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Literature review on design and development of vertical axis wind turbine blade

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Abstract:
The use of wind energy for energy generation is one of the oldest methods for harnessing renewable energy. Use of renewable energy is an essential ingredient of socio-economic development and economic growth. Renewable energy sources such as wind energy, tidal energy etc. is abundant and can help in reducing the dependency on fossil fuels. With increased concern for environment now days led to the research for more environment friendly sources of energy and with this considerations wind energy can be considered as a viable option in this regard. Different configurations of wind turbines such as horizontal axis wind turbine and vertical axis wind turbines are mainly used for energy extraction. Horizontal axis mainly used in large scale applications and thus its implementation is generally a concern due to huge installment setup and initial cost; whereas vertical axis wind turbines offer promising solution for smaller ruler areas or medium sized residential spaces. Energy generation from wind turbines will surely be affected by geometry of bade it is using and its orientation in turbine. For effective use of turbine both parameters should be optimally set and determined. This review work focuses on various stages for design and development of optimized vertical axis wind turbine which will studies various parameters such as general wind energy scenario, different available energy extraction methods, design and aerodynamic performance analysis of vertical axis wind turbines. Project work will include Optimization of design parameters of vertical axis turbine blades considering different parameters such as geometry orientation in assembly.
Keywords— Vertical axis wind turbine , Renewable energy , Wind Energy , Energy generation

I . INTRODUCTION

Wind is the indirect form of solar energy and is always being replenished by the sun energy. Wind energy is associated with the kinetic energy of flowing wind. It is created from point where the sun's radiation, which in combination with other factors such as tilt and displacement of the Earth in Space or we can say that it is caused due to differential heating of the earth’s surface by the sun. Wind energy provides a viable and environmental friendly option and national energy security at a time when decreasing global reserves of fossil fuels resources threatens the long-term sustainability of global economy.

A . Wind Energy Scenario

The focus on energy generation from Renewable Energy Resources has increased significantly in the recent years in the wake of growing environmental pollution, rising energy demand and depleting fossil fuel resources. Different sources of renewable energy include biomass, solar, geothermal, hydroelectric, and wind energy. Among these resources wind has proved to be a cheaper alternative energy resource and hence extensive research efforts have been put to improve the technology of electricity generation through wind energy. The world has enormous potential of wind energy that should be utilized for electricity generation.

The wind energy extraction technology has a unique technical identity in view of the methods used for design. Current research techniques used now a day 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 reduced to great extent over the last few years. Indian Renewable Energy Development Agency (IREDA) and the wind industry are working together to accomplish these improvements through various research and development programs.

Figure 1 shows the wind velocities at various locations all around the world. In areas where favourable sites exist, it has already been preferred over conventional fossil fuels resources for electricity generation. Wind power is now the world's fastest growing energy resource utilized. Figure 2 shows that installed wind generation units capacity has increased from 25,000 MW to more than 200,000 MW in 10 years from 2001 to 2010. Although the vertical axis wind turbine was the first ever used wind turbine for harnessing wind energy, researchers of the modern era lost interest in it due to the initial perception that VAWT cannot be used for large scale electricity generation also. [1]

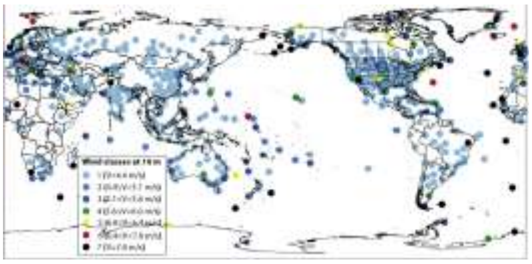

Fig. 1: Average wind velocity in different regions of the world [1]

Horizontal axis wind turbine remained in the focus of all wind energy related research activity for last few decades of research. That is why major portion of the installed capacity shown in Figure. 2 Comprises of it only. However, research work on vertical axis wind turbines continued in parallel at a relatively smaller scale as compared to prior one. Scientists and Engineers developed various wind turbine configurations and utilized different approaches for their analysis. Optimum conditions for the working of turbines were determined through most of research work carried out.

B . Wind farms in India

1. Muppandal–Perungudi (Tamil Nadu)
With an total wind power capacity of 450 MW, the Muppandal –Perungudi region near Kanyakumari in Tamil Nadu has the elite distinction of having one of the largest clusters of wind turbines. About investment Rs 2500 crores has been done in wind power in this region.
2. Kavdya Donger, Supa (Maharashtra)
A wind farm project developed at Kavdya Donger at Supa, off the Pune–Ahmednagar highway, nearly about 100 km from Pune. This wind farm has total 57 machines of 1-MW capacity each. Annual utilization capacity of nearly up to 22% has been reported from this site in total. This farm is connected through V-SAT to project developers and promoters for online performance monitoring of total unit.

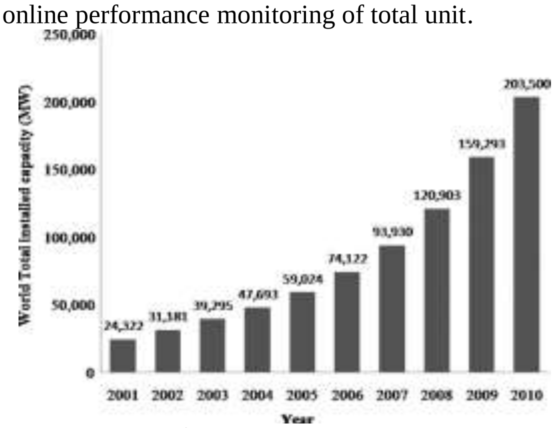

Fig 2: Installed wind potential of the world, source: World Wind Energy Association [1]

3. Satara district (Maharashtra)
With encouraging policy for private investment in wind power projects resulted in significant wind power development in Maharashtra state, particularly in the Satara district. Wind power capacity of about 340 MW been established at Vankusawade, Thosegarh, and Chalkewadi with a total investment of about Rs.1500 crores.

C . Different types and design configurations for wind turbine:

A great degree of design versatility is available in the wind turbines design configurations. There are a few problems inherent to the currently available designs including low starting torque, turbine blade lift forces, lower efficiency, poor building and foundation integration, etc. In the past few decades, the engineers came up with many innovative design approaches to address these issues associated with wind turbines design. Following sections mentions different available configurations with their respective features and concerns. [3]

Horizontal axis wind turbine (HAWT):

The rotational axis of this turbine must be oriented parallel to the wind in order to produce power. Numerous sources claim a major efficiency per same swept area and the majority of wind turbines are of this type. Currently horizontal axis turbines are the most used due to its higher performance featuring high winds, easy maintenance and low cost. Although there are various configurations of wind turbines, one blade, two blades, three and Multi blades, removing the one blade and multi blades which are for special cases, the two blades and three blades are the most used. But the three blades are used more because its energy produced is greater and its robustness makes them stronger to stronger winds and it is created less impact visual. Following are disadvantages of HAWT taken from study article of Young-Tae Lee [3].

Disadvantages of HAWT:

The tall towers and blades up to 90 meters long are difficult to transport. Transportation can now cost 20% of equipment costs. Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators. Massive tower construction is required to support the heavy blades, gearbox, and generator. Reflections from tall HAWTs may affect side lobes of radar installations creating signal clutter, although filtering can suppress it. Downwind variants suffer from fatigue and structural failure caused by turbulence when a blade passes through the tower's wind shadow (for this reason, the majority of HAWTs use an upwind design, with the rotor facing the wind in front of the tower). HAWTs require an additional yaw control mechanism to turn the blades toward the wind.

Vertical Axis Wind Turbines (VAWT):

The rotational axis is perpendicular to the wind direction or the mounting surface. The main advantage is that the generator is on ground level so they are more accessible and thus don't need a yaw system. Because of its proximity to ground, wind speeds available are lower. It is a vertical axis machine, very simple from the standpoint of constructive and operational. Besides simplicity, has the advantage of being very robust and have a strong starting torque, that possible the starting even with very weak winds. But can be used only with reduced powers and that the turbine works well with light winds, while its yield decreases with high winds and even becomes vulnerable, so their size cannot exceed certain limits.

Advantages of VAWT

A massive tower structure is less frequently used, as VAWTs are more frequently mounted with the lower bearing mounted near the ground. Designs without yaw mechanisms are possible with fixed pitch rotor designs. VAWTs have lower wind start-up speeds than HAWTs. Typically, they start creating electricity at 6 M.P.H. (10 km/h). VAWTs may have a lower noise signature.

Disadvantages of VAWT

Most VAWTs produce energy at only 50% of the efficiency of HAWTs in large part because of the additional drag that they have as their blades rotate into the wind. While VAWTs' parts are located on the ground, they are also located under the weight of the structure above it, which can make changing out parts nearly impossible without dismantling the structure if not designed properly. Having rotors located close to the ground where wind speeds are lower due to wind shear, VAWTs may not produce as much energy at a given site as a HAWT with the same footprint or height. Because VAWTs are not commonly deployed due mainly to the serious disadvantages mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

II. BLADE DESIGN AND PERFORMANCE ANALYSIS

Young-Tae Lee [3] in article "Numerical study of the aerodynamic performance of a 500 W Darrieus-type vertical-axis wind turbine" studied characteristic and the performance of a Darrieus-type vertical axis wind turbine with NACA airfoil blades. The performance of Darrieus-type turbine this can be characterized by torque and power. Various parameters especially related to blade design affect performance of turbine, parameters such as chord length, helical angle, pitch angle, and rotor diameter. To estimate the optimum shape of the Darrieus-type wind turbine in accordance with various design parameters, aerodynamic characteristics and the separated flow occurring in the vicinity of the blade, the interaction between the flow and the blade, and the torque and power characteristics is examined in this work.

In this study analyse through, wind tunnel experiment and numerical analysis concluded that Darrieus-type wind turbine with a NACA airfoil blade produces maximum output power with optimized design parameters. Additionally, variations of flow and performance characteristics which appear while design parameters are varied were derived numerically. The results of study can be summarized as follows.

The thickness ratio of the airfoil blade makes no significant difference in the performance of the wind rotor and turbine considered. However, similar to solidity, a thick airfoil is applied by a higher drag force, which leads to a low power coefficient from turbine.

In terms of power performance at varying pitch angles of blades, the highest efficiency occur pitch angle of 2 degree. The optimum pitch angle is predicted to change in accordance with the angle of attack.

Bavin Loganathan [4] investigated a domestic scale vertical axis wind turbine considering blade geometry with semi-circular shaped blades under a range of wind speeds during operation. A 16-bladed rotor was initially designed and its torques and angular speeds were measured over a range of wind speeds using a wind tunnel. Additionally, a new concept of cowling device was developed to enhance the turbine efficiency by directing air flow from the rear blades into the atmosphere. Another 8-bladed rotor was also manufactured to investigate the effect of blade number on the maximum power generation from turbine. The aerodynamic performance of the cowling device was also investigated in this study. Maximum power curves as a function of wind speeds were established for each configuration. The results indicated that the 16-bladed wind turbine can be used for domestic scale wind power generation also the results show that the cowling device has positive effect to increase the rotor speed to a significant amount. With the use of the cowling device, the average rotor speed increased by about 26% for the 16-bladed rotor compared to the baseline configuration. A significant increase about 40% of rotor speed was also found for the 8-bladed rotor with the implementation of cowling device. The results of article also indicated that the cowling device can be used to increase the power output of this cyclonic type vertical axis wind turbine especially with a reduce number of blades.

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In this paper [5], an energy and exergy analysis is performed on four different wind power systems considering especially blade performance, including both horizontal and vertical axis wind turbines. Significant variability in turbine designs and operating parameters are encompassed through the selection of systems. In particular, two airfoils that is blade geometries, commonly used in horizontal axis wind turbines are compared with two vertical axis wind turbines.

This paper analyzes each system with respect to both the first and second laws of thermodynamics for analysis. The aerodynamic performance of each system is numerically analyzed by computational fluid dynamics software in this case FLUENT. Key design variables are analysed and the predicted results are discussed during study. The exergetic efficiency of each wind turbine is studied for different geometries, design parameters and operating conditions, thereby providing a useful design tool for wind turbine blade power development.

Work concludes that the first and second laws were used to compare the performance of a variety of wind power systems. Exergy analysis was shown to allow a diverse range of geometric and operating designs to be compared with a common metric. Exergy is a useful parameter in wind power engineering, as it can represent a wide variety of turbine operating conditions, with a single unified metric. Through exergy methods, better site selection and turbine design can improve system efficiency, decrease economic cost, and increase capacity of wind energy systems.

III. AERODYNAMICS AND PERFORMANCE ANALYSIS OF VERTICAL AXIS WIND TURBINE BLADES

Achieving success in harvesting the power of wind requires a detailed understanding of the physics of the interaction between the moving air and wind turbine rotor blades. An optimum power production depends on perfect interaction between both blade and wind.

The wind consists of a combination of the mean flow as well as turbulent fluctuations about that mean flow. These are very complicated and time consuming for the analysis, and they can only be predicted by understanding the aerodynamics of steady state operation. An idealized wind turbine rotor will be examined along with the airflow around the generator rotor and wind turbine blade.

Aerodynamics Theory and Performance Characteristics:

The aerodynamic analysis of VAWTs is complicated due to their orientation to the oncoming wind. The VAWTs have a rotational axis perpendicular to the oncoming airflow. This accounts for aerodynamics that is more complicated as compared to a conventional HAWT. However, the configuration has an independence of wind direction. The main shortfalls of this are the high local angles of attack and the wake coming from the blades in the upwind part and axis. This disadvantage is more pronounced with VAWTs. The power output from the high speed lift VAWT can be appreciable.

Understanding the aerodynamics of the pure drag type of VAWT will give important insight for improving the lift coefficient, and designing this turbine for better and more efficient harnessing of the wind power.

Lift Force

The lift force is one of the major force components exerted on an airfoil blade section inserted in a moving fluid. It acts normal to the fluid flow direction. This force is a consequence of the uneven pressure distribution between the upper and lower blade surfaces.

Drag force

The drag force acts in the direction of the fluid flowing. Drag occurs due to the viscous friction forces on the airfoil surfaces, and the unequal pressure on surfaces of the airfoil. Drag is a function of the relative wind velocity at the rotor surface, which is the difference between the wind speed and the speed of the surface,

The lift and drag coefficient values are usually obtained experimentally and correlated against the Reynolds number for analysis purpose. This thesis uses a CFD code to predict these coefficient values over a range of operating conditions. The amount of power generated by the vertical axis wind turbine will be analysed through code.

Research work by Robert Howell [6] presents a combined experimental as well as computational study into the aerodynamics and performance of a small scale vertical axis wind turbine blades. Wind tunnel tests were carried out to ascertain overall performance of the turbine and two- and three-dimensional unsteady computational fluid dynamics models were generated to help and to understand the aerodynamics of this turbine performance.

Wind tunnel performance results are presented for cases of different wind velocities, tip-speed ratio and solidity as well as rotor blade surface finish. It is shown experimentally that the surface roughness present on the turbine rotor blades has a significant effect on performance of turbine. Below a critical wind speed (Reynolds number of 30,000) the performance of the turbine is degraded by a smooth rotor surface finish but above it, the turbine performance is enhanced by a smooth surface finish of blade. Both two bladed and three bladed rotors were tested and a significant increase in performance coefficient is observed for the higher solidity rotors (three bladed rotors) over most of the operating range. Dynamic stalling behaviour and the resulting large and rapid changes in force coefficients and the rotor torque are shown to be the likely cause of changes to rotor pitch angle that occurred during early testing. This small change in pitch angle of blade caused significant decreases in performance.

A small model research VAWT turbine has been manufactured as prototype and tested over a range of operating conditions. The straight turbine rotor blade, with an aspect ratio of 4:1, operates at relatively low tip speeds and its performance shows a clear dependence on the rotor blade surface finish. Below a critical Reynolds number (30,000), the performance is enhanced by having the surface of the turbine roughened, but above this Reynolds number the power coefficient is observed to be degraded. Computational predictions of the performance coefficient of this turbine were carried out and the 3D simulations were shown to be in reasonably good agreement with the experimental measurements, considering errors and uncertainties in both the CFD simulations and the wind tunnel measurements. The 2D simulations of flow showed a significantly increased performance compared to the 3D simulations and this was shown to be mainly due to the presence of the large tip vortices present in the real turbine and the 3D simulations. Simulations illustrated the periodic pulsing nature of the tip vortices caused by the changing lift generated by the rotor blades as they travel through each rotor revolution. At phases considered where higher amounts of lift are generated, stronger tip vortices are present, whereas at phases where little lift is generated, the vortices are observed to be significantly reduced as per work carried out.

IV. SUMMERY

Vertical axis wind turbine offer economically viable energy solution for remote areas away from the integrated grid systems. In order to spread the use of VAWT, the problems associated with various configurations, i.e. poor self-starting and low initial torque, low coefficient of power, poor building integration should be overcome. Furthermore, following conclusions can be drawn from the present review:

Sufficient wind energy potential is available in the world. In order to make best use of it efficient designs of wind turbines need to be developed. Various vertical axis wind turbines can offer solution to the energy requirements with a reasonable payback period. Coefficient of power can be maximized by selecting a suitable operating range for various configurations.

Remarkable advances in wind turbine design have been possible due to developments in modern technology. The advanced wind turbine technologies have been reviewed as follows considering overall performance point of view

The factors such as selection of site, height, choice of wind generators, wind velocity, wind power potential have been considered as an objective function of probabilistic models. Selection of windy site for wind power generation requires meteorological data for installation of wind generator. Experimental and theoretical methods are used to analyze vibration problems of wind turbines. Aeroaccoustic tests are used to find noise in the aerofoil.

Wind field modelling is an important part of a structural analysis of wind turbines. In aerodynamic modelling blade element moment theory is used for calculation of aerodynamic forces acting on the rotor blade. Control system modelling is used to keep the operating parameters of the wind turbine within the specified limit. These developments and growing trends towards wind energy signal is a promising future for the wind energy industry. With this improved technology wind turbine can be designed for its optimum power production at less cost.

V. CONCLUSION

Vertical axis wind turbine offer economically viable energy solution for remote areas away from the integrated electricity grid systems. Blade design plays critical role for performance and energy extraction from turbine. In order to spread the use of VAWT, the problems associated with various configurations, i.e. poor self-starting and low initial torque, low coefficient of power, poor building integration should be overcome.
With the assumption of placing the turbine in a location with moderate wind availability with optimized blade parameters and design specifications, high power generation is achieved with vertical axis wind turbine and can be serving as energy generation unit for remote areas.

REFERENCES

[1] *G.M. Joselin Herberta, S. Iniyanb,_, E. Sreevalsanc, S. Rajapandiand* "A review of wind energy technologies"*;* Department of Mechanical Engineering, St. Joseph's College of Engineering, Chennai-119, India

[2] *Muhammad Mahmood Aslam Bhutta, Nasir Hayat, Ahmed Uzair Farooq, Zain Ali, Sh. Rehan Jamil, Zahid Hussain* "Vertical axis wind turbine – A review of various configurations and design techniques" Department of Mechanical Engineering, University of Engineering and Technology Lahore, G.T. Road, Lahore, Punjab 54890, Pakistan

[3] *Young-Tae Lee, Hee-Chang Lim* "Numerical study of the aerodynamic performance of a 500 W Darrieus-type vertical-axis wind turbine",School of Mechanical Engineering, Pusan National University, San 30, Jangjeon-Dong, Geumjeong-Gu, Busan 609-735, South Korea

[4] *Bavin Loganathan, Harun Chowdhury, Israt Mustary and Firoz Alam* "An experimental study of a cyclonic vertical axis wind turbine for domestic scale power generation" School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, 3083, Australia

[5] *K. Pope, I. Dincer, G.F. Naterer* "Energy and exergy efficiency comparison of horizontal and vertical axis wind turbines" Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, Canada

[6] *Robert Howell, Ning Qin, Jonathan Edwards, Naveed Durrani* "Wind tunnel and numerical study of a small vertical axis wind turbine" Department of Mechanical Engineering, University of Sheffield, Sir Frederick Mappin Building, Mappin Street, Sheffield, UK