiency)
- lack of emission of polluting substances
- saving of fossil fuels
- reduced service (there are no costs for the fuel supply) and maintenance costs
- easy dismantlement of the wind turbines at end of life (20/25 years)
- the generation capability of the wind turbine ranges from few hundreds of Watts to some MWatts, thus meeting the requirements of both single dwelling houses, as well as of industrial applications or of injection into the network (through wind power stations. [2]

CHAPTER 2

BACKGROUND AND SITE SELECTION OF WIND TURBINE

2.1 Background of wind Turbine

Since early recorded history, people have been harnessing the energy of the wind. Wind energy propelled boats along the Nile River as early as 5000 B.C. By 200 B.C., simple windmills in China were pumping water, while vertical-axis windmills with woven reed sails were grinding grain in Persia and the Middle East.

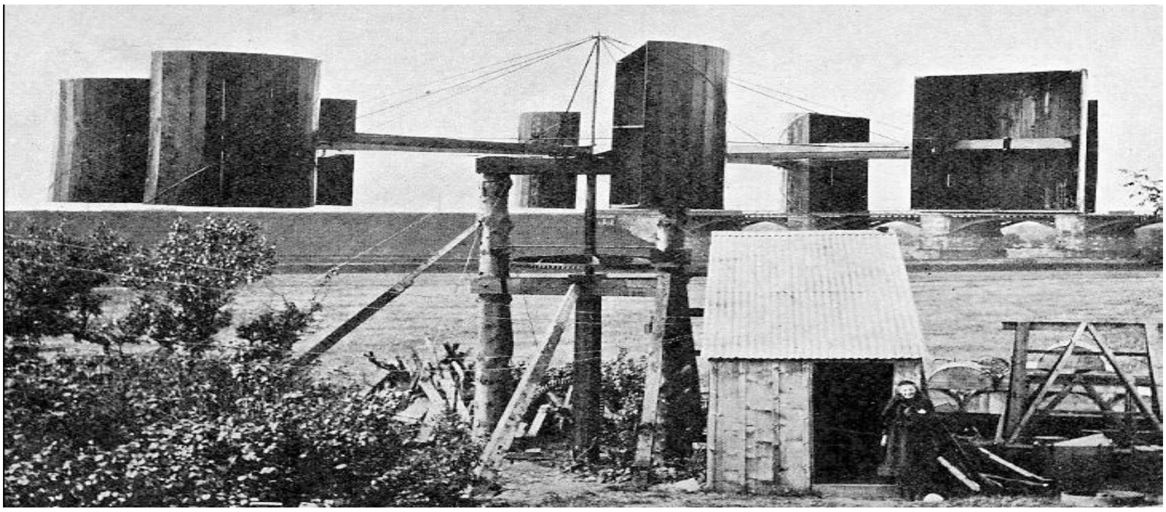


Fig:2.1 : James Blyth's electricity-generating wind turbine, photographed in 1891

New ways of using the energy of the wind eventually spread around the world. By the 11th century, people in the Middle East were using windmills extensively for food production; returning merchants and crusaders carried this idea back to Europe. The Dutch refined the windmill and adapted it for draining lakes and marshes in the Rhine River Delta. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches, and later, to generate electricity for homes and industry.

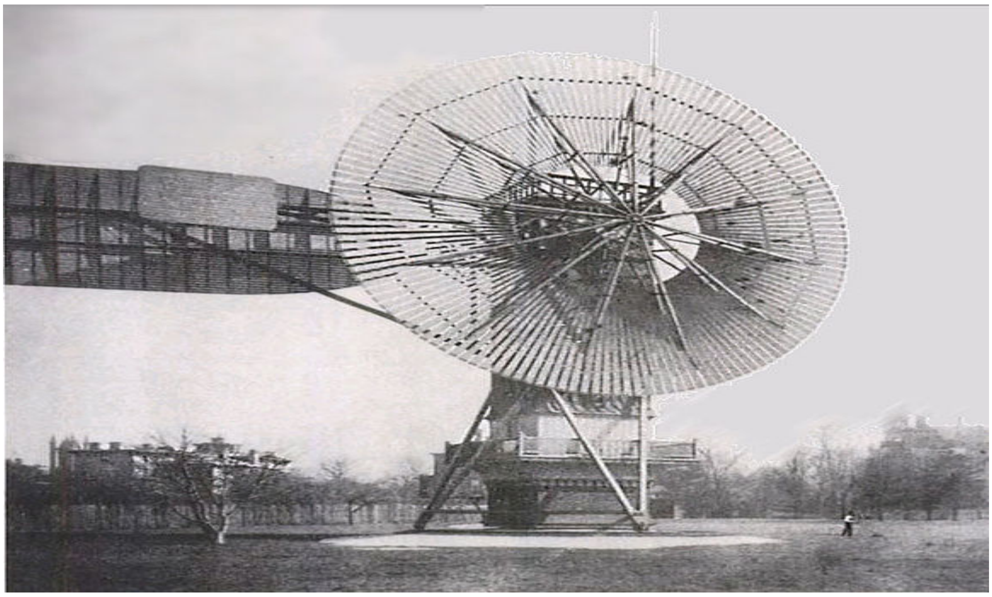


Fig: 2.2 The first automatically operated wind turbine, built in Cleveland in 1887 by Charles F. Brush. It was 60 feet (18 m) tall, weighed 4 tons (3.6 metric tonnes) and powered a 12 kW generator.

Industrialization, first in Europe and later in America, led to a gradual decline in the use of windmills. The steam engine replaced European water-pumping windmills. In the 1930s, the Rural Electrification Administration's programs brought inexpensive electric power to most rural areas in the United States. Commonly called wind turbines, these machines appeared in Denmark as early as 1890. In the 1940s the largest wind turbine of the time began operating on a Vermont hilltop known as Grandpa's Knob. This turbine, rated at 1.25 megawatts in winds of about 30 mph, fed electric power to the local utility network for several months during World War II. The popularity of using the energy in the wind has always fluctuated with the price of fossil fuels. When fuel prices fell after World War II, interest in wind turbines waned. But when the price of oil skyrocketed in the 1970s, so did worldwide interest in wind turbine generators. The wind turbine technology R&D that followed the oil embargoes of the 1970s refined old ideas and introduced new ways of converting wind energy into useful power. Many of these approaches have been demonstrated in "wind farms" or wind power plants — groups of turbines that feed electricity into the utility grid — in the United States and Europe.

Fig:2.3 wind turbine and house Nordex Launch their Latest Wind turbine in the Chinese and Asian Markets China's Big Wind Energy Ambition

Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity very close in cost to the power from conventional utility generation in some locations. Wind energy is the world's fastest-growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come. [6]

2.2 Site selection of Wind Turbine

Choosing the right site for wind turbine is the most important decision that anyone will make throughout the installation. In these sense, Location plays a vital part in the performance and efficiency of a wind turbine so get it wrong and it could be disastrous - but get it right and turbine will have a long, happy and profitable future together. To help to evaluate the site and confirm whether or not it is suitable for a wind turbine, designed the following guidelines could be followed for designing a wind turbine:

- Firstly, Turbines work and perform at the best when it will be placed on high exposed sites. Coastal sites are especially good.
- Town centers and highly populated residential areas are usually not suitable sites for wind turbines.
- It could be avoid roof mounted turbines as there is no guarantee that these device will not damage the property through vibration.
- The further the distance between turbine and power requirement, the more power will lose in the cable. The distance of the cabling will also impact the overall cost of the installation. [7]

2.3 Site-Specific Wind Data

If we wish to closely examine wind data from selected stations, several attributes about the data should be determined including:

i. Station location

ii. Local topography

iii. Anemometer height and exposure

iv. Type of observation (instantaneous or average)

v. Duration of record. [8]

2.4 Site Selection Effect

Roughness

Describing the characteristics of a terrain the roughness is mostly stated as a roughness class or roughness length. This parameter describes the height above the ground for which wind speed is zero. Roughness is influenced by the ground structure and by the size and number of obstacles in the landscape. The most important planning information is the roughness of the surface upwind in the prevailing wind direction and directly below the wind turbines. Even long grass increases the roughness value significantly, thus it is sometimes stated that 'sheep and wind turbines are best friends'. Bushes, shrubs, trees and especially buildings have a much greater influence on terrain roughness, because besides friction effects between wind stream and ground surface, obstacles like rock formations or buildings cause turbulence. The turbulent zone caused by an obstacle sometimes extends the height of an obstacle by three times. The slow down of the wind speed behind an obstacle increases with the length, the height and a parameter named porosity of the obstacle. The term porosity refers to the degree the wind can pass through the obstacle: A tree in winter time for instance, has a high porosity, while a rock formation has a porosity of zero. While for the planning process of a wind park a detailed description of landscape parameters is needed, for the installation of small wind turbines this may most often be a too big financial effort. For this purpose 30-feet rule of thumb can be used: To avoid effects of turbulence caused by obstacles a wind turbine should be installed at least 10 meters above any obstacle within a distance of 100 meter. A very cheap and simple, but clarifying tool to get a first hint about the character of a wind stream at a site for as small wind turbine is a kite. Threads can be tied to the cord of a kite every few meters. The behaviour of the threads while flying the kite gives a clue to develop an idea of the turbulence in different heights at the site. Certainly this could not be the basis for an greater investment, but it offers a possibility to gain first information about the quality of a wind site without any significant financial effort. [9]

The Hill Effect

Placing a wind turbine on a hill combines the positive effect of reducing influence of surrounding obstacles with some dynamic advantages of wind stream passing hills with low or moderate slopes: At the upwind side of a hill, the wind stream is compressed, while the pressure behind the hill is generally lowered. If the slope of a hill is not to steep, the compressed air can flow to the top of the hill where it expands and is accelerated at the same time. This hill effect causes additionally benefits for the wind turbine placed on the top of the hill. In contrast to this positive effect escarpments can cause intense turbulence and require the utilization of higher towers to avoid the negative effects of the disturbed wind stream on wind energy production .[9]

The Park Effect

In most cases wind turbines themselves are by far the biggest obstacles in the surrounding of other wind turbines. If a greater number of wind turbines should be installed, the placement of the machines will always be guided by the objective of enlarging the distance between the turbines as much as possible. As the distance is always limited by the available area for the wind park, today wind turbines are commonly placed in a distance of 5 to 9 rotor diameters in the prevailing wind direction and 3-5 rotor diameters in the direction perpendicular to this . [9]

CHAPTER 3

Wind Turbine Component And Theory

3.1 Main component of Wind turbine

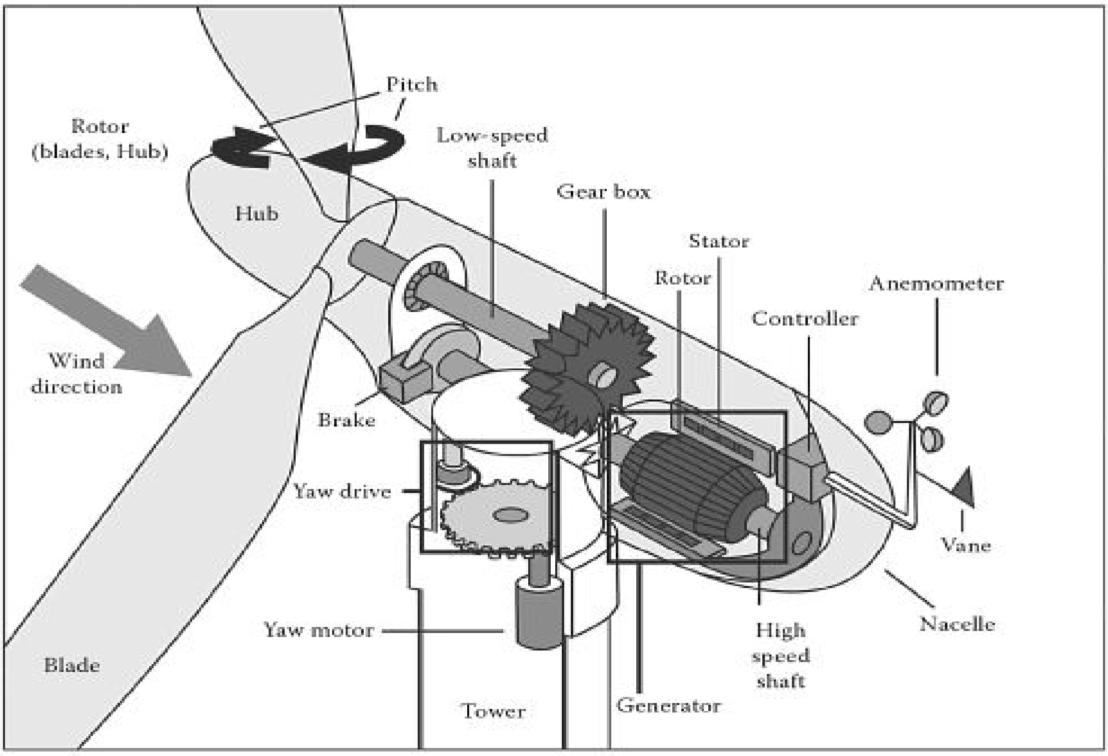


Fig: 3.1 Wind turbine component

Rotor

The rotor for a typical utility-scale wind turbine includes three high-tech blades, a hub, and a spinner. The blades are one of the most critical aspects for a wind turbine and are considered a strategic component by wind turbine . Most manufacturers create multiple blade types for a single wind turbine in order to enhance performance in different wind conditions. The blades range in size from about 34 to 55 meters and are made of laminated materials – such as composites, balsa wood, carbon fiber, and fiberglass – that have high strength-to-weight ratios. These materials are molded into airfoils to generate lift, which causes the rotor to turn. The blades also often include material to protect against lightning strikes. They are bolted onto the hub, with a pitch mechanism interposed to allow the blade to rotate about its axis to take advantage of varying wind speeds The hub – usually made of ductile cast iron – is one of a wind turbine's heaviest components, weighing 8 to 10 tons for a 2-MW turbine. [10]

Nacelle

The nacelle of a wind turbine is the box-like component that sits atop the tower and is connected to the rotor. The nacelle contains the majority of the approximately 8,000 components of the wind turbine, such as the gearbox, generator, main frame, etc. The nacelle housing is made of fiberglass and protects the internal components from the environment. The nacelle cover is fastened to the main frame, which also supports all the other components inside the nacelle. The main frames are large metal structures that must be able to withstand large fatigue loads.[10]

Yaw system

The nacelle is made to rotate on the top of the tower by an active yaw control system consisting of electrical actuators and relevant reduction gears , so that the rotor is always transversal to wind. The direction and speed of the wind are continuously controlled by the sensors connected on the roof of the nacelle. The rotor is generally positioned according to the average direction of the wind, calculated over a 10min period by the turbine control system. For horizontal axis turbines with downwind rotors, a yaw system is not necessary, since the turbine is intrinsically self-orienting and follows the wind direction as a wind vane. Instead, upwind turbines have either a rear orientation tail (small and medium size wind turbines) or active yaw control; therefore, the supporting tower shall be properly dimensioned also to withstand the tensional loads resulting from the use of yaw systems. [10]

Gearbox:

Most drive trains include a one- or more-stage gearbox between the rotor, which extracts kinetic energy from the wind and converts it into mechanical rotation energy, and the electric generator, which converts the available mechanical energy into electrical energy. The gearbox has the purpose of increasing the rotor speed to adapt it to the values required by conventional generators (in some turbines the ratio of the gearbox may exceed 1:100). The gearbox consists of one or more gears of epicycloidal or parallel axis type . In the last few years, the development of alternators with interposed converter has made it possible the construction of some models of wind turbines without gearbox. In fact, the gearbox is a source of noise and one of the elements requiring more maintenance; furthermore it may cause efficiency losses of the wind turbine. Therefore the lack of the gearbox implies a simplification of the mechanical part and thus allowing a reduction in the size and mass of the nacelle. [10]

Electric generator

Asynchronous generator

It is essentially an induction three-phase motor characterized by a synchronous speed which depends on the number of poles and on the network frequency. If the mechanical torque acting on the rotor shaft is motive instead of resistant and makes the rotation speed increase and exceed the synchronous speed, the asynchronous machine stops working as a motor and starts working as a generator, thus putting electrical energy into the grid. The relative difference between the synchronous speed and the effective rotation speed is called slip (s),which is negative when the machine is operated as a generator. In traditional asynchronous generators with squirrel cage rotor (short-circuit rotor), the slip is about 1% so that such devices are actually considered as having constant rotation speed. The magnetizing current of the stator, which generates the rotating magnetic field in the air-gap, is supplied by the grid. Besides, such generator consumes a certain amount of reactive power, which shall be supplied by compensation systems, such as capacitors. When a gust of wind hits a wind turbine equipped with a rotor asynchronous generator under short circuit, as the rotation speed is constant, there is a sudden variation of the torque and the consequent quick variation of the power output. If the short circuit power of the grid to which the wind turbine is connected is low, voltage fluctuations may occur on the electrical devices connected nearby and these fluctuations may cause malfunctioning of these devices. Moreover, it is possible to notice the quick variation of the luminous flux emitted by the lamps, generating that disturbing “fluttering” known as flicker. For this reason too, research has gone towards the development of variable speed systems which allow also the “torque pull” on the rotor to be reduced and the rotor to work at the point of maximum aerodynamic efficiency over a wide range of wind speed4. Variable speed solutions realized with induction generators are obtained by interposing a frequency converter between the stator of the generator with squirrel cage rotor and the grid, or by using a wound rotor asynchronous generator in which the rotor is supplied by an independent alternating current delivered by a frequency converter: thus, the synchronous speed results to be a function of the difference between the grid frequency and the frequency of the rotor current and it is possible to reach 30% speed variation. [11]

Synchronous generator

In this type of generator, also called alternator, the rotor consists of a direct current electromagnet or of permanent magnets. The frequency of the voltage induced on the stator (and consequently of the generated current) is directly proportional to the rotation speed of the rotor To allow functioning at variable speed, a frequency converter is interposed between alternator and grid; at first it transforms the current at variable frequency (as a function of the rotor speed and therefore of wind) coming out of the generator into direct current through an electronic rectifier, and then reconverts the direct current into alternating current at the network frequency through an inverter. Thus the frequency of the generated current is released from the grid frequency, which may also result into the abolition of the gearbox. Thanks to the synchronous motor and to the frequency converter, when the wind strength suddenly increases, the rotor is let free to accelerate for some seconds: the increase in the rotation speed accumulates kinetic energy in the rotor itself and allows constant power supply. Vice versa, when the wind falls, the energy stored in the rotor is released while the rotor itself is slowing down. [11]

Transformer

The electric power output from generators is usually in low voltage and shall be transformed into medium voltage through a transformer to reduce transmission losses by connection to the MV distribution network. The transformer is installed on the nacelle or at the base of the tower. The electric cables connecting the nacelle to the base of the tower form a ring under the nacelle so that yaw movements are allowed. These movements are controlled and, in case of excessive rotation, the nacelle is yawned in the opposite direction to prevent cables from entangling. These cables must have such an increased length that the wind turbine shall be able to make up to three complete turns for alignment. [11]

Fig: 3.2 Transformer of wind turbine

Hub

The hub of the wind turbine is the component that connects the blades to the main shaft, transmitting to it the power extracted from the wind; it includes pitching systems. Hubs are generally made of steel or spherical graphite iron and is protected externally by an oval enclosure called spinner. There are three main types of hub.

- rigid
- teetering
- hinged

A rigid hub is designed to keep all major parts in a fixed position relative to the main shaft. The blade Pitch can be varied, but no other blade motion is allowed. It is the type mostly used for rotors with three or more blades. A rigid hub must be strong enough to withstand all the loads that can arise from any aerodynamic load on the blades as well as those due to yawing.[2]

Teetering hubs are used on nearly all two-bladed wind turbines and are designed to reduce the aerodynamic imbalances transmitted to the shaft and typical of two bladed rotors; thus the rotor is free to oscillate some degrees with respect to the direction perpendicular to the rotation axis of the main shaft. Teetering hubs have been mainly coupled with turbines with fixed Pitch angle, but they can be used on variable pitched turbines as well. Also design of the pitching system is more complex since the relevant mechanisms and the switching/protection switchboards are located on the moving part with respect to the main shaft. A hinged hub is, in some ways, a cross between a rigid hub and a teetering hub and it is basically a rigid hub with hinges for the blades. It is used by downwind turbines to reduce excessive loads in case of strong winds. [2]

Tower

There are two main types of towers commonly used horizontal axis wind turbines

- Free-standing lattice (truss)
- Tubular

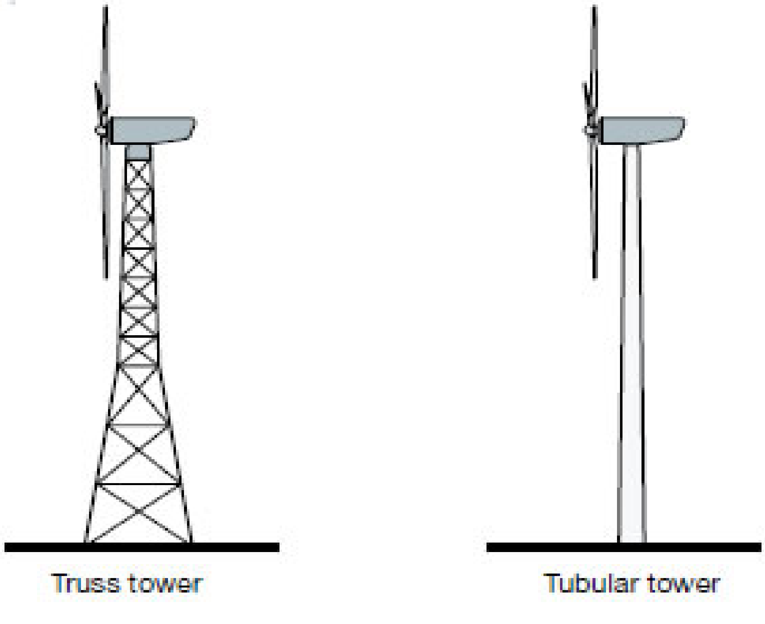


Fig: 3.3 Two type of horizontal axis wind turbines

The first wind turbines were on free-standing lattice towers, commonly used until the mid-1980s. Nowadays wind turbines are mostly of tubular type since they offer a number of advantages in comparison with the truss one. In particular, tubular towers do not require many bolted connections which need to be periodically checked; they provide a protected area to access the turbine and climbing to the nacelle is made safer and easier thanks to internal stairway or lift in case of larger turbines. Furthermore, they are aesthetically more acceptable in comparison with truss towers. There is a third type of tower, guyed lattice tower , but they are little used for medium and large size power plants.

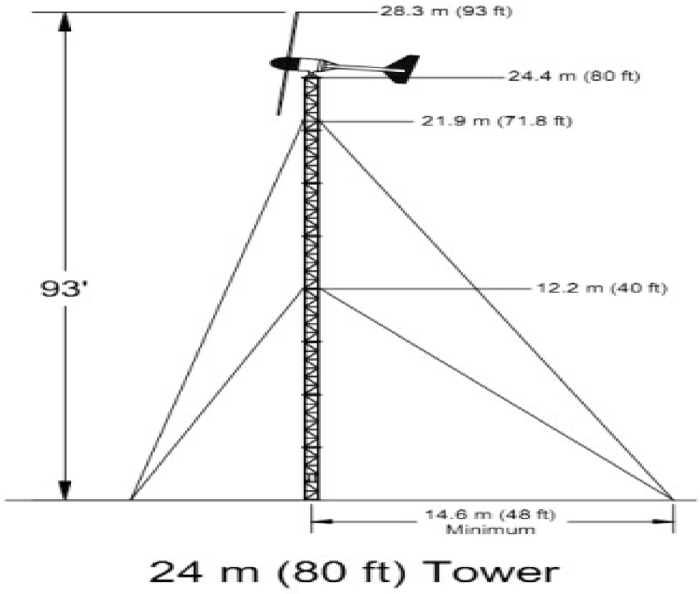


Fig: 3.4 Tubular Towers

In onshore plants the nacelle is usually at a height equal to 1 or 1.2 times the rotor diameter, whereas in offshore plants the height is equal to 0.8 times the rotor diameter. Tubular towers are Usually made of rolled steel, although sometimes reinforced concrete is used. They are cone Shaped, with the base diameter longer than that on the top where the nacelle is positioned. The Different sections are joined and fixed together by bolted flanges. These types of towers generate a remarkable downwind wake; that is why in most cases the rotor is positioned upwind.

Moreover, they are very visible structures and therefore they must not show signs of corrosion Over many years: to this purpose, adequate coating must be chosen. The towers are set into the Ground through foundations generally consisting in reinforced concrete plinths placed at a certain depth. [2]

3.2 The theory of wind turbines

Wind turbines work by converting the kinetic energy in the wind first into rotational kinetic energy in the turbine and then electrical energy that can be supplied, via the national grid, for any purpose around the world. The energy available for conversion mainly depends on the wind speed and the swept area of the turbine.

we get that the kinetic energy of a mass in motions is:

$$E=\frac{1}{2}mv^2 \text{ ....i}$$

The power in the wind is given by the rate of change of energy:

$$P=\frac{dE}{dt}=\frac{1}{2}v^2\frac{dm}{dt}\text{..........ii}$$

As mass flow rate is given by:

$$\frac{dm}{dt}=\rho A\frac{dx}{dt}$$

And the rate of change of distance is given by:

$$\frac{dx}{dt}=\mathrm{v}$$

We get:

$$\frac{dm}{dt}=\rho\, Av$$

Here from equation (iii), the power can be define as :

$$P = \frac{1}{2}\rho A v^3 \text{...............(iv)}$$

Or, $$P = \frac{1}{2}\ \rho \pi r^2 v^3$$

Where,

P = the power of the wind measured in W (Watt)

$\rho =$ (rho) = the density of dry air = 1.225 measured in kg/m 3 (kilogram's per cubic meter, at average atmospheric pressure at sea level at 15° C).

v = the velocity of the wind measured in m/s (meters per second). = (pi) = 3.1415926535...

r = the radius (i.e. half the diameter) of the rotor measured in m (meters).

As it can be noticed $P_{available}$ varies according to the cube of the wind speed V_1. For example, with a standard air density at sea level ρ = 1.225kg/m^3 , it is :

V(1) = 5 m/s => $P_{available}$ = 76 W/m^2

V(1) = 6 m/s => $P_{available}$ = 132 W/m^2

V(1) = 7 m/s => $P_{available}$ = 210 W/m^2

Therefore, with an increase of the wind speed of about 1 m/s only, the available specific power rises of about 60-70%. [12]

Betz Law

A German physicist Albert Betz concluded in 1919 that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the Betz Limit or Betz' Law. His book "Wind-Energies" published in 1926 gives a good account of the knowledge of wind energy and wind turbines at that moment. In practice, all real wind turbines extract less than this hypothetical maximum. [12]

Power coefficientC_p:

The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the “power coefficient” and is defined as:

$$C_{Pmax} = 0.59$$

wind turbines cannot operate at this maximum limit. The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in The factor 16/27 = 0.593 is sometimes called the Betz coefficient.

Wind turbine rotor performance is usually characterized by its power coefficient, CP:

$$C_p = \frac{P}{1/2\ \rho A V^3} = \frac{Rotor\ power}{Power\ in\ the\ Wind}$$

The ratio between power extracted and the available power of the wind is given by

$$\mathrm{P} = C_p.\frac{1}{2}\ \rho A V^3$$

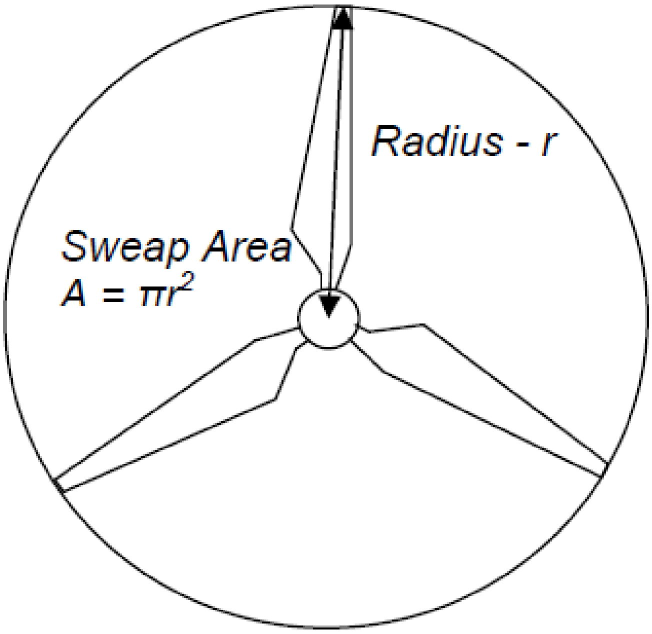
The real world limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. It’s varies with wind speed, turbulence and operating characteristic. [12]

3.3 Calculation of practical wind turbine

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

$$A = \pi r^2$$

Where the radius is equal to the blade length as shown in the figure below:



We are given the following data:

Blade length, l = 52 m

Wind speed, v = 12 m/sec

Air density, ρ = 1.23 kg/m3

Power Coefficient, Cp = 0.4

Inserting the value for blade length as the radius of the swept area into equation we have:

$$l = r = 52\text{m}$$

$$A = \pi r^2$$

$$= \pi * 52^2$$

$$= 8495 m^2$$

We can then calculate the power converted from the wind into rotational energy in the turbine using equation :

$$P_{available} = \frac{1}{2} \rho A v^3 C_p$$

$$= \frac{1}{2} * 1.23 * 8495 * 12^3 * 0.4$$

$$= 3.6\text{MW}[13]$$

Tip speed ratio (TSR)

Wind turbines is the ratio between the tangential speed of the tip of a blade and the actual velocity of the wind, v. The tip-speed ratio is related to efficiency, with the optimum varying with blade design. Higher tip speeds result in higher noise levels and require stronger blades due to large centrifugal forces.

$$\lambda = \frac{Tip\ speed\ of\ blade}{Wind\ speed}$$

This tip speed ratio is defined as

$$\lambda = R\omega/v$$

Where R is the maximum radius of the rotating turbine in m,

ω_m is the mechanical angular velocity of the turbine in rad/s

And v is the undisturbed wind speed in m/s.

The angular velocity ω_m is determined from the rotational speed n (r/min) by the equation

$$\omega_m = \frac{2\pi n}{60} \text{ rad/s}$$ [12]

Cp - λ curves:

The power co-efficient, C_p is a quantity that expresses what fraction of the power in the wind is being extracted by the wind turbine. It is generally assumed to be a function of both Tip-speed ratio and pitch angle. Below is a plot of the variation of the power coefficient with Variations in the tip-speed ratio when the pitch is held constant. [12]

Prove of Bet'z Limit

If the air stream is considered as a case of incompressible flow, the conservation of mass or continuity equation can be written as:

$$m = \rho S_1 V_1 = \rho SV = \rho S_2 V_2 = \text{constant} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

This expresses the fact that the mass flow rate is a constant along the wind stream. Continuing with the derivation, Euler's Theorem gives the force exerted by the wind on the rotor as:

$$F = ma$$

$$= m\frac{dv}{dt}$$

$$= m\Delta V$$

$$= \rho SV.(V_1 - V_2)$$

The incremental energy or the incremental work done in the wind stream is given by:

$$dE = Fdx$$

From which the power content of the wind stream is:

$$P = \frac{dE}{dt} = F\frac{dx}{dt} = FV$$

Substituting for the force F , we get for the extractable power from the wind:

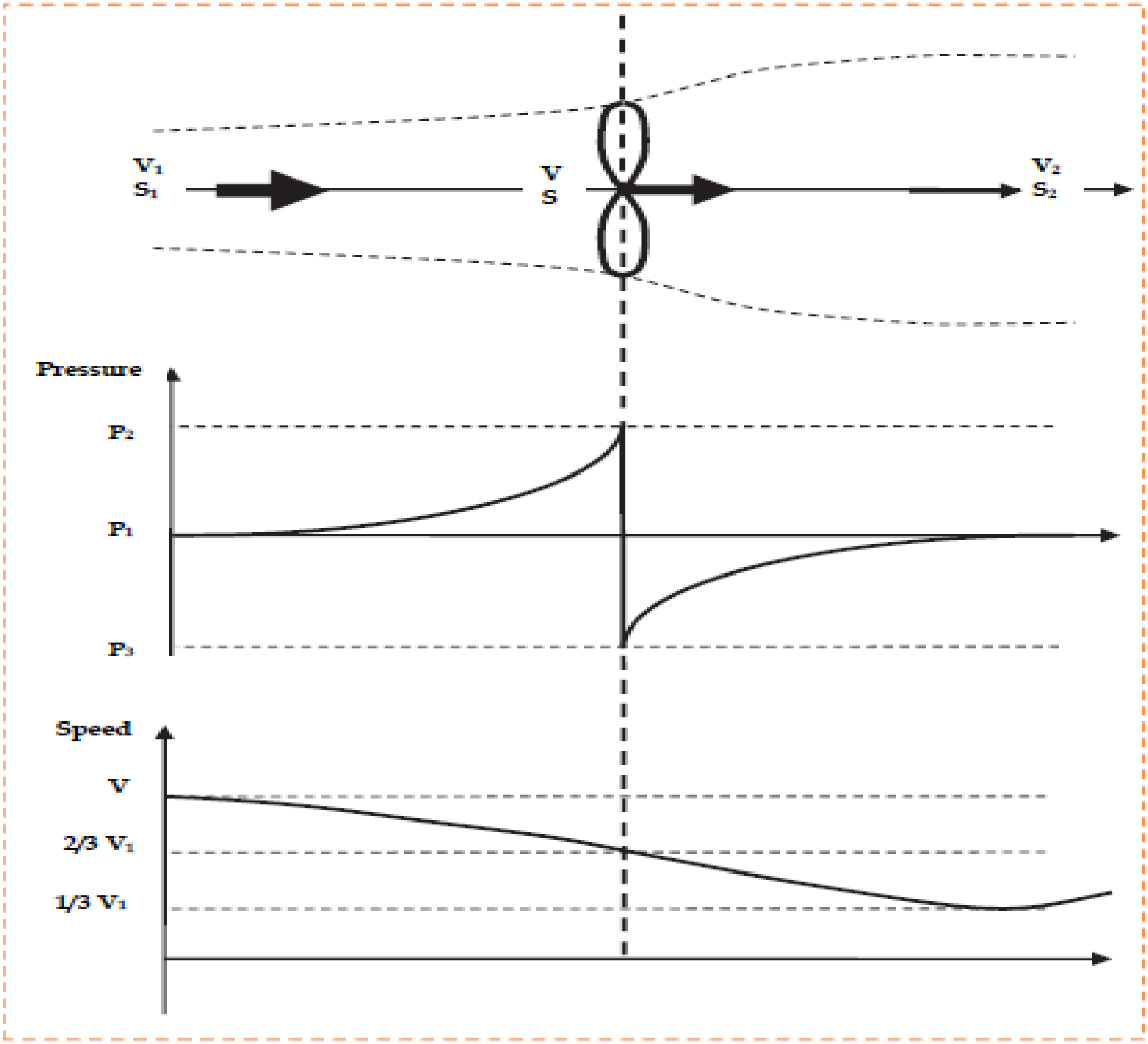


Fig: 3.5 **Pressure** and speed variation in an ideal model of a wind turbine

$$P = \rho S V^2 . (V_1 - V_2)$$

The power as the rate of change in kinetic energy from upstream to downstream is given by:

$$P = \frac{\Delta E}{\Delta t}$$

$$\frac{\frac{1}{2} m V_1^{\,2} - \frac{1}{2} m V_2^{\,2}}{\Delta t}$$

$$= \frac{1}{2} m (V_1^{\,2} - V_2^{\,2})$$

we can write:

$$P = \frac{1}{2} \rho S V \, (V_1^{\,2} - V_2^{\,2})$$

Equating the two expressions for the power P in Eqns. 6 and 8, we get:

$$P = \frac{1}{2} \rho S V (V_1^{\,2} - V_2^{\,2}) = \rho S V^2 (V_1 - V_2)$$

The last expression implies that:

$$\frac{1}{2} (V_1^{\,2} - V_2^{\,2}) = \frac{1}{2} (V_1 - V_2)\,(V_1 + V_1)$$

$$= V(V_1 - V_2)$$

Or , $V = \frac{1}{2} (V_1 + V_1), (V_1 - V_2) \neq 0 \; or \; V_1 \neq V_2$

This in turn suggests that the wind velocity at the rotor may be taken as the average of the upstream and downstream wind velocities. It also implies that the turbine must act as a brake, reducing the wind speed from V1 to V2, but not totally reducing it to V = 0, at which point the equation is no longer valid. To extract energy from the wind stream, its flow must be maintained and not totally stopped.

The last result allows us to write new expressions for the force F and power P in terms of the upstream and downstream velocities by substituting for the value of V as:

$$F = \rho SV(V_1 - V_2)$$

$$= \frac{1}{2}\rho S(V_1 - V_2)$$

$$= \rho SV^2(V_1 - V_2)$$

$$= \frac{1}{4}\rho S(V_{1+V_2})2(V_1 + V_1)$$

$$= \frac{1}{4}\rho S(V_{1+V_2})2(V_1 + V_1)$$

We can introduce the “downstream velocity factor,” or “interference factor,” b as the ratio of the downstream speed V2 to the upstream speed V1 as:

$$b = \frac{V_2}{V_2}$$

From Eqn. 10 the force F can be expressed as:

$$F = \frac{1}{2}\rho S.V^2(1 - b^2)$$

The extractable power P in terms of the interference factor b can be expressed as:

$$= \frac{1}{4}\rho S({V_1}^2 - V_2^2)(V_{1+} V_2)$$

$$= \frac{1}{4}\rho SV_1^3 (1 - b^2)(1 + b)$$

The most important observation pertaining to wind power production is that the extractable power from the wind is proportional to the cube of the upstream wind speed V1 and is function of the interference factor b.

The “power flux” or rate of energy flow per unit area, sometimes referred to as “power density” is defined using Eqn. 6 as:

$$\text{P} = \frac{P}{S}$$

$$= \frac{\frac{1}{2}\rho S v^3}{S}$$

$$= \frac{1}{2}\rho V^3, \left[\frac{Joules}{m^2.s}\right], \left[\frac{Watts}{m^2}\right]$$

The kinetic power content of the undisturbed upstream wind stream with V = V1 and over a cross sectional area S becomes:

$$= \frac{1}{2}\rho S V_1^3, \left[\frac{Joules}{m^2.s} m^2\right], [\text{Watts}]$$

The performance coefficient or efficiency is the dimensionless ratio of the extractable power P to the kinetic power W available in the undisturbed stream:

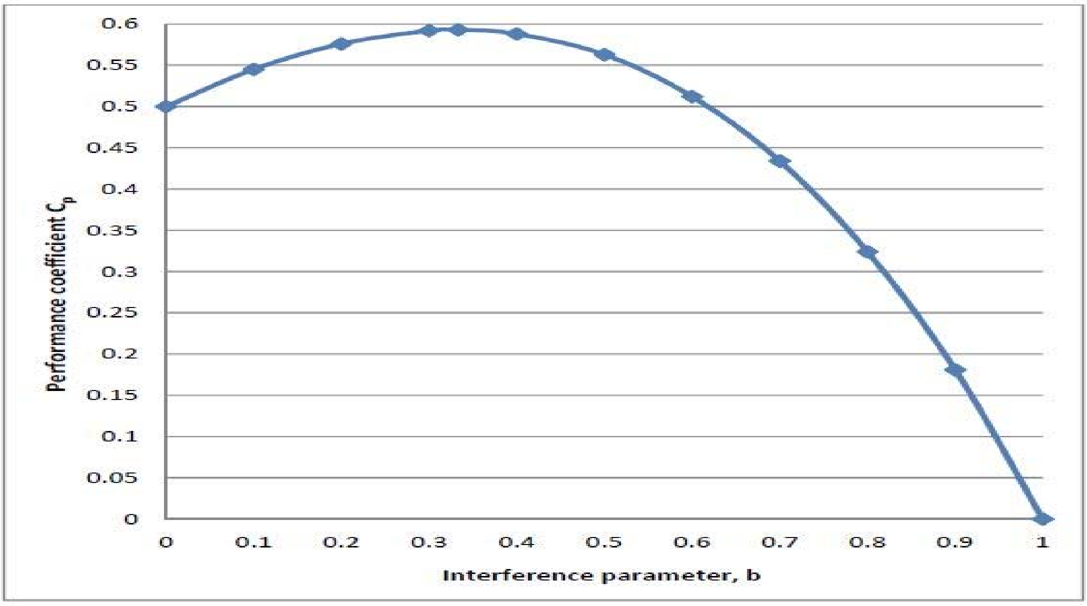
$$C_p = \frac{P}{W}$$

The performance coefficient is a dimensionless measure of the efficiency of a wind turbine in extracting the energy content of a wind stream. Substituting the expressions for P from Eqn. 14 and for W from Eqn. we have:

$$C_p = \frac{P}{W}$$

$$= \frac{\frac{1}{4}\rho S V_1^3 (1-b^2)(1+b)}{\frac{1}{4}\rho S V_1^3}$$

$$= \frac{1}{2}(1-b^2)(1+b)$$



b	0.0	0.1	0.2	0.3	1/3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
C_p	0.500	0.545	0.576	0.592	0.593	0.588	0.563	0.512	0.434	0.324	0.181	0.00

Fig: 3.6 The performance coefficient Cp as a function of the interference factor b.

When b = 1, V1 = V2 and the wind stream is undisturbed, leading to a performance coefficient of zero. When b = 0, V1 = 0, the turbine stops all the air flow and the performance coefficient is equal to 0.5. It can be noticed from the graph that the performance coefficient reaches a maximum around b = 1/3. A condition for maximum performance can be obtained by differentiation of Eq. with respect to the interference factor b. Applying the chain rule of differentiation (shown below) and setting the derivative equal to zero yields Eq.:

$$\frac{d}{dx}(uv) = \text{u}\frac{dv}{dx} + \text{v}\frac{du}{dx}$$

$$\frac{dC_p}{db} = \frac{1}{2}\frac{d}{db}[(1 - b^2)(1 + \text{b})]$$

$$= \frac{\mathbf{1}}{\mathbf{2}}[(1 - b^2) - 2\text{b}(1 + \text{b})]$$

$$= \frac{\mathbf{1}}{\mathbf{2}}(1 - b^2 - 2\text{b} - 2b^2)$$

$$= \frac{\mathbf{1}}{\mathbf{2}}(1 - 3b^2 - 2\text{b})$$

$$= \frac{1}{2}(1 - 3b^2)(1 + \text{b})$$

$$= 0$$

Equation has two solutions. The first is the trivial solution:

$$(1 + \text{b}) = 0$$

$$\text{b} = \frac{V_2}{V_1} = -1, \Rightarrow V_2 = -V_1$$

The second solution is the practical physical solution:

$$(1 - 3\text{b}) = 0$$

$$\text{b} = \frac{V_2}{V_1} = \frac{1}{3}, \Rightarrow V_2 = \frac{1}{3}V_1$$

Equation shows that for optimal operation, the downstream velocity V2 should be equal to one third of the upstream velocity V1. Using Eqn. 18, the maximum or optimal value of the performance coefficient Cp becomes:

$$C_{p.opt} = \frac{1}{2} (1 - b^2) (1 + b)$$

$$= \frac{1}{2} (1-(\frac{1}{3})2) (1+\frac{1}{3})$$

$$= \frac{16}{27}$$

$$= 59.26 \text{ percent}$$

This is referred to as the Betz Criterion or the Betz Limit. It was first formulated in 1919, and applies to all wind turbine designs. It is the theoretical power fraction that can be extracted from an ideal wind stream. Modern wind machines operate at a slightly lower practical non-ideal performance coefficient. It is generally reported to be in the range of:

$$C_{p,prac.\approx} \; 40 \text{ percent[14]}$$

3.4 Electrical component

Power converters

Power converters are devices used to change electrical power from one form to another, as in AC to DC, DC to AC, one voltage to another, or one frequency to another. Power converters have many applications in wind energy systems. They are being used more often as the technology develops and as costs drop. For example, power converters are used in generator starters, variable-speed wind turbines, and in isolated networks. Modern converters are power electronic devices. Basically, these consist of an electronic control system turning on and off electronic switches, often called ‘valves.’ Some of the key circuit elements used in the inverters include diodes, silicon-controlled rectifiers (SCRs, also known as thyristors), gate turn off thyristors (GTOs), and power transistors.

Diodes behave as one-way valves. SCRs are essentially diodes which can be turned on by an external pulse (at the 'gate'), but are turned off only by the voltage across them reversing. GTOs are SCRs which may be turned off as well as on. Transistors require the gate signal to be continuously applied to stay on. The overall function of power transistors is similar to GTOs, but the firing circuitry is simpler. The term 'power transistor,' as used here, includes Darlingtons, power MOSFETS, and insulated gate bipolar transistors (IGBTs). The present trend is towards increasing use of IGBTs. Figure 5.22 shows the symbols used in this chapter for the most important power converter circuit elements. [15]

Rectifier:

Rectifiers are devices which convert AC into DC. They may be used in: (1) battery-charging wind systems or (2) as part of a variable-speed wind power system.

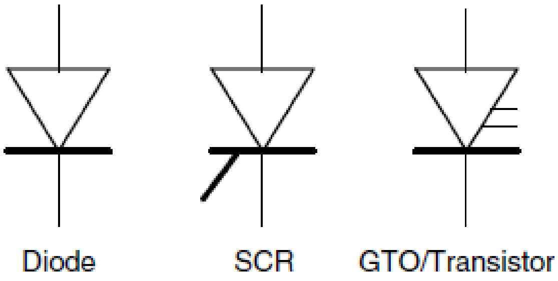


Fig : 3.7 Converter circuit elements; SCR, silicon-controlled rectifier; GTO, gate turn off thyristor.

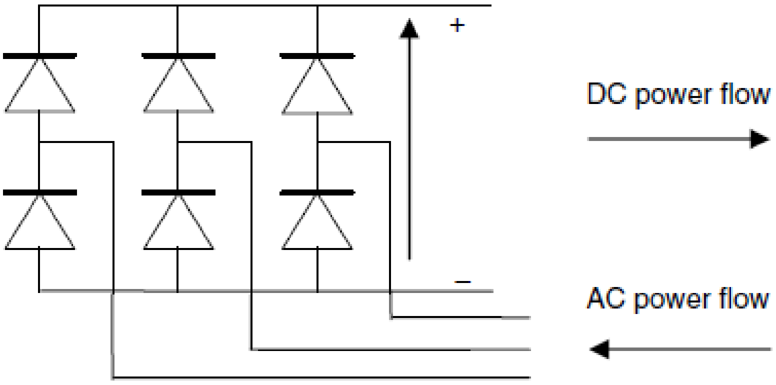


Fig: 3.8 Diode bridge rectifier using three-phase supply

The simplest type of rectifier utilizes a diode bridge circuit to convert the AC to fluctuating DC. An example of such a rectifier is shown in Figure 5.23. In this rectifier, the input is three phase AC power; the output is DC [15]

Inverters

In order to convert DC to AC, as from a battery or from rectified AC in a variable-speed wind turbine, an inverter is used. Historically, motor generator sets have been used to convert DC into AC. These are AC generators driven by DC motors. This method is very reliable, but is also expensive and inefficient. Because of their reliability, however, they are still used in some demanding situation.

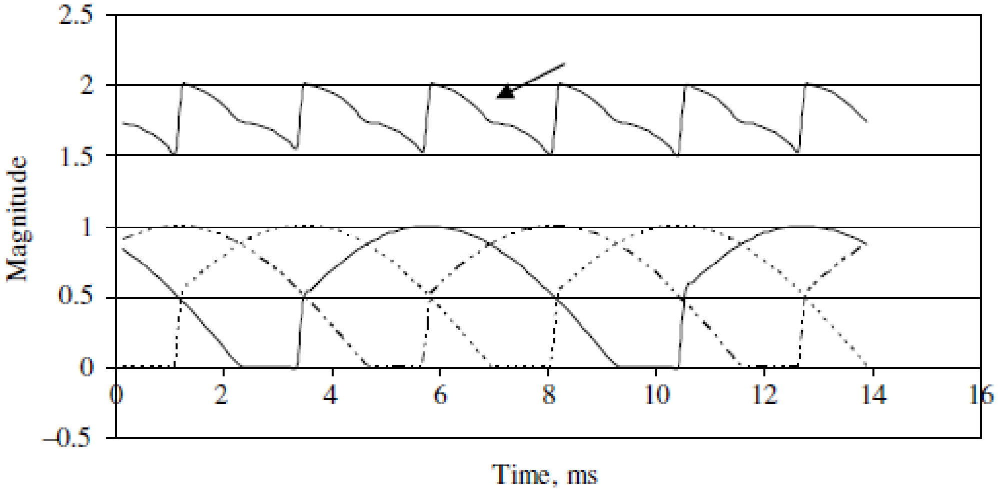


Fig :3.9 DC voltage from phase-controlled rectifier

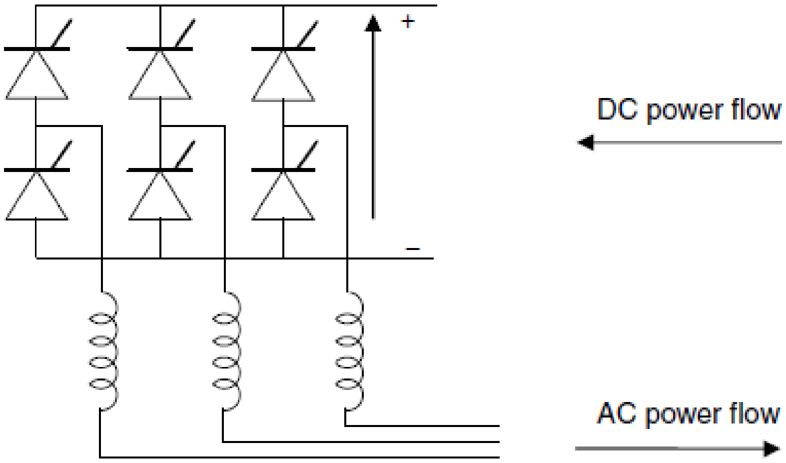


Fig :3.10 Line-commutated silicon-controlled rectifier (SCR) inverter[15]

3.5 Control systems in wind turbines:

The purpose of the control system of a wind turbine is to manage the safe, automatic operation of the turbine. This reduces operating costs, provides consistent dynamic response and improved product quality, and helps to ensure safety. Wind turbine control systems are typically divided, functionally if not physically, into three separate parts: (1) a controller that controls numerous wind turbines in a wind farm, (2) a supervisory controller for each individual turbine, and (3) separate dynamic controllers for the various turbine subsystems in each turbine.

3.5.1 Control System Components:

Control of mechanical and electrical processes requires five main functional components.

1. A process that has a point or points that allow the process to be changed or influenced.

2. Sensors or indicators to communicate the state of the process to the control system.

3. A controller, consisting of hardware or software logic, to determine what control actions should be taken. Controllers may consist of computers, electrical circuits, or mechanical systems.

5. Actuators or components for intervening in the process to change the operation of the system.

3.5.2 Protection/disconnection systems:

These systems are the “brain” of the wind turbine and provide the control logic to command start up and shut down procedures of the turbine and to guarantee turbine functioning in a defined range of operation parameters, by protecting the rotor, in particular, against over speed, and the different parts of the electric circuit against over currents and over voltages. The logic of control is usually programmed in a PLC. This state is entered when winds or power are above specified upper levels, when winds drop below specified lower levels, or when system monitoring indicates that the turbine should not be operated Shutdown may also include parking the blades in a specific orientation and engaging the yaw brake. Upon completely shutting down, unless for a component problem, the turbine is ready for another operating cycle. [16]

CHAPTER 4

Small Wind Turbine

4.1 Small wind turbine

Small wind turbines are an attractive alternative for off-grid electrification and water pumping, both as stand-alone applications and in combination with other energy technologies such as photovoltaic, small hydro or Diesel engines. Under these conditions, the cost of energy alone is often not the only criterion to consider, and aspects like system performance, suitability for a given wind regime, reliability under normal and extreme wind conditions, and overall system life are often equally important. Where no grid connection is available or the grid is unreliable, it is the energy-providing service that matters, not its precise cost. In grid-connected situations, the actual vs. the rated performance may be of more interest in order to achieve the cost saving benefits proposed in the design of the project. In either case, an uninterrupted service with a performance close to the one specified by the provider is a key requirement for a successful small wind project.

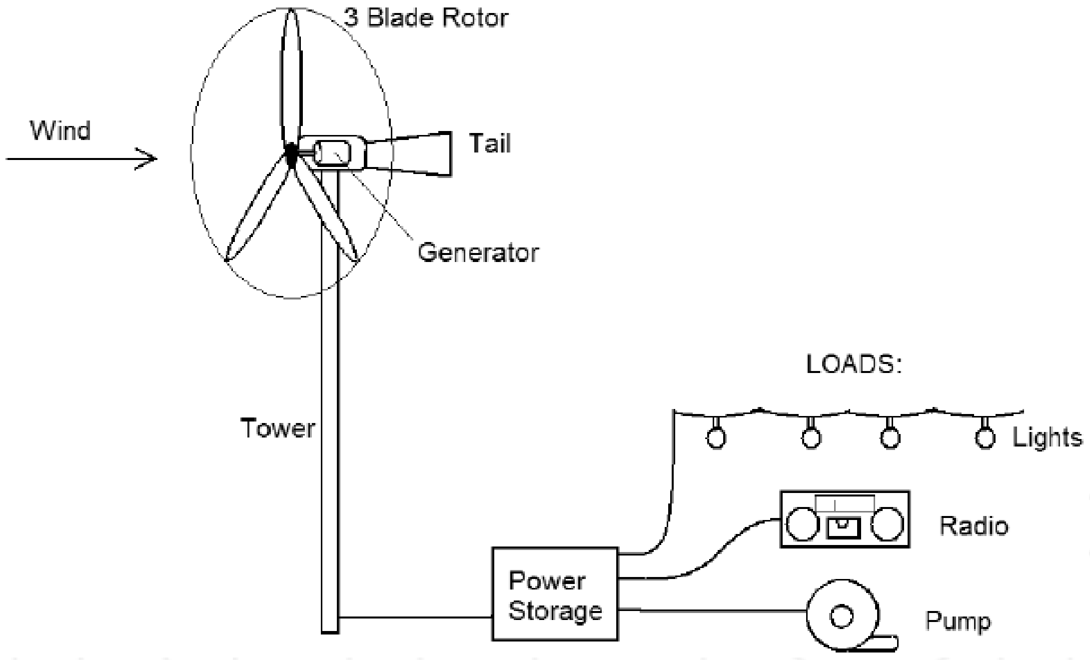


Fig: 4.1 Small wind turbine

Fig: Schematic of typical small wind power system including wind turbine, storage system and loads Small turbines are of a limited variety of designs due to cost and performance constraints. The most common design is a stall regulated, variable speed, horizontal axis, fixed pitch 3-blade, direct drive permanent magnet machine. Blade pitch control would be difficult to justify economically, so the blades are given a fixed pitch, and optimized for power production at the rated speed. This results in poorer performance at lower speeds than could be achieved by a turbine with active pitch control. The ultimate speed of the turbine is determined by the wind speed and the applied load. Usually a power controller is still required to prevent turbine over speed, and over charging of the batteries. This power controller may also incorporate power matching circuitry allowing optimized power extraction from the wind turbine at various wind speeds . Turbine over-speed is avoided by applying a low resistance dump load to the generator, increasing the load torque to the turbine, slowing the blades, and resulting in aerodynamic stall.[17]

4.2 Conceptual design of small wind turbine systems

While no strict definition of a small wind turbine exists in literature, wind turbines with a rated capacity of 10kW or less are generally considered small; this definition is sometimes extended up to about 50kW due to the recent appearance of higher rated machines suitable for servicing more energy demanding applications, including agricultural tasks such as water pumping for irrigation or livestock watering. As it will explained below, rated capacity is not a very well defined parameter for a small wind turbine, so the rotor diameter or, equivalently, the swept rotor area are often preferred for classifying small wind turbines, where rotor diameters of about 10m can be taken as the dividing line. Another means of distinguishing small from large wind turbines is by requiring a small wind turbine to have a tail vane . While in principle many of the aspects discussed in this chapter can be applied to vertical- and horizontal-axis wind turbines equally we will limit ourselves to the latter only A small wind turbine generally consists of the following minimal components: (1) A rotor with a variable number of blades , (2) an electric generator , and (3)passive or active electronic components for feeding electricity into a battery bank, the public grid or, occasionally, into a direct application such as a water-pump.

Upwind wind turbines are generally equipped with a tail vane to assure the rotor is facing the wind, while downwind turbines rely on the self-orienting effect of the axial forces acting on the rotor, albeit at the expense of a periodic tower shading effect acting on the turbine blades. Many upwind turbines rely on a furling mechanism for over speed and output power control at high wind speeds, although other mechanisms such as load-induced stall are used occasionally. Passively pitching blades, generally triggered by the action of the centrifugal forces acting on the rotor, have been used in the past but are currently less common. Most small wind turbines are variable-frequency devices, allowing for an optimal operation at all wind speeds below the threshold for the onset of the over speed and power control mechanism. While in the case of battery-charging applications the use of a passive rectifier together with the selection of an appropriate voltage level may be sufficient to maintain theoperating point close to the system optimum, especially when the aerodynamic efficiency curve is broad (Elizondo et al., 2009, Probst et al., 2006), some commercial systems rely on the use of an active load control in order to maintain the system at the optimal operating point for each wind speed (Martinez et al., 2006). In the case of a coupling to the electric grid, a full wild AC/fixed frequency AC conversion is generally feasible through the use of a back-to-back AC/DC/AC converter, as opposed to large wind turbines where a direct full conversion is still rather the exception than the rule and most commercial large wind turbines rely on doubly fed induction generators (DFIG) where only a fraction of the total power is passed through a converter. [17]

4.3 Commercial Small Turbines

There are significant differences between how various manufacturers state turbine specifications, however it is generally understood that the turbine will produce the rated power at the rated wind speed. Based on a survey of data published for small wind turbines we have selected the following typical commercial turbine specifications

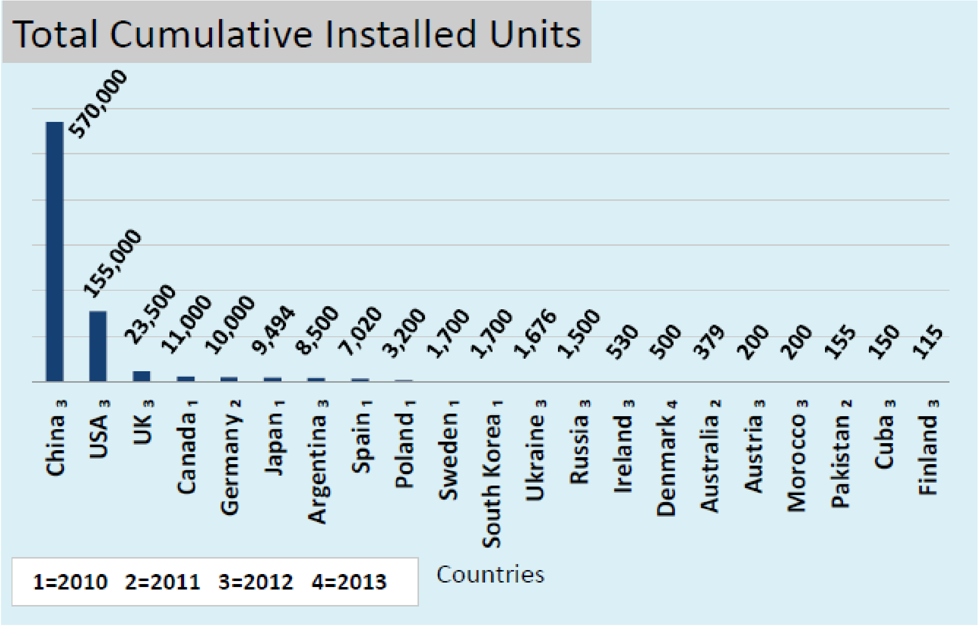
Turbine Diameter	M	1.6	2.7	5.5
Rated Wind Speed	m/s	10	10	10
Rated Power	W	300	1000	5000
Rated Turbine Speed	Rmp	400	300	200
Predicted Power at 3 m/s	W	8	27	135
Coefficient of Performance		0.25	0.30	0.36

Table: 4.1 typical commercial turbine specifications

When these turbines are installed in a lower wind region the actual power produced will be significantly less than the rated power. In much of South-East Asia, for example, the average wind speed is only 3m/s. While this may be below the turbines cut in speed (the lowest speed at which it can produce power) assuming power is proportional to the cube of the wind speed we can calculate the theoretical power production at 3m/s, as enumerated in the table. It can be seen that the power production of these machines is far below the rated power, underscoring the need for turbine optimization for low wind speed regions. [16]

4.4 Small Wind World Market continue growing

The world market for small wind has continued to grow: As of the end of 2012, a cumulative total of at least 806’000 small wind turbines were installed all over the world. This is an increase of 10 % compared with the previous year, when 730’000 units were registered. Most of the growth happens in only three countries: China, USA and UK. This situation is a clear indication that the world market for small wind turbines is still in its infancy stage. In most countries you can at least find a handful of small wind turbines, but the vast majority of these countries is far from market size which would enable companies to reach mass production. More and better policies are imperative for making small wind a success all over the world. The numbers presented here are based on available figures and even exclude major markets such as India and Italy so that WWEA estimates an actual total number of close to one million units to be installed



China is still the by far largest market in terms of units ever installed, and the number of cumulative installed units grew by 70’000 to a total of 570’000 by end of the year 2012. This represents 70% of the world market in terms of total as well as new installed units. According to estimations, around half of the turbines continue to produce electricity in China given that this market started already in the early 1980s.

The second largest market can be found in the USA with a total of 155’000 units installed, clearly behind China, but well ahead of a number of medium-sized small wind markets. The UK, Canada, Germany, Japan and Argentina are all medium-sized markets with total number of small wind turbines between 7’000 and 23’500 units. In terms of new installations China is again leading by far with 70’000 units, followed by two countries: The US and the British market had both similar size, with 3’700 respectively 3’646 units installed in 2012. However, both markets have only 5 % of the size of the Chinese market. [18]

CHAPTER 5

Wind Farm and Site selection

5.1 Wind Farm

“Wind farm” is the name used for any group of wind generators that are connected together into a single point for delivery of their energy. A wind farm consist of wind turbine generators, access tracks, Underground cabling ,hardstand areas, a switchyard, a control kiosk , a connection to the existing grid . A large wind farm may consist of several hundred individual wind turbines and cover an extended area of hundreds of square miles, but the land between the turbines may be used for agricultural or other purposes. A wind farm can also be located offshore. The name “wind Farm” is not a specific Australian name , although in some countries There is a subtle twist such as “wind ranch” in the southern states of the USA (where they have ranches rather than farms) or “Wind Park” in countries like Denmark and Germany[]. Many of the largest operational onshore wind farms are located in the United States and China For example, the Gansu Wind Farm in China has a capacity of over 5,000 MW of power with a goal of 20,000 MW by 2020. The Alta Wind Energy Center in California, United States is the largest onshore wind farm outside of China, with a capacity of 1,020 MW.[1] As of April 2013, the 630 MW London Array in the UK is the largest offshore wind farm in the world, followed by the 504 MW Greater Gabbard wind farm in the UK. There are many large wind farms under construction and these include Sinus Holding Wind Farm (700 MW), Lines Wind Farm (270), Lower Snake River Wind Project (343 MW), Macarthur Wind Farm (420 MW). [19]

5.2 Types of wind farms

On the basis of the location or the area of installation of the wind farms, wind farms are distributed in four different types. Different types and different number of wind turbines are used in different locations. The types of wind farms are given below. [20]

i. Onshore
ii. Near shore
iii. Offshore
iv. Airborne

5.2.1 Onshore

It is that type of wind farm in which the wind farms are created on the onshore areas and all the installations of the required amount of the turbines generally paced in the hilly or the mountain area is referred to as onshore wind farms. Wind turbines should be placed very carefully because a distance between wind turbines in the wind farms really matter because we can increase the output of the electrical energy.[20]

Fig: 5.1 Onshore Wind Farm

5.2.2 Near shore

Another type of the wind farm is the near shore, it is that type of wind farm in which the wind turbine are arranged on that location which is almost in the radius of 3 km is called as near shore wind farms. Those locations are beneficial for the created a wind farm because the pressure of the wind in those areas comparatively high from the other location. So they are able to generate more power. [20]

Fig: 5.2 Near shore Wind Farm

5.2.3 Offshore

The third type of the wind farm is that type in which wind turbines are installed on the areas that are out of the shoreline, almost 10 km from the land is referred to as the offshore wind farms. The wind farms in those areas are comparatively better because they are away from the obstacles like on the land and the pressure of the wind is also good. [20]

Fig: 5.3 Offshore Wind Farm

5.2.4 Airborne

Airborne is the type of wind farm in which towers are not required and such type of system is also not connected because the turbine do more rotation due to the power of high wind and that is why it is free from tower installation system.[20]

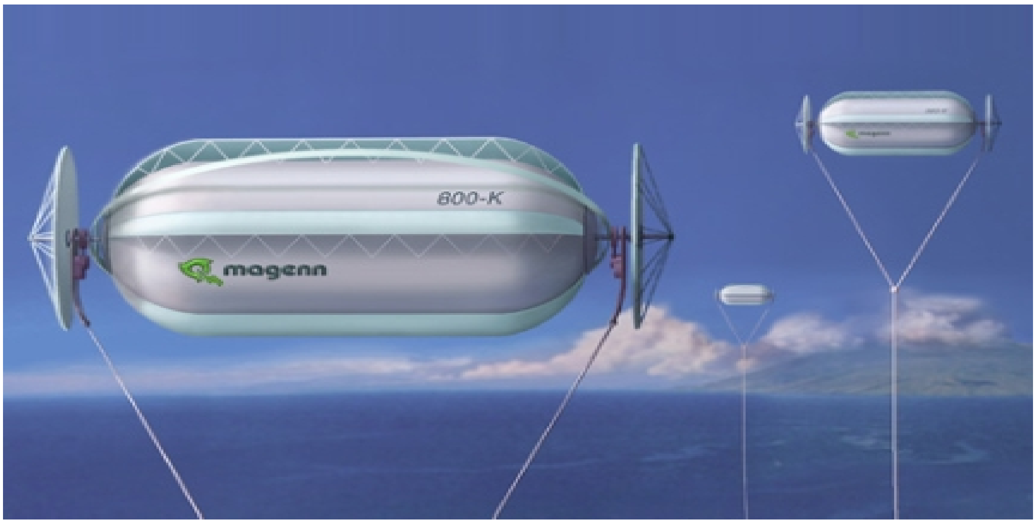


Fig: 5.4 Airborne Wind Farm

5.3 Wind farm design

This is important if the project is a wind farm, wind data is combined with topographical information to design the wind farm. Engineers used this data to model wind flow, turbine performance, sound levels and parameters to optimize the location of the wind turbines. They also design the access roads, turbine foundations and local electric network, as well as the connection to the electricity grid. [21]

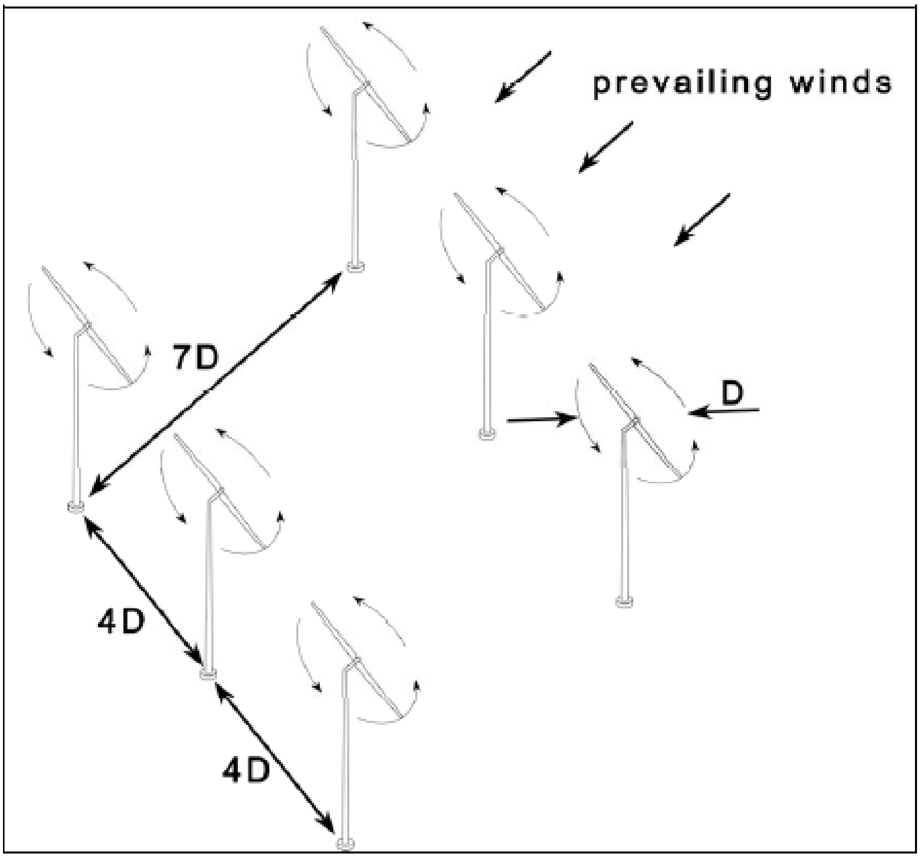


Fig: 5.5 wind farm optimal placement

Commissioning

Finally, the wind turbine is tested, all components are calibrated on site and verified against the suppliers specifications. Before becoming fully operational. [21]

5.4 Selection of Location for Wind Farms

The selection of the location for the wind farm need real importance during installation because the place selected for the creation of the wind farm should match the following factors

i. The speed of the wind in those locations should be high to produce large amount of energy.
ii. The farms should be build on higher altitudes
iii. Mutual inference in the working of the wind farms pr the wind turbines should be check by observing their effects because they really affects the output power.
iv. Check output effects of the wind farms or the wind turbines on the environment
v. Another important factor also carefully observe that what are the effects of the wind farms on the grid stations because it really helpful for the production of the power.

[20]

5.5 List of offshore wind farms and Lists of offshore wind farms by country

World's largest offshore wind farms

Wind Farm	Capacity(MW)	Country	Turbines and Model	Commissioned
Anholt	400	Denmark	111 × Siemens SWT-3.6 120	2013
Greater Gabbard	504	United Kingdom	140 × Siemens SWT-3.6	2012
Horns Rev II	209	Denmark	91 × Siemens 2.3-93	2009
London Array	630	United Kingdom	175 × Siemens SWT-3.6	2012
Lynn and Inner Dowsing	194	United Kingdom	54 × Siemens 3.6-107	2008
Rødsand II	207	Denmark	90 × Siemens 2.3-93	2010
Thanet	300	United Kingdom	100 × Vestas V90-3MW	2010
Walney	367	United Kingdom	102 × Siemens SWT-3.6	

Table: 5.1 list of World's largest offshore wind farms [22]

5.6 List of onshore wind farms and Lists of wind farms by country

World's largest onshore wind farms

Wind Farm	Current Capacity(MW)	Country
Alta (Oak Creek-Mojave)	1,320	United States
Jaisalmer Wind Park	1,064	India
Buffalo Gap Wind Farm	523.3	United States
Capricorn Ridge Wind Farm	662.5	United States
Dabancheng Wind Farm	500	People's Republic of China
Fântânele-Cogealac Wind Farm	600	Romania
Fowler Ridge Wind Farm	599.8	United States
Horse Hollow Wind Energy Center	735.5	United States
Meadow Lake Wind Farm	500	United States
Panther Creek Wind Farm	458	United States
Roscoe Wind Farm	781.5	United States
Shepherds Flat Wind Farm	845	United States
Sweetwater Wind Farm	585.3	United States

Table: 5.2 list of World's largest onshore wind farms [23]

5.5 Future of Wind Farms

Future of the wind farms is very bright because the resources that are used for the production of the electricity are very costly as compared to wind. And by using this free of cost resources wind farms can would produce handsome amount pf energy in the future. [24]

CHAPTER 6

Wind Turbine Grid & Distribution System

6.1 Electrical Connections

Now are producing energy with a windmill or solar panel, The technology behind renewable energy systems is confusing for those new to the field. Our renewable energy sources can be grid connected, or off-grid, with battery backup in case the grid goes out, or without, and that is just the beginning. This section intends to give an overview of the basics involved in connecting renewable energy sources together, and to the grid. There are several sections that are increasingly more complex:

1. Grid-connected wind power without battery backup
2. On- or off-grid wind power, with battery backup
3. Hybrid system [25]

6.2 Grid Connected Wind Turbine

The wind causes the blades to spin, the blades turn the alternator in the windmill, and it produces electricity. Depending on the wind turbine it is either AC or DC. In case of the Sirocco it is something called '3-phase wild AC'. This is because it uses three wires, and both the voltage and frequency of the electricity produced by the alternator vary with rotor RPM. We cannot dump this wild AC directly onto the grid, the electricity company would be very unhappy if you did, we need an inverter. The inverter takes care of turning that wild AC into the neatly organized form of AC that is used by the Electricity grid, matching its voltage, frequency, and phase exactly. From the inverter the power feeds through a breaker into your breaker panel, part will go towards providing electricity for your house, and if there is anything left over it will go out through your meter to the electrical grid. [25]

Battery Backup - Keeping The Lights On When The Grid Goes Out

Wind generator is used by a charge controller for charging a set of batteries, or if the batteries are full then power will go straight to the inverter. The charge controller takes care of converting the unregulated wind electricity into something the batteries like, and just as important, it protects the batteries from various conditions such as overcharging and excessive current. The inverter in this configuration is different from the simpler case (without batteries), and a little bit more sophisticated. It takes battery or charge controller power and converts this to grid power that goes towards powering household loads. If there's more power than needed, the excess will go out to the grid, just as before, spinning the meter backwards in the process. The inverter also takes care of charging the batteries if needed, using grid power. Of course, you want the wind generator to keep the batteries charged, but it is good to know that when needed the inverter will do the job so battery life will not suffer. [26]

6.3 Connection to the Network

Wind farms have until recently been most commonly connected to the distribution system. As wind farm sizes increase and local network power capacity differs, many wind farms are connected to the transmission system.

Fig: 6.1 Wind turbine connections in wind farm

Ideally wind farms should locate within approximately 15 km of a suitable grid connection point to minimize the associated costs. The electricity will be transported within the wind farm site by cables underground and from the site by overhead power cables usually mounted on wooden poles similar to those seen along most roads. These take the electricity to a nearby substation where it can link up with the national electricity grid. [29]

6.4 The Transmission System

A high voltage network using heavy duty wires to transport bulk power from the generating stations to transmission - distribution stations located at the major load centers (usually cities and larger towns) They are equivalent to the motorways and dual carriageways of the electricity network. The transmission system transports high voltage electricity to reduce losses over distance. [29]

Fig:6.2 Transmission line of electricity

6.5 Distributed Generation

Distributed generation (DG) refers to electrical power generation that occurs close to where the power is consumed, independent of the type of power-generating technology. Electricity that is primarily used on site by the system owner is often called “inside-the-fence” or “behind-the-meter” generation.

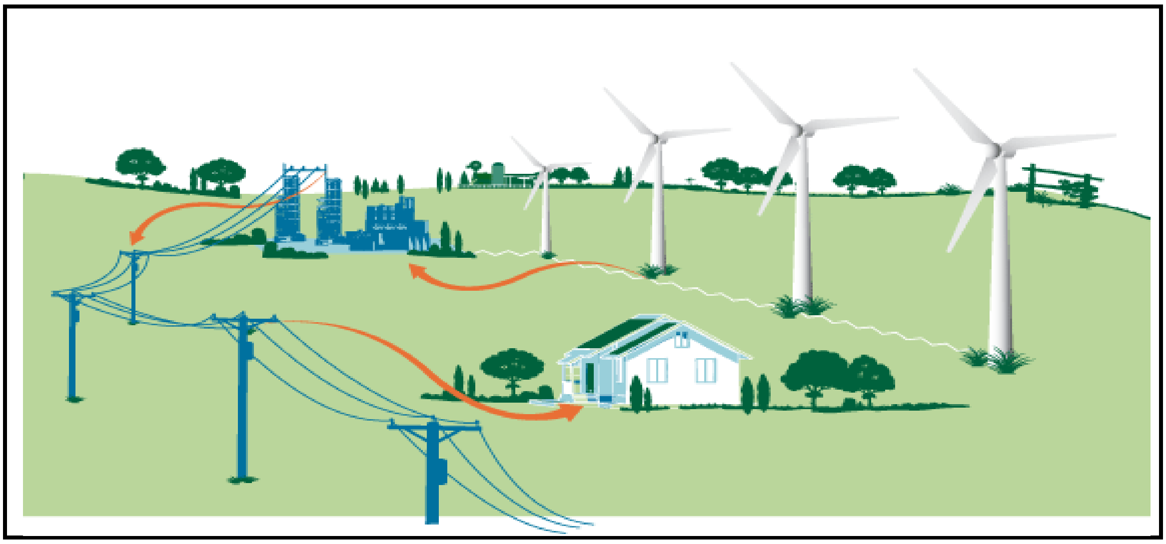


Fig: 6.3 Distribution system of wind energy

DG systems are typically small by comparison to centralized power plants, but they provide significant benefits including reduced energy loss during transmission and reduced load on utility transmission and distribution lines. A network of low and medium voltage wires that transport power from the transmission - distribution stations to small towns, industrial areas and individual customers. They are equivalent to the intermediate and minor roads of the electricity system. Different low voltages are used so that electricity is transported to medium and small loads (customers). Lower voltages than used on the transmission system are sufficient. [30]

CHAPTER 7

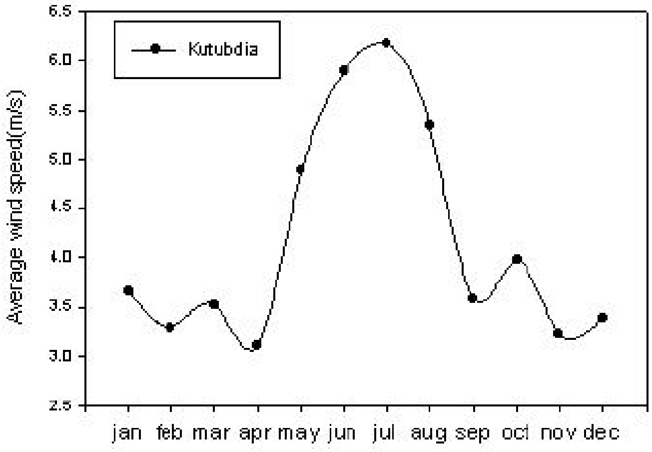
Wind Speed Data Analysis

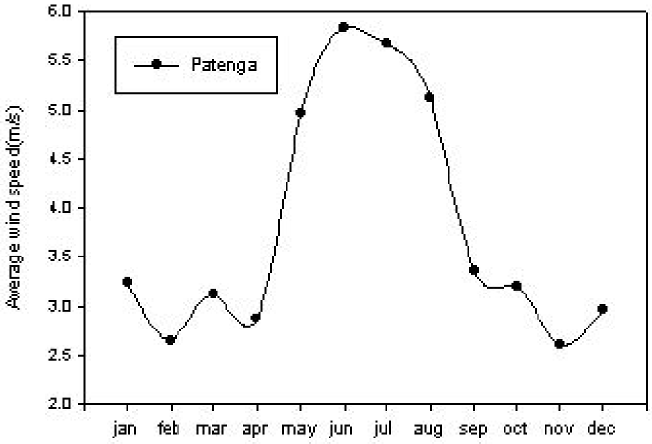
7.1 Wind Data Analysis Fom seven West Station (1996 – 1997)

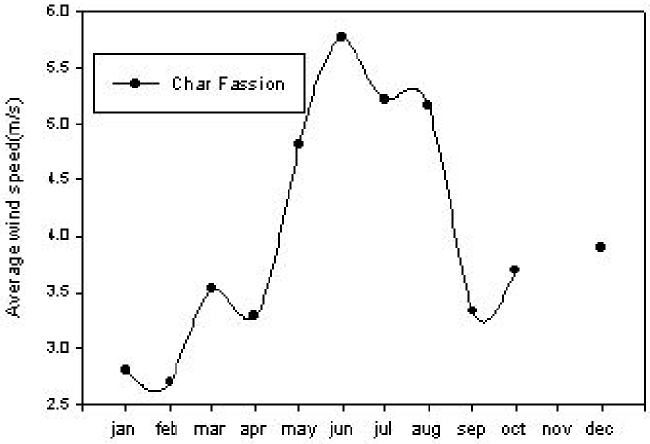
	Name of the wind speed monitoring station					
Month	**Patenga**	**Cox's Bazar**	**Teknaf**	**Char Fassion**	**Kuakata**	**Kutubdia**
Sep'96	3.36	3.69	3.46	3.34	3.77	3.58
Oct'96	3.2	3.74	3.3	3.7	2.18	3.98
Nov '96	2.61	2.93	2.29	Lost	1.98	3.23
Dec'96	2.97	1.78	1.44	3.9	3.35	3.38
Jan '97	3.25	2.33	1.99	2.8	3.18	3.67
Feb '97	2.66	1.99	1.9	2.69	3.37	3.29
Mar' 97	3.13	2.42	2.26	3.54	4.84	3.53
Apr '97	2.88	1.84	1.65	3.29	4.93	3.11
May '97	4.96	3.97	3.09	4.81	6.28	4.89
Jun '97	5.83	4.64	3.26	5.76	7.31	5.9
Jul '97	5.67	4.8	4.33	5.22	7.34	6.17
Aug '97	5.13	4.31	4.03	5.17	Lost	5.34

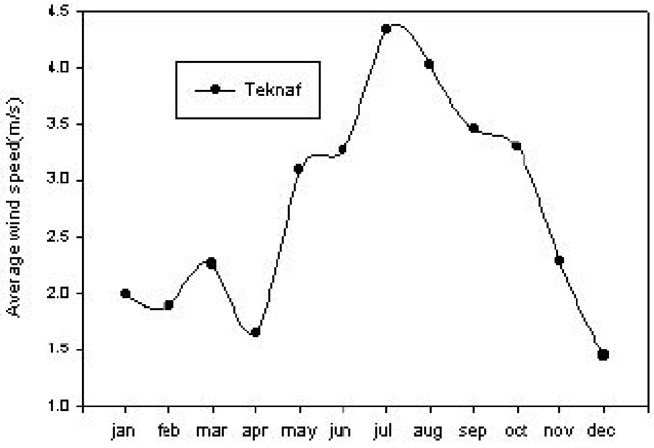
Table:7.1 Monthly average wind speeds from seven WEST stations at 25 metes height.

Monthly Average wind speed (1996-1997)




Patenga
Average wind speed(m/s)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec


Char Fassion
Average wind speed(m/s)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec


Teknaf
Average wind speed(m/s)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec

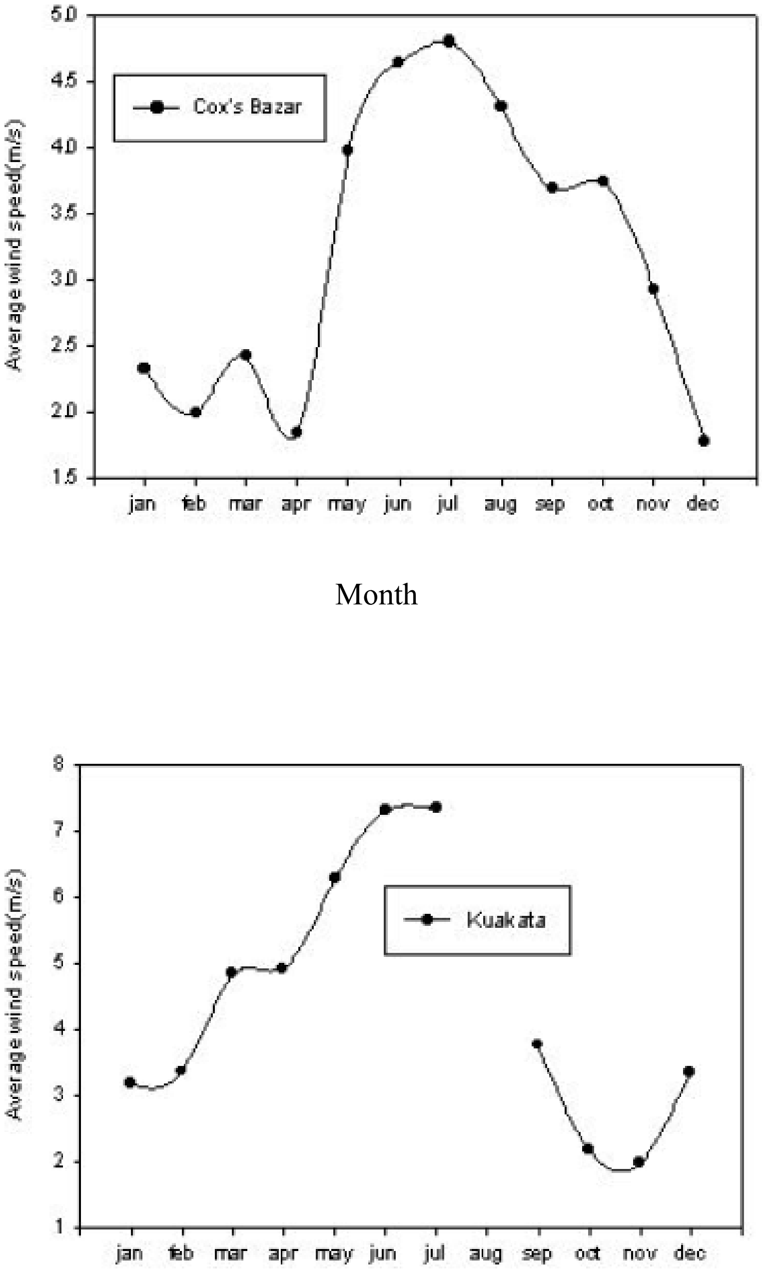
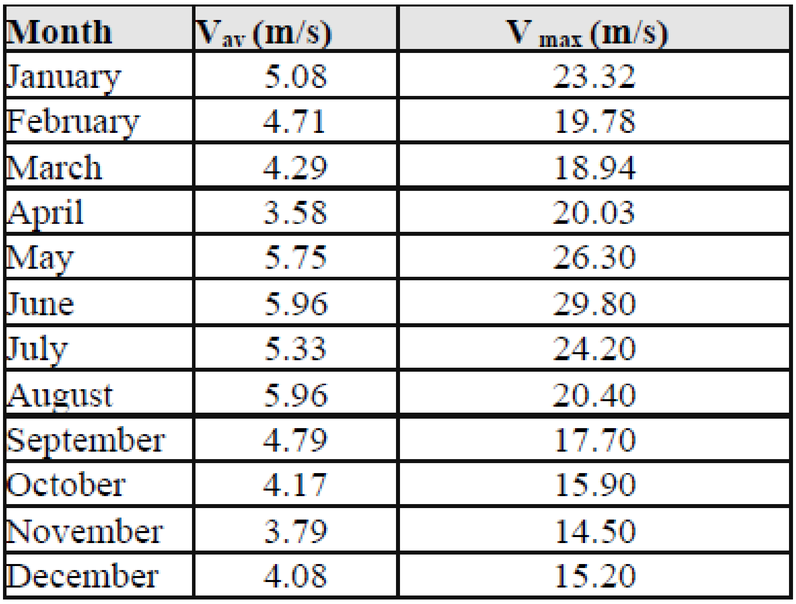


Fig:7.1 Monthly average wind speed at different locations.

A project on “Feasibility Study on R&D of Renewable Energy (Solar, Wind, and Micro-Mini Hydro)" has been undertaken by the Institute of Fuel Industrial Research (BCSIR). Under this program, wind speed data have been collected in the Saint Martin’s Island in 2002. Research Development (IFRD), of Bangladesh Council of Scientific .



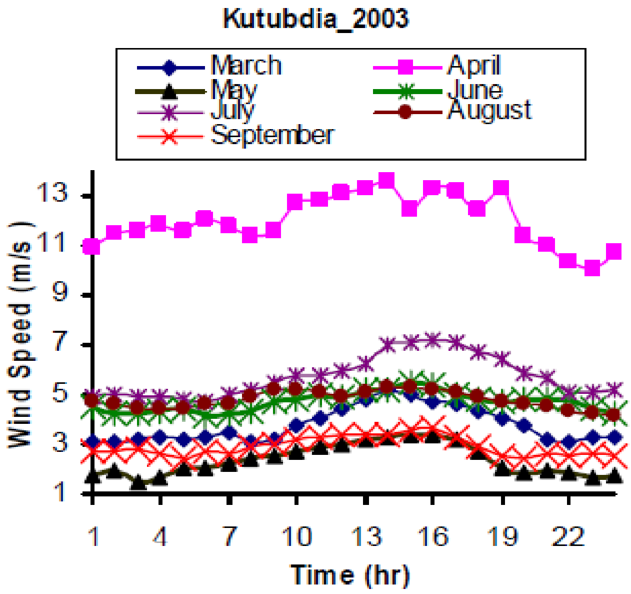
Month	V_{av} (m/s)	V_{max} (m/s)
January	5.08	23.32
February	4.71	19.78
March	4.29	18.94
April	3.58	20.03
May	5.75	26.30
June	5.96	29.80
July	5.33	24.20
August	5.96	20.40
September	4.79	17.70
October	4.17	15.90
November	3.79	14.50
December	4.08	15.20

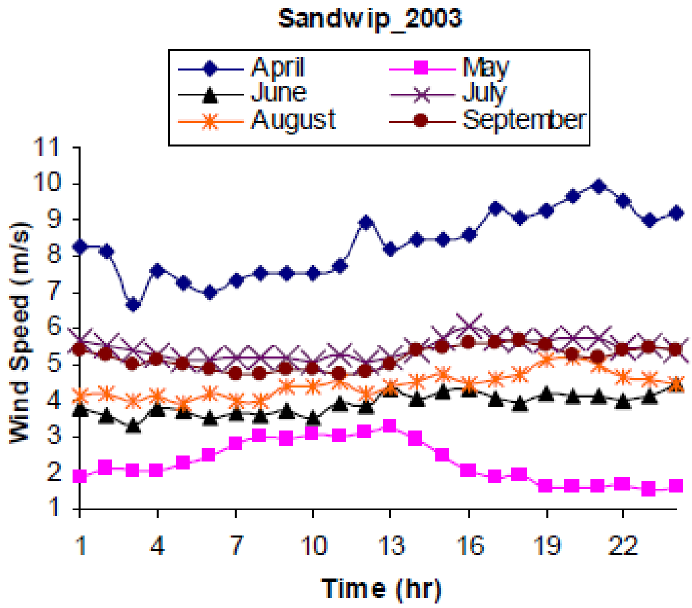
Table:7.2 Monthly average wind speeds in the Saint Martin’s island [IFRD, 2002] [32]

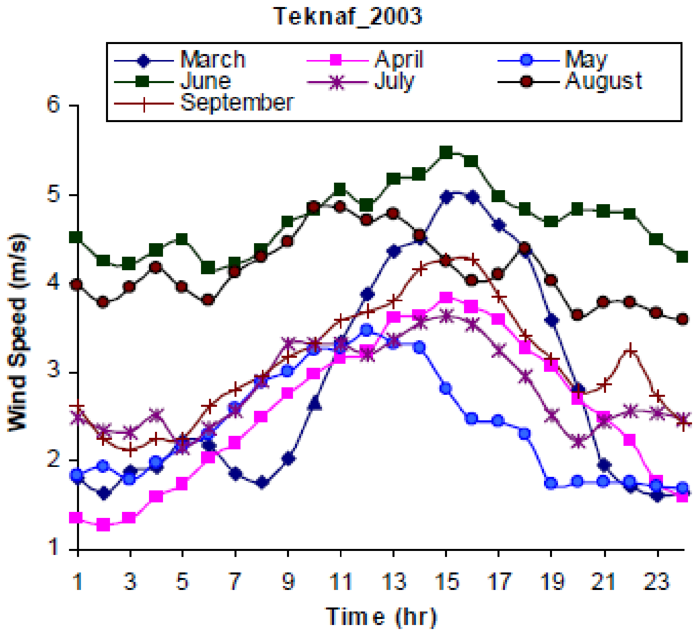
7.2 Wind Data Analysis in Bangladesh (2003)

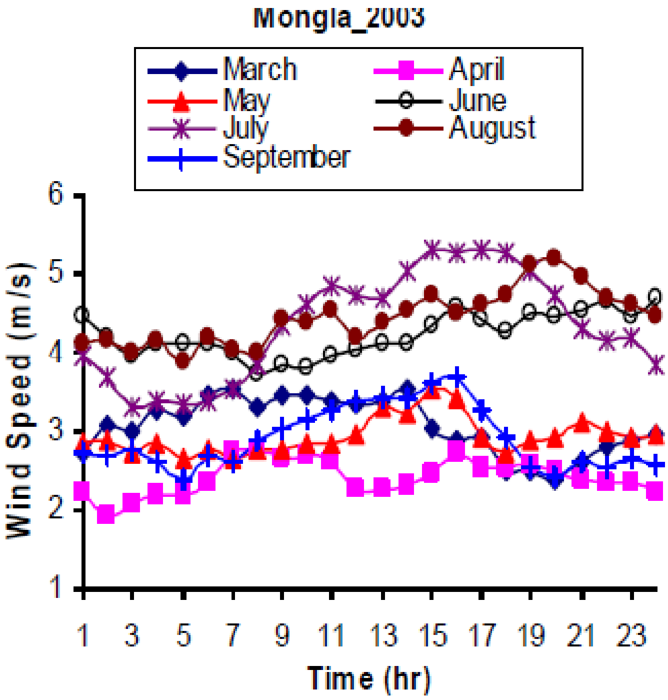
In Bangladesh, winds are available mainly during the Monsoons and around one to two months before and after the Monsoons . During the months starting from late October to the middle of February, winds either remain calm or too low to be of any use by a windmill. Except for the above mentioned period of four months, a windmill if properly designed and located, can supply enough energy. The wind energy distribution during the year in such that about 55% is available during the time when need for water pumping is low and about 25% is available in the season when the need for water pumping is at its peak . The wind speed of coastal area holds good prospect to make the best use of wind energy. wind data of coastal region in Bangladesh such asTeknaf, Kutubdia, Sandwip, Kuakata, and Mongla have been considered to evaluate the wind power availability. The peak rainfall occurs in the country during the months of June, July and August. But the peak wind speed above average occurs one to two months and in some cases three months before the peak rainfall occurs.

The average wind speed in Bangladesh is available from the month of March, April and May. That's why in this paper, the wind speed data from March to September are considered. During this period windmills may be used for pumping water for irrigation if it had been previously stored in a reservoir. Rain water is available in this country from May to October. During the operating seasons, subsoil water from shallow wells can also be pumped up by low lift pumps run by windmills. Wind power can also be incorporated in electricity grid on a substantial basis and could add reliability and consistency to the electricity generated by the Kaptai Hydro electric Power Station during the dry season. This is due to the electricity generated by the Kaptai Hydro electric Power Station during the dry season. This is due to the fact that in dry season, the required water head becomes rather low for total utilization of the entire generator. Thus power generation has to be curtailed during this period. So this deficit power could be compensated with the help of wind power plant. Characteristics of wind speed data of above mentioned coastal region have been studied from month of March to September, 2003.




Sandwip_2003
April
May
June
July
August
September
Wind Speed (m/s)
11
10
9
8
7
6
5
4
3
2
1
1
4
7
10
13
16
19
22
Time (hr)


Teknaf_2003
March
April
May
June
July
August
September
Wind Speed (m/s)
6
5
4
3
2
1
1
3
5
7
9
11
13
15
17
19
21
23
Time (hr)



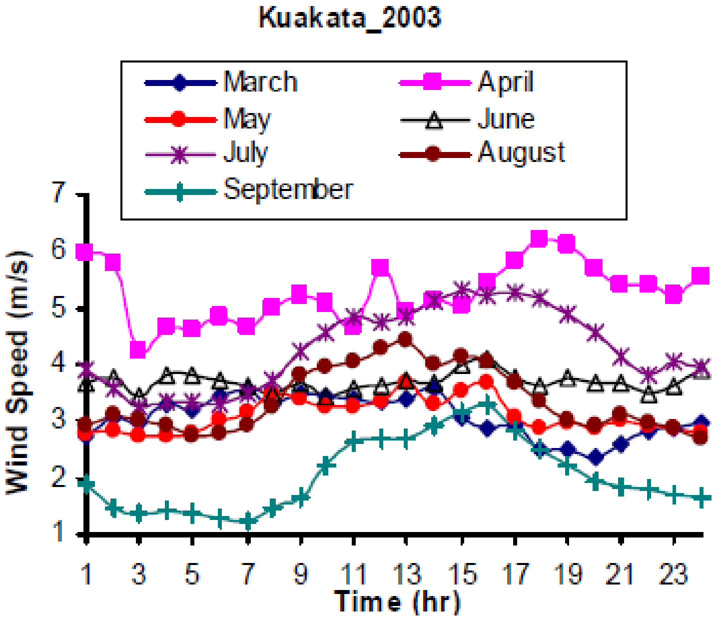
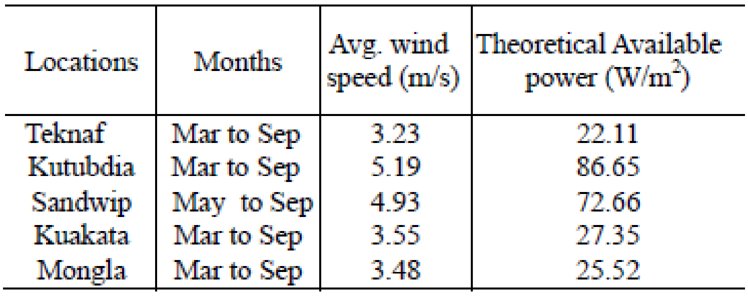


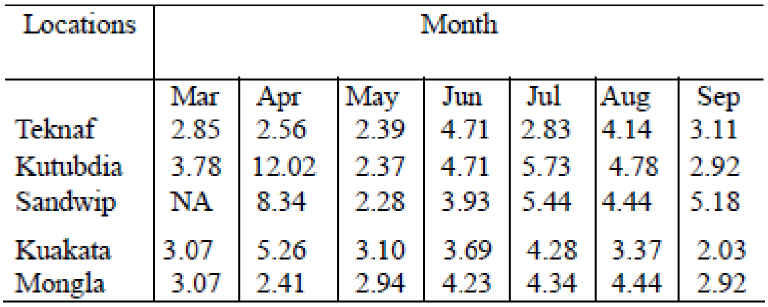
Fig:7.2 Mean hourly wind speed of different region of Bangladesh showing typical variation (2003)

The data have been used to compute the monthly average wind speed as shown in Table 1 and the energy availability for the stations presented in Table 2. Hourly wind speeds of the locations were plotted against the hour of day and it was found that for all the locations, the speed has a regular diurnal variation along with some fluctuation, and it attains a maximum value at around 10am-2pm local time. In all cases, there appears to be a seasonal effect and a stable wind speed is found for the month June. A typical case for Coastal region is shown in Table.



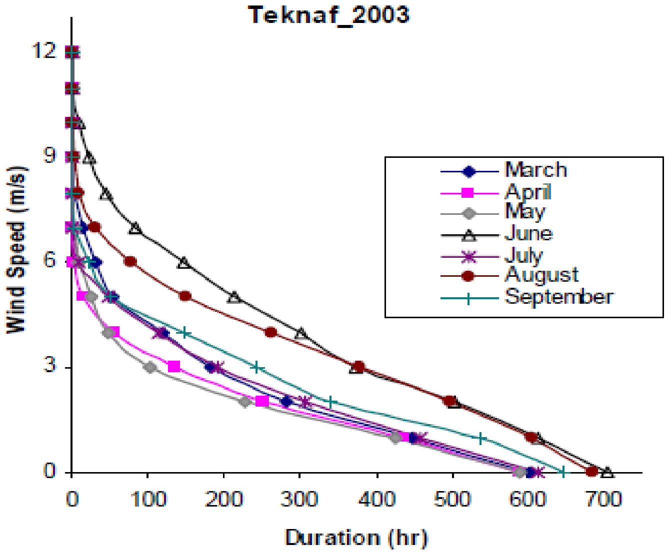
Locations	Months	Avg. wind speed (m/s)	Theoretical Available power (W/m^2)
Teknaf	Mar to Sep	3.23	22.11
Kutubdia	Mar to Sep	5.19	86.65
Sandwip	May to Sep	4.93	72.66
Kuakata	Mar to Sep	3.55	27.35
Mongla	Mar to Sep	3.48	25.52

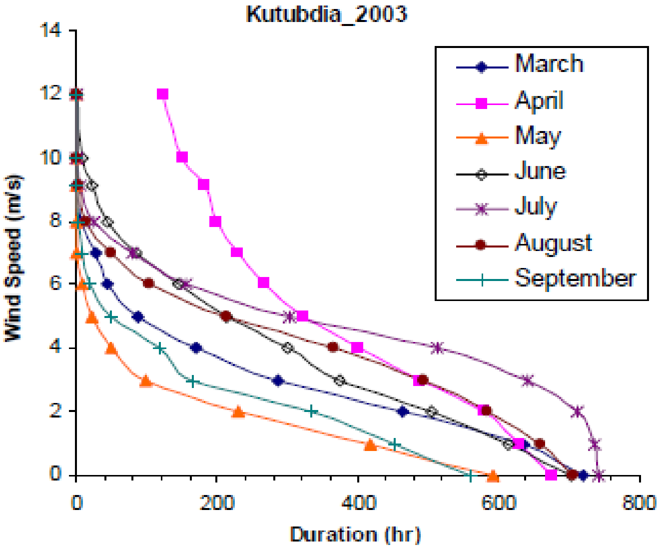
Table:7.3 Theoretical available power of different location in coastal region in Bangladesh (2003)

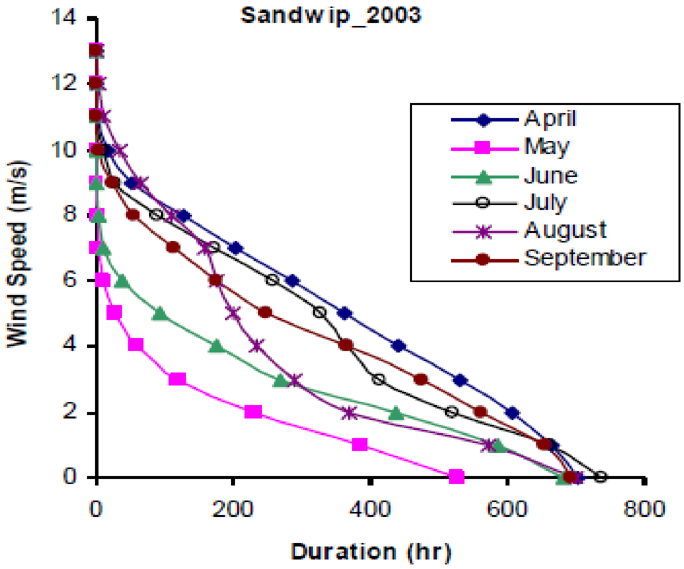


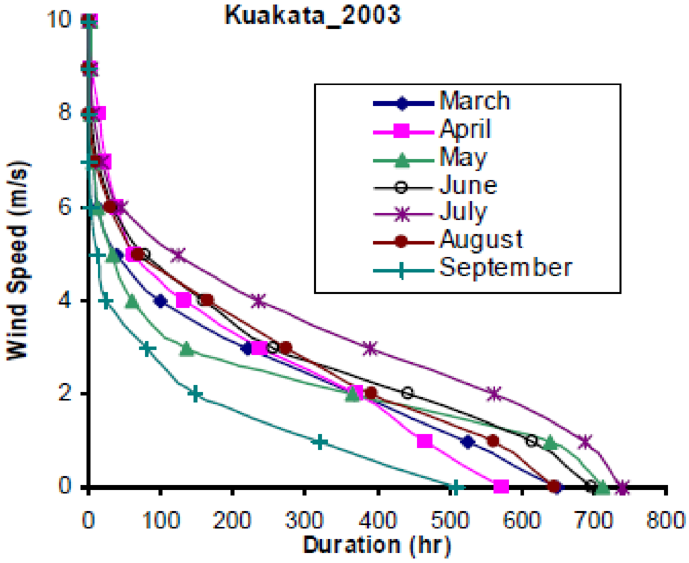
Locations	Month						
	Mar	Apr	May	Jun	Jul	Aug	Sep
Teknaf	2.85	2.56	2.39	4.71	2.83	4.14	3.11
Kutubdia	3.78	12.02	2.37	4.71	5.73	4.78	2.92
Sandwip	NA	8.34	2.28	3.93	5.44	4.44	5.18
Kuakata	3.07	5.26	3.10	3.69	4.28	3.37	2.03
Mongla	3.07	2.41	2.94	4.23	4.34	4.44	2.92

Table:7.4 Average wind speed in m/s at different location in coastal region in Bangladesh (2003).


Teknaf_2003
Wind Speed (m/s)
Duration (hr)
0
3
6
9
12
0
100
200
300
400
500
600
700
March
April
May
June
July
August
September


Kutubdia_2003
Wind Speed (m/s)
Duration (hr)
0
2
4
6
8
10
12
14
0
200
400
600
800
March
April
May
June
July
August
September


Sandwip_2003
Wind Speed (m/s)
Duration (hr)
0
2
4
6
8
10
12
14
0
200
400
600
800
April
May
June
July
August
September


Kuakata_2003
Wind Speed (m/s)
Duration (hr)
0
2
4
6
8
10
0
100
200
300
400
500
600
700
800
March
April
May
June
July
August
September

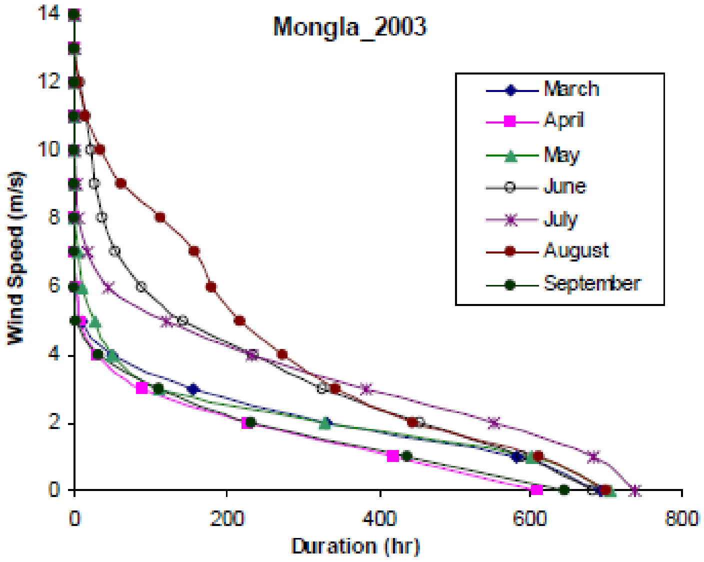


Fig:7.3 Velocity duration curve in various locations in Coastal region in year 2003

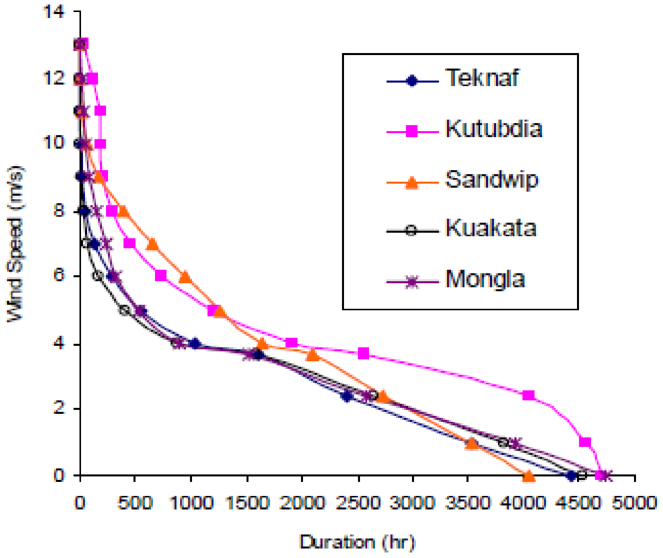


Fig:7.4 Variation of velocity duration curves among various location of coastal region

It is found that the average wind speed in Kutubdia is above 5m/s (March-September) and about 2.57m/s (5 knot) for 400 hrs in those six months. At this available speed a wind plant can operate both for generation of electricity an for driving pumps . But the average wind speed of rest of the location is below 5m/s and 2.57m/s (5knot) for 2500 hrs, at this available speed, these locations may not be recommended for electricity generation, these in locations may be recommended for pumping purpose . As the average wind speed of above all location is more than 3.2 m/s, hence sail wing rotor is recommended as its starting speed is around 2 m/s . The wind power per unit area of approach is proportional to the cube of wind speed and it can be expressed as P/A = 0.6 V3 where P/A is in W/m2 and V is in m/s. This wind power represents the strength of wind, and theoretically maximum 59% of this power can be extracted. The wind power, P/A is plotted in Figure 4 to show the strength of wind in different location.

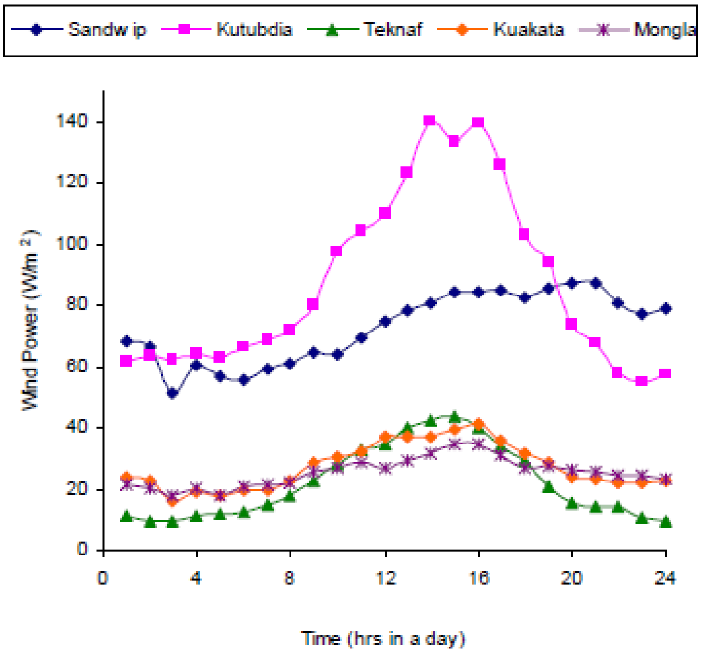
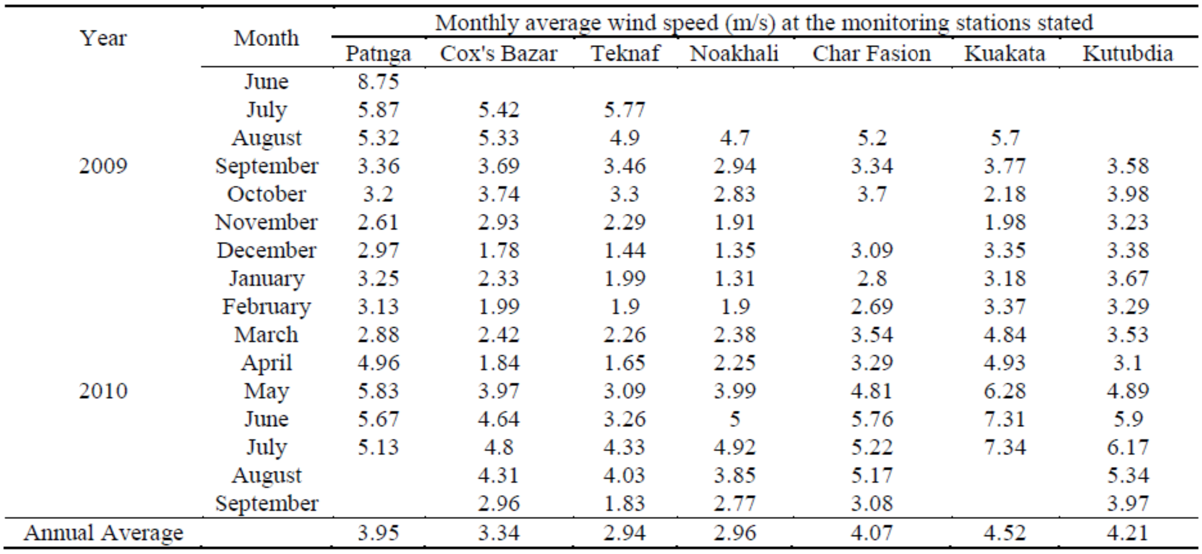


Fig:7.5 Wind power in different location in coastal region (March-September, 2003)

Figure, also shows that in Sandwip the average wind power is about 86.65 W/m2 which is higher than other location. [33]

7.3 Wind data Analysis of Bangladesh (2009-2010)

Wind speed Data for different sites has been collected from the Meteorological department of Bangladesh in 2009 to 2010. Bangladesh have the potential to utilize the wind velocity for power generation in both summer and winter season over the year . The study showed that the average annual wind speed measured in the seven coastal stations ranged from 2.94 m/s to 4.52 m/s which is shown in Table

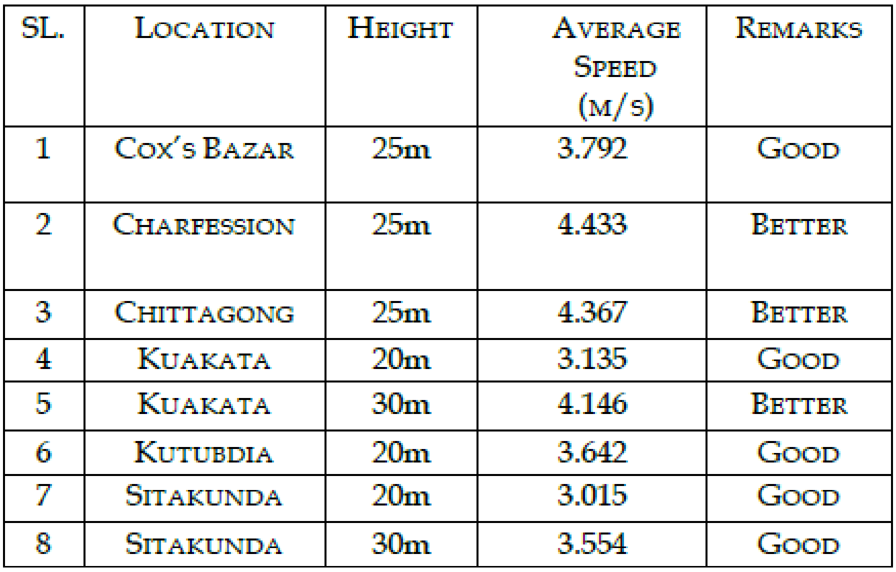


Year	Month	Monthly average wind speed (m/s) at the monitoring stations stated						
		Patnga	Cox's Bazar	Teknaf	Noakhali	Char Fasion	Kuakata	Kutubdia
2009	June	8.75						
	July	5.87	5.42	5.77				
	August	5.32	5.33	4.9	4.7	5.2	5.7	
	September	3.36	3.69	3.46	2.94	3.34	3.77	3.58
	October	3.2	3.74	3.3	2.83	3.7	2.18	3.98
	November	2.61	2.93	2.29	1.91		1.98	3.23
	December	2.97	1.78	1.44	1.35	3.09	3.35	3.38
2010	January	3.25	2.33	1.99	1.31	2.8	3.18	3.67
	February	3.13	1.99	1.9	1.9	2.69	3.37	3.29
	March	2.88	2.42	2.26	2.38	3.54	4.84	3.53
	April	4.96	1.84	1.65	2.25	3.29	4.93	3.1
	May	5.83	3.97	3.09	3.99	4.81	6.28	4.89
	June	5.67	4.64	3.26	5	5.76	7.31	5.9
	July	5.13	4.8	4.33	4.92	5.22	7.34	6.17
	August		4.31	4.03	3.85	5.17		5.34
	September		2.96	1.83	2.77	3.08		3.97
Annual Average		3.95	3.34	2.94	2.96	4.07	4.52	4.21

Table:7.5 Monthly average wind speeds at 25 meter height at seven coastal stations measured by WEST. [34]

7.4 Wind data analysis of Bangladesh (2012)

Wind speed for eight different sites has been collected from the Meteorological department of Bangladesh in 2012 (very recently) shown in table



SL.	Location	Height	Average Speed (m/s)	Remarks
1	Cox's Bazar	25m	3.792	Good
2	Charfession	25m	4.433	Better
3	Chittagong	25m	4.367	Better
4	Kuakata	20m	3.135	Good
5	Kuakata	30m	4.146	Better
6	Kutubdia	20m	3.642	Good
7	Sitakunda	20m	3.015	Good
8	Sitakunda	30m	3.554	Good

Table:7.6 Wind speed of different sites at different height

The wind speed is for a duration of twelve months for eight different sites which is the most recent data from the Meteorological department of Bangladesh. The coastal area includes Saint Martein, Teknaf, Cox'sBazar, Patenga, Chittagong, Sitakunda, Kuakata, Kutubdia, Hatiya, Sandwip, Mongla etc. In this section the wind speeds of these locations are shown at different heights. Figure represent that months versus wind speeds of Cox's Bazar, Kutubdia, Kuakata and Saint Martin respectively.

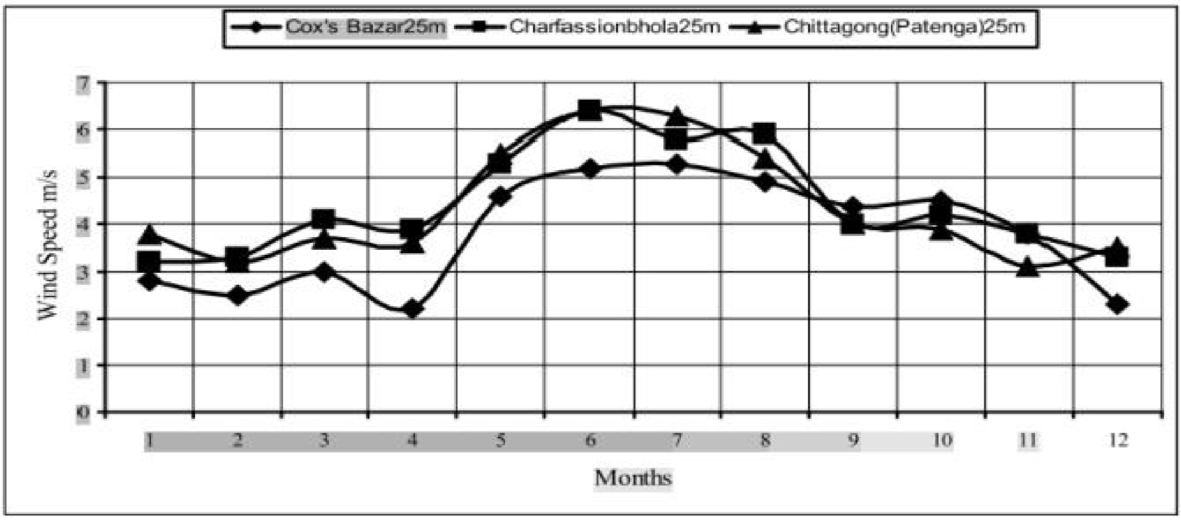


Fig:7.6 Month Vs Wind speed of Cox's Bazar, Charfassion & Chittagong

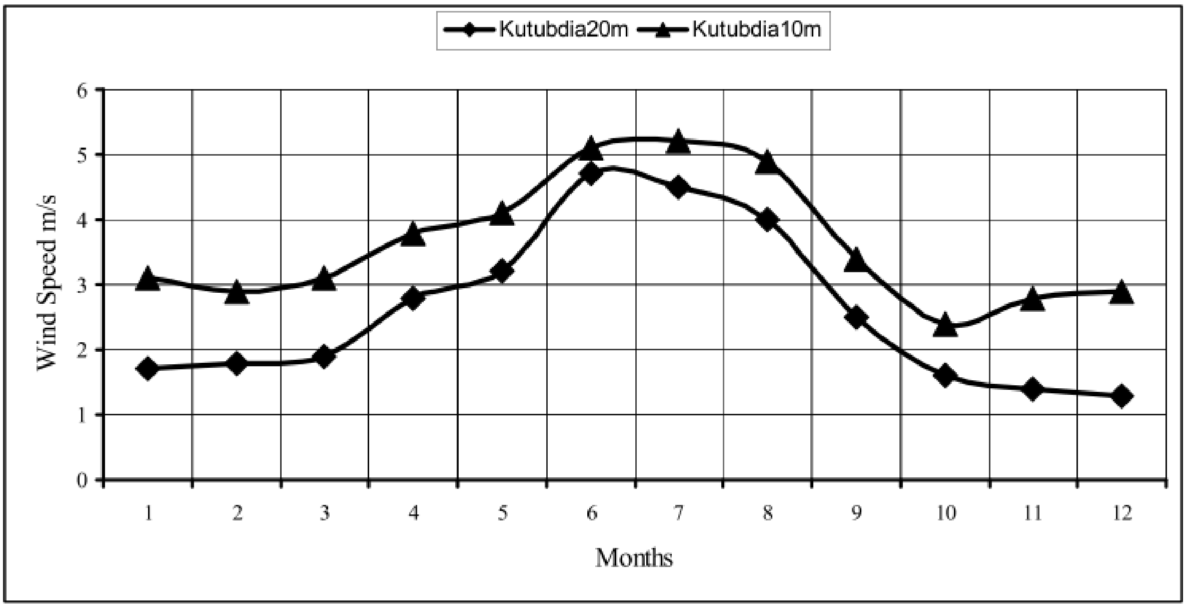


Fig:7.7 Month Vs Wind speed of Kutubdia.

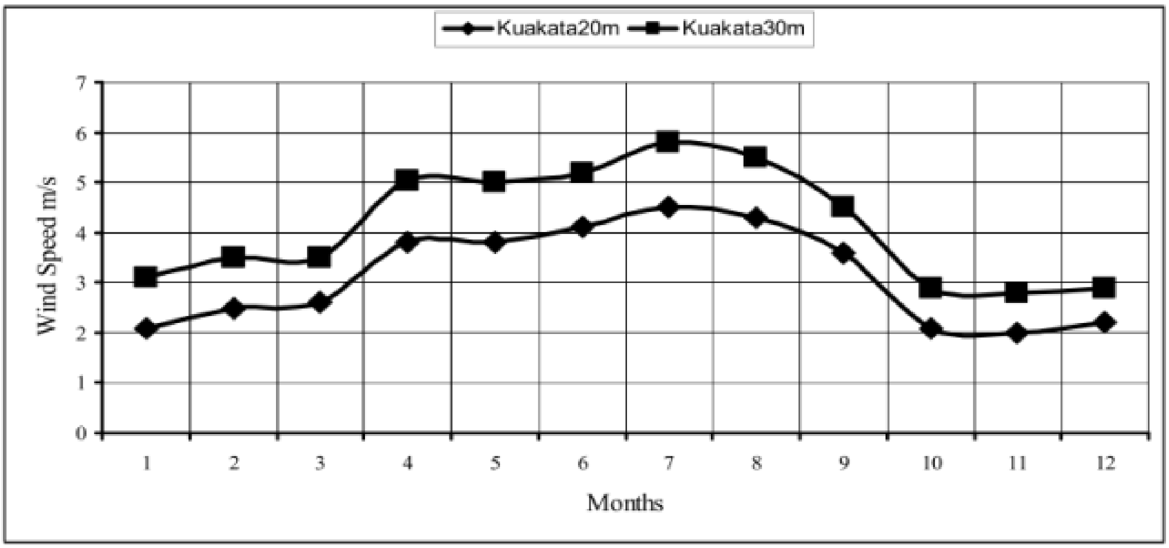


Fig:7.8 Month Vs Wind speed of Kuakata.

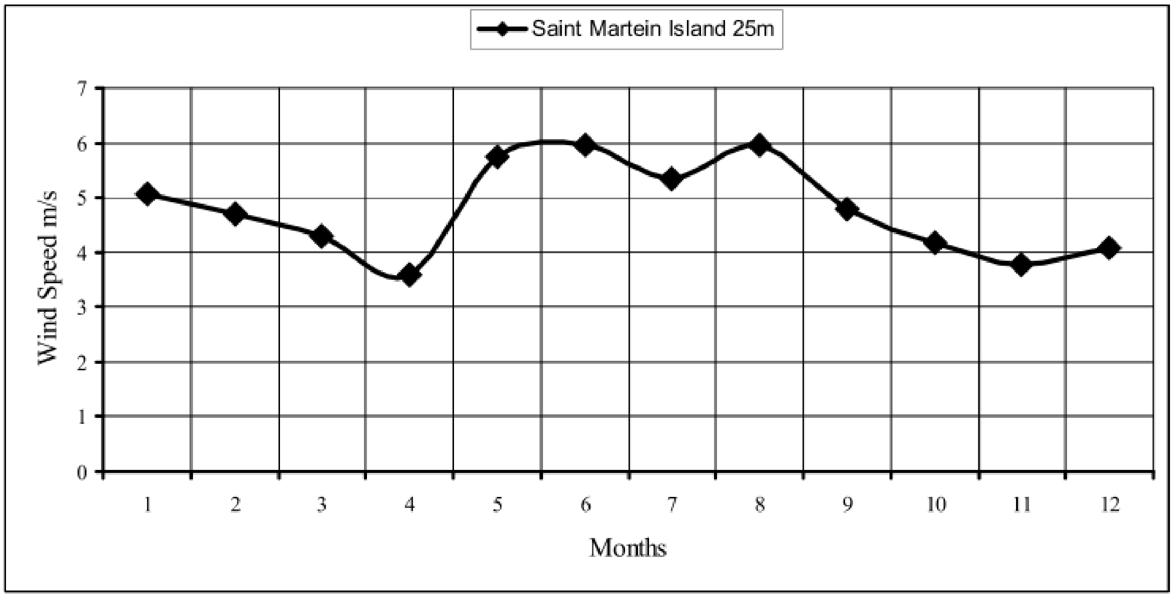
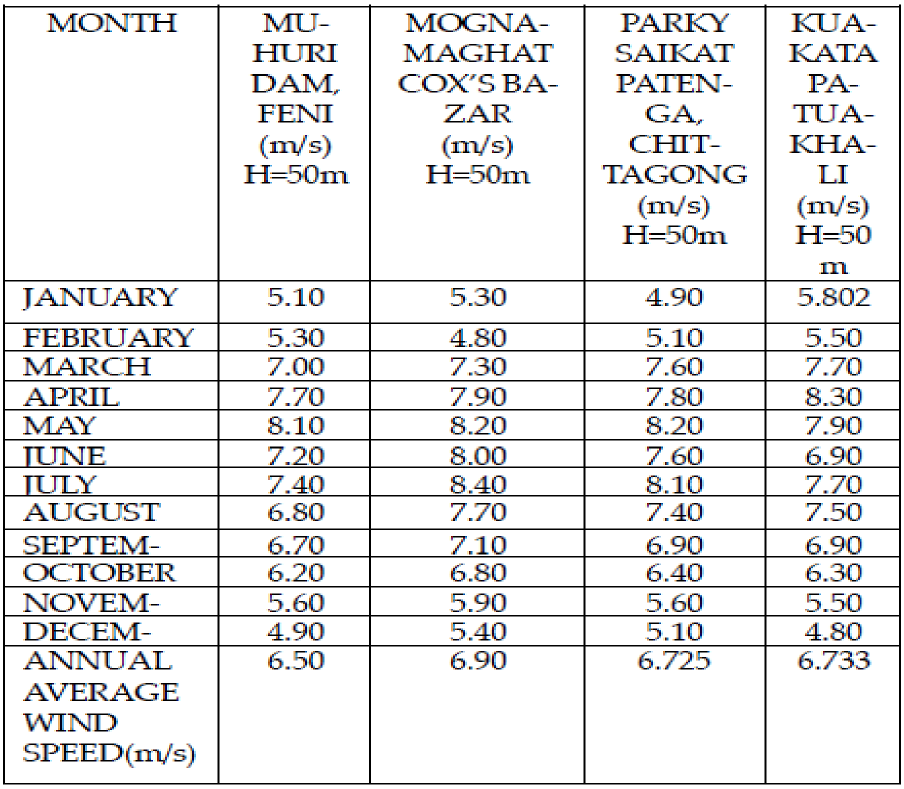


Fig:7.9 Month Vs Wind speed of Saint Martin Island



MONTH	MUHURI DAM, FENI (m/s) H=50m	MOGNAMAGHAT COX'S BAZAR (m/s) H=50m	PARKY SAIKAT PATENGA, CHITTAGONG (m/s) H=50m	KUAKATA PATUAKHALI (m/s) H=50 m
JANUARY	5.10	5.30	4.90	5.802
FEBRUARY	5.30	4.80	5.10	5.50
MARCH	7.00	7.30	7.60	7.70
APRIL	7.70	7.90	7.80	8.30
MAY	8.10	8.20	8.20	7.90
JUNE	7.20	8.00	7.60	6.90
JULY	7.40	8.40	8.10	7.70
AUGUST	6.80	7.70	7.40	7.50
SEPTEM-	6.70	7.10	6.90	6.90
OCTOBER	6.20	6.80	6.40	6.30
NOVEM-	5.60	5.90	5.60	5.50
DECEM-	4.90	5.40	5.10	4.80
ANNUAL AVERAGE WIND SPEED(m/s)	6.50	6.90	6.725	6.733

Table:7.7 Monthly annual average wind speed at 50 meter

Table 7.7 shows the wind speeds at four locations in the coastal areas of Bangladesh. These locations are Parky Saikat near Patenga, Chittagong; Mognamaghat, Pekua, Cox's Bazar; Muhuri Dam, Sonagazi, Feni; and Kuakata, Patuakhali. These four sites are representatives of the entire coastal areas of our country. It was found that the annual average wind speed in these four sites is more than 6.5 m/s. It an internationally ac-cepted thumb rule that a site having annual average wind speed of 6.0 m/s or higher is feasible for harnessing wind elec-tricity with commercial viability. From this data, we can understand that generating electrical energy with commercial viability in Bangladesh is possible. [35]

7.5 Wind data analysis of Bangladesh (2013)

Wind speed for Fourteen (14) different sites has been collected from the Meteorological department of Bangladesh in 2013 (very recently) . The study showed that the average annual wind speed measured in the seven coastal stations which is shown in Table

Month	Teknaf	Cox's Bazar	Kutubdia	Rangamati	Chittagong	Ambagan(ctg)	Sitakunda
January	2.5	4.2	2.1	1.3	5.9	2.8	1.1
Feb	2.9	4.6	1.7	1.5	7.3	2.7	1.5
Mar	4.3	3.3	1.8	1.9	7.2	3.3	1.7
Apr	4.5	3.4	1.9	2.1	6.7	3.6	1.8
May	3.4	4.6	2.4	2.4	7.4	4.1	2.6
Jun	4.3	3.5	2.1	2.1	7.0	3.5	1.8
Jul	4.1	2.9	2.3	1.7	6.3	3.4	2.3
Aug	2.2	3.2	1.9	1.9	6.1	3.4	2.8
Sep	2.6	3.3	1.7	1.0	5.3	3.0	2.5
Oct	2.4	2.8	1.5	1.5	5.2	2.2	2.1
Nov	2.0	2.8	1.4	1.0	5.1	2.7	1.0
Dec	3.7	2.4	1.4	1.1	4.6	2.3	1.2
Avg. Wind speed	3.24	3.41	1.83	1.62	6.175	3.083	1.867

Month	Feni	M. court	Mongla	Barisal	Bhola	Patuakhali	Khulna
Jan	2.4	3.7	2.2	2.4	1.5	2.6	1.9
Feb	2.9	4.1	3.2	2.1	1.5	3.0	2.2
Mar	3.2	3.8	2.3	2.9	1.3	1.9	2.1
Apr	3.4	3.6	3.0	3.1	1.5	2.2	2.4
May	3.9	5.7	3.5	4.2	2.1	3.3	2.6
Jun	2.7	4.5	2.4	2.7	6.0	2.2	2.3
Jul	3.3	5.9	2.4	3.1	2.9	2.3	2.3
Aug	3.3	4.7	2.4	2.8	2.5	2.1	2.2
Sep	2.9	3.7	1.9	3.1	2.5	1.8	2.2
Oct	2.6	3.5	2.9	4.5	2.5	2.0	3.9
Nov	2.1	3.4	2.2	1.8	1.1	2.2	1.9
Dec	2.0	3.2	2.2	2.7	1.9	1.8	2.0
Avg. Wind Speed	2.891	4.15	2.55	2.95	2.275	2.283	2.339

Table:7.8 Monthly Average wind speed data in 2013

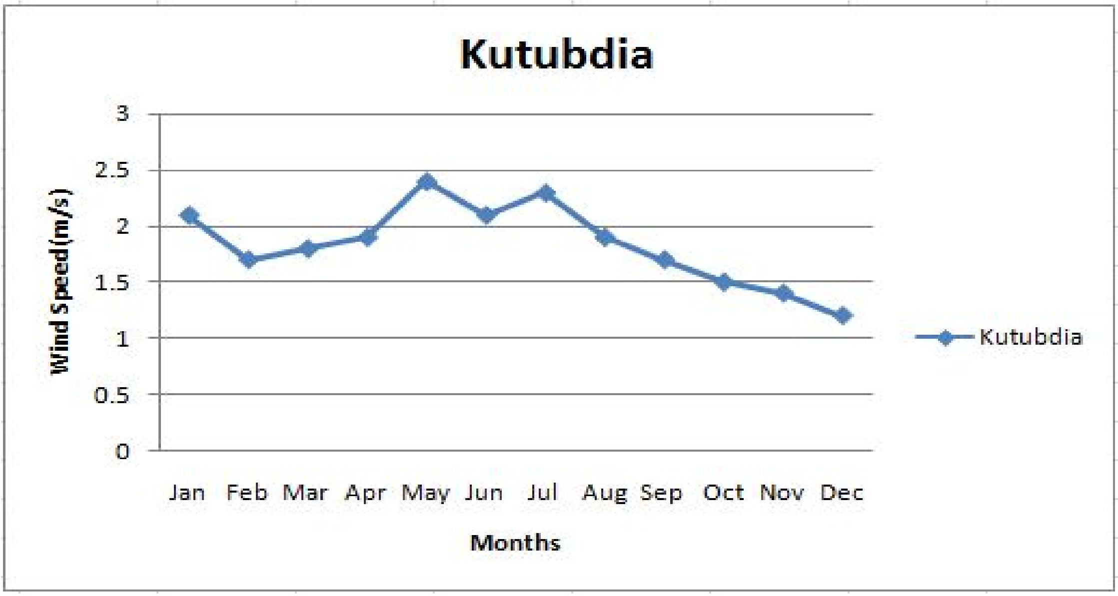


Fig: Monthly average wind speed at Kutubdia

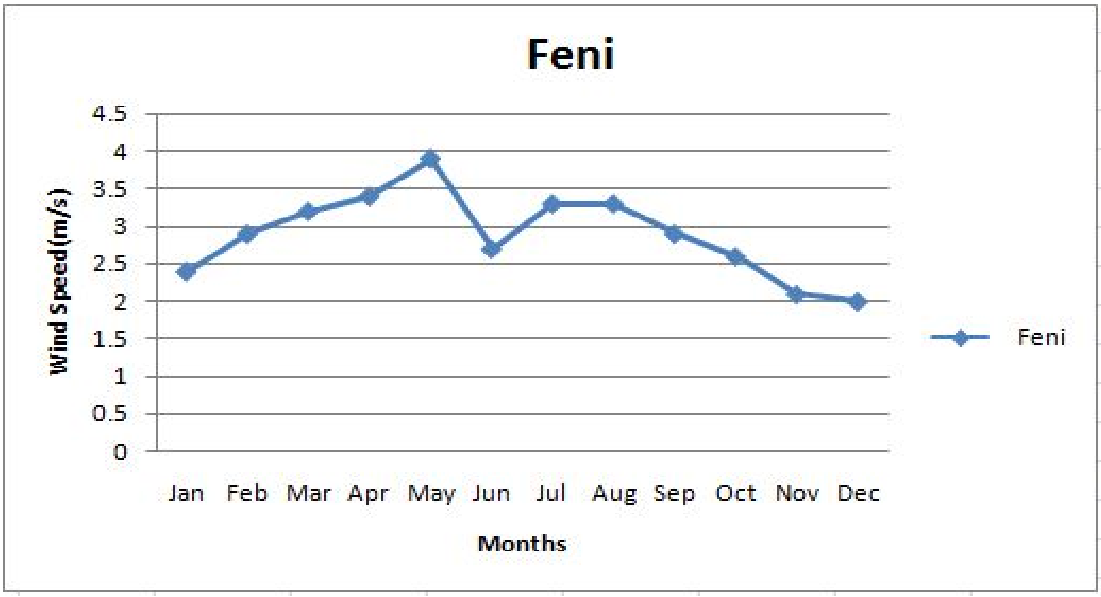


Fig: Monthly average wind speed at Feni

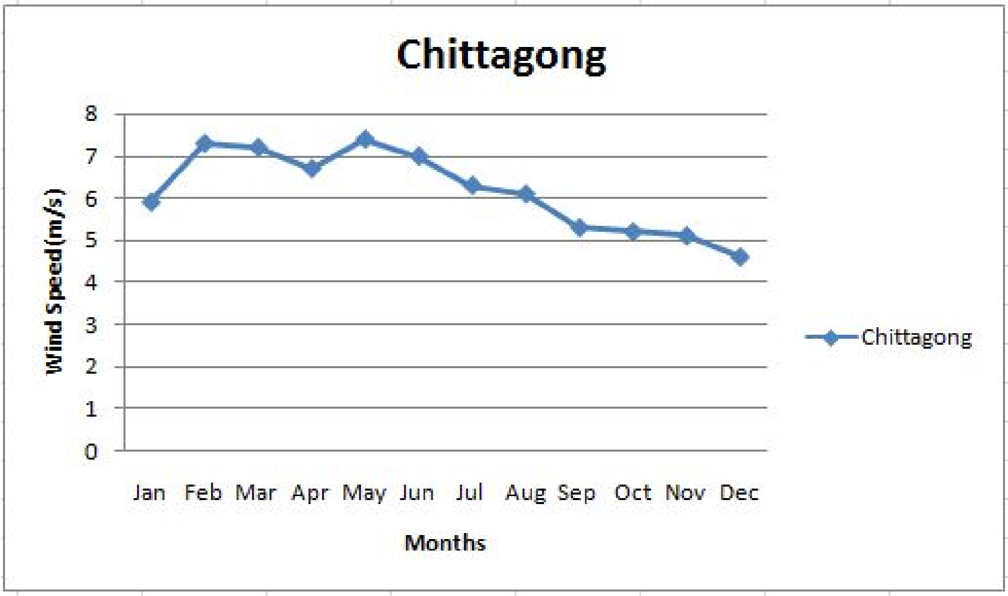


Fig: Monthly average wind speed at Chittagong

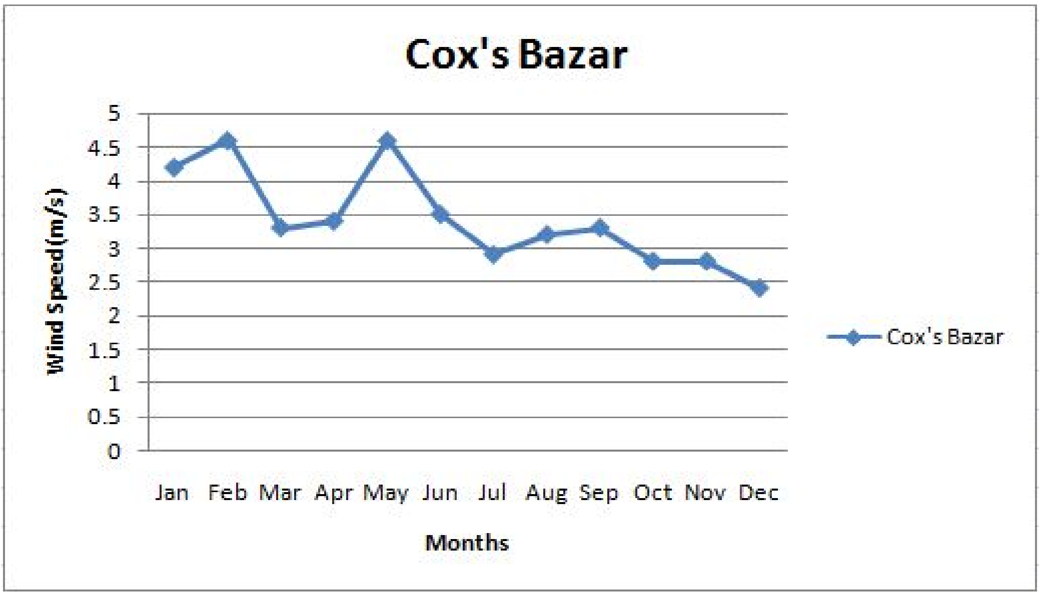


Fig: Monthly average wind speed at Cox’s Bazar

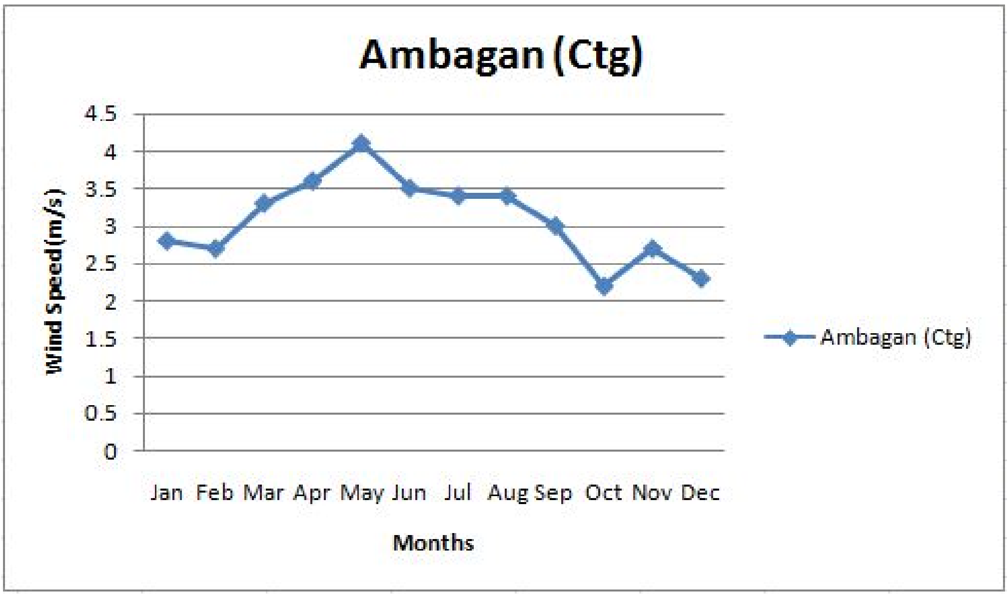


Fig: Monthly average wind speed at Ambagan (ctg)

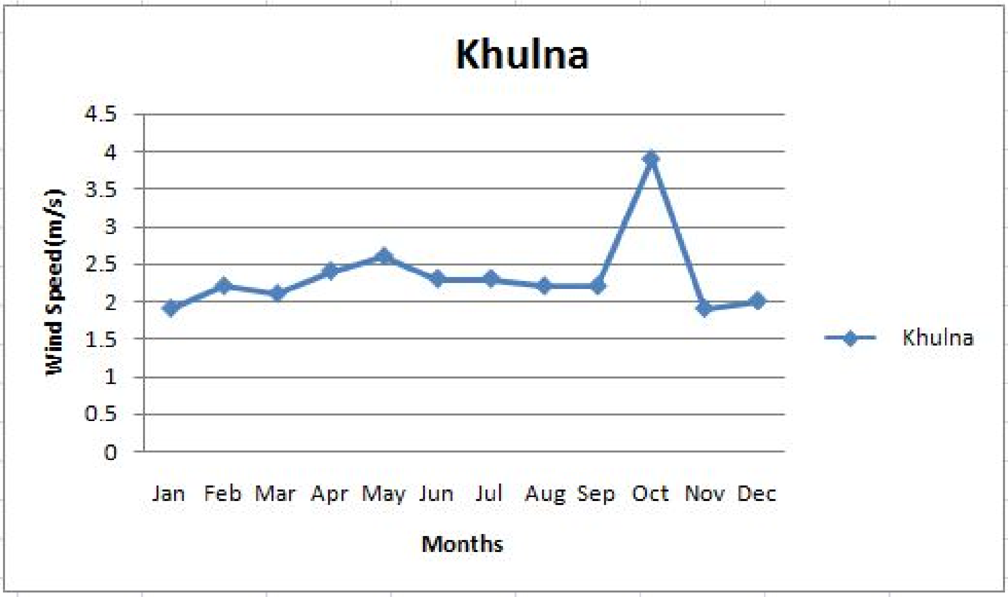


Fig: Monthly average wind speed at Khulna

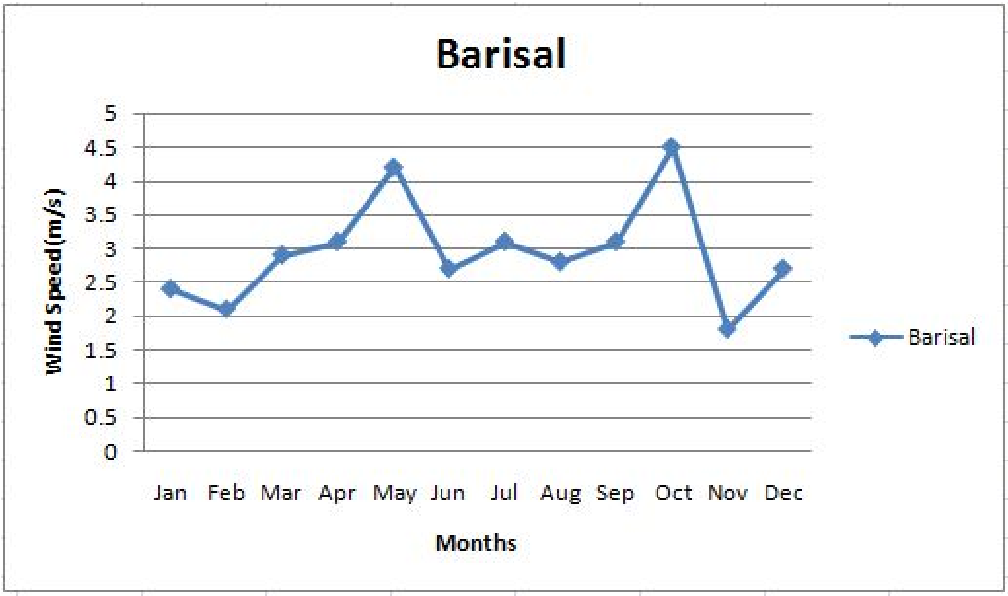


Fig: Monthly average wind speed at Barisal

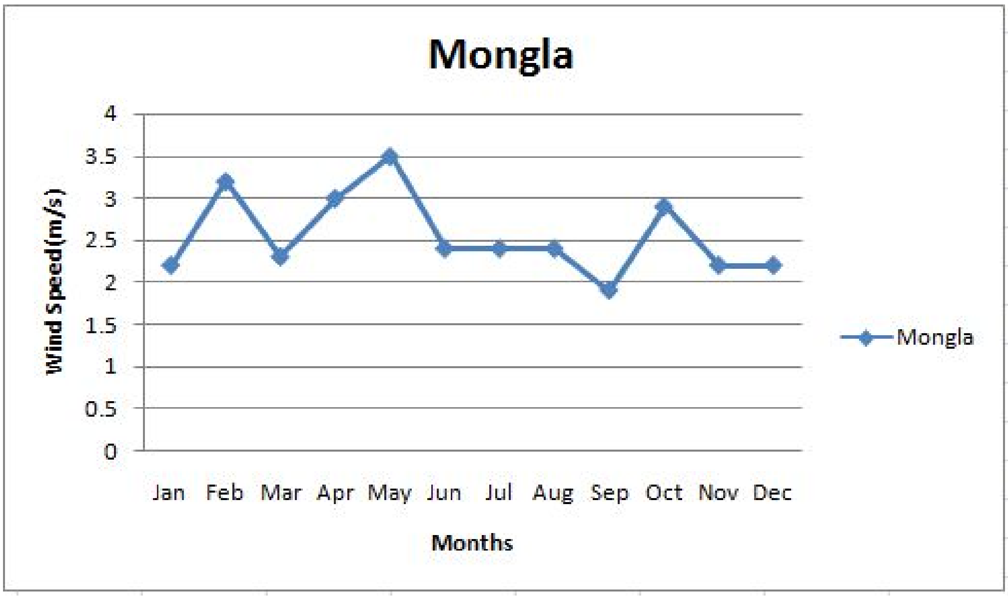


Fig: Monthly average wind speed at Mongla

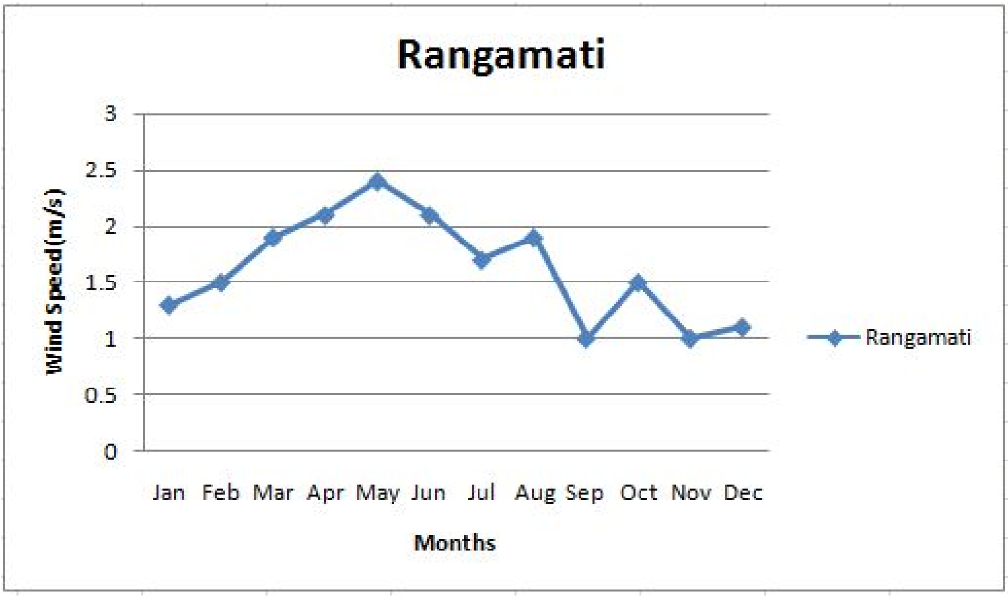


Fig: Monthly average wind speed at Rangamati

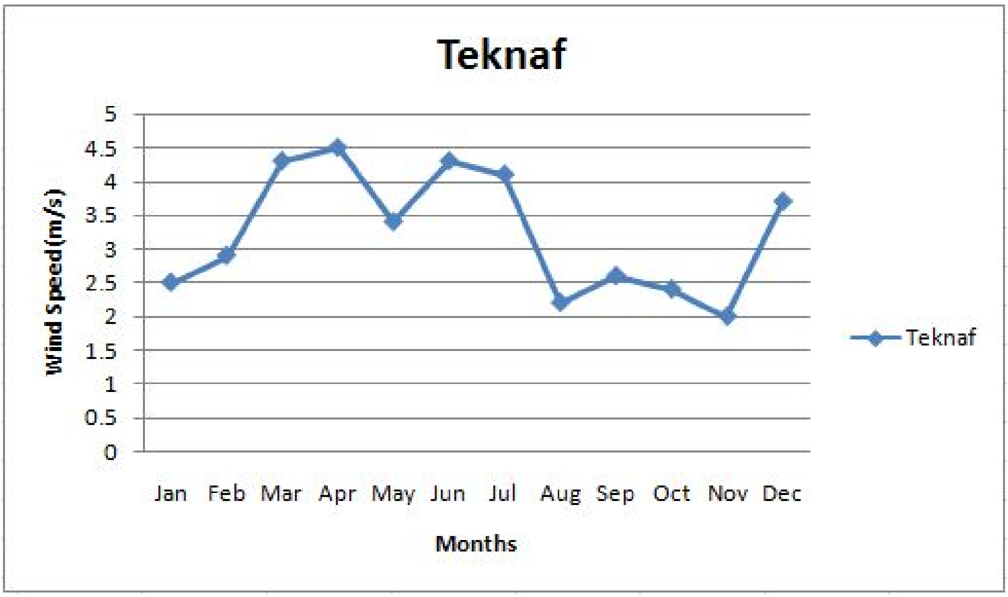


Fig:7.10 Monthly average wind speed data curve in different locations [36]

7.6 WIND SPEED STUDY

Recent analysis and study on wind energy assessment in Bangladesh show that some of the coastal areas are fairly potential for small scale wind electricity generation system. Wind speed varies from 4m/s to 5.5 m/s at the height between 25m to 50m. Therefore a technical and economical feasibility analysis has been done for small wind home system for the coastal region of Bangladesh. HOMER and RET Screen software and monthly averaged measured wind speed for four coastal locations have been used for this purpose. It has been found that depending on the home users, load demand, capacity shortage and fraction of excess electricity, cost of useful energy varies from 24 to 39 Tk/kWh which is comparable to solar home system and diesel generator system for low scale consumers. Considering diesel system as a base case, for a 400 W capacity of Wind Home System in coastal areas at a speed of 5m/s the IRR, payback period and benefit-cost ratio are found to be around 16%, 8 and 2 years respectively. As the turbine cost decreasing and diesel cost increasing therefore sensitivity analysis also has been done. Results show that considering energy consumption, environmental effects and remote accessibility most of the coastal regions are viable for wind home system. [37]

CHAPTER 8

Wind power generation in Bangladesh

8.1 Wind Energy in Bangladesh

Government has recognized the importance of renewable energy in our energy planning programmer and a draft Renewable Energy Policy is on the verge of being approved. In the context of Bangladesh, renewable energy consists mainly of biomass, solar energy and wind power. Hydropower potential appears very limited. Studies could be made for micro hydropower which could meet some of the local needs of electricity. This would, however, be seasonal and other forms of power generation may be required during some months of the year. There is little chance of geothermal power and further R&D would be needed to exploit wave/tidal power Wind energy has the potential to provide mechanical energy or electricity without generating pollutants. Historically it was used in many countries, especially, the Netherlands, as a source of mechanical energy, e.g. grinding corn or pumping water. In Bangladesh, as in many other countries, wind energy has also been used to provide some motive force to boats with sails of various designs. Unfortunately, not much research has been conducted in these areas, although renewed interest have recently been generated in utilizing the energy of wind for wind pumps and sailing boats. Wind electricity for decentralized system or hybrid generation of electricity using other energy sources as complementary to wind energy has now been given some attention and this could be suitable in low wind regimes for localized small grid systems or battery charging. For low wind speed, wind pumps could also be a viable option. Bangladesh is situated between 20O34'-26038 North Latitude and 88001'-92041' East Longitude. The country has a 724 km long coast line and many small islands in the Bay of Bengal, where strong south-westerly trade wind and sea-breeze blow in the summer months and there is gentle north-easterly trade wind and land breeze in winter months. In Bangladesh, little systematic wind speed study has been made. Data collected by the meteorology department are usually meant for weather forecasting and are insufficient for determining wind energy potential. In an early study report in 1982, a 30-year meteorological data from number stations throughout the country were considered. It was found that wind speeds in the districts of Chittagong and Cox's Bazar were the only ones which showed promise. Extending the idea, only coastal area and the bay islands showed promise for possible electricity generation from wind.

Fig8.1 A wind pump set up by BCAS at Patenga, Chittagong

The wind speed measurements by BCAS Group and GTZ group confirmed that wind speed is much higher in summer months (due to monsoon wind) than in winter months. Actual wind speed found by GTZ was slightly higher than those of BCAS Group; but the frequency distribution was similar. Diurnal variation confirmed the trend observed by the meteorological department. Power curves of wind turbines with two different installed capacities from two different manufacturers have been used to calculate energy generation. The estimated annual energy outputs for Kutubdia and Kuakata are 133 MWh and 160 MWh for a 150 KW wind turbine; while the outputs are about 200 MWh and 230 MWh respectively from a 250 KW station at these places. [31]

8.2 Wind Battery Hybrid Power Project (WBHPP) At the kutubdia Island

A wind Battery Hybrid Power Plant is the first grid quality 11 KV, largest and successful renewable energy project in Bangladesh and was supply 3 hours during day times and 3 to 4 hours during night times. Bangladesh Power Development Board (BPDB) implemented the 1000 kw capacity Wind Battery Hybrid Power Project (WBHPP) at the Kutubdia Island(Bay of Bengal) in the Cox's Bazar District.

Fig:8.2 **1000KW Wind Battery HyBrid Power Plant (so called Light House)**

Under this project, total 50 nos. of 20kWp capacity Stand Alone Type Wind Turbines are being installed at Taboler Char areas of the Ali Akbar Dell Union Parisahd of Kutubdia Upazilla. The total capacity of all the wind turbines is 1000 kWp(1 MW). The Wind turbines producing electricity which being stored in battery bank. The entire system tailed as Battery Hybrid Power Plant (WBHPP). This project being installed on turn-key basis at Kutubdia, Cox's Bazar, Bangladesh. The wind turbines produce electricity and charges the batteries at battery banks which consisting of 1000 numbers of 200AH with capacity of 12VDC. The stored electrical power from the battery banks being converted to AC (Alternative Current) by using inverters and distributed to the consumers through overhead power cable. This supply system exact having 3-phase, On-Grid form and matches with conventional power AC system and loads.

Fig:8.3 1000 Kwp capcity wind battery hybrid system power plant of Kutubdia

For the conversion of the DC power from the batteries, total 8 nos. of 150KW capacity each inverter has been installed. These inverters give pure sine wave output. These 8 nos. of inverters have been synchronized and paralleled. So the load out put on the system is shared by all these 8 nos. of inverters. The synchronized outputs from all these 8 nos. of inverters are put together in a common bus-bar LT pane. From the common bus-bar the totaled 3-φ out put is supplied to the LT side of a 630KVA, 0.415KV/11KV step-up transformer.

The 11KV output is taken away from the project site area to the Barghop Bazar which is about 8 km away from the project control room. This 11KV power is distributed through out the consumers of the Kutubdia Upazilla Sadar through the 11KV/0.415KV step down transformers and the distribution lines.

Calculation of KUTUBDIA :

Blade length = 14Feet
=4.26m

Blade diameter = 4.26 m

Swept area, A = π x (diameter/2) ^{2}
=3.1416 x (4.26/2)^2
= 14.25 m^2

Wind speed, v = 1.83 m/sec

Air density, ρ = 1.23 kg/m^3

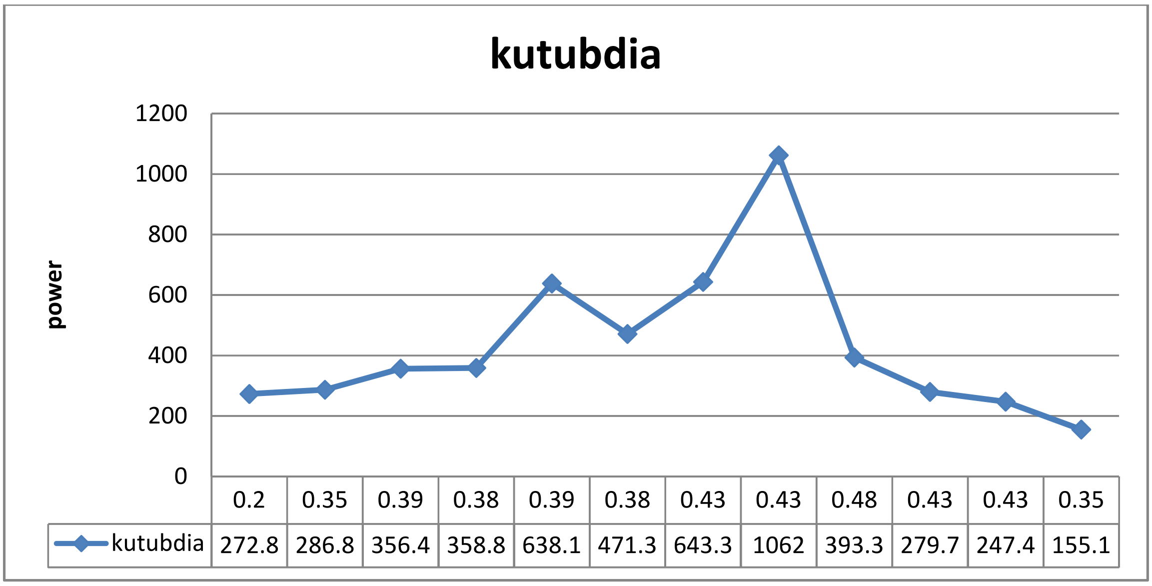
Power Coefficient, C_p = 0.35

Now putting these values we get:

Wind Power = 0.5 x C_p x Swept Area x Air Density x Velocity^3

= 0.5 x 0.35 x 14.25 x 1.23 x $(1.83)^3$

= 18.79 Watts per wind turbine



	0.2	0.35	0.39	0.38	0.39	0.38	0.43	0.43	0.48	0.43	0.43	0.35
kutubdia	272.8	286.8	356.4	358.8	638.1	471.3	643.3	1062	393.3	279.7	247.4	155.1

Fig:8.4 Relationship Between power coefficient vs power [38]

8.3 Full Specifications equipments of Kutubdia

- Technology imported from : China
- Daily production capacity : 800kW (in every 6 hours = 800kW Capacity)
- Turbine height : 50 feet
- Blade : 14 Feet
- Net weight (Blade+ Generator) : 1.2 ton
- Total Expenditure: 9 crore taka(90 million)
- Installation year : 2007
- Construction duration : 9 months
- Commissioned : March 30, 2008
- Financial sources : BPDB
- Batteries : 1000 (1kWh)
- Inverter : 8
- Power : 2 transformer providing electricity o 11000V grid line
- 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, we have used the following local materials.

- 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. [39]

8.4 Electricity Generation Achievements

The WBHPP has been running well for more than one and half years. We are supplying 0.60 to 0.80 MWH electrical energy every day at 11,000Volts. Till to date, we have 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. [39]

8.5 Grid Connected Wind Energy Project at Muhuri Dam areas

BPDB has implemented a pilot project of 0.90 MW capacity of the Grid Connected Wind Energy (GCWE) at the Muhuri Dam Areas in the Feni distrct in 2004. The installation, commissioning and erection works of 4 units of the 225 kWp GCWE turbines at this site had been completed in 2004. This is the first ever Grid Connected Wind Energy project in Bangladesh. The grid connected wind turbines generate electricity at 440V. This is stepped up by the 0.440KV/11KV step-up transformers at then fed into the nearly 11KV distribution lines.

Thus generating electricity from wind in the coastal areas can be transmitted to other regions of the country through the high voltage transmission lines. Very little operation and maintenance will be required during the whole life time of wind turbines and no fuel will be required for generating electricity from wind.

Fig:8.5 900kw grid connected of Muhuri dam

Calculation Of MUHURI DAM

Blade diameter = 27 m

Swept area, $A = \pi \times (\text{diameter}/2)^2$

$= 3.1416 \times (27/2)^2$

$= 572.55\ \text{m}^2$

Wind speed, v = 2.89 m/sec

Air density, ρ = 1.23 kg/m^3

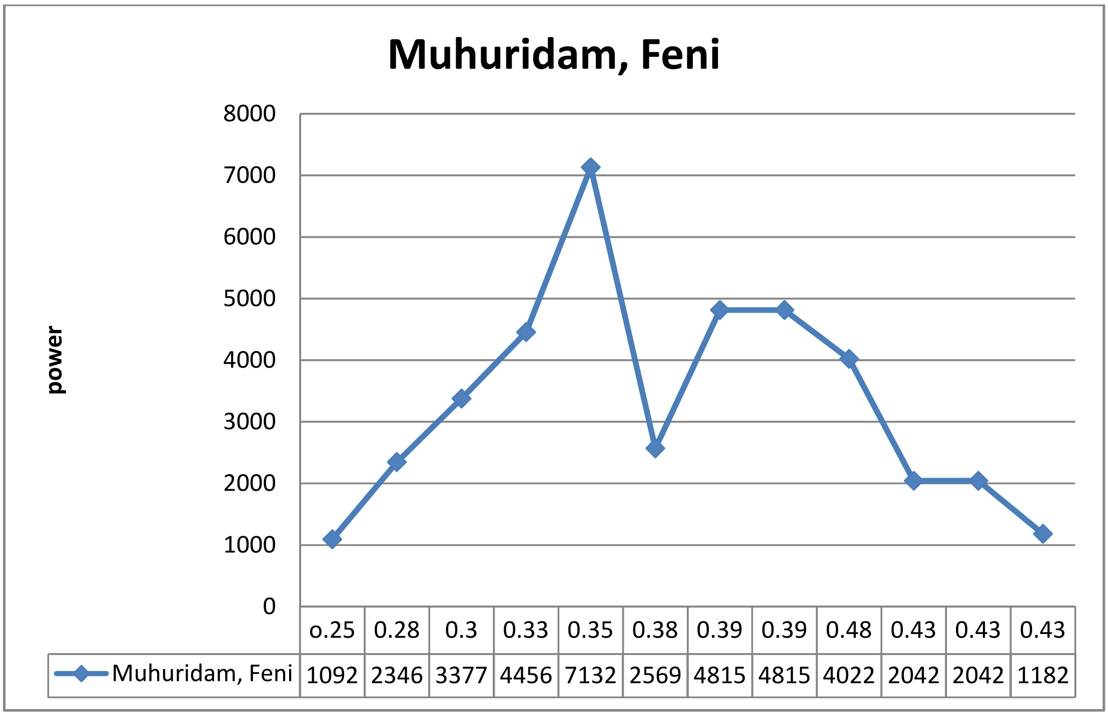
Power Coefficient, $C_p = 0.35$

Now putting these values we get:

$$\text{Wind Power} = 0.5 \times C_p \times \text{Swept Area} \times \text{Air Density} \times \text{Velocity}^3$$

$$= 0.5 \times 0.35 \times 572.55 \times 1.23 \times (2.89)^3$$

$$= 2974.74 \text{ Watt}$$



	o.25	0.28	0.3	0.33	0.35	0.38	0.39	0.39	0.48	0.43	0.43	0.43
Muhuridam, Feni	1092	2346	3377	4456	7132	2569	4815	4815	4022	2042	2042	1182

Fig:8.6 Relationship between power coefficient vs power [40]

8.6 Wind-Solar Hybrid System in Kuakakata Sea Beach

In the coastal belt of Bangladesh, the average wind speed is high and is sufficient to generate electricity. Conventional energy resources are being depleted and biomass face a growing risk of depletion in many parts of the world . Besides ,use of fossil fuels creates serious environmental problem. Emission of greenhouse gases through burning fossil fuels are linked with g local warming, sea-level-rise and degradation of environment quality. Limited production of conventional energy and high transmission and distribution cost would not permit the expansion of electricity network for the people living in the remote and coastal areas in the foreseeable future . Wind energy can be considered to be especially suitable for such inaccessible coastal areas which can meet the electricity demands of those deprived people. Currently appropriate lack of wind speed limits large-scale programme for harvesting wind energy on commercial basis. However small wind turbine hold potential for demonstrating the technology as well as raising awareness of the people about the prospect and benefit of use of wind energy in Bangladesh.

- Location: LGED Guest house cum cyclone shelter, Kuakata Sea-beach, Kalapara, Patuakhali.
- Capacity : 400 Watt
- Wind Turbine : 400 watt, Air 403 Model (Marine Version)
- Rotor Diameter : 46 Inches(1.17 meters)
- Start up wind speed : 7mph(3.0 m/s)
- Impact : Demonstration of Technology , Enhance tourism in Kuakata

Component	Description
Location	Kuakata, Latachapali UP, Kalapara Upazila under Patuakhali District
Rotor Diameter	46 Inches(1.17 meters)
Weight	13 lb.(6kg)
Start up wind speed	7mph(3.0 m/s)
Wind turbine	400 watt ,Air 403 Model(Marine Version)
Battery	100Ah x 3 Deep Cycle Batteries
Rated power	400 watts at 28 mph(12.5 m/s)
Regulator Set Range	12v 13.8v-17.8v preset to 14.1v 24v 27.6v-35.6v preset to 28.2v 36v 41.4v-53.4v preset to 42.3v 48v 55.2v-71.2v preset to 56.4v
Recommended Fuse Size	12v-100 amps slow-blow 24v-50 amps slow-blow 36v-35 amps slow-blow 48v-25 amps slow-blow
Yaw Wire Size	#10 AWG(American Wire Gage) stranded.
Pole Dimension	11/2 Schedule 40 pipes (outside diameter 1.875 inch, 48mm)
Minimum Battery Bank	400 amp hours(12v) 200 amp hours(24v)
Populations	4514
Number of House Holds	741
Commercial Activity	Residential/ Hotel/ Rest House/Guest House, Restaurant
Primary Source of Economic Activities	Agriculture, Business, Fishing.
Name of NGO’s working in the area	CODEC

Table:8.1 Full specification of Kuakakata Sea Beach Wind-Solar Hybrid power plan [4]

8.7 Wind Energy Programme under Grameen Shakti

8.7.1 Wind – solar Hybrid system

Wind Energy Program: Grameen Shakti is experimenting with the possibility of developing systems to utilize wind energy in the coastal areas of Bangladesh. GS installed 4 hybrid power stations (combination of wind turbine and diesel generator) in four cyclone shelters of Grameen Bank. Off which 3 are 1.5 kW and one is 10 kW. Power generated from the wind turbines is connected to four cyclone shelters for lighting . Three of which are Grameen Bank and one exclusively used as cyclone shelter. Appliances used with these systems are , Light, Fan, Television, Water pump, Incubator.

8.7.2 Hybrid System of Grameen Shakti

- Energy Resource : Wind-Diesel Hybrid System
- Type of installation : Hybrid
- No of installation : 7
- Capacity of installation : 4.32 KW
- Cost of Installation : 4.5 lacs
- Location of Installation :Coastal Area of Bangladesh
- The present phase of the program will allow Shakti to gather financial and technology.

8.7.3 Wind energy installation under Renewable Energy Programme (REP)

- Energy Resource : Wind Turbine
- Type of installation : Water pumping wind mill Irrigation
- No of installation : 1
- Capacity of installation : 1X1.0 Kw, 3X1.5 Kw, 1X10 Kw
- Cost of Installation :
- Location of Installation : Patenga (Coastal Area), Chittagong)
- Energy Resource : Wind
- Location of Installation : Coastal Districts

8.7.4 Wind energy installation under Renewable Energy Programme (REP)

- Energy Resource : Wind Turbine
- Type of installation : Stand-alone
- No of installation : 10
- Capacity of installation : 0.3 KW
- Cost of Installation :
- Location of Installation :Coastal Area of Bangladesh
- Functional Status : Functioning [43]

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