BLWT

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Title: **Unconventional energy harvesting from wind velocity and VIV resonance phenomena by using Bladeless wind turbine (BLWT)**

Chapter 1

Introduction

Due to providing the increasing demand of electricity, most of the electricity generation company are using conventional energy sources such as gas, coal, oil, nuclear reactor etc. But it causes a great harm for the environment like global warming, greenhouse effect, environment pollution (air, water, soil, eco system). Now a large number of companies are eagerly taken steps to collect clean energy from nonconventional energy sources from wind, water, sun, biomass etc. Almost 68 percent of the electrical energy produced in thermal power plant by using fossil fuel and 22 percent are produced by hydropower plant, nuclear power plant. Rest of 10 percent electric power collected from tidal, solar and the other sources. [1]

From the various renewable energy sources wind is the most efficient source among others renewable energy sources. Wind energy is available in everywhere from which we can collect energy by using wind turbine. Wind turbine utilize wind energy and transformed into electrical energy, but it has some demerits like pose a threat to wildlife, noisy movement, expensive, visual pollution etc. So, our main objective is that building a prototype of update version of "Vertical Axis Wind Turbine (VAWT)" called "Bladeless Wind Turbine (BLWT)" which is eco-friendly since it has no rotating blade, less noisy, no sharpen parts that can harm birds and animals.

In our proposed prototype, the vertical circular bluff body absorbed the energy from the wind which passes the outer side of the body. It causes a vortex induced vibration in its body due to vortices. The bottom side of this prototype is connected to a crankshaft which rotates the generator armature unidirectionally because of the displacement of bluff body. Generator produces the power by using "Vortex Induced Vibration (VIV)" from Wind. This arrangement can produce electricity with lest initial cost and maintenance cost. Produced electricity from the BLWT can contribute for reducing the scarcity of electrical power. The per unit cost of production of electricity from BLWT is less because of using wind which is abundant in environment and free of cost.

Present energy sources of Electricity Generation:

There are various types of energy sources are used for producing electricity. Some of these are given below:

Thermal power plant:

Thermal energy is produced from burning of coal and gas which is feed to a boiler with full of water. Steam have been produced from boilers by absorbing thermal energy which rotates the blade of alternator with the help of turbine. This unidirectional rotation of the blade producing the electrical energy in the stator end of alternator.

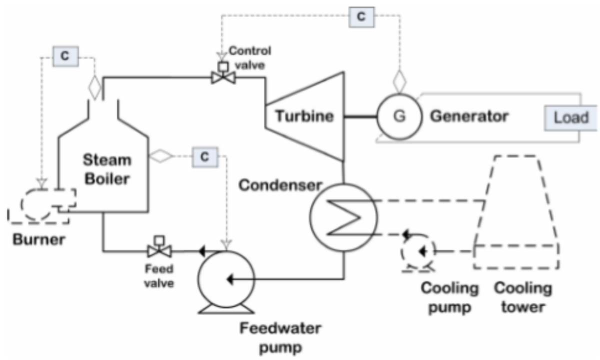

Fig.1.1: Thermal Power Plant[1] [2]

Others fossil fuel:

Diesel and natural gas are used in a power plant for the purpose of producing electricity. In every thermal power plant, there is a conversion chamber for running the fossil fuel and energy feed to steam boiler and steam rotates the turbine and the shaft is connected to the alternator shaft. The alternator produces the AC power.

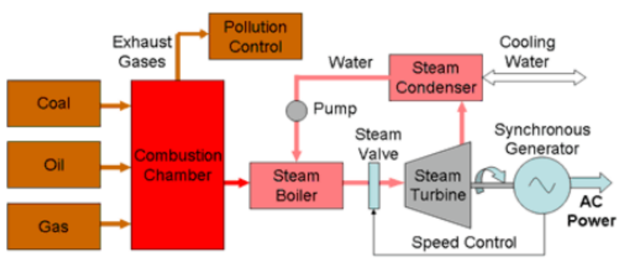

Fig. 1.2: Combined Fossil Fuel power plant schematic block diagram [3].

Nuclear Power Plant:

Nuclear energy is Produced by the chain reaction of Uranium atoms. Which is called Nuclear Fission reaction. Whenever a Uranium atoms splitted into different molecules and producing Nuclear energy which is used for producing steam. Then steam feed to the alternator for producing electricity.

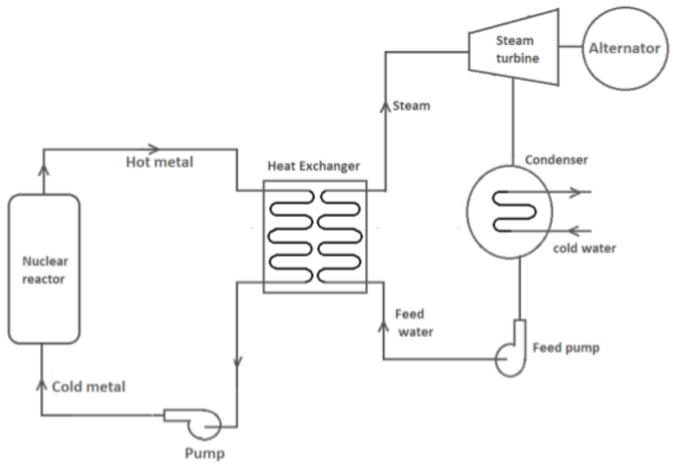

Fig. 1.3: Nuclear power plant schematic block diagram [4].

Hydro energy:

At ancient time hydro power are used as a renewable energy source for irrigation and the operation of conducting various devices such as gristmills, sawmills textile mills, trip hammers, dock cranes, domestic lifts, and ore mills.

When water stored in reservoir in a particular height to the ground, there stored potential energy. At the time of releasing the water from reservoir the potential energy converts into kinetic energy which rotates the blade of the alternator at the bottom part of the dam and produce the power from the stator part of the alternator.

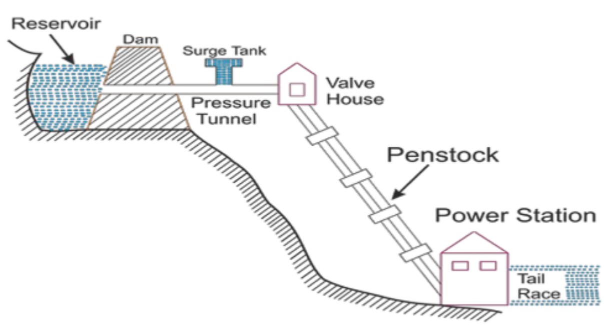

Fig. 1.4: Hydro energy Power Plant Block Diagram [5]

Wave Energy:

Wave energy is generated from winds and collected for useful work – such as power generation, desalination of water or drainage of water (into reservoirs). Waves are produced by winds that pass over the sea floor. As long as the waves disperse steadily over the water, there is a flow of force from the wind into the ocean. Both the variations in the air pressure between the wind and the lee of a wave crest, as well as the tension on the wind 's surface allows the waves to rise as the water reaches into the shear force. A wave-powering system is commonly referred to as a wave energy converter (WEC). The generation of wave power is actually not a commonly utilized, but efforts have been made to use it since at least 1890.

Fig.1.5: Wave power plant schematic block diagram [6].

Tidal Energy:

Tidal energy is another form of hydropower which converts the energy from tide to electricity using tidal generator or other system. Tides are produced due to gravitational interaction with the moon and sun and the rotation of earth. Tides are considered as a periodic wave which carries the energy and its used for the rotation of the blades of turbine generator. Tidal barrage resists the free flow of water which increases the potential energy in a certain height between high and low tides. Whenever the sea level rises the tide begins to come in through the tidal barrage resulting produces electricity by tidal generator using potential energy.

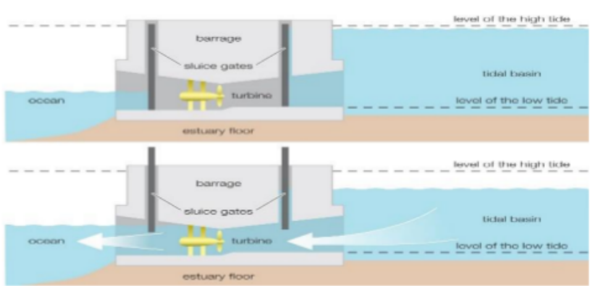

Fig.1.6: Tidal power plant schematic block diagram [7]

Ocean energy:

Ocean Thermal Energy Conversion (OTEC) uses the ocean thermal gradient between the deep colder and warmer shallower surface sea waters to conduct a heat engine so that it generates electricity. OTEC can be either closed-cycle or open-cycle. Closed-cycle uses the refrigerant like Ammonia or R-134a which has low boiling points and suitable for powering the systems generator for producing electricity. In Open-Cycle engines, vapor from the sea water used as a working fluid.

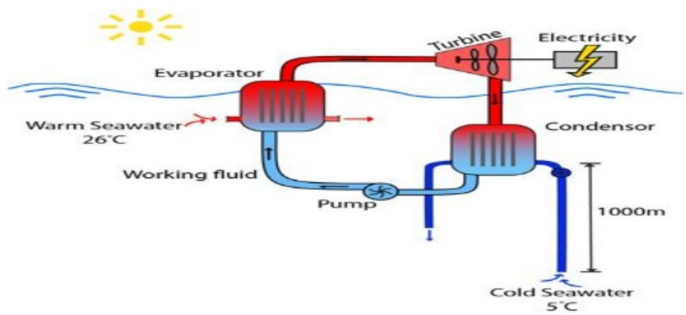

Fig.1.7: Ocean power plant schematic diagram [8]

Solar Energy:

Solar energy is radiating Sunlight and heat used for a number of scientific advances, including space heating, photovoltaic, space cooking, solar thermal energy, solar engineering, molten salt power plants and artificial photosynthesis. [9]

Solar energy is broadly characterized as either active solar or passive solar depending on how their capture and distribute solar energy or convert into electricity. Active solar energy system uses the devices to transform the sun's energy into a more usable form such as hot water or electricity. Passive system are structures design placement or materials to optimize the use of heat or light directly from the sun.

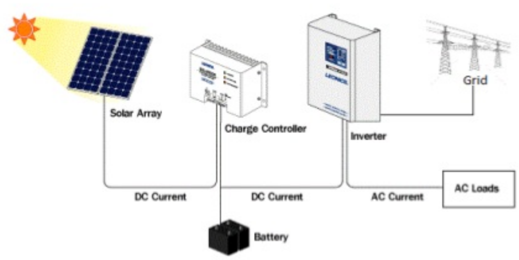

Fig.1.8: Solar power plant schematic diagram [10]

Wind Energy:

Wind energy is type of renewable energy source which carries mechanical energy. It is used for the rotation of wind turbines which produces the electricity. In world energy scenario On-shore wind is an affordable source of energy, equivalent and cheaper than coal or gas plants. Off-shore wind utilize the more frequent and powerful wind effectively than the On-shore wind but maintenance cost is considerably higher than the On-shore wind. On-shore wind firms can provide electric power to isolated off grid locations due to utilizing the higher wind speed at the Off-shore the efficiency is high. On-shore wind turbines often influence the environment, as they usually tend to be scattered over more ground than other power plants. On the other hand, Off shore firms have less visual impact but Off-shore wind is steadier and stronger than on land.

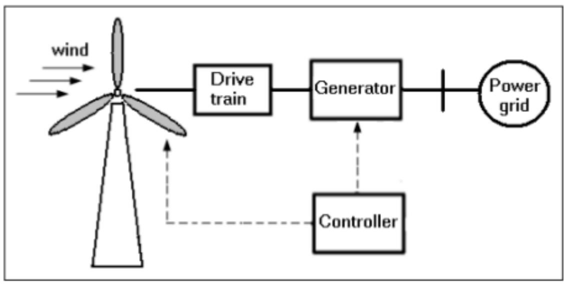

Fig.1.9: Wind power plant schematic block diagram [11]

Background Study:

The ratio of the dynamic viscosity to its density of a fluid is called kinematic viscosity.

$$V = \eta / \rho$$

where, η and ρ are the dynamic viscosity and density of a fluid respectively. V denotes the kinematic viscosity of fluid.

In general, Reynolds number associates the vortex shedding of a bluff body. For a maximum Reynolds number, the vorticity increases rapidly and also the oscillation of a bluff body which is emerged into fluid, which is called Von Karman Vortex effects. [12]

$$Re = (U\,D)/V$$

Where, U is the free drift velocity, D is the cylinder diameter of a mast V is the kinematic viscosity.

The range of the Reynolds number is $300<Re<3*10^5$ [13]

The Strouhal number 'Sn' is a dimensionless parameter that explains the product of vortex shedding frequency and diameter of mast to the free drift velocity of a fluid. It also relates with the Reynolds number. [14]

$$Sn = (fsD)/U$$

The Strouhal number of a stationary tube or circular cylinder is a function of Reynolds number but less of surface roughness and freestream turbulence

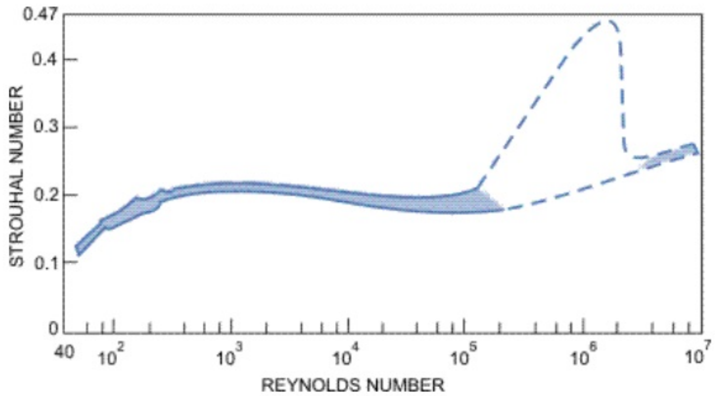

Fig.1.10: Strouhal number versus Reynolds number for circular cylinders (tubes). [15]

Lock in phenomenon denotes that when the vortex shedding frequency is approximately closer to the natural frequency of bluff body or mast, the linear resonance occurs. The vortex shedding frequency is related to the Strouhal number. It is a dimensionless ratio that relates the product of Strouhal number and Kinematic viscosity to the pipe diameter where displacement is negligible.

$$f = Sn*U/ D_o$$

where, f is the vortex shedding frequency, U is the free drift velocity and D_o is the pipe diameter where there is no oscillation.

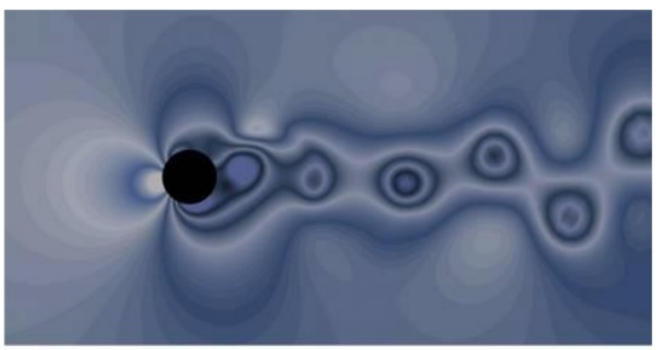

Fig.1.11: Vortex formation behind a circular cylinder. [16]

The oscillation of mast increases if the placement of project higher from the ground, because of increasing the velocity of the fluid. A vertical slender and circular cross-sectional structure are eligible to produce the oscillation of this body. [17] Betz law states that the maximum power can be unsheathed from the wind and converts the power about 16/27 (59.3%) of kinetic energy in wind. The factor 16/27 (0.597) is known as Betz co-efficient. [18] Mast is the inflexible and moving parts of this project. For achieving a synchronous oscillation of moving parts, circumference and diameter of body or Mast need to be changed with reference to height.

In moving parts where the oscillation is negligible obtain with

$$D=D_0+a\cdot X\ldots\ldots\ldots\ldots\ (5)$$

Where 'D' is sum of diameter of the Mast, 'X' is amplitude oscillation 'a' is the adjustment factor. Which is related to Reynolds number.

Let, a flexible carbon fiber rod length of 'L' which is attached with Mast lower part. At lower part of Mast i.e. at the height of y=L/2 where displacement of mast X=0. So, from equation (5) the diameter of the mast D= *D0* (L/2) =d. and the vortex shedding frequency 'f' with wind velocity *U∞(L/2)* is

$$f = \frac{Sn.U\infty(L/2)}{d}$$ ....(S.N: U is the wind velocity)

in different position, the displacement of Mast is different so for different length the frequency can be obtained.

$$f(y) = \frac{Sn.U\infty(y)}{D_0(y) + a.X(y)}$$

Where $U\infty(y)$ and X(y) are the free wind velocity and oscillation amplitude of mast at any height of y respectively.

H is the distance between ground of the flexible rod to the upper point of the mast. If the displacement of the upper part of the mast is γ times the mast diameter at its lowest part, as a result:

$$X(y) = \frac{y - \frac{L}{2}}{H - \frac{L}{2}}.\gamma.d$$

As the vortex shedding frequency is the same throughout the length of the mast, we finally obtain:

$$D(y) = d.\frac{U\infty(y)}{U\infty(L/2)} - a.X(y)$$

The right velocity gradient calculation can help to deduce the same frequency of vortex dissipating in the entire mast, including the discontinuity effect in the highest mast portion. This frequency must coincide with the usual pattern of oscillation in the entire system to obtain the necessary resonance.

relation between friction factor, pressure drop, drag coefficient which is denoted as adjustment factors.

Where U infinite L/2

Problem declaration and Plan proposed

Problem Identification:

By studying various literature, the following problems found for BLWT which are given below:

a) Reducing the complexity of our proposed prototype so that it may use the wind energy for the production of electricity efficient.

b) Due to high cost of per unit prototype the initial cost become higher for the based on **"Vortex Bladeless, SL''.**

c) Reducing the cost of the mast by using different material considering the climate change in Bangladesh.

Proposed Solution:

To eliminate the complexation of the prototype, the alternator part inside the mast are placed outside of the mast for our design, which reduces the weight of the bluff body(mast). Due to high cost of Neodymium Magnet which is used Vortex Bladeless, SL, we decided not to use this magnet but changing the mechanism of absorption of energy from the displacement of connecting rod by adding gear mechanism with generator. Using the PVC (Polyvinyl Chloride Polymer) pipe as a mast in lieu of other polymer for the reduction of the mast cost which makes our prototype efficient and reliable.

Steps to be taken:

a) Analysis of Mast

b) Prototype manufacturing

c) Testing and data collection.

Motivation:

In Bangladesh most of the Island are deprived from electricity such as Sandwip, Bhola Island, Manpura Island, Saint Martin's Island, Kutubdia etc. So, they are lack behind in the race of Modernization. But in this island, there is abundance of wind energy. So, our project can be efficient in this era for utilizing the wind energy to the electricity which can reduce the scarcity of electricity in this island. At a result, the socioeconomical development of this era will increased. The design can be used by adding solar system with stepper motor which facilitate the project to work in the absence of wind. The design can be used in the coastal area where the particular flow of wind present so it can be an effective solution towards our power crisis.

Objectives:

The main objectives of this project are:

a) To design a hybrid power generation system by using Bladeless wind turbine and solar cell module with stepper motor.

b) Analysis Vortex bladeless wind turbine mechanism and Hybrid power generation system.

c) This research work aims to analysis unidirectional wind flow system on vertical axis.

Chapter 2

An overview of wind and solar energy

Wind Energy:

Wind energy denotes the process of producing electricity by utilizing kinetic energy from wind which naturally existing in the earth atmosphere. Wind energy is a clean and reliable fuel free source. It doesn't harm to the environment because of utilizing natural energy from wind. In several different countries, the wind power technology is now being supported and precisely designed to make the use of wind energy more efficient to improve electricity generation.

Wind Energy Technology:

Wind turbines consist of rotor blades mechanical shaft ratchet-wheel, base. Rotor blades which are rotate around of horizontal hub of wind turbines. The hub is linked with gearbox and the gear box consist of two ratchet-wheel, one is larger and another is smaller. The larger ratchet-wheel is connected to a shaft called the low-speed shaft. And it drives the smaller ratchet-wheel for gaining higher speed that is suitable for the generator. When the velocity of wind is low the torque of wind turbine is high and for the higher velocity of the wind the torque is less. Gearboxes in wind power plants are large, heavy, complicated and expensive. So that, it is needed to avoid gear boxes in the constructions of wind turbine. In lieu of using gear box, the PMDC generator, permanent magnet induction generator, AC generator are used for the production of electricity. Now most of wind power plants three phase AC generator are used for producing electricity.

Wind turbine system:

A wind turbine utilizes the kinetic energy of wind into electrical energy by rotating the blade. The devices are typically called a wind turbine, as the kinetic energy is specifically used by equipment such as pumps or grinding stones. The system is also called a wind generator or a wind turbine or a wind power unit (WPU) or wind power converter (WEC) as the mechanical energy is transformed in electrical energy.

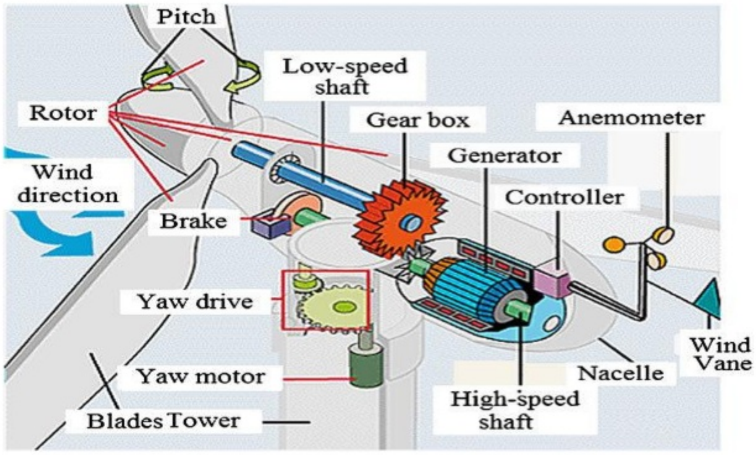

Fig 2.1: Wind Turbine major Components [19]

Components of a typical Wind turbine:

A wind turbine consists of five major and many auxiliary parts such as tower, rotor, nacelle, generator, and foundation or base. Without all of these, a wind turbine cannot function.

Tower: Tower protects the wind turbine rotor and nacelle at the appropriate altitude. The major types of towers in modern rolling turbines are lattice tower, a steel tubular tower and a tower for guides.

Rotor: Rotor is the main and most significant component of wind turbine. The rotor absorbs the kinetic energy of the wind stream and converts it into electrical power by rotating the shaft. Components of a wind turbine rotor are blades, hub, shaft, bearings and other internals. By using lighter and stronger carbon fiber blades, the rotor speed can be increased significantly.

Nacelle: Nacelle is covered frame which is isolated and protected machinery from the external environment, located behind the rotor blades. Nacelle consist of a set of gears, Generator and mechanical shaft. The inner shape of nacelle is supporting and distributing the weight of machinery. The movement of rotating blades absorbs the kinetic energy from wind which results the rotational blade as well as producing electricity by driving the generator through the gear.

Control and protection system: The control system monitors the gear box and generator temperature and pitch control is a technology used to operate and control the blades of wind turbine. It is made by generators, gears, hydraulic cylinder. The yaw mechanism is used to turn the turbine against the wind which make sure the efficient output from the generator. In protection system anemometer and the brake are used for measuring the speed of wind and shutdown the rotation of the blade at the time of critical situation respectively.

Foundation: The foundation or base provides the support to the wind turbine which is well suited on to the ground. It is usually made with solid concrete.

Types of wind turbine:

Horizontal and vertical axis are the basic types of wind turbine which are older and more common. They can also include blades (transparent or not) or be bladeless. Vertical designs produce less power and are less common but are highly efficient and more eco-friendly when compared to Horizontal Wind turbines.

Horizontal Axis Wind Turbines: HAWTs are the most common designs of today's wind machine. HAWTs use airfoils fitted on a rotor that can be positioned upwind or downwind. HAWTs use aerodynamic blades. Usually, HAWTs are either two or three-bladed and work at a high speed of the blade tip. Machinery with upwind rotors requires a raft or tail vane to direct them in the wind while downwind turbines have blades attached so that the turbine can be directed independently. But one downside found by downwind rotors was the fact that as they attempted to adjust winds at low pressure, they were known to 'hop.' This limited energy efficiency at low wind speeds. [20]

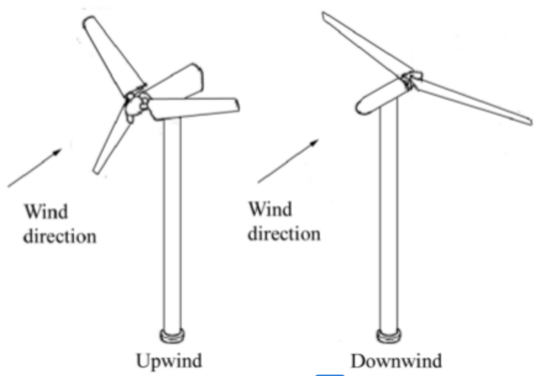

Fig 2.2: Horizontal Axis Wind Turbine [21]

vertical Axis wind turbines (or VAWT's): The main rotor shaft has been arranged vertically for vertical Axis wind turbines (or VAWT's). The turbine must not be oriented to the sky, which is a gain in a position where wind direction is highly unpredictable. A direct drive from the rotor movement to the ground transmission enables the generator and the driving unit to be mounted near the ground and increases the usability for maintenance. But these structures create a lot less electricity, which is a big downside over the course of the time.

Fig 2.3: Various types of Vertical Axis Wind Turbine [22]

Advantage of Vertical Axis Wind Turbine over Horizontal Axis Wind Turbine:

1. They are built below the ground so that maintenance is simple if necessary.
2. At speeds of 6 mph they start to produce electricity.
3. They can be built in positions that can't be bigger buildings, like horizontal form.
4. Increased electricity consumption – 20% more than HAWT.
5. Lower level of noise-around 27-37 DB, perfect for survival.
6. Safer operation — speed-speed spinner, reduced chance of hurting birds and also decreased noise level than horizontal turbines.
7. Simpler construction and servicing-far from the conventional assembly location, the turbine and related lines can be installed directly on the roof.

Disadvantages:

1. Even a Darrius wind energy transfer system is significantly less effective than the traditional horizontal rotor.
2. As a Darrius rotor typically lies close to the ground, it often has a lower speed wind than a traditional, tower-mounted wind energy conversion device with a comparable estimated rotor disk region. The production of energy can be lower.
3. The greatest drawback for devices for vertical axes is that far fewer of them are recognized than those with horizontal axis. This impairment is eliminated easily.
4. Since a Darrius engine has a lot of wind energy capture directional symmetry, external mechanical assistance is needed to startup. Tests demonstrate that the problem can be overcome with small machines by loading up the S-rotors and both the vertical (rotational) axis. This solution does not seem feasible with larger equipment, but the generator will act as a turbine starter if the wind power system is connected to the transmission grid. The load (alternative current) will also provide a way to regulate the speed of the spinner independent of the wind speed and thus not to require variable pitch blades. It stalls at very high speeds and ends the rotation automatically.
5. The limitations are that it takes twice as long to generate usable wind energy. The turbines have to be fitted on a flat floor and some versions need guiding wires that raise the tension on the tower's bottom and have limited starting torque.

Bladeless Wind Turbine (BLWT):

What is Solar Energy:

The sun disseminates a vast amount of energy to the earth which is called solar energy. It emits more energy which can be utilized in various ways. Solar system is one of them. The radiation produced due to the nuclear fusion in inner core of sun. The sun made up of Hydrogen and Helium gas. The amount of solar energy receives depends on the time of the day, the season of the year, the cloudless of the sky.

Working Principle:

If p-type silicon is used in bosom contact with a n-type silicon is called p-n junction or diode. When a huge number of diodes (60-72 solar cells approximately) connects in series it results a solar module or panel. There is depletion layer between p-type and n-type material. In p-type the majority carrier is hole and n-type the majority carrier is electron. When the light inclined into the p-n junction above a certain frequency energy from light is transferred to the electron n-type side of silicon. Then the recombination with the hole and electron takes place. Electric field is produced due to the imbalance of charge immediately either side of the junction. At the time of diffusion electron moves n-type to p-type and hole moves p-type to n-type which creates a depletion region. The action of the light (shower of photons) falling on the junction is to create electron- hole pairs which move under the influence of this built in field such that the electrons migrate to n-region and the holes migrate to p-region. This charge separation will create an electric field opposite to the electric field created by the diffusion. If the number of absorbed photons is enough, these two fields will cancel each other, leading to an open circuit voltage between the n and p regions. If these created electrons and holes are made to flow through an external load, electrical energy will be obtained from the absorbed photon. Once that happens, they start moving because of circuits electric field and this unidirectional movement of charge produces electricity. The output of the solar arrays is given to the inverter side which converts the DC voltage into AC voltage and distributed to the load side.

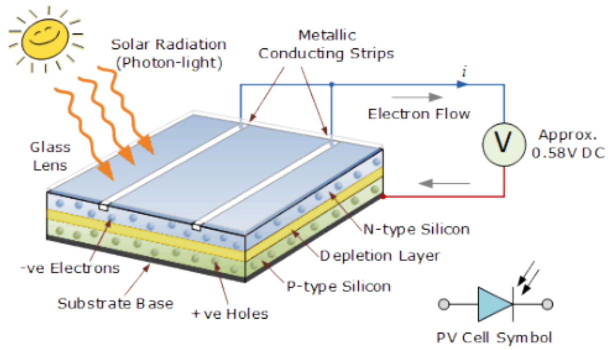

Fig 2.4: Basic operating principle of a Solar Cell [23]

Characteristics of solar cell:

A good photo voltaic material should have a large absorption coefficient at low temperature and optimum value of energy gap. If the photon energy is equal to (or) greater than the band gap leads to a large intrinsic carrier concentration and the possibility of photon absorption is less. The photon can be absorbed by the silicon, can generate heat if the photon energy is higher than the silicon band gap value. The construction of a solar cell is difficult because of the fact that one of the crystals (usually p-type) has to be in the form of a single crystal with a controlled impurity. The thickness of p layer is very small when we compare with n-layer to avoid recombination of charge carriers.

PV cells, Modules and Arrays:

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in a fundamental building block of PV systems. Photovoltaic panels include one or more PV modules assembled as a pre-wired, field-installable unit. A photovoltaic array is the complete power-generating unit, consisting of any number of PV modules and panels. The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module (cell) operating temperature of 250 C (770F), and incident solar irradiance level of 1000 W/m2 and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field, actual performance is usually 85 to 90 percent of the STC rating. Today's photovoltaic modules are extremely safe and reliable products, with minimal failure rates and projected service lifetimes of 20 to 30 years. Most major manufacturers offer warranties of twenty or more years for maintaining a high percentage of initial rated power output.

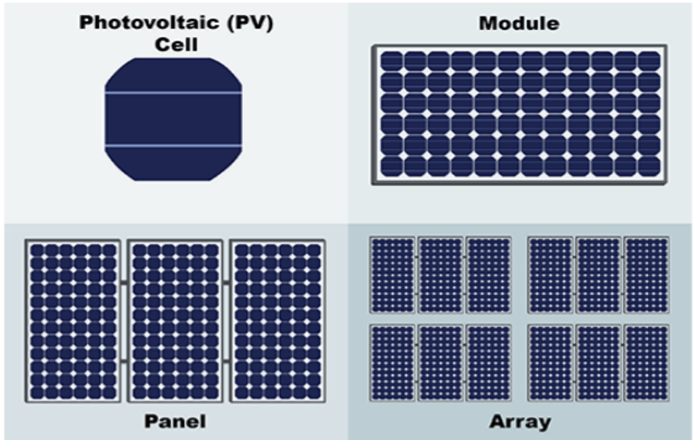

Fig 2.5: Diagram of Solar cell, Module, panel and array. [24]

Grid connected (Utility-interactive) PV systems:

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back onto the utility grid when the grid is down for service or repair.

Generations of Solar cells:

There are three generation of solar cell such as first generation, second generation and third generation solar cells. Each generation details are given below.

First generation:

Most of the times silicon are used for making traditional solar cell, this are currently the most efficient and available for residential use and around 80% solar panel sold around the world are silicon solar cell. Monocrystalline silicon cells are the oldest solar cell technology and efficient solar cell made from the thin wafer of silicon. The efficiency of monocrystalline solar cell is about (up to 24.2%) which is higher than the other first-generation silicon solar cell comparatively. Polycrystalline silicon solar cell is cheaper and make from silicon wafer in molds from multiple silicon crystal. The efficiency of polycrystalline silicon solar cell is slightly less efficient (up to 19.3%). In Amorphous silicon solar cells, silicon is decorated in a very thin layer on to a backing substrate such as glass, metal or even plastic. Sometimes several layers of silicon doped in slightly different ways. The efficiency per unit area up to 10% which is comparatively very low than the other solar cells of first generation.

Second generation Solar cell:

Second generation solar cells are called thin-film solar cells because they are made from layers of semiconductor materials which is a few micrometers of thickness. In this technology the materials are less and reducing the cost of manufacturing process. There are three major types of solar cells. Amporphous silicon made primarily of cadmium telluride and copper indium diselenide (CIGS) materials made from non-sylicone. The solar panels mentioned above reflect some 16.8 percent of the panels sold in 2009.

Venture capitally invested over $2.3 billion into companies for developing these cells and able to reach the efficiency level of 20% in the laboratory. In 2007 First solar produced 200 MW of CdTe solar cells making it the fifth largest producer of solar cells in 2007 and the first ever to reach the top 10 from production of second-generation technologies alone. Worth solar commercialized its CIGS technology 2007 producing 15 MW. Nano-solar commercialized its CIGS technology in 2007 with a production capacity of 430 MW for 2008 in the USA and Germany. Honda also began to commercialize their CIGS base solar panel in 2008.In 2007; CdTe production represented 4.7% of total market share, thin-film silicon 5.2% and CIGS 0.5 %.

Third generation solar cell:

Third generation photo voltaic cells are potentially able to overcome the Shockley-Queisser limit of 31% to 41% power efficiency for single band gap solar cells. Common third generation technology include multilayer ("tanden") cells made of amorphous silicon and Gallium Arsenide (GAs) frequency conversion is another procedure applied which is changing the frequencies of light that the cell can't use to light frequencies that the cell can use for the production of more power. Hot-carrier effects and other multiple carrier ejection technique are followed for the increasing of power efficiency.

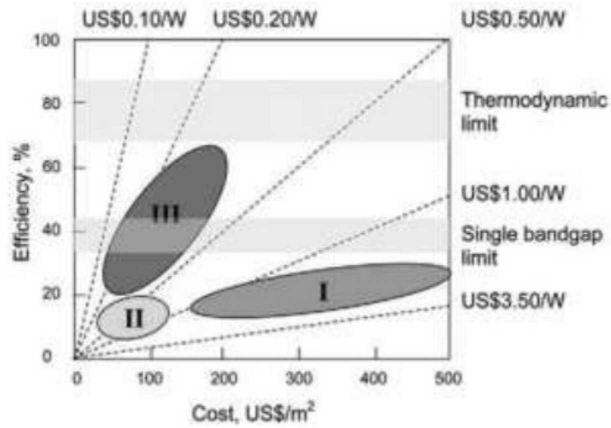

Fig. 2.6. Price Vs Efficiency among the different generation's solar cells. [25]

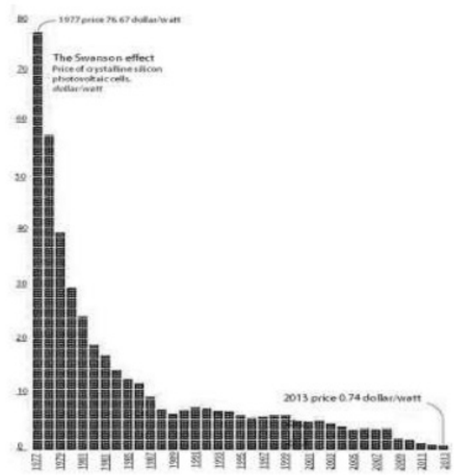

Fig. 2.7: Price variation of solar power generation from the year of 1970s to 2013. [25]

Chapter 3

Hybrid power generation system

Hybrid Power Generation System:

Hybrid power are the combinations between different technologies for producing power. Hybrid models have been used significantly for producing and generating electricity simultaneously throughout the world. Especially for solar and wind hybrid system with backup storage batteries were designed mobilized optimized to forecast the nature of generating system. In this project Solar photovoltaic and bladeless wind turbine (BLWT) are used combinedly as a small range alternative source of conventional energy.

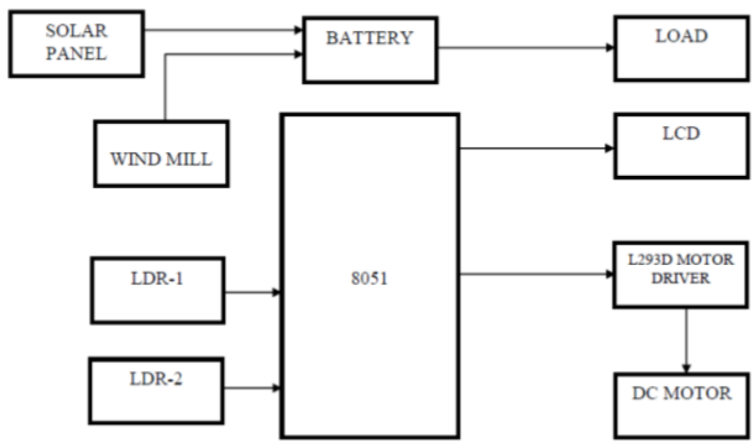

Fig. 3.1: Combined Hybrid Generation System [26].

Combined Sequence of Operations:

When sunlight fall upon to the LDR, it identified the directional sunlight and sends a signal to the tracking control unit (T.C.U). The IC in the T.C.U receives and processes the signal. It uses a C programming code to process the signal and transferred to the driving unit. This unit then processes the signal in order to from a command. This command is called driving command and delivered this command to the DC motor. It acts upon this command, rotates accordingly to align the solar panel attached to it. The rotational DC motor continuous to rotates until it gain the maximum irradiation position. The solar panel is generated current and stored in the batteries.

Load Circuit:

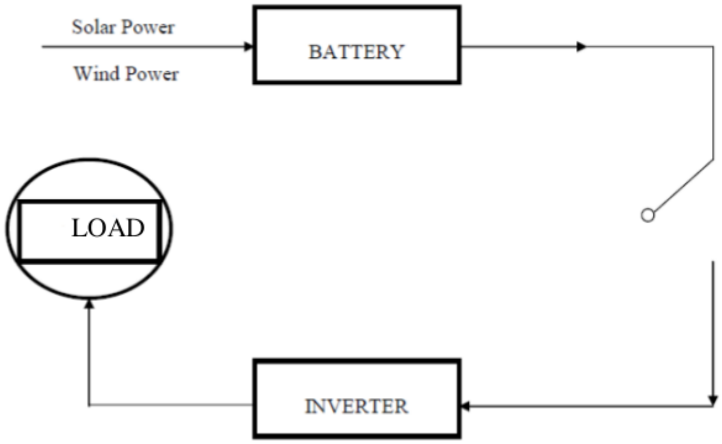

Fig. 3.2: Load arrangement for hybrid system [27]

The combination of solar power and wind power received from the solar panel and BLWT which are combinedly stored in the 12V battery. A power inverter or inverter is an electronic device that changes the direct current to the alternating current. It is consisting of MOSFET and stepper transformer for increasing the stored voltage. In figure 3.2, when the switch is on then the circuit is closed and conduct and convert DC to AC which results the load in operational mode.

Chapter 4

LITERATURE REVEW

Introduction:

Electricity is the impetus of modern civilization. For producing electricity, most of the windmill firms are used non-conventional energy sources for reducing the pollution of the environment. Such as, wind, sun, water, tides, biological wastes etc. On the contrary conventional energy sources are not only limited but also expensive and harm to the environment. It also causes a great harm to the environment. The only solution is that to use renewable sources of energy for the purpose of producing electricity.

There are a lot of non-conventional energy converter device. Wind turbine is one of them but in our review work we designed a bladeless wind turbine which provides the electrical energy without rotation of blade. Actually, we find the energy from the oscillation of mast in lieu of using blade. Which makes this prototype more efficient and more simplicity and less cost. It also provides the safety of any environmental elements such as birds. But for a wind turbine with blade rotates sometimes birds are killed by the rotational moving blade. Our project work focuses to make a prototype which is eco-friendly and simple to generate electricity without less losses and it will be installed at sea coasts because in that era the velocity of wind is high.

Background

The first known reference to a windmill was given by Hero of Alexandria, In his Pneumatics (Woodcroft,1851). His pneumatics narrates if air is given to a limb by means of a windmill the energy is achieved Which is shown in fig-1. In 1932, H.P Vowels appreciated Heros assumption to be reliable.

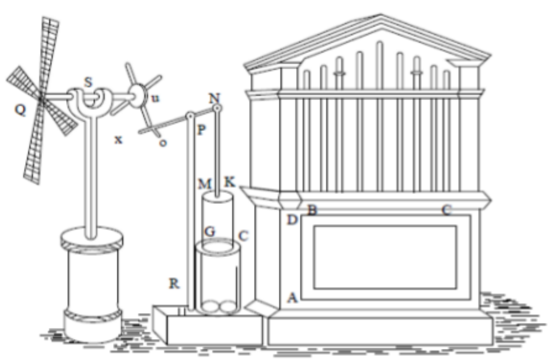

Fig 4.1.: Heros windmill (from Woodcroft, 1851) [28]

Except Heros windmill the reference reported by Vowels in 1932, from 9^{th} century A.D. (Al Masudi reported by Vowels) windmills were used in the Persian area of Seistan (Eastern Iran now) which is shown in fig 2.

Fig 4.2: Seistan windmill (Vowles, 1932) [29]

The Seistan rotors placed in vertical axis and directed by drag force that makes it null and void. Contrariwise, in 12th century Northern Europe (present England) the windmill mechanism was totally different from Seistan windmill mechanism because it used lift force for the rotation in lieu of draft force. [30]
In 18th century European windmills advanced the mechanism and increasing the efficiency of their windmill in which the mechanical power from wind converted into electrical power by crossing some steps or features of windmill system.

After rapid modification of previous wind machine in (1850-1970) at least 6 million wind machines installed in the US. The purpose of this machine was water pumping. Rotors up to the 18 meter in diameter used to pump water for the steam railroad provided the main source of transportation. [31]

In 1888 a large windmill was built by Charles F. Brush in Cleveland, Ohio. In this mill where used for the first time a step-up gear box (with ratio 50:1) which is connected to generator. By using 17meter rotor plates produced 12 kW which is comparatively large power provider machine with respect to previous windmill.

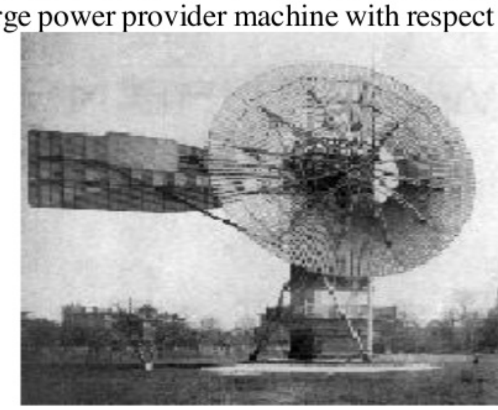

Fig 4.3: The Brush postmill in Cleveland, Ohio, 1888. The first use of a large windmill to generate electricity. Note the man mowing the lawn at lower right.[31]

The bulk power producing wind energy conversion system was first built in Russia in 1931. Which was placed on the shore of the Caspian-sea producing 200,000kWh of electricity.
In 1941, 1.25 MW smith Putnam machine installed in Vermont.
Up to 1960 in Denmark, 200kW Gedser mill wind turbine ran successfully.

The Tacoma Narrow Bridge was built in 1940. But it collapsed after four months because of aerodynamic resonance in 7th November 1940. [32] Resonance produces because of oscillation due to wind flow which match to the natural frequency of the structure resulting the failure of Tacoma Narrow Bridge. David Suriol, David J. Yanez, Raul Martin, they were inspired by seeing the phenomena of Tacoma Narrow Bridge collapsing and they wanted to design a bladeless wind power turbine by using Vortex Induced Vibration (VIV) phenomena. The vibration induced in a body by rolling is called Vortex Induced Vibration or VIV phenomenon. [33]. The team started to design a Vortex bladeless wind turbine in 2010. As a way to turn this vibrating energy into electrical power.

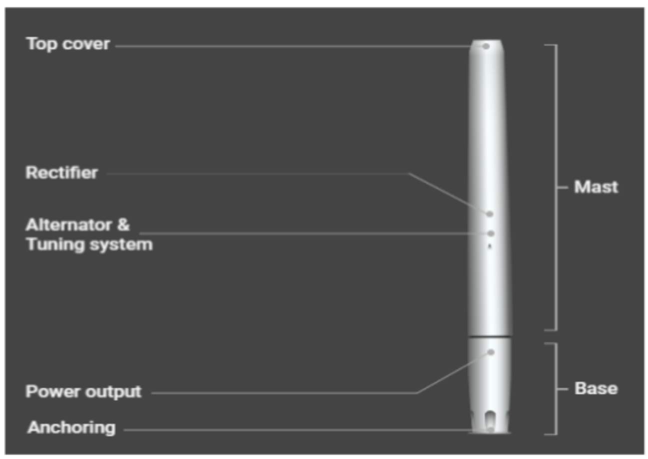

Fig 4.4: Vortex Tacoma [34]

Comparison with previous work:

The efficiency of bladeless wind turbine is dependent on Reynold's number free-fluid velocity, cylinder of diameter, kinematic viscosity of fluid and non-dimensional parameter Strouhal number.

In previous work, Russian researchers developed their bladeless wind turbine and now they are prone to commercialization. The main mechanism of their project is to use displacement of mast which rotates a circular set of magnets unidirectionally. Magnets are fitted with rotor shaft circularly. The stator winding is stationary, because of rotation of rotor i.e. the magnets are moving and the moving flux cut to the stator which produces electricity.

In our project work, we used “Crankshaft and Pulley mechanism” for producing electricity. For the complete explanation, the displacement of mast which rotates a drive pulley and the driven pulley is connected with the armature shaft of Permanent Magnet Direct Current (PMDC) generator. Because of unidirectional movement of pulley which drives the armature of PMDC generator and produces the electric power.

In previous they used a set of magnets and complex design of alternator which makes the turbine bulkier, the cost of making a particular turbine is very high. Which is not suitable for developing countries like Bangladesh.
But our project is designed for developing countries where there is no power station in a specific era, we can install it because of low cost and simple mechanism. For the comparison making of same rating of turbine, our project can produce same power with low initial cost. The main advantage of our project is that less weight of Mast. Since we used the generator outside of the Mast which makes the Mast lighter and our project efficient.

Theory/ Methodology:

The ratio of the dynamic viscosity to its density of a fluid is called kinematic viscosity.

$$V = \eta / \rho$$

where, η and ρ are the dynamic viscosity and density of a fluid respectively. V denotes the kinematic viscosity of fluid.

In general, Reynolds number associates the vortex shedding of a bluff body. For a maximum Reynolds number, the vorticity increases rapidly and also the oscillation of a bluff body which is emerged into fluid, which is called Von Karman Vortex effects. [35]

$$Re = (U D)/V$$

Where, U is the free drift velocity, D is the cylinder diameter of a mast V is the kinematic viscosity.
The range of the Reynolds number is $300<Re<3*10^5$ [36]

The Strouhal number 'Sn' is a dimensionless parameter that explains the product of vortex shedding frequency and diameter of mast to the free drift velocity of a fluid. It also relates with the Reynolds number. [37]

$$Sn = (f_s D)/U$$

The Strouhal number of a stationary tube or circular cylinder is a function of Reynolds number but less of surface roughness and freestream turbulence

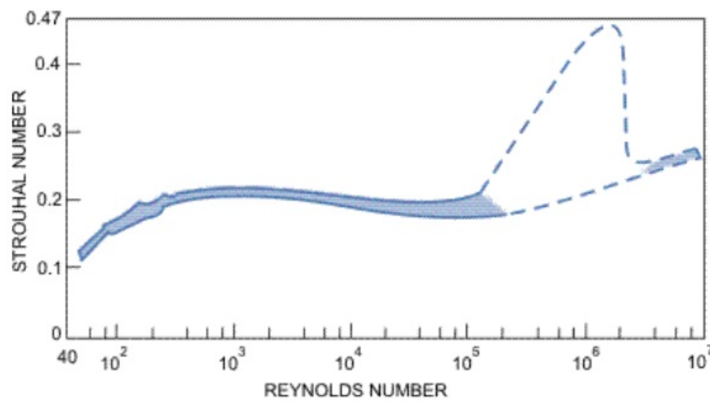

Fig 4.5: Strouhal number versus Reynolds number for circular cylinders (tubes). [37]

Lock in phenomenon denotes that when the vortex shedding frequency is approximately close to the natural frequency of bluff body or mast, the linear resonance occurs.

The vortex shedding frequency is related to the Strouhal number. It is a dimensionless ratio that relates the product of Strouhal number and Kinematic viscosity to the pipe diameter where displacement is negligible.

$$f = Sn*U/ D_o$$

where, f is the vortex shedding frequency, U is the free drift velocity and D_o is the pipe diameter where there is no oscillation.

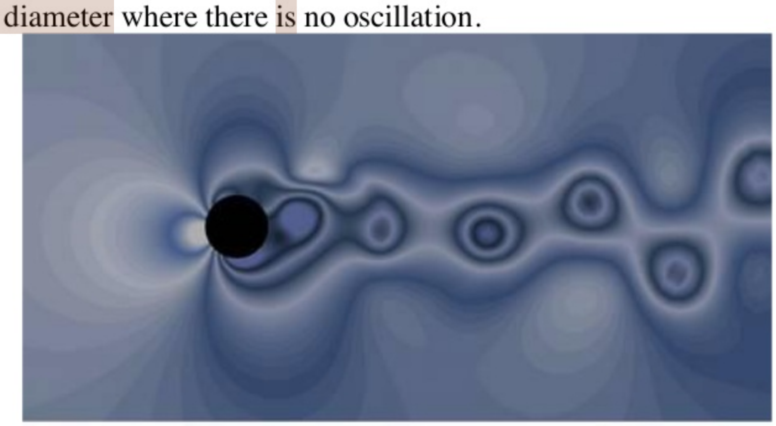

Fig 4.6: Vortex formation behind a circular cylinder. [38]

The oscillation of mast increases if the placement of project higher from the ground, because of increasing the velocity of the fluid. A vertical slender and circular cross-sectional structure are eligible to produce the oscillation of this body.[39]

Betz law states that the maximum power can be unsheathed from the wind and converts the power about 16/27 (59.3%) of kinetic energy in wind. The factor 16/27 (0.597) is known as Betz co-efficient. [18]

Mast is the inflexible and moving parts of this project. For achieving a synchronous oscillation of moving parts, circumference and diameter of body or Mast need to be changed with reference to height.

In moving parts where the oscillation is negligible obtain with

$$D = D_0 + a \cdot X \quad \ldots\ldots\ldots\ldots (5)$$

Where 'D' is sum of diameter of the Mast, 'X' is amplitude oscillation 'a' is the adjustment factor. Which is related to Reynolds number.

Let, a flexible carbon fiber rod length of 'L' which is attached with Mast lower part. At lower part of Mast i.e. at the height of y=L/2 where displacement of mast X=0. So, from equation (5) the diameter of the mast D= D_0 (L/2) =d. and the vortex shedding frequency 'f' with wind velocity $U\infty(L/2)$ is

$$f = \frac{Sn.U\infty(L/2)}{d} \quad \ldots\ldots\ldots\ldots \text{(S.N: U is the wind velocity)}$$

in different position, the displacement of Mast is different so for different length the frequency can be obtained.

$$f(y) = \frac{Sn.U\infty(y)}{D_0(y) + a.X(y)}$$

Where $U\infty(y)$ and X(y) are the free wind velocity and oscillation amplitude of mast at any height of y respectively.

H is the distance between ground of the flexible rod to the upper point of the mast. If the displacement of the upper part of the mast is γ times the mast diameter at its lowest part, as a result:

$$X(y) = \frac{y - \frac{L}{2}}{H - \frac{L}{2}} . \gamma . d$$

As the vortex shedding frequency is the same throughout the length of the mast, we finally obtain:

$$D(y) = d . \frac{U\infty(y)}{U\infty(L/2)} - a.X(y)$$

The right velocity gradient calculation can help to deduce the same frequency of vortex dissipating in the entire mast, including the discontinuity effect in the highest mast portion.

This frequency must coincide with the usual pattern of oscillation in the entire system to obtain the necessary resonance. Where U infinite L/2.

Chapter 5

METHODOLOGY

5.1 Introduction:

The objectives of this prototype are to build a reliable, cost effective and eco-friendly power system that can produce power both utilizing wind and solar energy. The power system consists of a Bladeless Wind Turbine (BLWT), a solar panel, a charge controller, a battery and inverter. The output power of BLWT and solar panel are used to charge the battery via a controller. Since maximum load are designed for working the AC power supply in Asian region. So, an inverter set to convert DC power into AC power of suitable voltage for using domestic load. A large battery bank is used for the storage of electricity so that it can lead the continuous supply to the electric load.

5.2 Designing component description

5.2.1 Specifications of Turbine

Height of the Mast: 1230mm or 1.23m

Diameter of the Mast: 160 mm or 0.16m

Mass of the Mast: 2800gm

Diameter of Spring: 87mm or 0.087m

Diameter of spring rod: 9mm or 0.009m

Height of the spring: 160mm or o.16m

Height of the Connecting rod (attached to spring): 558mm or 0.558m

Crank shaft 1: 220mm or 0.22m

Crank shaft 2: 305mm or 0.305m

Crank shaft 3: 220mm or 0.22m

Pulley 1: diameter 102mm or 0.102m, thickness 5mm

Pulley 2: diameter 176mm or 0.176m, thickness- 8mm

Pulley 3: diameter- 30mm or 0.03m, thickness- 8mm

Belt- length 762mm or 0.762m, diameter- 6mm

Bearing – inner diameter -10mm, outer diameter- 26mm, thickness- 8mm,

Screw 1 diameter - 8mm (with pulley and crank shaft)

Screw 2 diameter - 5mm (with Mast)

Total height of the turbine- 1650mm or 1.65m

Total weight of the Turbine- 15kg

Base- height: 254mm or 0.254m, Area: (0.3175*0.3556) m = 0.112903m sq.

Fig 5.1: Proposed Model of BLWT

5.2.2 Calculation of Pulley:

Velocity ratio calculation:

Velocity ratio = diameter of the driven pulley / diameter of the driver pulley

= 176/30

=5.87

=6 (approximate)

Driver pulley: driven pulley = 1:6

5.2.3 Generator design:

The generator shaft is connected with pulley by a belt for the rotation of armature of PMDC generator. In this prototype we used a 24v, 300rpm, 200watt PMDC generator.

Fig. 5.2: Generator.

5.2.4 Bearing design:

Bearing is used for the sleek operation of pulley which is connect to the roller. It provides frictionless movement of the pulley as well as the generator shaft.

Fig. 5.3: Bearings

5.2.5 Roller design:

Roller is basically made by cast iron which is hollowed in the inner side of this cylinder. A connecting rod is traversed and two ends of the connecting rod is fitted with bearing. Bearing is connected with the two ends of the roller. Connecting rod connects the pulley for receiving the rotational force. In roller mechanism cast iron is stationary but connecting rod can rotate by the rotational force.

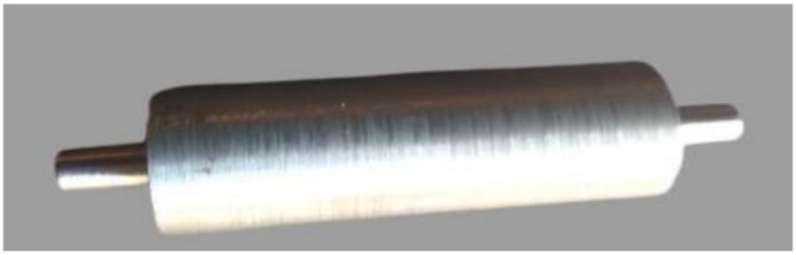

Fig. 5.4: Roller

5.2.6 Connecting rod:

A cast iron used as a connecting rod which is connected with a bearing in bottom side of the base and spring with circular plate with screw simultaneously. It is supporting the spring at the time of vibration of the mast. Bearing of connecting rod assist the free movement or frictionless movement of the vertical rod.

Fig. 5.5: Connecting rod

5.2.7 Spring:

An elastic material that retains mechanical energy is used as an 87 mm diameter of the spring. An Extension or compression springs rate is expressed in units of force divided by distance. It is commonly made from spring steel and larger one is made from annealed steel.

Fig. 5.6: Spring

5.2.8 Crankshaft:

A crankshaft is a rotating shaft which is connected with the main rod or connecting rod at 45-degree angle and it converts the reciprocating motion of the mast into rotational motion.

Fig. 5.7: Crankshaft

5.2.9 Pulley:

Pulley is the wheel that guides and smoothest the rotation of an axle or shaft. By using the main driver pulley, the torque of the roller with regard to the pulley may be increased.

Fig. 5.8: Pulley

5.2.10 Belt:

A belt is a circle of flexible materials used to mechanically connect two spinning pulleys that rotate the pulley and transfer rotational energy through the mechanical shaft.

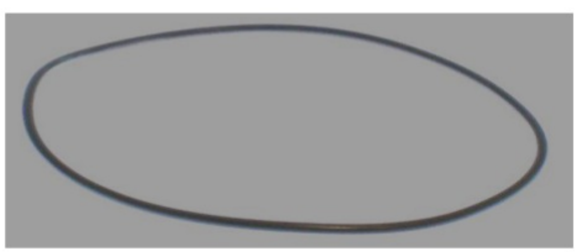

Fig. 5.9: Belt

5.2.11 Mast:

A mast is a rigid body that is made by lighter-weight, the strongest attribute of materials such as Aluminum, Magnesium, Titanium and Beryllium alloys, Carbon fibre sheet, PVC etc. Mast utilizes the mechanical energy of wind which produces vibration or VIV resonance. The reciprocating of the displacement of the mast converts into electrical energy by the use of crankshaft.

Fig. 5.10: Mast

5.2.12 Design of base:

A strong base is made by iron rod so that it assists and support the turbine and withstand the large force of wind at the time of natural disaster. It also provides the stability to the turbine When it vibrates.

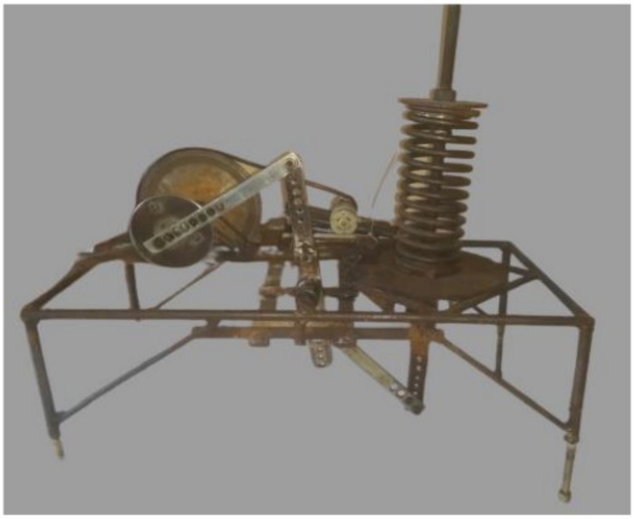

Fig. 5.11: Base of BLWT

5.2.13 Inverter:

An inverter is a power electronic device or circuitry that converts Direct Current to Alternating Current. This is done by switching transistors such as IGBT's and there are several switching modes such as square wave switching and pulse width modulation switching. The input voltage is setup with required and specific design.

Specifications:

Input = 12VDC

Output = 220 V

Fig. 5.12: Inverter

5.2.14 Battery:

The output voltage of BLWT is transferred to the battery through a charge controller circuit for storing the electrical energy. We used restorable 12Volt lead acid type battery for the storage. It will charge or store the energy and continuously supply to the load using of inverter where needed.

Fig. 5.13: Battery

5.2.15 Charge controller:

The rate at which electric current is applied to or extracted by electric batteries is restricted by a charge controller, charge controller and battery regulator. This avoids overloading and can guard against overvoltage, reducing battery power or battery life and posing a safety risk. It can either keep a battery from being fully depleted, or can conduct controlled battery-driven discharges to protect battery life based on battery technology. The words "charging governor" or "charge regulator" could be used either for a separate equipment, a battery-powered or battery-powered control circuit.

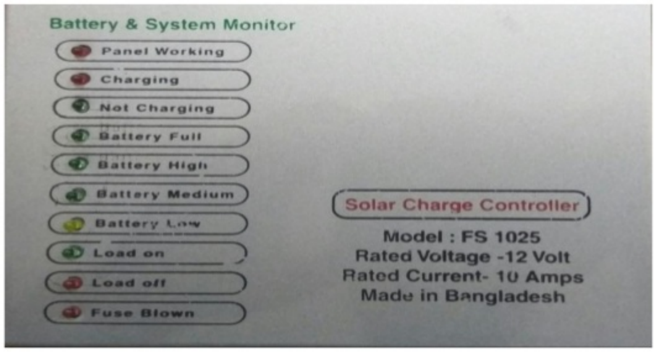

Fig. 5.14: Charge Controller

5.3 Block diagram:

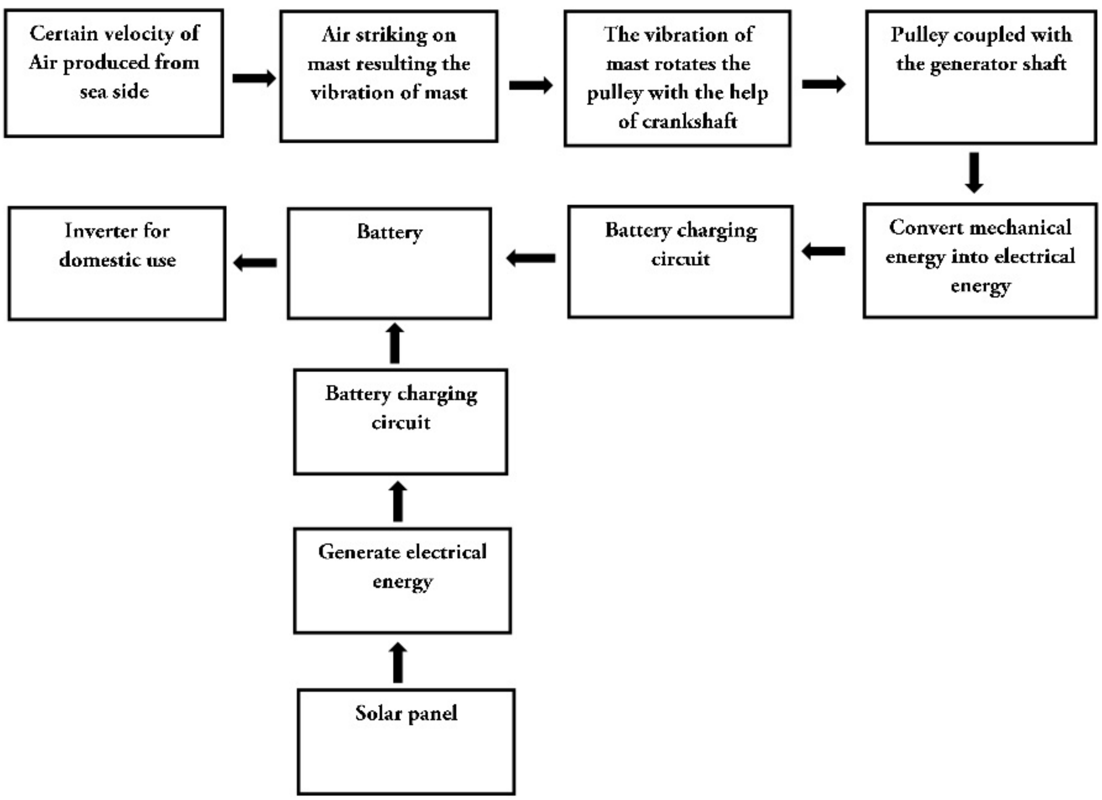

Fig: Block diagram of BLWT and solar hybrid system

The main purpose of this prototype utilizes the wind energy from the sea side. Initially air is available in sea side with a variable velocity due to the speed of wind strikes on the mast of the turbine, the vorticity induced in mast. For VIV resonance phenomena mast begins to vibrate. By using crankshaft, the displacement of the mast used for the rotation of pulley. The pulley converts and transfer the mechanical energy from the mast into the electrical energy to the generator shaft. A solar system is also converting the light energy into electrical energy. The output from both wind turbine and solar cell are transferred to the battery so the via charge controller circuit. The charge controller is used to prevent the battery from being over charged. The battery is connected to an inverter so that it converts from DC to AC for the domestic purpose.

5.4 Fabrication

5.4.1 Metal Cutting

Cutting operates by allowing the substance being extracted to become fractured. Normally the broken part is considered chips in small bits. Technology, formation (or planning), broaching, potting, spinning, turning and spinning are traditional cutting processes. Although the equipment, tools and cutting methods are somewhat different from each other, it is possible to consider the basic mechanism for fracture caused by a specific orthogonal model.

The work piece is a design which can cover the final element form fully in all machining processes. The goal is to eliminate the excess material to accomplish the end component. This trimming typically has to be performed in several stages – the part is kept in a holder at each point and the exposed component can be reached by the machine's tool in that component. Popular fittings include vise, clamps, 3 yellow or 4 yellow jackets, etc. Each position in which the portion is kept is called an arrangement. Each setup can perform one or more cutting activities using one or more cutting tools. To shift from one configuration to another, the machine part must be extracted from the prior fixture, the machine fixture adjusted, the component fixed in a different position on the different fixture, the machine tool co-ordinates set for the new part position and, eventually, machine operations began for this configuration. Setup adjustments are both time-consuming and costly. We should therefore aim to make a minimum number of settings for the whole cutting process; the job of sequencing the individual.

5.4.2 Welding

Welding is a method in which two or more pieces are permanently connected together through an appropriate application of heat and/or pressure on their touching surfaces. A filler material is also applied to make coalesce smoother. The integrated pieces which are welded together are called a weld. The welding of the metal components and their alloys is used in particular. The welding method is split into two primary classes.

5.4.2.1 Solid-state welding

This method is done by using pressure alone or a mixture of heat and pressure. The pieces are joined together. There is no need of filler wire. The major processes of solid-state soldering are: diffusion soldering, frozen soldering, and ultrasound welding.

5.4.2.12 Fusion welding

Basic metal is melted by heat in this process. The filler metal is also applied to the molten pool in fusion welding to accelerate the operation and provide the joints with bulk and strength. Commonly used techniques for fusion welding include: arc welding, power welding, oxyfuel welding, electron beam welding and laser beam welding.

5.4.2.3 Arc welding and similar processes

Arc welding is a means to attach two or more metal fragments permanently. The coalescence is created by combining the various soldering processes with the electrical arc (mostly without pressure) and by filler metals depending on the thickness of the base platform, or without them. The melting and fusion of the corresponding components of the different sections contributes to a homogeneous joint. The unit strength is almost the same as the base steel of the final welded joint. The temperature of the arc is about 4400 ° C. An oxidation flux fluid that sinks under the welding thermal device and releases a gas that covers the arc and the hot metal. The second fundamental approach uses inert or almost inert gas to shape a protective envelope around the arc and solder. The most widely used gasses are oxygen, argon and carbon dioxide.

5.4.2.4 Shielded-Metal Arc (SMAW) or Stick Welding

This is a coalescence arc welding procedure by heating the working part with an electric arc installation between a flow-coated electrode and the working part. The electrode is rod-shaped and flux-coated. The mechanism as seen in Figure 5.11.

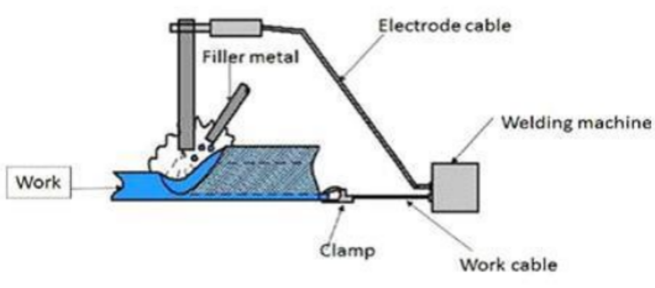

Fig. 5.11: Shielded-Metal Arc (SMAW) [40]

CHAPTER -6

IMPLEMENTATION AND RESULT

Introduction:

The fundamental principle of Bladeless wind turbine (BLWT) is to convert the kinetic energy of wind into mechanical energy. This mechanical energy is used for the unidirectional rotation of the pulley as well as the rotation of mechanical shaft of generator to produce electricity.

The kinetic energy of wind is given by-

K.E = ½ m v^2 ………………………………………………………………….(1)

m = mass

v= velocity

m is equal to volume multiplied by its density ρ of air,

Mass (m)= ρ AV ……………………………………………………………………….(2)

Combining equation (1) into equation (2) gives

P= ½ ρ AV^3

Where

P= wind power (w)

P=density of air. In our location wind density (1.225 kg/m^3)

v = wind speed (m/s)

A=swept area (m^2)

= triangle area + half area of circle

= (½ *a*h) + (½ $* \pi * r^2$)

= (½ *0.381*1.2192) m^2 + (½ *3.1416*0.1905) m^2

= 0.23 m2 + 0.299 m^2

= 0.529 m^2

Where, a = base of the triangle, h = height of the triangle, r = radius of circle.

[Input here Mechanical equation from other paper]

Theoretical power calculation:

Observation 1

For velocity = 4.1 m/s

Wind power P =½ ρ A v^3

= ½ * 1.225 * 0.529 * $(4.1)^3$

= 22.33 watt

Observation 2

For velocity = 4.6 m/s

Wind power P =½ ρ A v^3

= ½ * 1.225 * 0.529 * $(4.6)^3$

= 31.53 watt

Observation 3

For velocity = 4.9 m/s

Wind power P =½ ρ A v^3

= ½ * 1.225 * 0.529 * $(4.9)^3$

= 38.11 watt

Observation 4

For velocity = 5.3 m/s

Wind power P =½ ρ A v^3

= ½ * 1.225 * 0.529 * $(5.3)^3$

= 48.23 watt

Observation 5

For velocity = 5.7 m/s

Wind power P =½ ρ A v^3

= ½ * 1.225 * 0.529 * $(5.7)^3$

= 60.0 watt

Observation 6

For velocity = 5.9 m/s

Wind power P =½ ρ A v^3

$= ½ * 1.225 * 0.529 * (5.9)^3$

$= 66.54$ watt

Observation 7

For velocity = 6.2 m/s

Wind power $P = ½ \rho A v^3$

$= ½ * 1.225 * 0.529 * (6.2)^3$

$= 77.22$ watt

Observation 8

For velocity = 6.5 m/s

Wind power $P = ½ \rho A v^3$

$= ½ * 1.225 * 0.529 * (6.5)^3$

$= 88.98$ watt

Average wind speed, $\mathbf{V_{avg}}$= 5.40

Average wind power, $\mathbf{P_{avg}} = ½ \rho A v^3$

$= 51.02$ watt

Theoretical Data:

Table 6.1: Wind Velocity vs. power output (Theoretical)

S/No	Wind velocity (m/s)	Output power (watt)
1	4.1	22.33
2	4.6	31.53
3	4.9	38.11
4	5.3	48.23
5	5.7	60.00
6	5.9	66.54
7	6.2	77.22
8	6.5	88.98

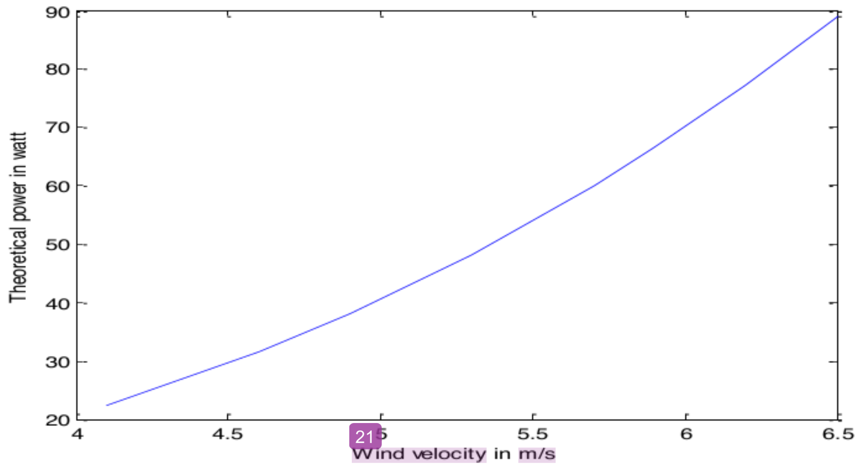

Fig. 6.1: Wind velocity vs. Theoretical power output curve.

Experimental Data:

Table 6.2: Wind Velocity vs. power output (Experimental)

S/N	Wind Speed (m/s)	Shaft Speed (rpm)	Voltage (V)	Current (A)	Power (W)
1	4.1	32	2.93	2.38	6.97
2	4.6	59	4.72	3.06	14.44
3	4.9	77	5.17	3.95	20.42
4	5.3	92	6.26	4.19	26.23
5	5.7	124	7.20	4.97	35.78
6	5.9	139	7.42	5.63	41.77
7	6.2	146	7.75	6.15	47.66
8	6.5	154	7.98	6.65	53.07

Average Power = 30.60 watt

Comparison between the theoretical and experimental power:

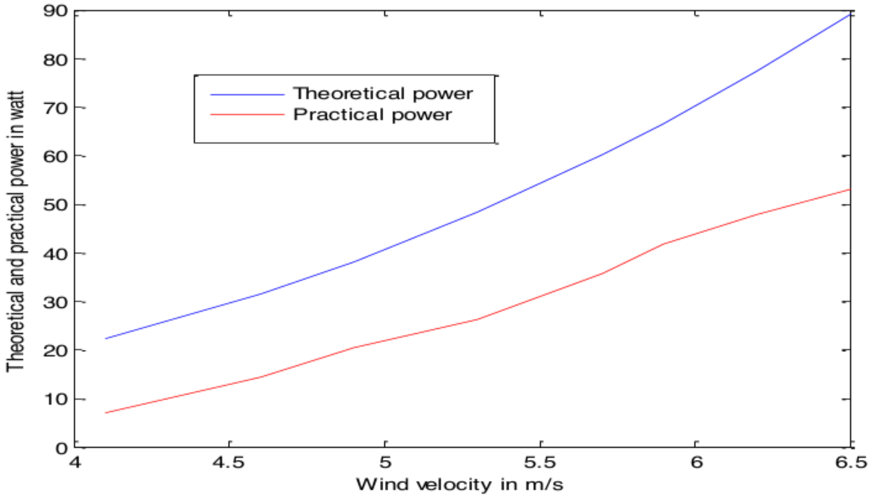

Fig. 6.2: Theoretical vs Experimental power curve.

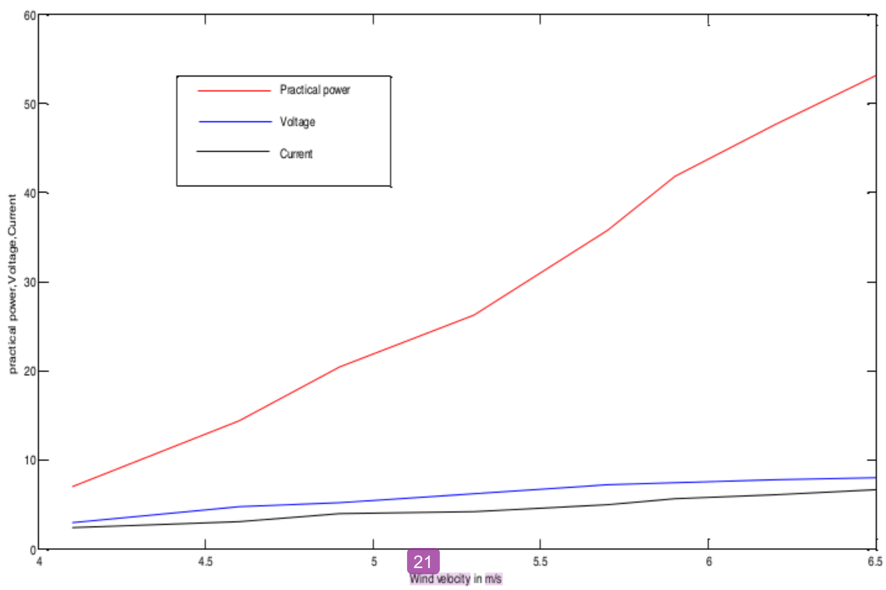

Fig. 6.3: Wind speed vs practical power, voltage, current curve.

Output data constantly varies between theoretical and practical power. The key source of the energy loss is pulley friction, turbine friction and the loss of power generator. Wind speed is the primary explanation for the difference in wind turbine power output, which varies constantly.

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