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Performance Analysis of Savonius Rotor Type Wind Turbines An Analytical Case Study

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ABSTRACT

This paper presents a performance analysis of the Savonius wind turbines. This type of turbine is unusual and its application for obtaining useful energy from air stream is an alternative to the use of conventional wind turbines. Simple construction, high startup and full operation moment, wind acceptance from any direction, low noise and angular velocity in operation, reducing wear on moving parts, are some advantages of using this type of machine. Over the years, numerous adaptations for this device were proposed. As a drag-driven type Vertical Axis Wind Turbine (VAWT), traditional Savonius wind rotor has disadvantage of low wind energy utilization but has a lot of the advantages compared with Horizontal Axis Wind Turbines (HAWTs) and lift-driven VAWTs. The variety of possible configurations of the rotor is another advantage in using such machine. Each different arrangement of Savonius rotor affects its performance with lowering the carbon emissions and their by its performance is environmental, ecological and energy efficient. Savonius rotor performance is affected by operational conditions, geometric and air flow parameters. The range of reported CFD values for maximum averaged power coefficient includes values around 0.05–0.30 for most settings. Performance gains of up to 50% for tip speed ratio of maximum averaged power coefficient are also reported with the use of stators. Present article aims to gather relevant information about Savonius turbines by incorporating flux machines and bringing a discussion about their performance. It is intended to provide useful knowledge for future studies.

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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. 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.

However, there exist other types of wind turbines, one of which will be the primary focus of this paper, the Vertical Axis Wind Turbine (VAWT). These devices can operate in flows coming from any direction, and take up much less space than a traditional HAWT, and VAWT are definitely a credible source of energy for the future.

VAWTs have a number of advantages over HAWTs, such as,

1) Simple construction, they can be made from oil barrels cut in two halves.

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2) Extremely (low cost), simplicity reduces cost of construction, and aids installation.
3) They can accept wind from any direction, thus eliminating the need for re-orienting towards the wind.

VAWTs work well in places with relatively low wind strength, and constant winds, VAWTs include both a drag-type configuration, such as the Savonius rotor, and a lift-type configuration, such as the Darrieus rotor.Savonius rotors are used for a variety of purposes including water pumping, driving an electrical generator, providing ventilation, and agitating water to keep stock ponds ice-free during winter. The Savonius rotor is a slow-running wind turbine which explains its lower efficiency when considering the standard design. However, it has many advantages for specific applications thanks to its simplicity, robustness, compactness and low cost.

Thus, if the efficiency of the Savonius rotor could be improved, then it would provide a very interesting complementary source of electricity from wind energy. Researchers around the world have carried out a good deal of research to improve the efficiency of the Savonius rotors for its small scale uses. The major advantage of Savonius type wind rotor is that it works within well balanced turbulence of air transmits minimum vibrations and bending stresses to the walls or roofs. The Savonius wind rotor is fluid-mechanical device with S-type cross sectional blades in which wind power acts perpendicular on the blades and converts into the rotating motion of the central shaft.

Principles Of Savonius Rotor Wind Turbine:

The turbine's a/d ratio values are chosen for computation. The grid for computation is tri mesh with 0.3 million cells. The moving reference frame method is usually applicable for such rotational problems. With a dense grid in the boundaries, in order to calculate the velocity profiles with more certainty. The turbulence equation chosen for solving is K-ω SST (shear stress transport) model was selected in order effectively solve for the wake distributions and torque coefficients of the turbine. The effect of gap to overlap ratio is considered and an optimum value of 5.3 % is chosen from simulations.

The model is created for Diameter1.52 m and height of 3.3m a 2-Dimensional analysis is preferred for simulating the model as the area of the turbine is generally considered straight without twist (helix in the turbine) moreover less computational power is sufficient to run the analysis. The basic model is as shown in figure 1 and the modified model is shown in figure 2.

The power available in the Wind is P maximum (free stream generally refers to Velocity cubed given by "V") is given by,

$$P_{max} = \frac{1}{2} \rho A V^3 \qquad (1)$$

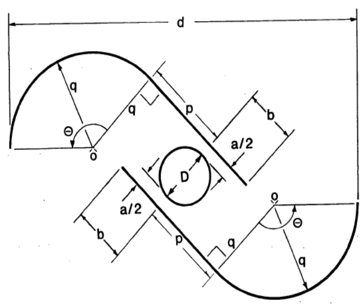

Fig. 1: Basic Savonius.

Where, ρ is the Density of air 1.225 Kg/ m^3 and A is the area of the S-VAWT 5.01 m^2.

$$C_p = \frac{P_{mech}}{P_{max}} \qquad (2)$$

Where, P_{mech}refers to the mechanical power available in the shaft after considering the losses and C_p is the Coefficient of performance.

Losses are occurring while operation include air frictional losses, Frictional losses due to bearing usually accounted for 10 % for moderate maintenance in remote places, Aerodynamic losses - drag etc., Aerodynamic performance is limited and given by Betz Limit which describes the $C_p$value is 0.59 theoretically.

It indicates that a maximum harnessing potential of any aero generator is theoretically limited to 59% and the practical values are really low in the range of 0.35 to 0.49 for most operating HAWT turbines.

Whereas the VAWTs possesses very low $C_p$of 0.3 for practically operated savonius turbines.

$$Torque = c_m \frac{1}{2} \rho V^2 S \qquad (3)$$

Where, S is the span area 5.01 m^2 and c_m is the Coefficient of moment or torque.

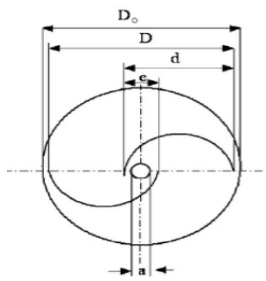

Fig. 2: Modified Savonius.

Comparison Of Two And Three Blade Design:

Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices, consisting of two or three blades (vertical – half cylinders). A two blades savonius wind turbine would look like an "S" letter shape in cross section (figure 3).The savonius wind turbine works due to the difference in forces exert on each blade. The

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lower blade (the concave half to the wind direction) caught the air wind and forces the blade to rotate around its central vertical shaft. Whereas, the upper blade (the convex half to wind direction) hits the blade and causes the air wind to be deflected sideway around it.

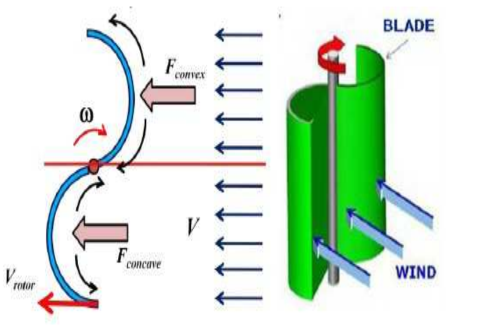

Fig. 3: Schematic drawing showing the drag forces exert on two blade Savonius.

Because of the blades curvature, the blades experience less drag force (F_{convex}) when moving against the wind than the blades when moving with the wind ($F_{concave}$). Hence, the half cylinder with concave side facing the wind will experience more drag force than the other cylinder, thus forcing the rotor to rotate. The differential drag causes the Savonius turbine to spin. For this reason, Savonius turbines extract much less of the wind's power than other similarly sized lift type turbines because much of the power that might be captured has used up pushing the convex half, so savonius wind turbine has a lower efficiency.

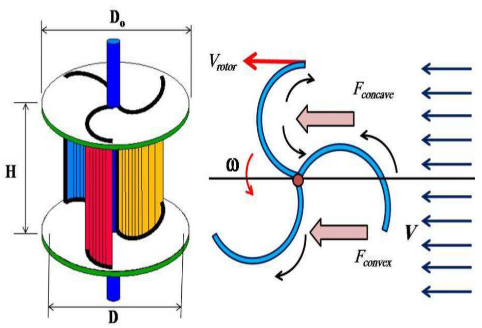

Fig. 4: Schematic drawing showing the drag forces exert on three blade Savonius.

Similarly, the three blade savonius wind turbine is constructed from three half cylinders, they are arranged at (120^o) relative to each other as shown in figure (4).

This paper focuses a study and makes a comparison in performance between two and three blades savonius wind turbine at low wind speed, the reasons to study them at low speed are:

1. In many areas in the world apart from coastal region, the average wind speed is relatively low and varies appreciably with seasons. It is around 20 km/h.
2. A Savonius rotor requires (30 times) more surface for the same power as a conventional rotor blade wind turbine. Therefore it is only useful and economical for small power requirements.
3. It has a high starting torque; a Savonius rotor can theoretically produce energy at low wind velocities.
4. It is difficult to protect them from extreme winds.
5. The peak power coefficient for any Savonius rotor occurs at a tip speed ratio (less than 1).
6. Lower wind speeds found at lower heights, thus VAWT like savonius can be installed close to the ground without an extended post with the generator and the driven train mounting at the base near the ground level which makes these components easier to service and repair.

Experimental Setup:

The relationship between the power coefficient $C_p$and the tip speed ratio TSR or λas an effect of solidity of thewind turbine performance is shown in Figure 5.

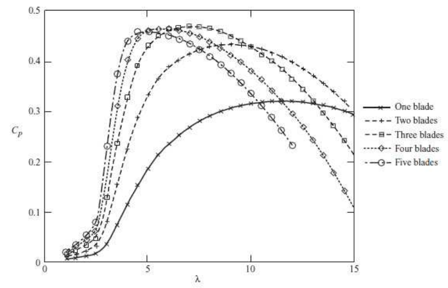

Fig. 5: The curve of power coefficient C_p and tip speed ratio λ of wind turbine.

The curve shows that single blade of wind turbine has smaller solidity and the shape of curve $C_p$relatively flat which caused by higher drag force. The three blades wind turbine gave optimal solidity with $C_p$maximum and the result it produces more energy.

The experiment used a model of Savonius wind turbine with two, three and four blades as shown in Figure 6. The model of wind turbine was built with overlap ratio (e: d) equal to 0.15; aspect ratio (D: h) equal to 1.0 and end plate parameter (D_0: D) equal to 1.1.

Dimensions of the blades of Savonius wind turbine model are diameter of blades (d) = 200 mm ; gap (e) = 0.15 x d = 0.15 x 200 = 30 mm ; rotor diameter (D) = 200 + 200 – 30 = 370 mm ; rotor height (h) = 370 mm ; end plate diameter

(D_0) = 1.1 x D = 1.1 x 370 = 407 mm ; and thickness of blades and end plates (t) = 2 mm. The low speed wind tunnel was started to produce wind and an anemometer measured the velocity of wind.

When the wind produced by wind tunnel pushed the blades (halves of cylinder) of the model, the rotor

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of wind turbine will rotate. The rotation of rotor was measured by tachometer and noted three times of experiments.

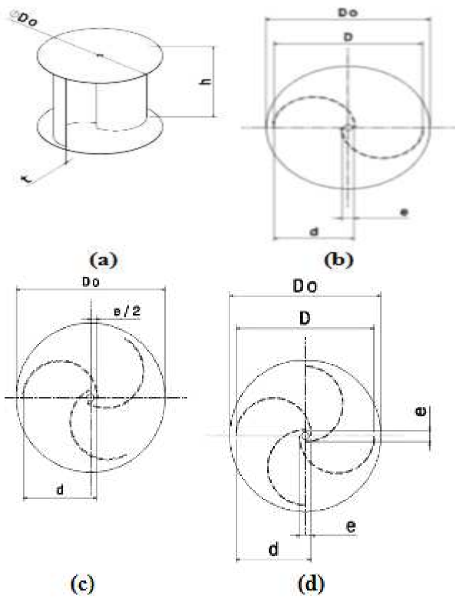

Fig. 6: Design of wind turbine model (a) and the cross section of turbines with (b) two blades (c) three blades, and (d) four blades

Each experiment with two, three and four blades respectively used the speed of wind from 1 to 10 m/s. The torque of wind turbine was also measured by a torque meter related with the speed of wind. The specified speed of wind from the wind tunnel (1 to 10 m/s) were determined based on the assumption that small wind turbine, like the model of Savonius wind turbine, will tend to split in angular motion if using high speed wind.

High speed of wind exerts high pressure on blades causing the rotation of rotor may exceed its design limit and become difficult to measure.

Results:

Results of the experiments indicated the relationships between wind speeds and tip speed ratio or actual torque as shown in Figure 7 and Figure 8.

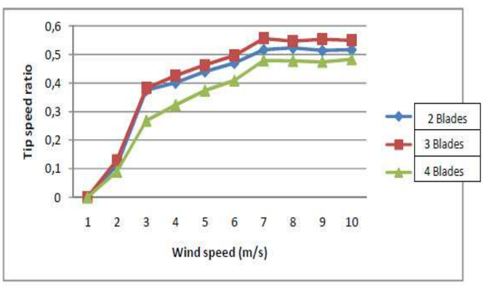

Fig. 7: Tip speed ratio related with wind speed (m/s) in wind tunnel.

Figure 7 shows that the three blades wind turbine model has the highest tip speed ratio. Ingeneral the three wind turbine models have significant tip speed ratio at lower wind speed and more stable at windspeed of 7 m/s.

It means that the wind turbine models has optimal rotational speed at the wind speed above 7 m/s.Tip speed ratio is related with the performance of rotational speed of wind turbine rotor. Wind turbine with higherrotation will result in higher tip speed ratio.

Three blades wind turbine model has the highest tip speed ratio at 0.555with the wind speed of 7 m/s.

Windturbine rotor with more number of blades will deliver higher torque for the shaft of the turbine. Number of bladesrelated with the solidity of wind turbine, higher solidity will give also higher torque for the wind turbine.

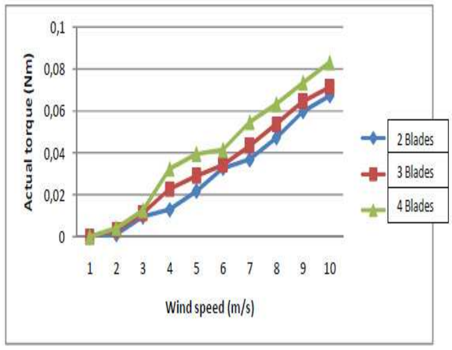

Fig. 8: Actual torque of wind turbine rotor for different wind speeds.

Figure 8 shows the relationship between the actual torques of the shaft of wind turbine models for different windspeed. Four blades wind turbine model has higher torque than that two or three blades wind turbine. Wind turbinemodel with four blades has more drag force at any position when the wind rotor is in rotational position.

Conclusion:

It is concluded that, the two blades rotor is more efficient than three and four blades rotors. The rotor with end plates gives higher efficiency than those without end plates. Double stages rotor have higher performance than single stage rotor. The rotors without overlap ratios are better in operation than those with overlap. The study show also that the power coefficient increases with the rise in aspect ratio.

The power coefficient is a function of the tip speed ratio and varies with different geometries of the Savonius rotor. Recently the Computational Fluid Dynamics (CFD), become a useful tool for the study of wind rotors, since it allows obtaining values for the aerodynamic coefficients and the visualization of the flow without the need for instrumentation.

Further the research can be extended for different variation in parameters such as overlap rations, number of blades in turbine, size of blades and different type blades. Research can move towards the development of small size vertical axis wind turbine for house hold purpose to fulfill the need of power at domestic level.

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