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Research Article

Estimated Design and performance evaluation of standalone wind machine for Rural Area

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Abstract

The depletion of conventional sources of energy like fossil fuel has compelled man for search for the alternative sources of energy. Owing to acute energy crisis that most developing countries including India are facing today, the interest in alternative energy sources has increased manifolds in recent past. And the potential of wind energy as a source of alternative energy perhaps cannot be underestimated. Growth in wind power is tremendous, with capacity more than doubling every three years. In this seminar I am focusing on selection of wind turbine according to our requirement and which factors are considered while selecting wind turbine. By using appropriate wind turbine we can provide a good alternative source of energy thus providing a solution to the acute energy crisis.

Keywords: *Wing, turbines etc.*

1. Introduction

This project envisions the design and appropriate implementation of a 0.50 kW electricity producing wind turbine. The turbine will ideally be designed for implementation in remote communities to power individual house's electrical needs or to be fed directly into a local energy grid. The aim of the project is to design a wind energy converter comprising of a rotor system, a gearbox and a generator that will successfully produce the specified electrical power. As wind turbines are not new technology the project will be aimed at proving and optimizing a system based on existing technology to achieve the desired power output. Considerations are taken in designing the turbine with an effective post life recycling scheme in mind so that there will be minimum wastage of resources once the turbine is made redundant. Ultimately the aim of this project is to make use of a natural resource to supply mankind's energy requirements in a sustainable manner. If a wind turbine can be designed and constructed so that it can produce more power over its life time than it takes to be produced and maintained over its useful life, then it is a sustainable answer to our global energy requirements. It is obvious now that we are facing an oncoming global energy shortage. Fossil fuel prices are rising in conjunction with the decrease in their stockpiles and it is vital that alternative methods of energy production be investigated and introduced on a global scale to maintain our standard of life. Wind energy has the potential to meet our requirements and several nations have already begun effectively producing and harvesting this form of green energy.

2. Objective

As previously mentioned, the electricity producing wind turbine is an already existing technology and this project is focused on redesigning and adapting mechanical and electrical engineering principles to achieve the specified energy output. Realistically the simplest method to achieve the goal in this project would be to scale down an existing turbine until its power output fell into the category of 0.5 kW. However it is vital that a good understanding of the concepts and principles behind wind turbine design is developed, so that existing methods of wind energy production can be improved and made more efficient. There are a wide variety of wind energy converters already available on the market and many of these will be investigated throughout the course of the report. The research objectives aim to be specific, measurable and achievable. The key technical research objectives of this project are:

- To develop a comprehensive understanding of the physical principles of harnessing wind energy. This will include an understanding of both the wind as a resource, and the mechanical and electrical components required to convert the wind energy to a usable form.
- To apply this knowledge and produce a conceptual design of a Small Wind Turbine with a power output of at least 0.5 kW.

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- To apply engineering knowledge and skill to develop the conceptual ideas into a reliable, functional and efficient design, with appropriate consideration for manufacture, transport, installation, maintenance, operation and decommissioning.
- To critically analyze the design and where possible, use sound engineering judgments to make improvements.
- To calculate specifications and outputs of the design.
- To perform a Cost Benefit Analysis that will provide a measure of how competitive the design will be in comparison to other forms of energy. In conjunction with the specifications of the design, this will also facilitate direct comparison with similar products.

The main objective of the design project is to develop a mechanical system that is capable of providing driving force to a generator using only the energy contained in wind. The generator in the system is the mechanical-electrical converter in the wind turbine and the gearbox and rotor blades need to be designed to supply the generator with an input that will yield the desired output power. This being said, a suitable generator first needs to be selected and tested to determine the input speed required to produce 0.5 kW before any other design goes ahead. Once this has been determined a rotor system and gearbox can be designed to produce the required revolution speed and torque to supply mechanical power to the generator. In selecting a generator consideration needs to be made as to what type of current is being produced and where it will flow to, if it will be stored or if it will be directly applied in an electrical device.

3. Conceptual design

Design and build a 500 W, Wind turbine that is capable of producing the power in the real world situations. The design of the turbine will includes exploration of various new techniques of power control as well as construction of the both model and full scale turbine. The full scale turbine is design such way that, it can be connected to generator and facility to connect it with, external examination unit and data collection unit to measures the power output, torque and speed of the turbine. The design is also include the facility of power optimization by pitching and yawing.

A SWT is a device that enables the extraction of the power in a moving mass of air, and converts this power to a usable form, namely, electricity. The objective of this chapter is to formulate a conceptual design for a SWT, and then by using typical engineering methods create a refined and viable final design. To achieve this objective a conceptual design will initially be devised, with a general operational description and a list of the required components. The fundamental principles that govern the operation of a HWT will be investigated to develop further understanding of the system requirements.

These principles will assist in identifying the requirements of the design. Once the design requirements have been ascertained, the major part of the SWT design can commence. This firstly requires an investigation of the wind as a resource, and selection of a target location for the designed device. The second step is the development of the turbine design itself. A breakdown of the components will identify those that are to be designed, and those that are to be obtained through commercial sources. Each of the major components in the wind energy conversion system will be designed or specified according to normal engineering methods. This chapter will conclude with an overview of the final design and its expected outputs and specifications.

- **2D and 3 D Conceptual Model**
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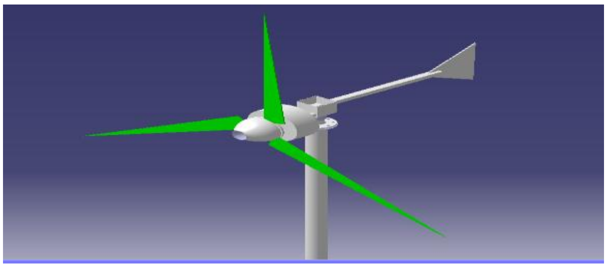

Fig.1.1 Blade Arrangement for Straight Blade Vertical Axis Wind Turbine

Component Tree Diagram

The vertical axis wind turbine is having No. of assemblies and sub assemblies. To understand the location in system, here we have to give the tree diagram showing total component of turbine.

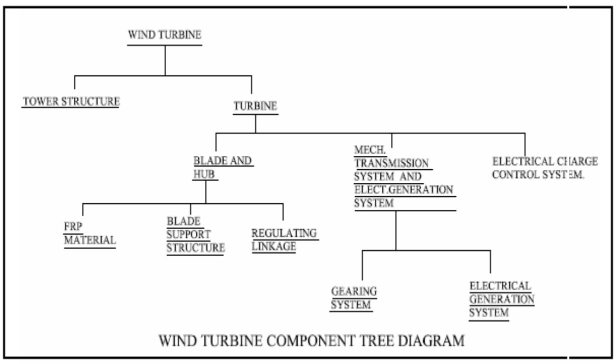

Fig. 1.2 Major Component of the Wind Turbine System Tree Diagram

ABC Analysis

The analysis gives the reliability of the various elements of the system. It also helps the inventory-control methodology and techno-economical analysis of the system.

A- Normal component (Non-critical and less cost elements)
B- Normal but functionally important and partially critical.
C- Critical component and functionally very important and higher cost.

4. Material selection and property study

At present, Aluminum blades fabricated by extrusion and bending are the most common type of HAWT materials. The major problem with Aluminum alloy for wind turbine application is its poor fatigue properties and its allowable stress levels in dynamic application decrease quite markedly at increasing numbers of cyclic stress applications. Under this backdrop, an attempt has been made in this paper to investigate alternative materials as FB-HAWT blade material

The smaller wind turbine blades are usually made of aluminum, or laminated wood. Metals were initially a popular material because they yield a low-cost blade and can be manufactured with a high degree of reliability, however most metallic blades (like steel) proved to be relatively heavy which limits their application in commercial turbines. In the past, laminated wood was also tried on early machines in 1977. At present, the most popular materials for design of different types of wind turbines are wood, aluminum and fiberglass composites that are briefly discussed below. Wood and Wood Epoxy Wood, a naturally occurring composite material, is readily available as an inexpensive blade material with good fatigue properties. Wood has been a popular wind turbine blade material since ancient time. Wood has relatively high strength-to-weight ratio, good stiffness and high resilience. Wood and wood epoxy blades have been used extensively by the designer of small and medium sized HAWTs. However, wood does have an inherent problem with moisture and stability.

This problem can be controlled with good design procedures and quality controlled manufacturing processes. The application of wood to large blades is hindered by its joining efficiency which in many cases has forced designers to examine other materials.

- **Aluminum**

Aluminum blades fabricated by extrusion and bending are the most common type of HAWT materials. The early blades of Darrieus type VAWTs were made from stretches and formed steel sheets or from helicopter like combinations of aluminum alloy extrusions and fiberglass. It has been reported by Parashivoiu that the former were difficult to shape into smooth airfoil, while the latter were expensive. The major problem that aluminum alloys for wind turbine application is its poor fatigue properties and its allowable stress levels in dynamic application decreases quite markedly at increasing numbers of cyclic stress applications when compared to other materials such as steel, wood or fiberglass reinforced plastics.

- **Fiberglass Composites**

Composites constructed with fiberglass reinforcements are currently the blade materials of choice for wind turbine blades of HAWT types. This class of materials is called fiberglass composites or fiber reinforced plastics (FRP). In turbine designs they are usually composed of E-glass in polyester, vinyl ester or epoxy matrix and blades are typically produced using hand-lay-up techniques. Recent advances in resin transfer molding and pultrusion technology have provided the blade manufacturers to examine new procedures for increasing the quality of the final product and reducing manufacturing costs. The characteristics that make composites, especially glass fiber-reinforced and wood/epoxy composites, suitable for wind turbine blades are.

5. Aerodynamics and power calculations

Analytical design of wind turbine is basically a part of aerodynamic and power optimization. While designing an aero-generator we will have to optimize the aerodynamic shape of the blade for optimum power extraction as well as manufacturing feasibility. In this project work we specifically observed,

- NACA-0018
- NACA-4415
- NACA-7622

0018-is previously used for vertical axis H-shape windmills and most optimum performance in this range. While 7622-63 is specifically design for horizontal axis turbine and easy to fabricate.

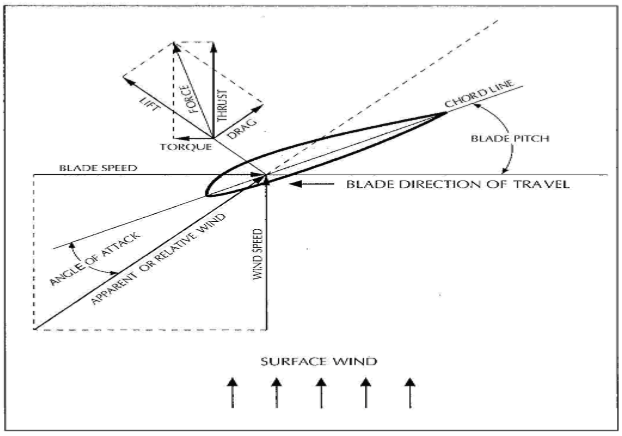

Fig.1.3 Lifts generation in wind turbine blade

We are going to use the newly developed profile as 4415.As per the graph generated by the design-foil, the lift characteristic of this profile is better for self starting capability of the vertical axis wind turbine.

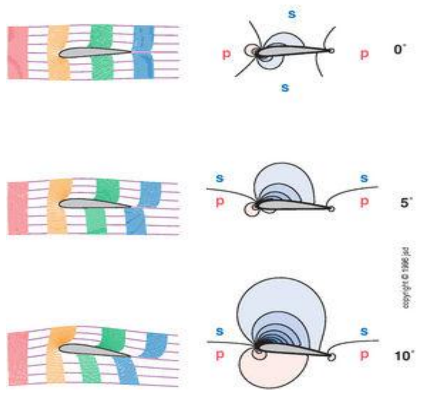

Fig.2.1 Lifts generation in wind turbine blade in different angle of attack

Turbine solidity as a function of TSR

The operating tip–speed ratio (TSR) for a Darrieus rotor lies between 4 and 6. This design TSR then determines the solidity, gear ratios, generator speeds, and structural design of the rotor. Using this TSR and the graph in figure 1.4, a value of the solidity is selected. As with the prop–type rotor, the solidity allows for the calculation of blade area.

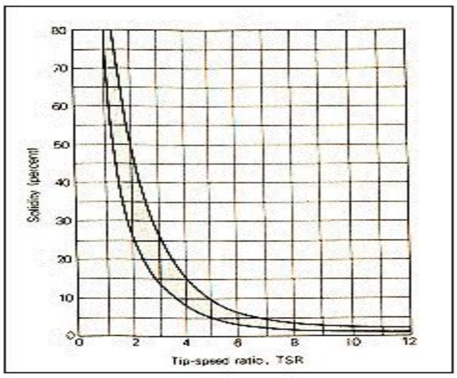

Fig.2.2 tip speed ratio and blade solidity relation

Turbine size as a function of power required. The power of the wind is proportional to air density, area of the segment of wind being considered, and the natural wind speed.

The relationships between the above variables are provided in equation

$$Pw = \frac{1}{2}\rho A V^3 Cp\ \eta o \quad (1)$$

Where
Pw=Power of the wind turbine (W)
ρ= air density (kg/m3)
A= area of wind turbine rotor (m2)
V =u= wind speed (m/s)
Cp = coefficient of performance
ηo = combine efficiency of electric generator + mechanical coupling

At standard temperature and pressure (STP = 273K and 101.3 KPa), equation reduces to:

$$Pw = 0.678\ A\ V^3 \quad (2)$$

A turbine cannot extract 100% of the winds energy because some of the winds energy is used in pressure changes occurring across the turbine blades. This pressure change causes a decrease in velocity and therefore usable energy.

- The mechanical power that can be obtained from the wind with an ideal turbine is given as:

$$P_m = ½\ \rho\ (16/27\ Au^3) \quad (3)$$

Where
P_m: mechanical power (W)
In equation [3], the area, A, is referred to as the swept area of a turbine. For a VAWT, this area depends on both the turbine diameter and turbine blade length.

- For an HAWT the equation for swept area is:

$$A_s = \frac{\pi}{4} d^2 \quad (4)$$

Where
A_s: swept area (m^2)
D=diameter of the turbine (m)

The constant 16/27 = 0.593 from equation [3] is referred to as the Betz coefficient. The Betz coefficient tells us that 59.3% of the power in the wind can be extracted in the case of an ideal turbine. However, an ideal turbine is a theoretical case. Turbine efficiencies in the range of 35-40% are very good, and this is the case for most large-scale turbines.

It should also be noted that the pressure drop across the turbine blades is very small, around 0.02% of the ambient air pressure. Equation [3] can be re-written as

$$P_m = Cp\ Pw \quad (5)$$

Where
Cp: coefficient of performance.

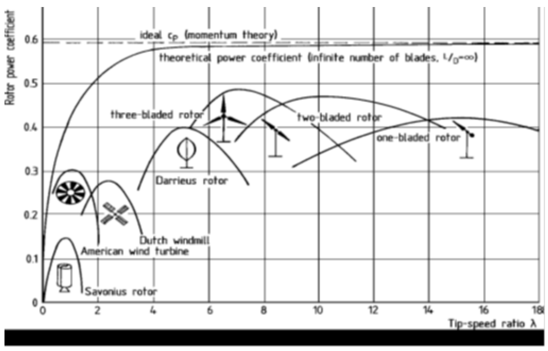

Fig.2.3 Rotor Power Coefficient Vs Tip Speed Ratio

The coefficient of performance depends on wind speed, rotational speed of the turbine and blade parameters such as pitch angle and angle of attack. The pitch angle for a HAWT is the angle between the blades motion and the chord line of the blade, whereas for a VAWT the pitch angle is between the line perpendicular to the blades motion and the chord line of the blade. The angle of attack is the angle between the relative wind velocity and the centerline of the blade. For fixed pitch turbines, these angles do not change and the Cp is directly related to the Tip Speed Ratio. See graph 1 for typical Cp values for various types of wind turbines.

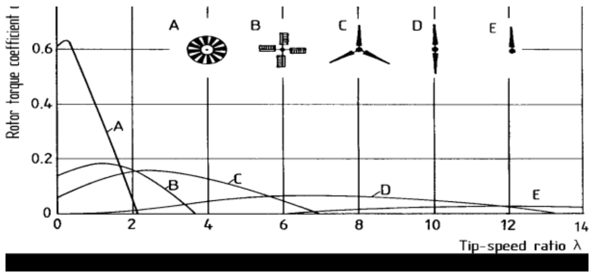

Fig.2.4 Rotor Power Coefficient Vs Tip Speed Ratio

6. Basic Aerodynamics

The 3-D turbine can be modeled as a 2-D cross section, as shown below

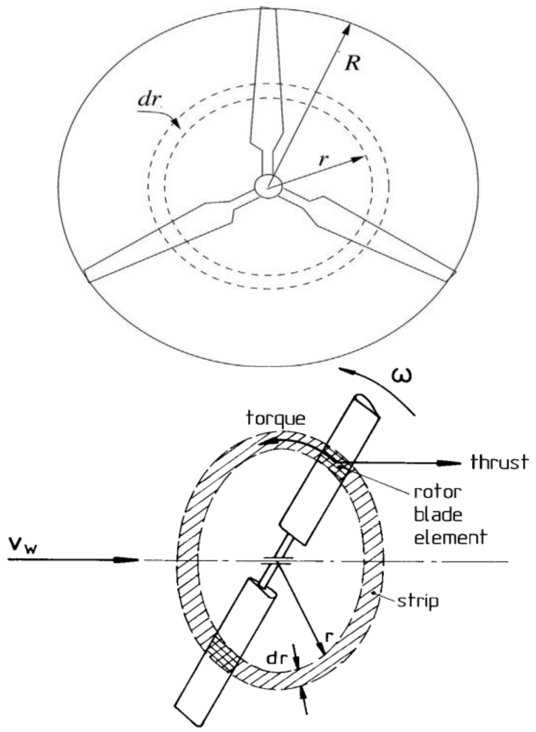

Fig.3.1 HAWT model

The forces felt by each blade of turbine depend on wind speed, rotational speed, and the angle of attack (angle between oncoming wind and the chord line). A positive angle attack is when the nose of the airfoil points upwards with respect to the oncoming wind. To calculate torque, angle of attack α was determined for each point in the cycle.

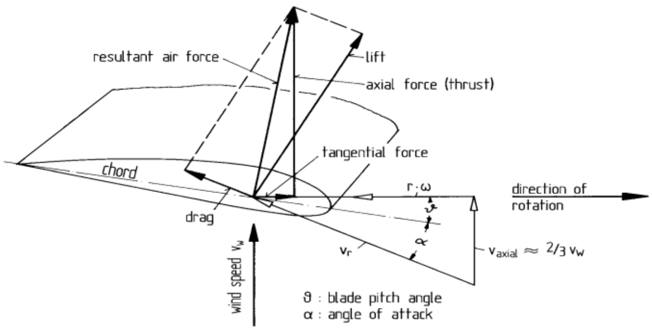

Fig.3.2 Air foils Force acting

- The equation for angle of attack is given as:

$\alpha = \tan^{-1} \{ V_w \cos\theta \div V_w \sin\theta + V_t\}$ (6)

Where,
V_w is the wind speed.
V_t tangential speed of the airfoils.
θ position of the airfoil in the rotation cycle.

- The tip speed ratio (TSR) is defined as:

$\lambda = TSR = V_w / V_t$
V_w=tangential speed of wind turbine blade tips.
V_u= wind speed or Wind velocity rated

The torque is dependent on the lift and drag coefficients. Plots of lift and drag coefficients verses angle of attack are shown below. These were calculated using the Design Foil software with a Reynolds number of 230,000 (the average Reynolds number expected with a TSR of 6 at higher angles of attack, it is apparent that drag increases significantly and lift drops off. High angles of attack also cause separation further up along the airfoil, increasing drag. At very high angles of attack, this drag takes over. It is thus important to maintain lower angles of attack throughout the rotation cycle to improve efficiency.

- Forces

The forces on the airfoil can be calculated using Figure below. It is difficult to do simple analysis of the airfoils due to the large variation in airspeeds and angles of attack that the airfoils encounter as they move around the cycle. The airfoils are traveling with the chord line perpendicular to the turbine radius (they are not pitched). The rotational force from lift and drag for each blade is thus:

$F\ motion = \{L \sin\alpha - D \cos\alpha\}$ (7)

Where
L is the lift,
D is the drag,

α is the angle of attack.

- The power produced by the turbine from each blade is

$$P = \{L \sin \alpha - D \cos \alpha\}*V \quad (8)$$

Where

V is the speed of the turbine blades.

- Available Power

The power available in the wind is proportional to the cube of the wind speed and the area of the turbine,

$$A= D\ h\ A_S \quad (9)$$

Where

D and h are the diameter and height, respectively.

- The total power available is given as

$$P=0.5.0AV^3\rho \quad (10)$$

Where

ρ is the density of the air ,

V_w is the undisturbed

This is the power that would be produced if 100% of the wind energy were harnessed. However, this would require making the wind velocity go to zero, which is not possible. On the other extreme, if the turbine did not slow the wind down at all, the turbine would not capture any energy. Between these two extremes lies a velocity change that yields the maximum amount of power. The physicist Albert Betz proved that the maximum amount of power that can be captured is 59% of the power in the wind.

Airfoils geometry

The first step in designing a Darrieus turbine is to choose the optimal number of blades. Blades in rotational motion leave turbulent flow in their paths. As the number of blades is increased, airfoils run into more turbulent flow and work less efficiently. However, a turbine with fewer blades has more wind passing through the turbine that does not contribute to power. An even number of blades is more likely to cause vibration problems. For these reasons, a three bladed design will yield the flattest power coefficient curve over 360 degrees of rotation. For these reasons, the three-bladed design was chosen. The blades will be symmetrical airfoils type NACA 0018-63. This airfoil profile was found to have the most optimal performance for use with Darrieus wind turbines [Source: Migliore]. The NACA 6-series airfoils are designed to increase the amount of laminar flow and reduce drag. A profile of the airfoil chosen is shown in the figure below The tip speed ratio is an important design aspect. Most Darrieus wind turbines are designed to have a TSR between 4 and 6. Power curves show that optimal TSRs for a Darrieus design with wind speeds of 6 m/s are between 4 and 8, depending on solidity (see Appendix). Lower TSRs have been shown to reduce noise generation, an important issue in urban settings. With this as a consideration, a TSR of 6 was chosen. TSR varies with wind speed. To achieve a TSR of 4.0 at a wind speed of 6 m/s with the 63-018 airfoil, the solidity (ratio of total blade area to total frontal area) should be 0.20 as shown in Figure.

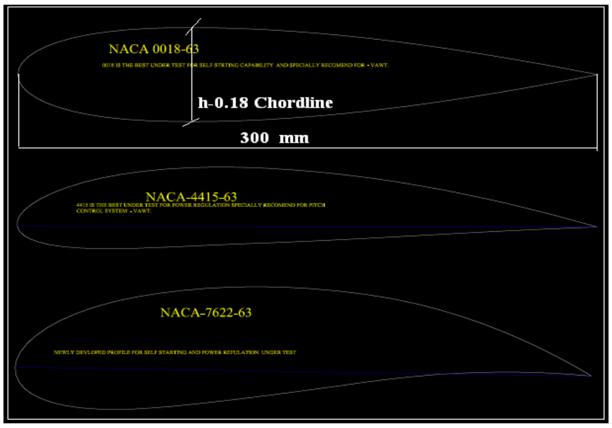

Fig. 3.3 Blade profile studied in design foil

Aerofoil Performance

The performance of aerofoil is depend on various factors. We are using Design -foil software to analyses the performance of the of the various blade profile in virtual wind tunnel. This software gives the freedom to make the profile as per our choice and find out the result at the various wind conditions and other parametric changes. This software provides the graphs and co-ordinate points in excel format to analyze the data as per requirement. Table No.4.1Input needed for design foil software for aerofoil analysis.

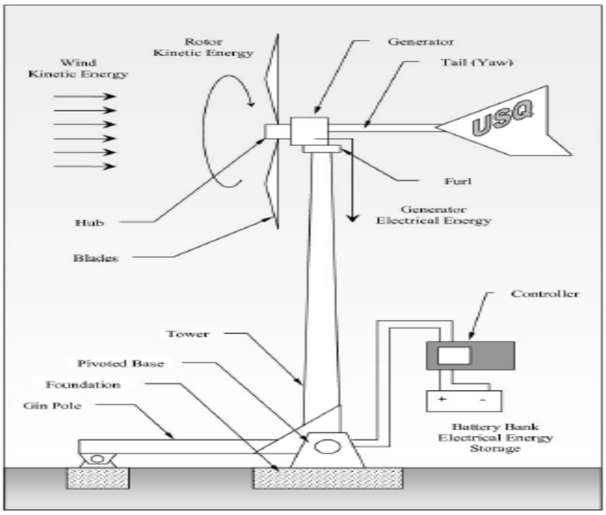

Fig 3.4 Expected conceptual model before manufacturing

7. Conceptual modeling

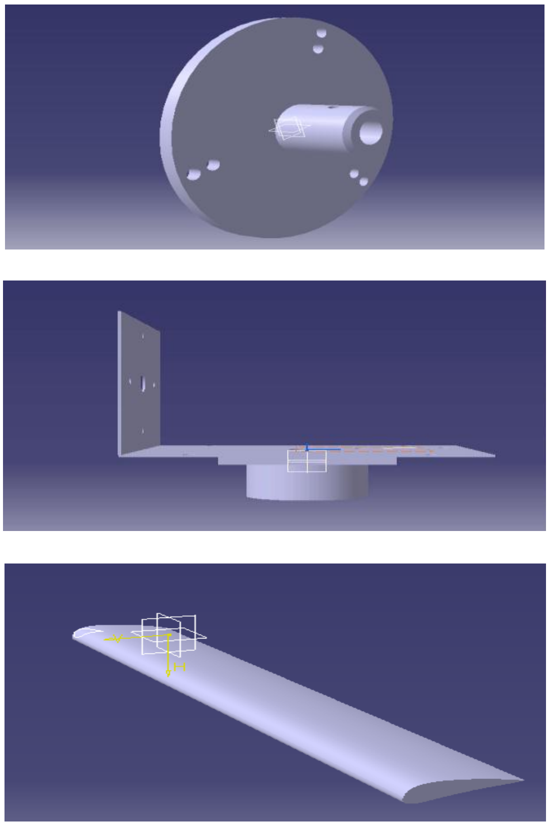

Fig.4.1 CAD Model

8. Result

Wind speed	Power O/p	Theoretical power	Betz's limit	Gen efficiency	Efficiency
3	5	292.99968	172.8698112	138.2958	3.615438
4	50	694.51776	409.7654784	327.8124	15.25263
5	135	1356.48	800.3232	640.2586	21.08523
6	235	2343.99744	1382.95849	1106.367	21.2407
7	279	3722.18112	2196.086861	1756.869	15.88052
8	325	5556.14208	3278.123827	2622.499	12.39276
9	367	7910.99136	4667.484902	3733.988	9.828634

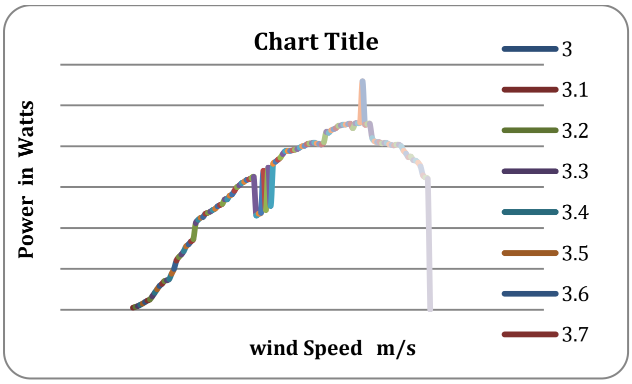

Fig.5.1 Power Vs Wind Speed

As per the result shows in the graph, we analyses various important entities from it. From the simple observation we analyses the wind speed directly proportional to power output of wind turbine and this is up to the designed rated speed limit. After the rated speed this power curve is getting decrimental due to the internal losses in the wind turbine generator also losses in electronic control and conversion unit due to excess voltage.

Also we observed from the readings in table the wind speed is continuously changing due to that the desire power output will always varies. This will not complete the target power output in given time. We observed, if the variation in the wind is 1 %, the power will vary by 3% rate. This is due to the velocity cube is directly proportional to power. From the results, we understand the wind energy power output is strongly dependent and not consistent throughout the day, due to exact power produced by turbine per day at actual is very difficult to calculate. Here our objective of the project is well satisfied, as turbine producing adequate power at available wind speed, this power is quite less then theoretical power output because of losses.

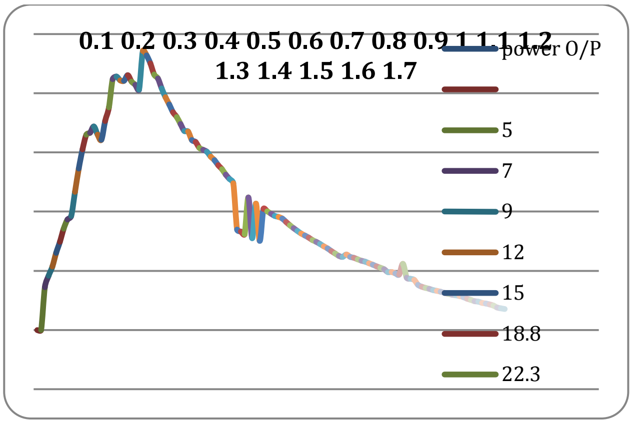

Fig 5.2 Wind Speed Vs Power

Conclusion

The structure in which the project was based firstly aimed to study of traditional and modern machines, permitting a selection of models for fabrication. The results of prototypes fabrication were satisfactory about the fidelity to the drafts and to material used, especially about weight and finishing. Tests in wind turbine at field permit to obtain information of the model prototype, such as power output, torque as function of TSR. With this information, tests with high solidity models, to which were presented the main results obtained in laboratory were emphasized. In function of the qualities techniques, permanent magnet generators were used, due to the high energetic concentration of the magnets, the brushes absence and the largest number of magnets that can be placed. The necessity of a study on the electric generators area ended up creating the PRO-GIP program, used in the project of permanent magnets generators. The result is satisfactory and it observed that output is strongly depending on whether conditions. Wind flow is varies rapidly due to continuous variation in output observed.

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