A Review Paper on Horizontal and Vertical Axis Wind Turbine

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***Abstract*- Energy is an essential ingredient of socio-economic development and economic growth. Renewable energy sources like wind energy is indigenous and can help in reducing the dependency on fossil fuels. Wind is the indirect form of solar energy and is always being replenished by the sun. Wind is caused by differential heating of the earth's surface by the sun. It has been estimated that roughly 10 million MW of energy are continuously available in the earth's wind. Wind energy provides a variable and environmental friendly option and national energy security at a time when decreasing global reserves of fossil fuels threatens the long-term sustainability of global economy. This paper presents review of on different types of small scale wind turbines i.e., horizontal axis and vertical axis wind turbines. The performance, blade design, control and manufacturing of horizontal axis wind turbines were reviewed. Vertical axis wind turbines were categorized based on experimental and numerical studies.**

Index terms- Blade momentum theory, Computational fluid dynamics, Horizontal Axis Wind Turbine, Blade air foil.

I. INTRODUCTION

The wind turbine technology has a unique technical identity and unique demands in terms of the methods used for design. Remarkable advances in the wind power design have been achieved due to modern technological developments. Since 1980, advances in aerodynamics, structural dynamics, and ‘‘micrometeorology’’ have contributed to a 5% annual increase in the energy yield of the turbines. Current research techniques are producing stronger, lighter and more efficient blades for the turbines. The annual energy output for turbine has increased enormously and the weights of the turbine and the noise they emit have been halved over the last few years. We can generate more power from wind energy by establishment of more number of wind monitoring stations, selection of wind farm site with suitable wind electric generator, improved maintenance procedure of wind turbine to increase the machine availability, use of high capacity machine, low wind regime turbine, higher tower height, wider swept area of the rotor blade, better aerodynamic and structural design, faster computer-based machining technique, increasing power factor and better policies from Government.

Even among other applications of renewable energy technologies, power generation through wind has an edge because of its technological maturity, good infrastructure and relative cost competitiveness. Wind energy is expected to play an increasingly important role in the future national energy scene [1, 2]. Wind turbines convert the kinetic energy of the wind to electrical energy by rotating the blades. Greenpeace states that about 10% electricity can be supplied by the wind by the year 2020. At good windy sites, it is already competitive with that of traditional fossil fuel generation technologies. With this improved technology and superior economics, experts predict wind power would capture 5% of the world energy market by the year 2020. Advanced wind turbine must be more efficient, more robust and less costly than current turbines. Ministry of Non-conventional Energy Sources (MNES), Indian Renewable Energy Development Agency (IREDA) and the wind industry are working together to accomplish these improvements through various research and development programs. This article gives a brief overview of various wind turbine technologies.

1.1 Wind Turbine

A wind turbine is a complex system which consists of several components, including a rotor, a transmission system, a generator, a nacelle, a tower and other electro-mechanical subsystems. The rotor blades are the most important components. In order to transfer wind energy into mechanical power, the blade is designed as aerodynamics geometry with nonlinear chord and twist angle distributions. The section view of a wind turbine blade is of an aerofoil shape, which is generated to high lift and low drag forces. The shape of the blade is vital as it determines the energy captured, and the loads experienced. The study of interaction between wind flows and wind turbines is wind turbine aerodynamics which plays an important role in wind turbine design and analysis.

1.2 Wind Turbine Aerodynamics

Aerodynamic performance is fundamental for efficient rotor design. Aerodynamic lift is the force responsible for the power yield generated by the turbine and it is therefore essential to maximize this force using appropriate design. A resistant drag force which opposes the motion of the blade is also generated by friction which must be minimized.

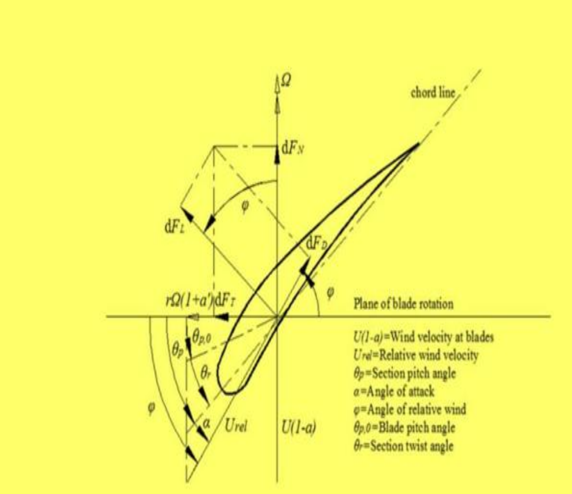

Figure 1: Schematic diagram of blade, angle of attack, pitch angle etc.

It is then apparent that an aerofoil section with a high lift to drag ratio typically greater than 30, be chosen for rotor blade Coefficient of lift, Lift to Drag Ratio, Coefficient of drag.

In general, there are two forces and one moment that act upon an aerofoil; these being lift, drag and pitching moment. The definitions of those three forces are explained in this section. Lift is the force used to overcome gravity and is defined to be perpendicular to direction of the oncoming airflow .It is formed as a consequence of the unequal pressure on the upper and lower airfoil surfaces. The drag force is defined as a force parallel to the direction of oncoming air flow. The drag force is due both to viscous friction forces at the surface of the aerofoil and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow. The lift is the force used to overcome gravity and the higher the lift the higher the mass that can be lifted off the ground. For an aerofoil, Hansen stated that the lift to drag ratio should be maximized. As a result, it can improve efficiency when wind turbine generates electricity. Lift and drag coefficients CL and CD are defined as follows.

Lift coefficient $C_L = F_L/0.5\rho V^2 C$ (1)

Drag coefficient $C_D = F_D/0.5\rho V^2 C$. (2)

Where ρ is the air density and c is the length of the aerofoil, often denoted by the chord, unit for the lift and drag in Equations 1and 2 is force per length (in N/m). To describe the forces completely, it is also necessary to know the pitching moment M. It has been found both experimentally and theoretically by NASA that, if the aerodynamic force is applied at allocation ¼ chords back from the leading edge on most low speed airfoils, the magnitude of the aerodynamic pitching moment remains nearly constant with angle of attack. In most aerofoil simulations, the pitching moment center is set up at ¼ chord length to get an approximate value and the pitching moment coefficient is defined as follows.

Moment coefficient CM= M/0.5ρV2C...(3)

The tip speed ratio is the ratio of the blade tip speed over wind speed. It is a significant parameter for wind turbine design and its definition is shown in Equation 4.

Definition of tip speed ratio λ=ωR/v0...............(4)

Where ω is the angular velocity of the wind turbine rotor, R is radius of the rotor and v0 is the wind speed. A higher tip speed ratio generally indicates a higher efficiency but is also related to higher noise levels. Generally a low speed wind turbine chooses value of tip speed ratio from1to4 and a high speed wind turbine chooses its value from 5 to 9.

1.3 Small scale wind turbine

A typical large scale wind turbine is one which has a rotor diameter ranging from 50 m to 100 m. It produces power between 1 and 3 MW. When compared to large scale wind turbines, small scale wind turbines are those which have their rotor diameter ranging from 3 m to 10 m and having a power capacity of 1.4–20 kW.

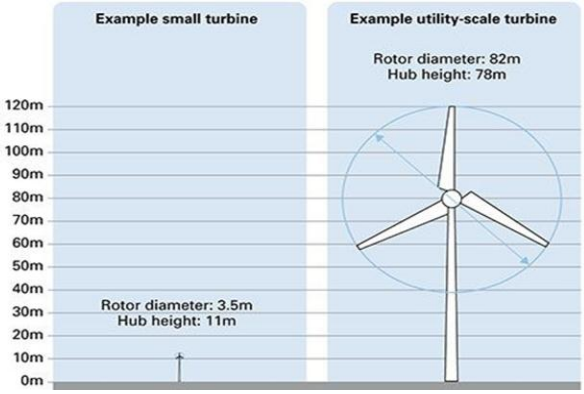

Figure 2: Small scale wind turbines.

Small scale wind turbines which have a nominal power rating of 50 W produce more costly electricity than the medium and large scale wind turbines especially in poor wind sites. They are also handy in some autonomous applications which require a very high level of reliability. These wind turbines can be used as a reliable source of energy when they are sized properly and are used at their optimum conditions. They can also become the source for producing socio-economically valuable energy for most of the developing countries. In locations which are far away from the grid power, these small scale turbines can act as a useful power source even in the developed countries. But the future of the continuous growth of small scale wind turbines depends upon the cost at which it is being generated. Two major factors are the initial cost per W power and the unit cost per kW-h it produces. Given that these two factors are at an affordable rate, small scale wind turbines can become a potential source for power production. Hence the small scale wind turbines must be cost efficient. Hence it is very much necessary to study and understand the different kinds of small scale wind turbines available at present. Hence this paper presents a detailed review on small scale wind turbines.

Small axis wind turbines can be classified on the basis of axis of rotation are as follows:

1.3.1 Horizontal Axis Wind Turbine (HAWT)

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbines are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor. Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator. Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower. Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount. Downwind machines have been built, despite the problem of turbulence, because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds, the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since turbulence leads to fatigue failures, and reliability is so important, most HAWTs are upwind machines. Types of HAWT wind farm installations are:

On-Shore: Mountains and hilly areas have been the original choice to setup these farms. Individual wind turbines at these farms contribute towards power generation of 100 MW or more. The land occupied by the wind parks are often used for agriculture or animal grazing. Denmark, Spain and Portugal are some of the leading countries in the onshore wind farm electricity production.

Offshore wind farms are the results of revolutionary technology that has encouraged man to set up wind energy harvesting farms on the water surface. Apart from oceans, lakes also act as sites for the installation of wind parks. An advantage of offshore wind farm is that it makes use of powerful winds blowing over the water surface. Moreover, it is easy to transport huge parts of a wind turbine to the offshore sites using big ships and vessels. Some of the other advantages of these farms include mitigation of noise due to distance from land and higher capacity factors.

1.3.2 Vertical Axis Wind Turbine (VAWT)

VAWTs, have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on sites where the wind direction is highly variable or has turbulent winds. With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT is that it generally creates drag when rotating into the wind. It is difficult to mount vertical-axis turbines on towers, meaning they are often installed nearer to the base on which they rest, such as the ground or a building rooftop. Hence these models are not frequently used for off-shore installations which if used might require water proof casings that adds to extra costs. Also, offshore installations require very high height towers. The wind speed is slower at a lower altitude, so less wind energy is available for a given size turbine. Air flow near the ground and other objects can create turbulent flow, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and these can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence. Various types of VAWT are:

Darrieus wind turbine: "Eggbeater" turbines, or Darrieus turbines, were named after the French inventor, Georges Darrieus. They have good efficiency, but produce large torque ripple and cyclical stress on the tower, which contributes to poor reliability. They also generally require some external power source, or an additional Savonius rotor to start turning, because the starting torque is very low. The torque ripple is reduced by using three or more blades which results in greater solidity of the rotor. Solidity is measured by blade area divided by the rotor area. Newer Darrieus type turbines are not held up by guy-wires but have an external superstructure connected to the top bearing.

Giromill: It is a subtype of Darrieus turbine with straight, as opposed to curved, blades. The cyclo turbine variety has variable pitch to reduce the torque pulsation and is self-starting. The advantages of variable pitch are: high starting torque; a wide, relatively flat torque curve; a lower blade speed ratio; a higher coefficient of performance; more efficient operation in turbulent winds; and a lower blade speed ratio which lowers blade bending stresses. Straight, V, or curved blades may be used.

Savonius wind turbine: These are drag-type devices with two (or more) scoops that are used in anemometers, Flettner vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines. They are always self-starting if there are at least three scoops.

Twisted Savonius: Twisted Savonius is a modified savonius, with long helical scoops to give a smooth torque, this is mostly used as roof wind turbine or on some boats (like the Horn blower Hybrid).

II. LITERATURE REVIEW

The energy conversion efficiency of a wind turbine is usually characterized by its power coefficient, which is the ratio of the power extracted from the wind to the power available in the wind A counter-rotating wind turbine having two rotors rotating in opposite direction on the same axis has been proposed as a new concept to enhance the maximum power coefficient of the wind turbine. Using classical momentum theory, Newman found that the maximum power coefficient of a wind turbine having two rotors without any losses increased to about 64%.

The utilization of wind energy is not a new technology but draws on the rediscovery of a long tradition of wind power technology. It is no longer possible now to tell from the remainders of historical wind power plants just how important a role wind power played in the past. In this study a comprehensive review of wind turbine is presented. The objective of this literature is to review available literature for blade design, wind turbine airfoils and rotor wakes, Aerodynamic behavior of wind turbine and fatigue design of wind turbine rotor. Review on optimization is also taken in this work. The article reviews the details of design and optimization aspect of rotor of horizontal axis wind turbines.

Relating to the current stated work a literature survey was carried out. The summary of the reviewed papers is given below.

Muljadi et al. [2000] to evaluate the feasibility of constraining rotor speed and power output without the benefit of active aerodynamic control devices. A strategy was postulated to control rotational speed by specifying the demanded generator torque. By controlling rotor speed in relation to wind speed, the aerodynamic power extracted by the blades from the wind was manipulated. Specifically, the blades were caused to stall in high winds. In low and moderate winds, the demanded generator torque and the resulting rotor speed were controlled and the wind turbine operated near maximum efficiency. Turbine models were developed and simulations of operation in turbulent winds were conducted. Results indicated that rotor speed and power output were well regulated.

Ebert and Wood [2002] completes a series which describes measurements within two chord lengths of the blades of a small horizontal-axis wind turbine over a wide range of operating conditions. Prior to the present experiment, the turbine was rebuilt to allow operation at its runaway point, where no power is produced. Runaway can be viewed as the upper limits on wind turbine performance at which thrust and wake expansion are maximized. The measurements, which approximate the mean and fluctuating velocity fields seen by an observer rotating with the blades, were obtained from a stationary X-probe hot-wire anemometer by the technique of phase-locked averaging. It is shown conclusively that there is negative (power-producing) angular momentum extracted from the wake, but a balancing positive angular momentum resides in the tip vortices. The mean velocity through the blades increases significantly with radius, in contrast to the near-constant velocity when the turbine is producing its maximum power. Comparisons with conventional blade calculations suggest that the circulation in the wake is related to the difference between the circumferential components of the lift and drag, rather than the magnitude of the lift as is often assumed. Within the range and accuracy of measurement, the pitch of the tip vortices is constant and proportional to the inverse of the tip speed ratio.

Saranyasoontorn and Manuel [2004], gives rise to relatively compact analytic expressions for the average power output in stochastic wind fields. It may be an efficient tool to assess the effect of wind speed fluctuations on the average power output of a wind turbine. The model is particularly suitable to examine the dynamic effect of turbulent wind fields which can be described by standard models of boundary layer meteorology. In a simplified shutdown model, wind fluctuations tend to weaken the relaxation towards standstill. Moreover, in the case of a special stationary power curve, we find a dynamic enhancement of the average power output with increasing turbulence intensity.

Maheri et al. [2006] presents a method for decoupled design of Bend-Twist Adaptive Blades (BTABs) in which the aerodynamic and structural designs take place separately. In this approach the induced twist is considered as an aerodynamic design parameter, whilst its dependency on the structural characteristics of the blade is taken into account by imposing a proper constraint on the structure design. The main advantage of this method is the significant reduction in evaluation time by replacing a finite element analysis (FEA)-based coupled-aero-structure (CAS) simulation in the aerodynamic objective evaluation by a non-FEA-based CAS simulation. Through a re-design case study an ordinary blade has been converted to a BTAB and the efficiency of the method in performing decoupled design of BTABs has been illustrated.

Ahmed et al. [2009] deal with a new method based on analytical approach. In their design of rotor and its peak performance production, a blade is divided into 100 radial elements. The blade chord, its twist and its elementary power co-efficient at each station were determined. The iterative process required for the convergence of speed interference factor and for maximization of power coefficient. The design process begins right at maximum power point, rather than searching of point of maximum power and then doing the computations. Mathematical Simulation based on analytical approach for energy estimation correlate with practical reading of 10 kW H.A.W.T rotors at Rajeev Gandhi Proudyogiki Vishwavidyalaya (RGPV), Bhopal India.

Kunduru Akhil Reddy et al. [2015] investigated a brief research, study, design and analysis on wind turbine. This paper evaluates the aerodynamic performance of variable speed fixed pitch horizontal axis wind turbine blade using two and three dimensional computational fluid dynamics. The primary objective of the paper is to increases the aero dynamic efficiency of a wind turbine. The blades are designed using different type of airfoils which are associated with angle of attack. The blade design is responsible for the efficiency of the wind turbine. The design of the blade is done using Q- blade software. The result indicates that the power output is determined using blade elemental theory. The power output of designed blade design is higher when compare to existing design of the blade.

Parth Rathod et al. [2016] analyzed a review on combined vertical axis wind turbine. In this paper, the increased efficiency is achieved based on the characteristics such as aspect ratio, tip speed ratio, velocity and other geometry parameter. The experiment is conducted to increase the power production and efficiency of a wind turbine. The development of design is optimized by combining the blade structure and the flow performance. The result indicates that the efficiency of turbine is always based on the wind speed and climatic conditions. The lowest aspect ratio improves the power coefficient of the turbine. The power generation of combined rotor is high compare to the single savonius and darrieus rotor.

Xinghui Q. and Qinkai H. [2018] have studied Load sharing characteristics of planetary gear transmission in horizontal axis wind turbines. With the increase of wind turbine size gravity becomes an important non-torque excitation source. Gravity disrupts the cyclic symmetry of the planetary gear and causes unequal load-sharing. Because of the specific operation conditions, the bedplate will tilt and lead to the offset of the gear plane and vertical plane. Taking gravity, tooth separation, backside contact and bedplate tilt angle into consideration, a rotational-translational-axial dynamic model of the spur planetary gear is developed. With two different load-sharing factor models, the load-sharing characteristics of the planetary gear in horizontal axis wind turbines are numerically investigated. The effects of gravity, ring support stiffness and bedplate tilt angle on load-sharing characteristics are systematically examined. When planets move to certain positions, severe unequal load-sharing and backside contact are more likely to happen. Load-sharing characteristics change with the bedplate tilt angle and the ring support stiffness, and the variation trend is closely related to the occurrence of tooth separation and backside contact.

Germano D. and Ettore P. [2019] have studied Kinematic and power-flow analysis of bevel gears planetary gear trains with gyroscopic complexity. In this paper a method for the kinematic and power - flow analysis of bevel epicyclic gear trains with gyroscopic complexity. By gyroscopic complexity, we mean the possibility of the gear carrier to be a floating link as, for instance, in robotic gear wrists. Thanks to the new formulas herein deduced, the methods based on the graph representation of planetary spur gear trains have been extended to bevel gear trains. In particular, the well-known Willis equation has been modified to maintain its validity for bevel gears. The modified Willis equation was then embodied in new power ratio expressions. Under our simplifying hypotheses of absence of friction and constant angular speeds, it is shown that gyroscopic torques do not enter into power flow analysis. Two numerical examples are discussed. A fundamental step in mechanical efficiency analysis is the ascertainment of the amount of power flow through the meshing gears. Although not self-evident, due to power circulation, some meshing gears may sustain a power higher than the input one. Power circulation that usually occurs with very low transmission ratio must be detected at the early design stages in order to dimension properly meshing gears and lubricating methods. Most of the contributions are related to spur gear trains. In this case the kinematics can be studied with the classic scalar Willis equation.1 The relationship between the absolute angular speeds of bevel gear trains is not scalar and this complicates the analysis. This paper focuses on kinematic and power flow analysis of planetary trains with bevel gears. It can be considered as an attempt to extend the modus operandi of the analysis methods devised for spur gear trains to bevel gear trains.

Renewable technology which is emerging technology rapidly expands as a good option in the power generation sector. In India, due to Jawaharlal Nehru solar mission which have a target to established

20,000 MW till 2020, Wind industries expand in electricity generation. Very important role played by deregulation act of government that is electricity act 2003 technology is one of the glowing technology compare to other wind energy technology because of its high efficiency. The flow field is three-dimensional, incompressible, unsteady, turbulent, and separated to a large extent.

From the above literature review, it is clearly understood that the efficiency of wind turbine is always based on the parameters such as design and size of the blade, aspect ratio, tip speed ratio, blade angles and velocity. The power production of combined vertical and horizontal wind mill is high compare to vertical axis wind turbine and horizontal axis wind turbine. It requires less space for high generation of electricity.

III. CONCLUSIONS

Renewable technology which is emerging technology rapidly expands as a good option in the power generation sector. In India, due to Jawaharlal Nehru solar mission which have a target to established 20,000 MW till 2020, Wind industries expand in electricity generation. Very important role played by deregulation act of government that is electricity act 2003 technology is one of the glowing technology compare to other wind energy technology because of its high efficiency. The flow field is three-dimensional, incompressible, unsteady, turbulent, and separated to a large extent.

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Verification of wind turbine prediction data does justify the use of BEM prediction methods which analyses the blades from a two-dimensional aerodynamic perspective. BEM does have shortcomings, such as no stall-delay model and an inadequate tip-loss model. However, its ability for robust analysis and low computational cost make it advantageous. Furthermore, assuming a two-dimensional nature for the flow In essence, the literature review provided a guideline for defining the model for use in this optimization project. The literature review recognized those design features to be prioritized and laid out those analysis techniques which would be the most suitable. A simplified model of the wind turbine blade with four radial stations, analyzed according to BEM methods with tip loss corrections, was justified. Furthermore, representation of the airfoil profiles as blended shape functions became a feasible concept.

The problems identified from the study of literature review are as follows:

- Design of play an important role in aerodynamic performance of different aerofoil.
- The success of any optimization design is dependent on the clear definition of the design objective as well as the limitations on the solution space. Definition of the solution space is dependent on the extent of freedom of the design variables.
- Wind turbines should be optimized, by taking swept area into consideration, in terms of the local area conditions to capture power as maximum as possible. The output power of a wind turbine is directly related to the wind speed as well as to the swept area of its blades.

REFERENCES:

[1] Niranjana.S.J, “Power Generation by Vertical Axis Wind Turbine”, International Journal of Emerging Research in Management &Technology ISSN: 2278-9359, Volume-4, Issue-7, 2015.

[2] Mr.Abhijit N Roy, Mr.SyedMohiuddin, “Design and Fabrication of Vertical Axis Economical wind mill”, International Journal on Recent and Innovation Trends in Computing and Communication, ISSN: 2321-8169, Volume: 3 Issue: 2, 133 – 139, 2015.

[3] D. A. Nikam, S. M. Kherde, “Literature review on design and development of vertical axis wind turbine blade”, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622, 156-161, 2015.

[4] Altab Hossain, A.K.M.P. Iqbal, Ataur Rahman, M. Arifin, M. Mazian, "Design and Development of A 1/3 Scale Vertical Axis Wind Turbine for Electrical Power Generation", Journal of Urban and Environmental Engineering (JUEE), ISSN 1982-3932, volume: 1 Issue:2, 53-60, 2007.

[5] M. Abid, K. S. Karimov, H. A. Wajid, F. Farooq, H. Ahmed, O. H. Khan, " Design, Development and Testing of a Combined Savonius and Darrieus Vertical Axis Wind Turbine", Iranica Journal of Energy and Environment, ISSN: 2079-2115, volume: 6, Issue:1, 1-4, 2015.

[6] ParthRathod, KapilKhatik, Ketul Shah , Het Desai , Jay Shah, "A Review on Combined Vertical Axis Wind Turbine", International Journal of Innovative Research in Science, Engineering and Technology, ISSN: 2347-6710, volume: 5, Issue:4, 5748-5754, 2016.

[7] B.O.Omijeh, C. S. Nmom, E. Nlewem, " Modeling of a Vertical Axis Wind Turbine with Permanent Magnet Synchronous Generator for Nigeria", International Journal of Engineering and Technology, ISSN: 2049-3444, volume: 3. Issue: 2, 212-220, 2013.

[8] KunduruAkhil Reddy, KalyanDagamoori, ArimalaParamasivamSruthi, SaiApurva .N, Nimmala Naga Maha Lakshmi Naidu, A.Vamsi Krishna Reddy, Beri Rajesh, KudaKiran Kumar, Chithaluri Shivasri, SumamaYaqub Ali, "A Brief Research, Study, Design and Analysis on Wind turbine", International journal of modern Engineering research(IJMER), ISSN: 2249–6645, volume: 5,Issue: 10, 5- 30, 2015.

[9] PiyushGulve, Dr. S.B.Barve, "Design and Construction of Vertical Axis Wind Turbine", International Journal of Mechanical Engineering and Technology (IJMET), ISSN 0976 – 6340, volume: 5, Issue: 10, 148-155, 2014.

[10] Changduk, K., T. Kim, D. Han and Y. Sugiyama, 2006. Investigation of fatigue life for a medium scale composite wind turbine blade. Int. J. Fatigue, 28: 1382-1388.

[11] Bermudez, L., A.Velazquez and A. Matesanz, 2000. Numerical simulation of unsteady aerodynamics effect in horizontal axis wind turbine. Solar Energy, 68: 9-21.