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Review Paper of Savonius Vertical Axis Wind Turbine Rotor Blade

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ABSTRACT: *This paper involves study of Savonius Vertical Axis Wind Turbine (SVAWT) blades. In past few years more research works are carried out to increase efficiency of Vertical Axis Wind Turbine. Review of all these papers shows that the experiments are conducted only on semi cylindrical bucket shape blades, twisted blades, blades with end flap edges and blades having frames with cavity vanes, for two blades, three blades and four bladed Savonius Vertical Axis Wind Turbine(SVAWT) to increase performance. They also conducted experiments by providing curtains or flow guide to the rotor, increasing in the stages of rotor and combining both Savonius and Darrieus rotor (i.e. hybrid rotors) to increase the efficiency of rotor. Research work or experiments on semi cylindrical bucket rotor blade edges, having extrusion or leading edges with different angles are not carried out. Development of these designs includes a multidisciplinary design optimization approach for optimizing the Vertical Axis Wind Turbine blade, considering both structural and fluid flow performance requirements. Weighted Property Method, Cost Property Method, limits Property Methods are used for Selection of suitable material. ANSYS and Computational Fluid Dynamics are used for structural analysis and fluid flow performance of newly designed blade.*

Key words: *Savonius Vertical Axis Wind Turbine, Flow guides, hybrid rotors, leading edge, CFD.*

I. Introduction

Change in climate is the biggest and most urgent environmental threat in the world. The greenhouse effect which is produced by human activity, by burning of fossil fuels such as coal, oil and gas for energy produced CO_2, cause increases in global temperatures, leading to more severe weather patterns such as floods, droughts and storms, rising sea levels and threats to entire ecosystems. To avoid inconsistent environmental condition rising global emissions must decrease within the next 10 years. This means we need to adopt those forms of energy that do not produce CO_2. [1]

With the recent deficiency in fossil fuels, demands for renewable energy sources are increasing, wind energy have become a most reliable technology for power generation. Currently, horizontal axis wind turbines (HAWT) dominate the wind energy market due to their large size and high power generation characteristics. However, vertical axis wind turbines (VAWT) are capable of producing a lot of power, and offer many advantages such as they are small, quiet, easy to install, can take wind from any direction, and operate efficiently in turbulent wind conditions, a new area in wind turbine research has opened up to meet the demands of individuals willing to take control and invest in small wind energy technology.

II. Energy Scenario

2.1 Non Renewable Energy

India is a country with more than 1.2 billion people accounting for more than 17% of world's population. It is the seventh largest country in the world with total land area of 3,287,263 sq kilometers. India measures 3214 km from north to south and 2993 km from east to west. It has a land frontier of 15,200 km and coastline of 7,517 km. India has 29 states and 7 union territories. It faces a formidable challenge in providing adequate energy supplies to users at a reasonable cost. [2] It has economy which is fastest growing economies in the world and experienced an average 7 % growth rate in the last decade. India accounts for 2.4 % of world energy production and stands at eleventh position in the world in energy production. But the country accounts for 3.5 % of total energy consumption and holds the sixth position in energy consumption. There is a wide gap between energy production and energy consumption which leads to increase in the energy production.

In 2010 India its self consumes 8 per cent of the world's coal and ranked as the third-largest consumer of coal in the world after China and the USA. Coal is important fuel than the Oil and gas. In 2010 India was the fourth-largest consumer of oil in the world, after the USA, China and Japan; it consumes 3.9 per cent of the world's oil consumption. In 2010, fossil fuels accounted for 74 per cent of the total energy consumed in India from all the sources of energy in the world. However, the per capita consumption is very low—around 0.59 Tone Oil Equivalent in 2010, and this has not changed much since then. Similarly in the case of energy-related CO_2 emissions, India's emissions in 2010 amounted to 1.6 Giga tone CO_2 and have been steeply rising in the past years, making the country the world's third largest emitter. However, its per capita emission of 1.4 tones CO_2 is still much lower than that of China, OECD (Organization for Economic Co-operation and Development) countries or the world average (IEA 2012b).[1]

India has the fifth-largest power generation portfolio worldwide. Coal and gas are the popular sources and account for 58% and 9%, share, respectively. The country has been rapidly adding capacity over the last few years; it installed power plants which increase capacity from 98 GW to 223 GW in Five Year Plan of 1998 to 2013. Within a decade the country became fourth largest energy consumer in the world. Economic growth and increasing prosperity, coupled with factors such as growing rate of urbanization, rising per capita energy consumption and widening access to energy in the country, are likely to push energy demand further in the country. The government has permitted 100% FDI, with no added requirement of procuring license to set up a power plant.. [3]

2.2 Renewable Energy

The research works on renewable energy sources over the past decade has increased energy production rate. The primary energy supply from renewable sources in 2004 to2013 – increase annually by 30% of the total supply. In 2013, renewable sources supplied approximately 19% of the world's final energy consumption, a little less than half of which came from traditional biomass. [1]

India had about 28.1 GW of installed renewable energy capacity as of 31 March 2013. India is the world's fifth largest wind energy producer because wind accounts for 68% of the capacity, with 19.1 GW of installed capacity. Small hydro power (3.6 GW), bio-energy (3.6 GW) and solar energy (1.7 GW) constitute the remaining capacity. In FY 2013, wind capacity increases from 1.7 GW to almost 3.2 GW in FY 2012 as a result of withdrawal of accelerated depreciation and Generation Based Incentive (GBI) benefit. Although the share of renewable energy in the generation mix has been rising over the years, India still has large untapped renewable energy potential.

III. Wind Energy

Wind is everywhere. As long as the Earth continues to rotate in the right conditions, it will remain that way. Wind generates when movement of air from areas of high pressure to areas of low pressure. When this mass of air is moving, it has energy that has been used to provide thrust to sailboats and ships crossing the oceans, to windmills used to pump water for irrigation or grinding up grain. Even today, wind is still used for much of the same reason as it was thousands of years ago, now days they are much used for to provide electricity. Today, only a small fraction of the world's electricity is generated by wind however, demand for this renewable energy resource will continue to increase with the depletion of fossil fuels. With an ever increasing energy crisis occurring in the world it will be important to investigate alternative methods of generating power in ways different than, fossil fuels. In fact, one of the biggest sources of energy is all around us all of the time, the wind. It can be harnessed not only by big corporations but by individuals using Vertical Axis Wind Turbines (VAWT). VAWT's offer similar efficiencies as compared with the horizontal axis wind turbines (HAWT) and in fact have several distinct advantages. One advantage is that VAWT can be placed independently of wind direction. This makes them perfect for locations where the wind direction can change daily. [2]

The technology of HAWT has dominated the market for over 30 years. Based on the study of 327 small wind manufacturers as of the end of 2011, 74 % of the commercialized one-piece small wind manufacturers invested in the horizontal axis orientation while only 18 % have adopted the vertical design. 6% of the manufactures have attempted to develop both technologies. As the majority of the vertical axis models have been developed in the past 5 to 7 years, the scale of market share remains relatively small. [4]

As the world continues to use up non-renewable energy resources, wind energy will continue to gain popularity. A new market in wind energy technology has emerged that has the means of efficiently transforming the energy available in the wind to a useable form of energy, such as electricity. The best example of this new technology is the wind turbine. Depending on whether the flow is parallel to the axis of rotation (axial flow) or perpendicular (radial flow), determines the classification of the wind turbine. Each type of wind turbine has its strengths and weaknesses, but in the end, all wind turbines accomplish the same task.

3.1 Types of Wind Turbines

Two major types of wind turbines exist based on their blade configuration and operation. The first type is the horizontal axis wind turbine (HAWT). HAWTs sit atop a large tower and have a set of blades that rotate about an axis parallel to the flow direction. These wind turbine blades operates similar to the rotary air craft. The second major type of wind turbine is the vertical axis wind turbine (VAWT). This type of wind turbine rotates about an axis that is perpendicular to the oncoming flow; hence, it can take wind from any direction. VAWTs consist of two major types, the Darrieus rotor and Savonius rotor. The Darrieus wind turbine is a VAWT that rotates around a central axis due to the lift produced by the rotating airfoils, whereas a Savonius rotor rotates due to the drag force created in blades. There is also a new type of VAWT emerging in the wind power industry which is a mixture between the Darrieus and Savonius designs.

3.1.1 Horizontal Axis Wind Turbines

The blades of a HAWT work to extract energy from the wind by generating lift, resulting in a net torque about the axis of rotation. To accomplish this task efficiently, especially for large HAWTs, active pitch controllers are used to ensure that each blade is adjusted to maintain an optimal angle of attack for maximum power extraction for a given wind speed. However, in HAWT contains more complex parts like control system and it require more moving parts and effort to install than a VAWT assembly where the only moving part is the rotor and the majority of components are located at the base of the turbine.

3.1.2 Vertical Axis Wind Turbines

Now days VAWTs have been gaining popularity due to interest in personal green energy solutions. Small companies all over the world have been marketing these new devices such as Helix Wind, Urban Green Energy, and Wind spire. VAWTs target individual homes, farms, or small residential areas as a way of providing local and personal wind energy. This produces an external energy resource and opens up a whole new market in alternative energy technology. Because VAWTs are small, quiet, easy to install, can take wind from any direction, and operate efficiently in turbulent wind conditions. VAWT is relatively simple its major moving component is the rotor and the more complex parts like the gearbox and generator are located at the base of the wind turbine. This makes installing a VAWT a painless undertaking and can be accomplished quickly. Manufacturing a VAWT is much simpler than a HAWT due to the constant cross section blades. Because of the VAWTs shows simple manufacturing process and installation, they are perfectly suited for residential applications.

An S-VAWT generates electricity through drag force rather than lift force like the D-VAWT. As the wind hits the concave portion of the blade (the bucket), it becomes trapped and pushes the blade around, advancing the next bucket into position. This continues as long as the wind is blowing and can overcome the friction of the shaft about which the blades rotate. A Savonius rotor typically rotates with a velocity equivalent to the speed of the free stream velocity, or a tip speed ratio of one. Because of its lower rotation speed, Savonius rotors shows lower efficiencies and are not capable of providing adequate electricity, but it is used to reduce the overall dependence on other energy resources. However, due to the Savonius wind turbines simplicity, manufacturing is very easy; some have even been built using large plastic blue poly drums with the capability of providing up to 10% of a household's electricity In drag-based wind turbines, the force of the wind pushes against a surface, like an open sail. It works because the drag force of the open, or concave, face of the cylinder is greater than the drag force on the closed or convex section. [4]

IV. Literature survey

VAWTs consist of two major types, the Darrieus rotor and Savonius rotor. The Darrieus wind turbine is a VAWT that rotates around a central axis due to the lift force produced by the rotating airfoils, whereas a Savonius rotor rotates due to the drag force created by its blades. To increase the efficiency of the wind turbine the designing of blade plays an very important role, according to literature there are many experiments were conducted on design and analysis of Savonius VAWT blade, the following are some of the literature reviews on design and analysis of Savonius VAWT blades, they conducted many experiments and analysis has been carried out for different overlap ratio, blades having with end plate or without end plate, for different wind speed, different tip speed ratio, different Reynolds numbers, pressure distribution at the convex and concave surfaces, velocity contour, vortocity, static torque coefficient (Cts), coefficient of power (Cp) and coefficient of torque (Ct).

The following are some of the literature reviews on Savonius Vertical Axis Wind Turbine blades:

A.A. Kadam, et al [5]; has studied about Savonius wind rotors and identify the various performance parameters to increase its efficiency. The experimental results show that two blades rotor is more stable in operation than three or more rotor blades, the power coefficient increases with increasing the aspect ratio. The rotor blades with end plates gave higher efficiency than those of without end plates. CFD analysis was carried out to study the flow behavior of a rotating two bucket Savonius rotor. Model the complex flow physics around the rotating rotor was carried out by Fluent 6.3.26 software. For this purpose, data were taken from the experiments conducted earlier on the rotor in a subsonic wind tunnel for five different overlap conditions are 16.2%, 20%, 25%, 30% & 35%.and results shows that the maximum pressure drop is found in case of 16.2% overlap and minimum in case of 35% overlap, means that at 16.2% overlap condition power extraction is maximum from the wind.

Mohammed Hadi Al [6]; has carried out experimental comparison and investigation of performance between two and three blades Savonius wind turbine. Due to this purpose, two models of two and three semi-cylindrical blades were designed and fabricated from Aluminum sheet, with having an Aspect ratio of (As = H/D =1), the dimension is (H = 200 mm height and diameter D = 200 mm). These two models were assembled to have overlap zero (e = 0) and a separation gap zero (e' = 0). Subsonic wind tunnel is used to investigate these two models under low wind speed condition, which shows that maximum performance at (λ = TSR = 1) and a high starting torque at low wind speed, and also gives reason for two bladed rotors is more efficient than the three blades, that by increasing the number of blades will increase the drag surfaces against the wind air flow and causes to increase the reverse torque and leads to decrease the net torque working on the blades of savonius wind turbine.

K.K. Sharma, et al [7]; has studied the performance of three-bucket Savonius rotor by Fluent 6.0 Computational Fluid Dynamics software. Moreover, the flow behavior around the rotor was also analyzed with the help of pressure, velocity and vorticity contours, for different overlap ratios.

Sukanta Roy, et al [8]; has presents effect of overlap ratios in unsteady two-dimensional computational study on static torque characteristics of a vertical axis wind turbine (VAWT) with Finite Volume based computational Fluid Dynamics software package Fluent 6.3. The analysis was carried out for a two-bladed conventional VAWT having overlap ratios of 0, 0.10, 0.15, 0.20, 0.25 and 0.30. Initially, a comparative analysis was made using various $k - \epsilon$ turbulence models and then the results were compared with the experimental data available in literature. The flow field around the turbine model was also studied with the help of static pressure contour analysis. Analysis by the computational study shows an overlap ratio of 0.20 eliminates the effects of negative static torque coefficient, provides a low static torque variation at different turbine angular positions and also gives a higher mean static torque coefficient as compared to the other overlap ratios.

B. Wahyudi, et al [9]; has studied the performance of hydrokinetic turbines of Savonius using a Tandem Blade Savonius (TBS) rotor. There were three types of TBS: Overlap (Type I), symmetrically (Type II) and Convergence (Type III). The simulation work shows the way of the flow characteristic and pressure distribution pattern in and around of the blade swept area. The results show that the convergence TBS (Type III) have a higher gap pressure between upstream and downstream or they have best performance than other types.

Sumpun Chaitep, et al [10]; has studied the effect of the operating conditions (tip speed ratio) to the starting rotation, reverse up rotation, power and torque coefficients of Curved Blades Vertical Axis Wind Turbine (CB-VAWT). CBVAWT was tested in the laboratory scale in wind tunnel with different velocities of 1.5, 2.0, 3.0, 4.0 and 5.0 m/s.

N.H. Mahmoud, et al [11].has conducted an experimental analysis by using, wind tunnel experimental setup, the experimental results shows that -Two bladed Savonius rotors are more efficient than the three and four bladed Savonius rotors. The rotor with end plates gives higher efficiency than the without end plates. Blades having overlap ratios are better than the blades with without over lap ratios. By increasing Aspect Ratio Coefficient of performance (Cp) will also increase.

Bhaskar Jyoti Choudhury, et al [12] has analyzed flow characteristics of two bladed Savonius rotor with 2 Dimensional and 3 Dimensional analyses by using CFD ANSYS Fluent software. In this work they mainly concentrated on variations of drag and torque coefficient for every 10 degree rotor blade angle. They also studied about the static pressure, velocity, vorticity and turbulent kinetic energy with 2dimensional analysis by using CFD software. By analyzing they came to conclusions that drag and torque co-efficient are maximum at 0 and 30 degree rotor blade angles respectively, vorticity and turbulent kinetic energy shows maximum value at 30 degree rotor blade angle.

Widodo, W.S, et al [13] has intention to design and analysis of the Savonius rotor blade to generate 5 kW power Output. They designed blades and done structural analysis with the help of Solid Work flow simulations and pressure difference between the concave and convex blade surface Savonius rotor surfaces was analyzed with help of computational Fluid Dynamics (CFD) analysis. The two flow types were analyzed in this paper one was external flow and other one was internal flow analysis. Both analyses were static analysis. The presented study was limited by the software and computer capability. In real world condition, when the air flows through the blade, it will induce a force to turn the rotor blade. However, the Solid Works software is unable to perform the CFD analysis while the blades are rotating (dynamic condition). Therefore, only the static CFD analysis was performed in this paper, was for both external and internal flow analysis.

Ivan Dobrev, et al [14] has studied about flow through savonius vertical axis wind turbine type with aspect ratio having equal to almost 1. They studied simulation with both two dimensional and three dimensional models.CFD analysis was carried out to find the behavior of savonius wind turbine under flow field condition and performance evaluation , the flow analysis helps in determining the design was stable or not. The simulation was validated by the experimental investigation in wind tunnel carried out with PIV(Particle image velocimetry) with rotor azimuthal position.PIV was used to measure the instantaneous velocity field in the middle of the rotor normally to the axis of rotation.

K.K. Matrawy, et al [15]; has considered main design and performance parameters of a small scale vertical axis wind turbine (VAWT). They design two models (Two and Four cambered blades) and tested in an open wind tunnel. The studied parameters including: variation of rotational speed at different blade angles as well as variation of torque and power coefficients at different tip-speed ratios. They also carried out to investigation on the performance of (VAWT) with/without leading edge flap blades. The experimental data obtained at different blade angles for different ranges are noted down and analyzed in order to give an optimal blade angle through the study. A simple theoretical model is developed to verify and check up some experimental results. The final experimental results showed that the blade angle of 45^o increase the performance of (VAWT) comparing the other ones for both two and four bladed rotors. Using of flap blade which shows increase power coefficient by 2.4% compared with the same model without flap blade.

Anum [16] has studied and proved that improvement of Savonius rotor performance is depending on partial differential equation. Investigations were conducted to show the effect of geometrical configuration on the rotor performance in terms of coefficient of torque and power, and power output. In proving the above case, the analysis was carried out with the CFD (computational Fluid Dynamics). The equations of continuity and Reynolds Averaged Navier-Stokes together with the realizable K- ϵ epsilon turbulence model were helped in to solve this problem. The results obtained shows that partial differential equation was important in the increasing in the performance of the savonius rotor.

Patel C.R, et al [17]; has investigated the aerodynamic performance of Savonius wind turbine. Wind tunnel was used to find the aerodynamic characteristics like, drag coefficient, torque coefficient, and power coefficient of three bladed Savonius wind turbine rotor models, with and without overlap ratio, at various Reynolds numbers. Numerical investigation was also carried out to find those aerodynamic characteristics. Commercial computational fluid dynamic (CFD) software GAMBIT and FLUENT were used for numerical investigation. Three different models with different overlap ratio were designed and fabricated for the current study to find the effect of overlap ratios. At higher Reynolds number, turbine Model without overlap ratio gives better aerodynamic coefficients and at lower Reynolds number Model with moderate overlap ratio gives better results.

K.K. Sharma, et al [18]; has studied about the performance of a two-stage two-bladed configuration of the Savonius rotor. Experiments were conducted in a subsonic wind tunnel. The parameters studied are overlap, tip speed ratio, power coefficient (Cp) and torque coefficient (Ct). Optimized Overlap ratio was used to generate maximum performance of the rotor. The study showed that a maximum Cp of 0.517 was obtained at 9.37% overlap condition. Similarly power and torque coefficients decrease with the increase of overlap from 9.37% to 19.87%.

Ahmed Y., et al [19]; has designed vertical axis wind turbine model having three frames with cavity vanes, fabricated and tested in a low speed wind tunnel. This type of model has a high drag coefficient when the vanes close the frame on one side while rotating with wind direction and capture the wind efficiently. On the other side, the frame rotates in the opposite direction of the wind which opens the frame causing the wind to pass through the frame with low resistance. The model is tested in a wind tunnel with the different wind speeds. This new model gives the maximum power coefficient of 0.32 at a wind speed of 8.2 m/s and tip speed ratio of 0.31.

Burcin Deda Altan, et al [20]; has introduced a new curtaining arrangement to improve the performance of Savonius wind rotors. The curtain arrangement was placed in front of the rotor to avoid negative torque opposite the rotor rotation. The geometrical parameters were designed to increase the performance. The rotor with different curtain arrangements were tested out of a wind tunnel and its performance was compared with that of the conventional rotor. The maximum power coefficient of the Savonius wind rotor is increased to about 38.5% with the optimum curtain arrangement. The experimental results showed that the performance of Savonius wind rotors could be improved with a suitable curtain arrangement.

R. D. Maldonado, et al [21]; has done detailed investigation on Savonius wind rotor in order to obtain the optimal characteristics. They designed Savonius wind rotor assembly with CAD software. Simulations of the interaction between the flow of air and blades were developed through finite element analysis (FEA). A result of these simulations shows the velocity distribution of the profile blades. The formations of vortices were studied with the finality to improve the performance of the Savonius rotor. Blades with different geometry and gap distance between the blades were simulated, the results shown better geometry for the blade and gap distance between blades that improved the power coefficient (Cp) of the Savonius rotor. Simulations results show that the geometry and gap distance of the blades increases the Cp about 20%. Through gap distance between the blades, the wind was directed to the surface of following blade to induce its rotation. An air deflector was located front the Savonius rotor to increase and guide the flow of air to the blades. The deflector increased the velocity of the Savonius rotor up to 32%.

Dhrubajyoti Rajbongshi, et al [22]; has studied about the effect of semicircular deflector. They fabricate three bladed Savonius rotor and its base is fixed on square plate of cast iron. Around the savonius rotor eight semi-circular (non movable) deflectors had been kept and are fixed on the square cast iron plate. The model is kept in front of the circular pipe just after the blower and the speed of the air coming out from the blower controlled by the valve. The X-axis of the square of the plate is kept in alignment with the axis of the pipe of the blower and the rotational speed of the rotor was measured in the case when the X-axis of the square plate has been rotated by 30°, 45°, 60°, 75° and 90°. Results show that at 15% valve opening at 60^0 of rotation of cast iron plate has maximum rotation speed. Table shows percentage of valve opening and maximum RPM obtained (in case of without Deflectors and with deflectors)

Sl.No.	Percentage of Valve Opening	Speed of rotor without deflectors (rpm)	Speed of rotor with deflector (rpm)
1	5	64	130
2	10	148	218
3	15	254	390
4	20	340	530

They also conducted experiments with increasing number of deflectors from 8 to 10 which shows increase in rotation of rotor than previous result.

Animesh Ghosh, et al [23]; has studied about design and performance of Savonius, H-Darrieus and combined Savonius-Darrieus turbines. The experiments were conducted for Savonius rotor for different overlap ratios from 16.2% to 35%. Results show that optimum value of overlap is 20% at which the maximum Coefficient of performance (Cp) is 0.38, for a Tip Speed Ratio 0.625. Wind tunnel experiments were conducted for two bladed and three bladed H-Darrieus turbine to find the performances. Results show that both the turbines produced a similar value of maximum aerodynamic torque and two bladed H-Darrieus turbine shows higher coefficient of performance than the three bladed turbines. They also did comparative study on a three bucket Savonius turbine & a combined three-bucket Savonius and three-bladed Darrieus turbines with and without overlap ratios with different Tip Speed Ratio. The maximum Cp of 0.51 was obtained without the overlap condition. The performance of the combined Darrieus-Savonius turbine both theoretically and experimentally holds good. It was found that the combined Savonius-Darrieus turbine was the best of all the turbines reviewed in terms of power coefficient. Thus, the combined Savonius-Darrieus turbine may be used for small-scale applications by scaling-up the turbine.

K.K. Sharma, et al [24];has studied about the Combination of Savonius and Darrieus type of Vertical Axis Wind Turbine (VAWT) rotors, which possess many advantages over their individual designs, like low starting torque, high power coefficient, low cut-in wind speed etc. They measured the performance of a three-bladed combined Darrieus-Savonius rotor, with Darrieus mounted on top of Savonius rotor, for overlap variations from 10.8% to 25.8%. Power coefficients (Cp) and torque coefficients (Ct) were calculated in a low range of Tip Speed Ratio for each overlap condition. It is found that Cp increases with the increase of overlap. However, there is an optimum value of overlap for which, Cp is maximum, beyond this Cp starts decreasing. The similar trend is observed for Ct as well. The maximum Cp of 0.53 is obtained at 0.604 Tip Speed Ratio (TSR) for an optimum 16.8% overlap ratio. The performance of the rotor is also compared with another version of this hybrid design with Savonius mounted on top of Darrieus rotor. The present Darrieus-Savonius rotor can be suitably placed in the built environment where it can harness more power from wind and, at the same time, would self-start in low wind condition prevalent in such environment.

V. Conclusion

The reviews show that there is lot of research work is going on Vertical Axis Wind Turbine to increase performance. Computational Fluid Dynamics is used to analysis the flow behavior of the rotor in both 2-Dimensional and 3-Dimensional.The experimental work shows that

1. Two bladed Savonius rotor is more efficient than the three bladed Savonius rotor.
2. The rotor with end plate shows more performance than the rotor without a end plate.
3. Rotor with Overlap have higher performance than without over lap ratio.
4. By increasing stages of rotor, shows the increase in coefficient of performance.
5. The research work is going on hybrid wind turbine to equate the performance with the Horizontal Axis Wind Turbine.
6. Flow guides or curtains are providing to increase the velocity or rotation speed of the rotor. This helps in increase the performance.

The experimental work on the leading edge of the semi cylindrical blade is not conducted, which believes that it will increase in swept area and flow behavior performance, helps to increase in performance of newly designed rotor blade.

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