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A Review on Design and Analysis of Micro-Capacity Wind Turbine Components

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Abstract — *One of the fastest and economical source of energy is the wind energy. Amongst all it is the cleanest and renewable source of energy. In today's time many researches are directed towards the large sized wind turbines for producing the more and more energy at a minimum cost. Above all wind turbine blade is the most important part of the wind-mill to produce electricity from win. The main aim of the blade is to capture most of the electrical energy from wind energy. Hence, blade and other important sub-parts should be designed in such a particular way that more and more energy can be produced from wind. Also, the blade is supposed to have a good strength and should be of less mass, so that it can be rotated with a much higher speed as compared to others. This review paper describes the available ways for structural analysis of wind turbine components. A wind mill particularly consists of a blade and a tower structure. Hence, the proper designing and analysis of the whole structure is of at most importance for desired output energy.*

Keywords- *Aerodynamics, Micro-Capacity, Wind Turbine, Renewable Energy, Rotor Blade, Wind Energy, Design & Analysis*

I. INTRODUCTION

Blade is a very important component in a wind turbine. Extraction of energy from the wind mainly depends on the blade's structure. Wind is very highly variable in nature, due to lower density of air blades of larger surface area are required to obtain higher efficiency. Hence, the design and manufacturing processes of the blade has very much influence on the blade's structural performance.

Designing of blade profile can be done through various methods such as FEM (finite element method) based software ANSYS, CFD (computer fluid dynamics), BEM (blade element method). CFD analysis can be used for prediction of aerodynamics. For calculating various types of loads on the wind turbine blade BEM theory is applied. Analysis of various stresses producing in the blade can be done by using ANSYS CFX. [1]

The blade consists of two faces i.e. suction and pressure side which are joined together by adhesives and stiffened by many shear webs. Wind turbine blades are subjected to many types of loading like gravitational forces, tensional loading, flap wise and edgewise bending. Flap wise bending is caused due to wind pressure whereas edgewise bending is caused by gravitational forces and torque of blade.

1.1 Wind as Energy Resource

Wind turbine was one of the earliest non-animal sources of power used by humans. The earliest wind turbine designs were very simple and less complex; turbines were allowed to rotate at a rate corresponding to the wind's velocity. Wind turbines were used to pump water, grind grain and perform various other tasks. For these purposes, varying speed of the wind turbine impacted the effectiveness of the windmill. Further this clearly justified that controlling the rotational speed of the wind turbine will vary its output. Hence, allowing machines to run at variable speed greatly increased the total energy that can be extracted from the wind.

In rural areas of India, the word "electricity" is still like a dream, still millions of people in our country do not have access to electricity in their homes. According to facts, eight out of these ten homes without electricity are situated in far flung villages, some of which are geographically isolated and are often too sparsely populated. Thus, to supply electricity in these rural areas renewable energy like wind power is the cost effective and most feasible solution.

In recent years the cost of electric power generated using wind energy has dropped substantially. Since 2004, the price in the United States is now lower than the price of fuel generated electric power. Wind power is growing quickly, at 38%, up from 25% growth in 2002. It is proved to be the fastest growing form of electricity generation.

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1.2 Categories of Wind Turbines

1.2.1 Large Capacity Turbine

Large wind turbines are classified by the wind speed. Turbines are designed from class I to class IV, with A or B referring to the turbulence. Below table describes the various classes of wind turbines.

Table 1: Classes of Wind Turbine

Class	Avg. Wind Speed (m/s)	Turbulence
IA	10	18%
IB	10	16%
IIA	8.5	18%
IIB	8.5	16%
IIIA	7.5	18%
IIIB	7.5	16%
IVA	6	18%
IVB	6	16%

1.2.2 Small Capacity Turbine

Small wind turbines are used for a variety of applications such as on- or off-grid residences, offshore platforms, telecom towers, rural schools, remote monitoring and various other purposes that require energy where there is no electric grid. Small wind turbines can be as small as a 50-watt electric generator for boats. In rural areas hybrid solar and wind powered units are used increasingly for traffic signage as they avoid the need of laying long cables from the nearest mains connection point.

1.2.3 Micro Capacity Turbine

Micro capacity wind turbines are turbine with power range in between 50 W to 2 KW. These turbines are mostly used for domestic application.

1.3 Aerodynamics Vs Structural Blade Concept

The aerodynamics is a very important aspect of wind turbines. There are different types of wind turbines in use and all of them are based on various energy extraction techniques.

Though the details of the aerodynamics depend very much on the topology. Topology are some fundamental concepts apply to all wind turbines. Every topology has a maximum power for a given flow. In general, all turbines can be classified as being either lift-based, or drag-based. The difference between these groups is the aerodynamic force which is used for energy extraction.

Designing of wind turbine is the process of defining the specifications of a wind turbine to extract maximum energy from the wind. Installation of a wind turbine consists of the necessary systems required to store the wind energy, convert mechanical rotation into electrical power, point the turbine into the wind and other systems for controlling of the wind turbine. Below are the certain structural concepts for particular components of wind turbine:

Blade: For wind turbine blades the ratio between the speed of the blade tips and the speed of the wind is called tip speed ratio. 3-blade-turbines are highly efficient with tip speed/wind speed ratios of around 6 to 7. Composite materials like E-glass fibre are used to produce blades. They result in low rotational inertia, which depicts that new wind turbines can accelerate quickly while keeping the tip speed ratio constant.

Tower: At higher altitudes wind velocities increases due to surface aerodynamic drag and air's viscosity. The variation in velocity with altitude is most dramatic near the surface. This variation follows the wind profile power law, which states that wind speed rises in proportion to the seventh root of altitude. On doubling the altitude of a turbine, there is an 10% increase in the expected wind speeds and 34% increase in expected power. Whenever the tower height is doubled to avoid the buckling, then the diameter of the tower is also doubled, which increases the amount of material required by a factor of at least four [8].

Generator: For larger horizontal-axis wind turbines, the electrical generator is mounted in a nacelle behind the hub of the turbine rotor, at the top of a tower. Typically wind turbines generate electricity using asynchronous machines which are directly connected with the electricity grid. Usually the rotational speed of the wind turbine is slower as compared to the equivalent rotation speed of the electrical network. Hence, a gearbox is installed between the rotor hub and the generator. [10]

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Shaft and Foundation: Wind turbines are very tall slender structures which can cause a number of issues if all the structural design of the foundations are considered. The foundations for a conventional structure are designed mainly to transfer the vertical load to the ground. However, in the case of wind turbines, due to the high wind and environmental loads experienced, a significant horizontal dynamic load is present which needs to be restrained appropriately.

Gearbox: In wind turbines, the blades spin a shaft which is connected through a gearbox to the generator. The gearbox varies the turning speed of the blades around 15 to 20 rotations/minute for 1MW turbine that results in faster rotations which is required by the generator to generate electricity. The use of magnetic gearboxes helps in reducing the maintenance cost of wind turbines. [12]

II. LITERATURE REVIEW

Kebin peter Abraham *et.al* [1] they had done the finite element analysis of wind turbine blade to find out which material is suitable for blade. In this work they modelled blade in CATIA V5 and done analysis for different five blade materials viz, Structural steel, Stainless steel, Titanium alloy, Aluminium alloy, T-Graphite Epoxy. They found out the value of less Von Mises stress and less deflection in stainless steel.

Sulakhe Vishal *et.al* [2] they designed and done analysis of jet wind turbines blades they had given the design and calculation for 100 Watt electricity production and found that the efficiency of jet wind turbine is 3 to 4 times more than conventional wind turbine the efficiency of jet wind turbines increases due to its aerodynamic shape.

Amer C. *et.al* [3] they had done the structural analysis of a composite wind turbine blade in this work they developed a 5 m long wind turbine rotor blade, and done the finite element analysis and investigated both static and dynamic behaviour of blade. They found that tip deflections as flap-wise and edge-wise are 0.0186 m and 0.0039 m respectively.

Rohit K. Singh *et.al* [4] they stated that at Reynolds numbers of 75,000, 128,000 and 205,000 maximum lift coefficients of 1.72, 1.81 and 1.86 respectively can be obtained at the stall angle of 14 º. Also the lift coefficient is increased from 0.41 to 1.05 at Re= 38000 in the angle of attack 0-18º.

B. Bavanish *et.al* [5] they found that the goal in optimizing is to maximize the aerodynamics efficiency at single design wind speed. The optimized set obtained at blade solidity 0.15 are angle of attack 5 degree, tip speed ratio 8 and ratio of drag coefficient to lift coefficient as 0.025.

Sandra Eriksson *et.al* [6] they presented that there were significant differences between wind turbines depending on the direction of their axis of rotation.

C. Sicot *et.al* [7] they investigated the aerodynamic properties of wind turbine air foil and the influence of the inflow turbulence level on the stall mechanisms on the blade.

III. COMPONENTS OF WIND TURBINE

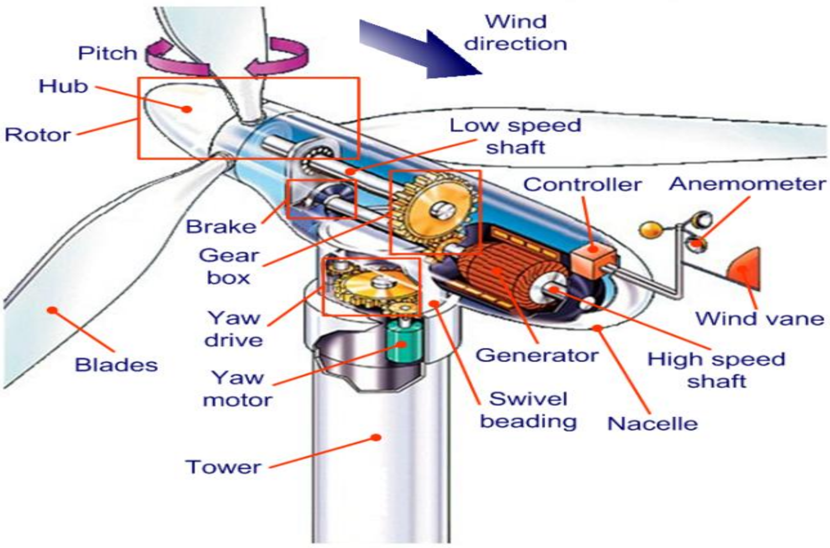

Fig 1: Major Components of a horizontal axis wind turbine

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Anemometer:
It is a device used for measuring wind speed and it is also a common weather station instrument. The name is derived from “anemos”, a greek word which means wind, which is used to describe any wind speed measurement instrument that can be is used in meteorology. The first known description of this device was given by Leon Battista Alberti in 1450.

Generator torque:
When the wind speed is below rated speed, generator torque is used to control the rotor speed to capture as much power as possible. When the tip speed ratio is held constant at its optimum value the most of the power is captured. This means that as the wind speed increases, rotor speed will increase proportionally. The difference between the aerodynamic torque and generator torque is that aerodynamic torque is captured by the blades and the generator torque is applied to controls the rotor speed. The generator torque control is active when the blade pitch is typically held at a certain constant angle which captures the most power. The generator torque is typically held constant while the blade pitch is active.

Fig 2: permanent magnet generator

Generators convert mechanical power of rotating blades into electrical power. Two most common types of generators in large capacity wind turbines are induction generators and synchronous generators whereas for small capacity turbines they use direct drive generators. No gearbox is required in these direct drive generators.

Inverter:
An inverter is an electronic device or circuitry that helps to change direct current (DC) into alternating current (AC). The input voltage, output voltage and handling of power depends on the design of the specific circuitry. The inverter does not produce any power. The required power is generally provided by the DC source. A power inverter can be a complete electronic circuit or a combination of mechanical effect and electronic circuit.

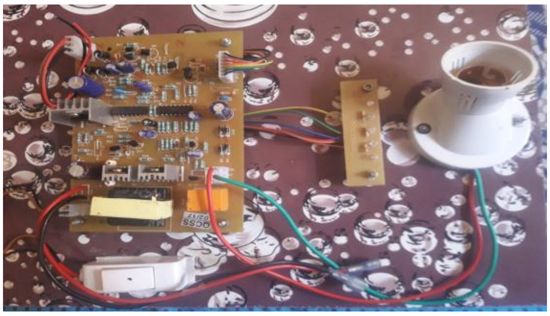

Fig 3: Inverter Circuitry

Battery:
Battery is used for storage purpose. Generated energy from generator is transferred towards the controller through battery. Micro capacity wind turbine uses battery to store energy and once it is fully charged it can be used for various domestic applications. Afterwards it can be replaced with another battery to store energy.

Fig 4: 12V Battery

IV. REVIEW ON STRUCTURAL ANALYSIS

The aerodynamics is a very important aspect of wind turbines. There are different types of wind turbines in use and all of them are based on various energy extraction techniques.

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Designing of wind turbine is the process of defining the specifications of a wind turbine to extract maximum energy from the wind. Installation of a wind turbine consists of the necessary systems required to store the wind energy, convert mechanical rotation into electrical power, point the turbine into the wind, and other systems for controlling of the wind turbine. Reason behind the structural analysis of wind turbine is that the stability of wind turbine is very important aspect.

4.1 Structural Analysis of Blade

Structural analysis of blade starts with the development of the blade model which is done using CATIA. Afterwards its file is imported in ANSYS workbench for static structural analysis purpose. Then from engineering data blade material is selected as E-glass fibre and its properties are mentioned as input to the software such as density, young modulus, poisons ratio. Thereafter the task of meshing is performed with automatic generation of mesh after proper sizing, numbered of element's, cores and fine meshing. Accuracy of solver, structured or unstructured grids are also taken into consideration when meshing operation is performed. After mesh generation boundary conditions on model are applied. Mainly two forces are always in consideration i.e.:

Lift force: On upper surface of blade in vertical direction lift force is nothing but force required to rotates wind turbines blades. It arises due to wind speed impact on blade.

Drag Force: It is amount of force on blade surfaces which arises due to wind whirling action or wake rotation which causes opposing motion to rotation of blade and reduces the blade rotating speed. It drags the blade in opposite direction of rotation.

4.2 Structural analysis of Tower

The structural model of the tower can be represented by long, slender cantilever beam built from different segments having divergent but also uniform cross-sectional properties. The tower carries concentrated mass at its free end and it is cantilevered to the ground, approximating the inertia properties of rotor unit. The mass is assumed to be rigidly attached with the tower.
To check stability of tower structural analysis is more important. Also it is standalone type so safety issues are always considered. Wind impact may cause damage to pole or total weight of all components may exceed and it can result in bending of pole or buckling may takes placed so as to avoid all this safety problems structural analysis is done on ANSYS workbench. For tower we have used mild steel material. All the properties of mild steel are taken for analysis such as young's modulus, density, poison's ratio.

V. REVIEW ON COMPONENT FABRICATION

5.1 Fabrication of Rotor Blade

The blades are made up of fibre glass, rather than wood as for following reasons:

1. The time for manufacture will be much lower and a number of blades can be produced in one batch. This will also reduce costs.
2. The use of moulds allows good repeatability and hence well balanced blades
3. Straight grained wood will be very difficult to find and expensive as well.

5.2 Fabrication of hub plate

Hub plate are made up of mild steel material plate having clamping arrangement for blades on it. It also has central hole to locate it with generator main shaft, additional holes are provided to reduce weight and heat dissipation rate.

5.3 Fabrication of Tower

We are using mild steel material for tower which is roof mounted and pole type. It was installed on top floor of the building. So as to achieve maximum wind condition and it was helpful for extraction of more energy from wind.

VI. SUMMARY & CONCLUSION

For Micro capacity wind turbines proper selection of all electrical components such as generator, battery, inverter plays a major role as well as selection of blade material is very important aspect in accordance to cost estimation, strength & properties of material. Selection of manufacturing process should be done on the basis of blade size, turbine capacity, blade material, manpower available.
Aerodynamic efficiency as well as structural efficiency both plays important role in design aspects of turbine. Structural requirement means blade must be thicker at root section where the hub is attached with blade, at that point bending stresses are more, and thin towards tip end.

Micro capacity wind turbine design is very important. These turbines are simple in construction and requires less amount of investment, since turbines are small in size that's why it can harness a limited amount of wind. Therefore, it can be used for low power applications, such as storage of batteries, street lighting, on busy road. As number of vehicles increased on busy road it will produce whirling motion due to which wind speed will increase and it results in faster rotation of wind turbine rotors. As the battery is portable we can use it at some other remote location for low voltage domestic applications.

From this review we proposed selection of major electrical components in details as well as foundation required for the installation of micro wind turbine. It is easy to develop micro wind turbine at minimum cost and fulfil the daily life electricity requirements.

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