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A Review Paper on Vertical Axis Wind Turbine for Design and Performance Study to Generate Electricity on Highway

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Abstract — *The use of wind power for energy production, renewable energy is one of the oldest methods for tapping. Socio-economic development and use of renewable energy is an essential component of economic development. Tidal energy, wind energy, etc., such as abundant renewable energy sources and reduce dependence on fossil fuels can help. With increased concern for environment now days led to the research for more eco-friendly sources of energy and with this considerations wind energy can be deliberated as a feasible option in this regard. Different types of wind turbines such as horizontal axis wind turbines and vertical axis wind turbines are mostly used for energy extraction. Horizontal axis mainly used in huge scale applications and thus its implementation is generally a concern due to enormous instalment setup and initial budget; whereas vertical axis wind turbines offer promising solution for medium sized residential spaces or smaller ruler areas. Energy production from wind turbines will certainly be affected by geometry of bade it is using and its orientation in turbine. For effective and operational use of turbine both parameters must be optimally set and determined. This review emphases on several stages for design and development of improved vertical axis wind turbine which will studies various factors such as wind energy scenario, different accessible energy extraction techniques, design and performance analysis of vertical axis wind turbines. It will comprise Optimization of design parameters of vertical axis turbine blades in view of different parameters such as geometry orientation in assembly*

Keywords- *Wind Energy, Energy generation, Vertical axis wind turbine, Renewable energy*

I. INTRODUCTION

Wind is the secondary 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 formed 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 affected due to differential heating of the earth's surface by the sun. Wind energy provides a useful and ecological option and national energy security at a time when falling global reserves of fossil fuels resources threatens the long-term sustainability of global economy. However, VAWT research work endures in parallel on one relatively small. Scientists and engineers have established various Wind turbine structures and use different Methodologies for their analysis. The optimum conditions for working VAWTs were determined. The details of these methods and alignments the major findings of the researchers on the vertical axis Wind turbines are reviewed in this paper. A closer look at the concepts The fact that VAWTs are suitable for power leads Where the conditions are not overly traditional HAWTs Such as high wind velocity and turbulent due to capacity the wind blows. Another major advantage is that VAWTs Omni-directional wind from any direction, without any accepted Mechanism yawing [7]. And a comparison between VAWTs vs. HAWTs is made in Table 1. This table makes it clear that a number the promising features which, if properly exploited can a better option.

1.1 WIND ENERGY SCENARIO IN WORLD

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]

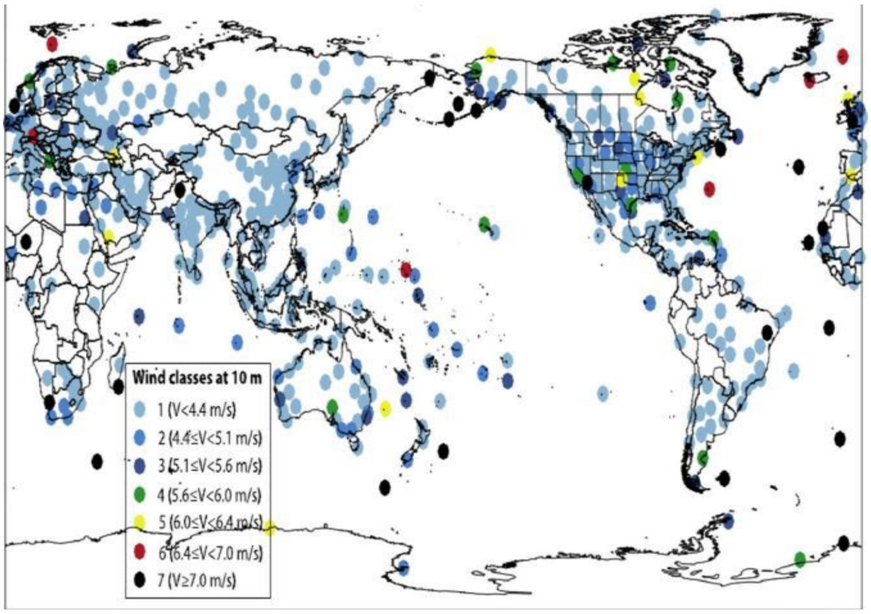

Fig. 1: Average wind velocity in different regions of the world [1]

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.

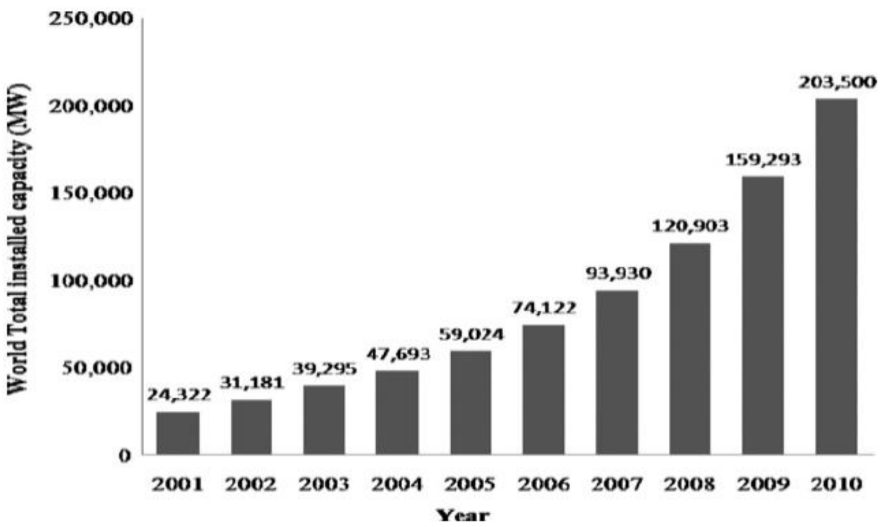

Fig. 2: Installed wind potential of the world, source: World Wind Energy Association [1]

1.2 WIND ENERGY SCENARIO IN INDIA

Wind energy program was started in India by the end of the 6th five yearly plan during 1983-84 and in the last few years it has increased significantly. The main objective of this program was the commercialization of wind energy generation, support research and development, deliver help to wind projects and to build awareness among people. Ministry of Non Renewable Energy (MNRE) has done various amendment regarding incentives, schemes and policies for wind energy under this program. India is relatively beginner to the wind energy sector as compared to Denmark or USA. But Indian policy support for wind energy has directed India and it ranked fourth with largest installed wind power capacity [12]. The total installed power capacity is 26867.11 MW on April 30, 2016[13] and now India is just after China, USA and Germany. Global installed wind power capacity displays India's better performance in wind energy sector. The five leading wind power countries are China, USA, Germany, Spain and India and they together represent a share of 73.5% of the global wind capacity. As per MNRE, wind power accounts for the largest share of renewable power installed capacity i.e.70 percent (2012), other than the other renewable sources. The total installed wind power capacity in India reached 26.9 GW in April, 2016. A rapid growth in wind power installation has been measured in southern and western states in India. A need for about 350- 360 GW of total energy production capacity was reported by the Central Electricity Authority in its National Electricity Plan (2012), by the year 2022[15]. Only onshore wind potential has been utilised so far by India. Despite the fact that India are having long coast line over 7500 km, we have not yet appointed our offshore wind source for energy generation. The Capacity Utilization Factor (CUF) of offshore wind turbines is much higher other than the onshore turbines for the reason that of the high offshore wind speed [13]. Offshore Wind Steering Committee was formed by MNRE in August 2012, which passed a draft of the National Offshore Wind Energy Policy in May 2013.

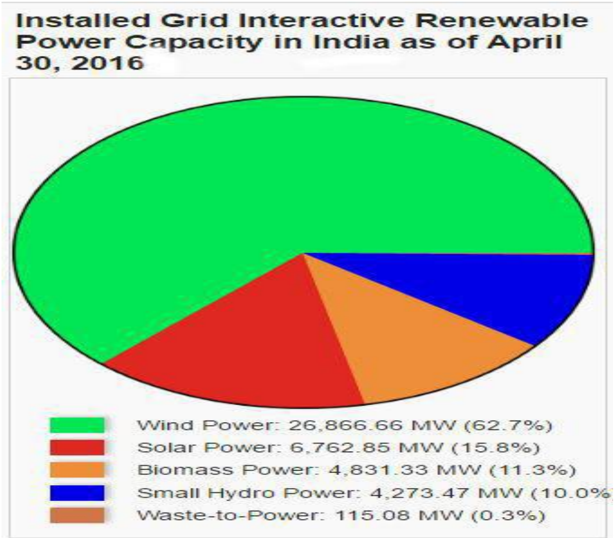

Fig. 3: Installed capacity of wind power in India comparing to other renewable energy power

1.3WIND FARMS IN INDIA

a. Muppandal–Perungudi (Tamil Nadu)

With a total wind power capacity of 1500 MW, the Muppandal –Perungudi region near Kanyakumari in Tamil Nadu has the best distinction of having one of the largest groups of wind turbines around 35% of India's total. During the financial year 2014-15, the electricity production is 9.521 billion Kwh which is nearly 15% CUF.

b. Satara district (Maharashtra) and Kavdya Donger, Supa (Maharashtra)

As on 30/09/2014, wind energy installed capacity is 4167.26 MW. As of now there are 50 developers listed with state nodal agency "Maharashtra energy Development Agency" for expansion of wind power projects. All the major companies of wind turbines counting Suzlon, Vestas, Gamesa, Regen, Leitner Shriram have presence in Maharashtra. With promising policy for private share in wind power projects lead to in significant wind power development in Maharashtra state, mainly in the Satara district. Wind power capacity of about 340 MW has been recognised at Vankusawade, Thosegarh, and Chalkewadi with a total venture of about Rs.1500 crores. A wind farm project established at Kavdya Donger at Supa, off the Pune–Ahmednagar highway, nearly about 100 km from Pune. This wind farm contains total 57 machines of 1-MW capacity each. Annual utilization capacity of almost 22% has been testified from this site in total. This farm is coupled through V-SAT to project developers and sponsors for online performance monitoring of total unit.

1.4 DIFFERENT TYPES AND DESIGN CONFIGURATIONS FOR VERICAL AXIS WIND TURBINE

A great degree of design versatility is available in the vertical 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 vertical wind turbines design. Following sections mentions different available configurations. [3]

VERTICAL AXIS WIND TURBINES (VAWT):

In the VAWTs, the rotational axis is perpendicular to the wind direction or the mounting surface. The main advantage, the generator is on ground level that provides accessibility and thus don’t need a yaw system. Because of its closeness to ground, wind speeds available are lesser. It is a vertical axis machine, very simple from the standpoint of constructive and operational. In addition to simplicity, they have the advantage of being very robust and have a strong starting torque, that possible the starting even with very low speed winds. But it can be used only with reduced powers and that the turbine works well with weak winds, while its yield drops with high winds and even becomes vulnerable, so their size cannot go beyond a certain limits.

Types of VAWTs:-
1. Darrieus type
2. Savonius type
3. Combined Darrieus-savonius
4. H-type and Modified H-type

MERITS OF VAWT

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

DEMERITS OF VAWT

Most VAWTs yield energy at only 50% of the efficiency of HAWTs in large part due to the additional drag as their blades rotate into the wind. While VAWTs' parts are situated on the ground, they are also placed under the weight of the structure above it that can nearly impossible make changing out parts without disassembling the structure if not designed appropriately. Having rotors located close to the ground where wind speeds are lower because of wind shear, VAWTs may not harvest as much energy at a given site as a HAWT with the same track or height. That's why VAWTs are not normally deployed due mostly to the serious drawbacks mentioned above, they appear novel to those not familiar with the wind industry. This has frequently made them the subject of wild claims and investment scams over the last 50 years.

Table 1. Merits of vertical axis wind turbines over horizontal axis wind turbines

	Horizontal axis wind turbine (HAWT)	Vertical axis wind turbine (VAWT)
Tower sway	Large	Small
Yaw mechanism	Yes	No
Self-starting	Yes	No
Overall Set-up Formation	Complex	Simple
Generator location	Not on ground	On ground
Height from ground	Large	Small
Blade's operation space	Large	Small
Noise produced	high	Relatively Less
Wind direction	Dependent	Independent
Obstruction for birds	High	Less
Ideal efficiency	50–60%	More than 70%

II. PERFORMANCE ANALYSIS ON BLADE DESIGN

Ryan McGowan et al. [11] started to integrate prediction, design, and testing of a 2m*2m vertical axis wind turbine with slanted double blades. Predictions of the operating points incorporating multiple streamtube theory and accounting for interactions are validated against published results elsewhere. Reynolds number effects are clearly seen in the predictions, and their appropriate insertion allows the predictions to match experimental data exceptionally well. A self-starting device using drag tubes is included in the simulation. It is found that the vertical axis wind turbine must operate at a tip speed ratio that is considerably greater than 1. Limiting the turbine speed for safety indicates that high tip speed ratio is best gained at low wind speeds by taking the turbine to a good operating speed using human pedaling action or an electric motor. This will permit extraction of considerable amounts of power from the wind compared to what we have been able to achieve using purely self-powered machine operation. With this state of predictions we are in a position to go to detailed time-resolved simulations and thus to control algorithms for adapting to given wind patterns and optimizing power extraction and safety. Young-Tae Lee et al. [3] in article ―Numerical study of the aerodynamic performance of a 500 W Darrieus-type vertical-axis wind turbine studied characteristics and the performance of a Darrieus-type vertical axis wind turbine with NACA airfoil blades. Darrieus-type turbine performance can be characterized by torque and power. Many parameters especially related to blade design have impact on performance of turbine, parameters such as chord length, pitch angle, and rotor diameter etc. To estimate the optimum shape of the Darrieus-type wind turbine in accordance with various design parameters, the separated flow arising in the vicinity of the blade, the interaction between the flow and the blade, and the torque and power characteristics is examined in this review. 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 act 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 greater drag force, which implies 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˚. The optimum pitch angle is anticipated to change in accordance with the angle of attack.

Conaill Soraghan et al. [15] have investigated the influence of lift to drag ratio on optimal aerodynamic performance of straight blade vertical axis wind turbines .they have reported an effective lift to drag for a VAWT design on the basis of average torque per cycle. This technique is used to characterize the relationship between overall optimum aerodynamic performance and design parameters. A prediction model of double multiple stream tube aerodynamic is employed to prove the effect of lift to drag ratio on optimal power performance for the H-rotor and the V-rotor concept VAWT.This metric can be used to characterize the relationship between overall optimum aerodynamic performance and design parameters. An investigation into the effect of lift to drag ratio on performance of a base case H-rotor revealed that the metric has a significant impact on maximum attainable power coefficient. Bavin Loganathan et al. [4] studied 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 calculated over a range of wind speeds using a wind tunnel. Furthermore, a new concept of cowling device was established to enhance the turbine efficiency by directing air flow from the rear blades into the atmosphere. Another 8-bladed rotor was also manufactured to examine the effect of blade number on the maximum power generation from turbine. The results of article indicates that the cowling device can be used to increase the power output of this cyclonic type vertical axis wind turbine particularly with a reduce number of blades. It also shows that the wind turbine device has positive effect to increase the rotor speed to a significant amount. The average rotor speed increased by about 26% for the 16-bladed rotor in the comparison of the baseline configuration with implementation if new cowling device. K. Pope et al. [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 involved through the selection of systems. In particular, two airfoils that is blade geometries, generally used in horizontal axis wind turbines are compared with two vertical axis wind turbines. This paper reports thoroughly 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 considered and studied for different geometries, design parameters and operating conditions, thereby providing a useful design tool for wind turbine blade power development. Exergy analysis was shown to allow a various range of geometric and operating designs to be compared with a common metric. As useful parameter in wind power engineering, exergy can characterise a wide variety of turbine operating conditions, with a single unified metric. Better site selection and turbine design can improve system efficiency, decrease economic cost, and increase capacity of wind energy systems through exergy methods.

III. PERFORMANCE ANALYSIS OF VERTICAL AXIS WIND TURBINE BLADES

For harvesting the power of wind turbine, requires a detailed understanding of the physics of the interaction between the moving air and wind turbine rotor blades. An optimal power generation 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.

3.1 AERODYNAMICS THEORY AND PERFORMANCE TECHNIQUES: The aerodynamic analysis of VAWTs is complex due to their co-ordination to the oncoming wind. The VAWTs have a rotational axis perpendicular to the approaching airflow. This accounts for aerodynamics that is more complicated as compared to a conventional HAWT. On the other hand, 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 pure drag type of VAWT's aerodynamics will give important insight for improving the lift coefficient, and for better and more efficient designing this turbine harnessing of the wind power

3.2 DRAG FORCE AND LIFT 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 imbalanced pressure on surfaces of the airfoil. Drag as a function of the relative wind velocity at the rotor surface, is the difference between the wind speed and the speed of the surface, the lift and drag coefficient values are usually achieved experimentally and correlated against the Reynolds number for analysis purpose. This work 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. 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 irregular pressure distribution between the upper and lower blade surfaces.

David A. Spera et al. [16] investigated the Lift and Drag Coefficients of Stalled and Installed Airfoils in Wind Turbines and Wind Tunnels. They have reported a mathematical equation to calculate lift and drag coefficients along the spans of torsional-stiff rotating airfoils of the type used in wind turbine rotors and wind tunnel fans. These airfoils operate in both the uninstalled and stalled aerodynamic regimes, and acceptable models must be able to move seamlessly from one regime to the other. The input factors in the equations defining these models should also be derivable from a minimum of test statistics, because often only a limited number of lift and drag data points in just the pre-stall system are available. Because having finite lengths, wind turbine and fan airfoils, model equations must contain explicit corrections for the effects of aspect ratio of length to chord width on lift and drag. Because the torsion stiffness of a wind turbine airfoil about own longitudinal axis is normally high, airfoil moment coefficients are less significant than lift and drag coefficients, that's why moment coefficients are not addressed in this study.

3.3 CFD ANALYSIS:- Research work by Robert Howell [6] presents a combined experimental as well as computational study into the aerodynamics and performance of a small scale VAWT blades. Wind tunnel tests were carried out to ascertain overall performance of the turbine and 2D and 3D unsteady computational fluid dynamics (CFD) models were generated to help and to understand the aerodynamics of this turbine performance. Wind tunnel performance results are given for cases of different wind velocities, tip-speed ratio and solidity along with rotor blade surface finish. It is shown experimentally that the surface roughness present on the turbine rotor blades has a substantial effect on performance of turbine. Below a critical wind speed (Reynolds number of 30,000) the performance of the turbine goes down 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 identified for the higher solidity rotors (three bladed rotors) over most of the operating range. Dynamic stalling behaviour and the resultant large and rapid changes in force coefficients and the rotor torque are presented 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. Marco Raciti Castelli et al. [17] have Numerical evaluated the aerodynamic and inertial contributions to Darrieus wind turbine blade deformation. The author has presented a model for the evaluation of aerodynamic and inertial contributions to a VAWT blade deformation. Through the use of a specially designed coupling code, solid modelling software, capable of generating the desired blade geometry having dependency on the design geometric parameters, is linked to a finite volume CFD code for the measurement of rotor performance and to a Finite Element Method (FEM) code for the structural design analysis of rotor blades.

3.4 VORTEX METHODS Wilhelm et al. [9] developed 'Vortex Analytical Model' for aerodynamic load calculations. It measured vortices' circulation strength and location that was used to estimate the velocity of air around the rotor at any point. The velocity measurements were then used to measure the rotor performance under different flow conditions. The advantages of this model include its ability to decide blade-wake interactions, estimate results in unsteady flow conditions and for finite aspect ratios of rotor blades. Kopeika and Tereshchenko [9] also discussed the vortex models for load calculations on rotor blades. They have modelled non-stationary structure of streamlines for every rotor blade using vortex lattice method. No quantitative findings are however discoursed by them in the paper. Ponta and Jakovkis [10] described the equations convoluted in the calculation of stresses and other parameters of Darrieus wind turbine analysis with Vortex Model. The equation to calculate stresses are simplified to the following form: In the above formulation, '' is the stress induced in the rotor blade, 'K' is the kinematic viscosity, '' is the density of air, and '' is given as the boundary layer thickness. The vortex methods can also be used for the determination of aerodynamic coefficients and measurement of efficiency of the turbine.

IV. DISSCUSSION AND CONCLUSION

Vertical axis wind turbine provides economically sustainable energy solution for remote areas away from the integrated grid systems. With the purpose of spread the use of VAWT, the problems associated with various patterns, i.e. poor self-starting and low initial torque etc., should be overcome. Furthermore, following conclusions can be drawn from the present review: In the world, enough wind energy potential is available. In order to make best use of it effective designs of wind turbines need to be developed. Several vertical axis wind turbines can offer solution to the energy necessities with a rational payback period. Coefficient of power can be improved by going for a proper operating range for various configurations. Incredible 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 features such as selection of choice of wind generators, wind velocity, site, height, wind power potential have been considered as an impartial function of probabilistic models. Selection of windy site for wind power generation requires meteorological data for setting up of wind generator. Experimental and theoretical methods are used to analyze vibration difficulties of wind turbines. Aeroaccoustic tests are used to detect 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 stands for calculation of aerodynamic forces acting on the rotor blade. Control system modelling is used to have the operating parameters of the wind turbine within the specified limit. These progresses and developing trends towards wind energy signal is an encouraging prospect for the wind energy industry. With this upgraded technology wind turbine can be designed for its optimum power generation at comparatively less cost. Blade design plays critical role for performance and energy extraction from turbine. 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

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