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A Review Study on Savonius Wind Rotors for Accessing the Power Performance

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ABSTRACT : *Savonius type Small Vertical Axis Wind Turbines (SVAWT) are self-starting, Omni-directional, requires no yaw mechanism to continuously orient towards the wind direction. Savonius wind turbines are viable in low wind speed regimes and which can be fitted on rooftops and also suitable for the urban areas. This paper deals with the review study of Savonius wind rotors and identifying the various performance parameters to increase its power performance. It has been concluded that, the 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 give higher efficiency than those of without end plates.*

Keywords *- Renewable energy, Savonius wind rotor, Vertical axis wind turbines (VAWT), Wind Energy.*

I. INTRODUCTION

The global small wind turbine (SWT) market has been on the upswing in the last two or three years. The main drivers of this growth are the demand-supply gap in energy, increasing fossil fuel prices, improved small wind turbine technology and the diverse application to which it can be put to both ‘grid-tied’ and ‘stand-alone’ system. The market for SWT technology is encouraging in India also, and may require market drivers like favourable policies, adoption of micro generation technologies, reduced costs etc., to reach a significant level. Savonius wind turbine is generally categorized in a ‘small’ type VAWT, specifically which is a Omni-directional for accepting the drag force of wind with good starting characteristics and operates on lower wind speeds which generally produces the power from a few watt to 20 kW. Therefore on domestic level these can be widely used to charge the batteries. The efficiency is low as compared to horizontal axis wind turbines and Darrieus type vertical axis wind turbine. The reason for lower efficiency is the nature of fluid flow over the rotor blades which produces positive and negative torque on leading and trailing rotor blades respectively. As smaller size Savonius wind rotors reduces in the use of material and manufacturing cost. The location of Savonius wind rotor is at lower altitudes provides easier installation and maintenance. Also the use of long electric cables can be avoided for the supply of power due to lower altitude of the rotor blades. Location at higher altitudes is also possible which leads to higher wind speed, lower turbulence and higher generation of power. No need to use larger land area like wind farms since the location for the use of Savonius wind rotor is Multi storey building and roof mounting. 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. [1]. 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 [2]. The two-bucket configurations have better aerodynamic performance than the three-bucket configurations, with the exception of starting torque. Performance of the Savonius rotors increases slightly with increasing height-to-diameter ratio (Aspect Ratio ‘α’).The recommended configuration is two sets of two-bucket rotors, rotated 90° apart, with each rotor having a gap width (Overlap ‘e’) of s/d = 0.1-0.15 [3]. N.H. Mahmoud et al studied different geometries of Savonius wind turbine in order to determine the most effective operation parameters. It was found 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 [4]. U. K. Saha has explored the feasibility of twisted bladed Savonius rotor for power generation. The twisted blade in a three-bladed rotor system has been tested in a low speed wind tunnel, and its performance has been compared with conventional semicircular blades (with twist angle of 0^0). Performance analysis has been made on the basis of starting characteristics, static torque and rotational speed. Experimental evidence shows the potential of the twisted bladed rotor in terms of smooth running, higher efficiency and self-starting capability as compared to that of the conventional bladed rotor [5]. In his study, M.A. Kamoji [6] tests on helical Savonius rotors are conducted in an open jet wind tunnel. Coefficient of static torque, coefficient of torque and coefficient of power for each helical Savonius rotor are measured. The performance of helical rotor with shaft between the end plates and helical rotor without shaft between the end plates at different overlap ratios namely 0.0, 0.1 and 0.16 is compared. Helical Savonius rotor without shaft is also compared with the performance of the conventional Savonius rotor. The results indicate that all the helical Savonius rotors have positive coefficient of static torque at all the rotor angles. The helical rotors with shaft have lower coefficient of power than the helical rotors without shaft. Helical rotor without shaft at an overlap ratio of 0.0 and an aspect ratio of 0.88 is found to have almost the same coefficient of power when compared with the conventional Savonius rotor [6]. Kunio Irabu investigated the various ways to improve and adjust the output power of Savonius rotor under various wind power conditions, for which he employed a guide-box tunnel. He concluded that using the guide-box tunnel, the maximum output power coefficient for two blades rotor is about 1.23 times at the largest compared with that without GBT and 1.5 times for three blades rotor of which reasonable width ratio of guide-box tunnel is 1.4 and area ratio of it is 0.43 [7]. CFD analysis was carried out by Rajat Gupta to study the flow behaviour of a rotating two bucket Savonius rotor using Computational Fluid Dynamics.CFD analysis was carried out using Fluent 6.3.26 software to model the complex flow physics around the rotating rotor, as it consumes less time and computational cost. For this purpose, data were taken from the experiments conducted earlier on the rotor in a subsonic wind tunnel for five overlap conditions, namely 16.2%, 20%, 25%, 30% & 35%. He concluded that the maximum pressure drop is found in case of 16.2% overlap and minimum in case of 35% overlap meaning maximum power extraction from wind by the rotor at 16.2% overlap condition [8]. This paper describes the review study on effect on mechanical power and power coefficient in small vertical axis wind turbine (VAWT).

II. THEORETICAL METHODOLOGY

The theoretical energy possessed by the wind flowing at a certain velocity $'v'$ can be expressed mathematically,

$$\boldsymbol{POWER},\ 'P_t' = \frac{1}{2}\rho A v^3 \tag{1}$$

The performance of the Savonius wind turbine is determined by the coefficient of performance (Cp). It is theoretically defined as the ratio of the aerodynamic power generated by the wind turbine to the power possessed by the wind incoming on the surface of the rotor.

Savonius wind rotor is constructed simply of two vertical half cylinders, as shown in Fig. 1. The ratio between rotor height (H) and rotor diameter (D) is called the aspect ratio (α).

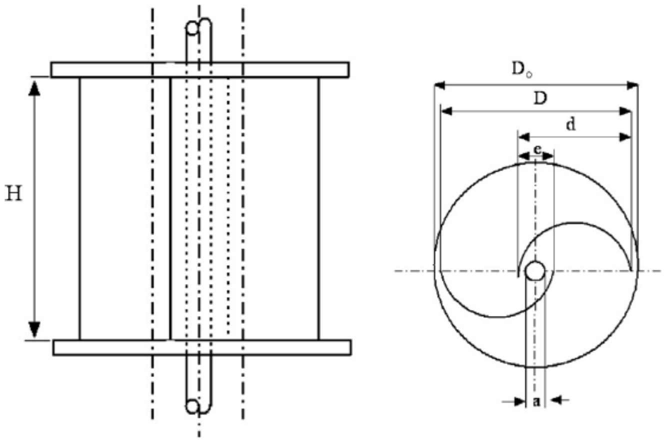

Fig. 1 Schematic of a single-stage Savonius rotor [4]

Some parameters can be defined through the following relations:

$$\text{Tip speed ratio}(\lambda) = \frac{\omega R}{V} \tag{3}$$

$$\text{Aspect ratio}(\alpha) = \frac{\text{Rotor Height (H)}}{\text{Rotor diameter (D)}} \tag{4}$$

$$\text{Overlap ratio}\,(\beta) = \frac{\text{Overlap (e)} - \text{Diameter of the shaft (a)}}{\text{Rotor diameter (D)}} \tag{5}$$

From the measured values of mechanical torque and rotational speed, the mechanical power can be estimated at each wind speed as:

$$P_m = \omega T \text{(Watt)} \tag{6}$$

Where, ‘T’ is the mechanical torque and ‘ω’ is the angular speed.

The angular speed is defined in rad/s as:

$$\omega = \frac{2\pi N}{60} \tag{7}$$

Where ‘N’ is the shaft rotational speed in rpm.

Now, the Mechanical torque is obtained in (N-m) by

$$T = Fr \tag{8}$$

Where ‘r’ is the pulley radius (mm).

The force acting on the rotor shaft obtained in (N) by:

$$F = (m - s)g \tag{9}$$

Where ‘m’ is the mass loaded on the pan in (kg), ‘s’ is the spring balance reading in (kg) and ‘g’ is the gravitational acceleration (m/s^2).

The power coefficient C_p and static torque coefficient C_{ts} can be determined from the following equations:

$$C_p = \frac{P_m}{P_t} \tag{10}$$

Where ‘P_t’ is theoretical power calculated from the equation (1).

Finally, the power coefficient can be formulated as:

$$C_p = \frac{g\, r\, \pi\, N\, (m-s)}{15 \cdot \frac{1}{2}\rho A v3} \tag{11}$$

The static torque coefficient is calculated from

$$C_{ts} = \frac{4\,T}{\rho\, D^2\, V^2\, H} \tag{12}$$

III. MEASUREMENTS AND INSTRUMENTATION

The mechanical power for the tested Savonius rotor is can br determined by measuring the mechanical torque on the rotating shaft and rotational speed at different values of wind speed. The arrangement used to do that is shown in Fig. 2. It contains pulley system, nylon string, weighing pan and spring balance. The weighing pan, pulley and spring balance are connected by a nylon string of 1 mm diameter as shown in Fig. 2. The wind speed will measured by a propeller type digital anemometer. While the shaft’s rotational speed measured using a digital DC tachometer. The nomenclature of the Fig. 2 is as1: pulley; 2: nylon string; 3: weighing pan; 4: spring balance; 5: Savonius rotor; 6: rotating shaft and 7: structure, X: Height of the rotor from ground surface

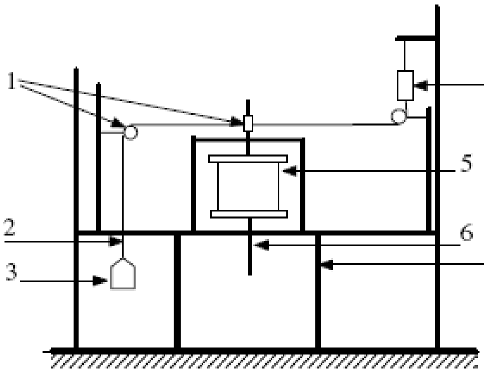

Fig. 2 Schematic diagram of Savonius rotor connected with mechanical torque measurement arrangement [4]

IV. EFFECT ON VARIATION IN MECHANICAL POWER AND POWER COEFFICIENT

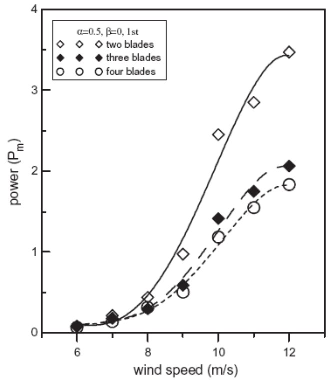

Fig. 3 Variation in mechanical power with wind speed for rotors with two, three and four blades [4]

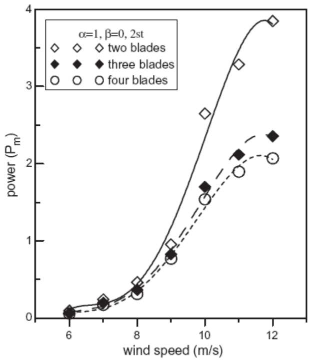

Fig. 4 Variation in mechanical power with wind speed for double stage rotor [4]

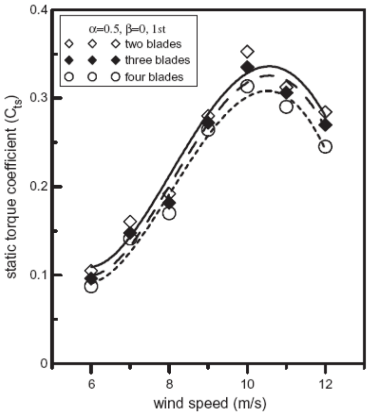

Fig. 5 Relation between static torque coefficient and wind speed for α=0.5 [4]

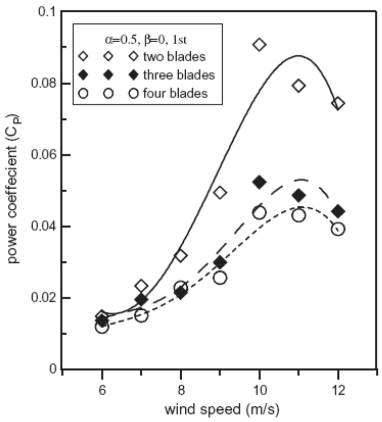

Fig. 6 Relation between power coefficient and wind speed for rotors with two, three and four blades [4]

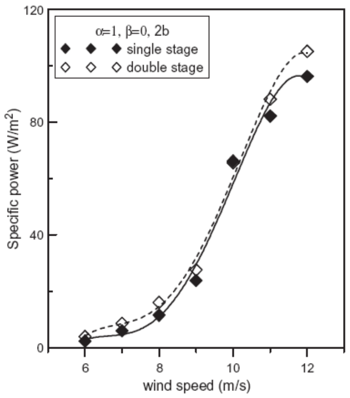

Fig. 7 Variation of specific power with wind speed for single and double stage rotors [4]

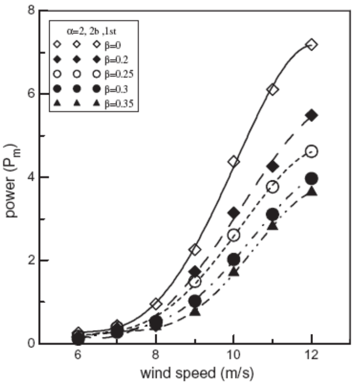

Fig. 8 Variation of mechanical power with wind speed for different overlap ratios [4]

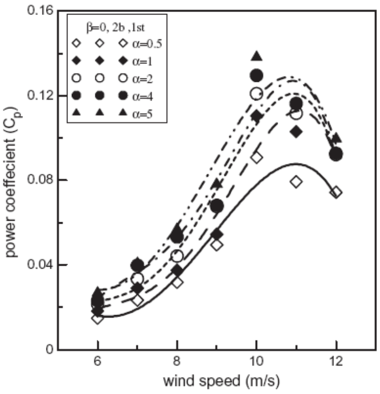

Fig. 9 Variation of power coefficient with wind speed for different aspect ratios [4]

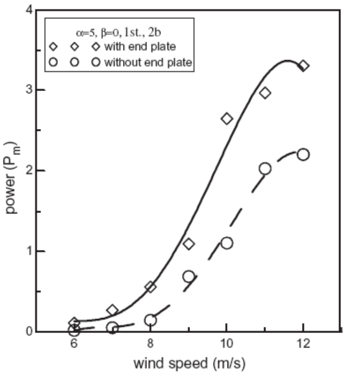

Fig. 10 Variation of mechanical power with wind speed for rotors with and without end plates [4]

Fig. 3 and Fig. 4 illustrates the variation in mechanical power with wind speed for the investigated rotors. The two blades rotor gives higher mechanical power compared to three and four blades rotors. The two blades rotor is more efficient also for double stages rotor. The static torque in the present work is defined as the torque affected on rotor to stop its rotation. The static torque coefficient can then be calculated from Eq. (12). It is seen from Fig. 5 that, the static torque on two blades rotor exceeds static torque on both three and four blades rotor. Fig. 6 shows the power coefficients for two blades rotor is higher than power coefficients obtained for both three and four blades rotors. This may be due to the net drag force affected on rotor in two blades case is higher than those for three and four blades cases. The two stages rotor gives higher specific power than single stage rotor as shown in Fig. 7. The specific power is defined as the power obtained from unit projected area of the rotor. In order to verify this result, the static torque affected on rotor blades for both single and double stages rotors is measured at the same angle of rotation and at different wind speeds. Fig. 8 illustrates the relation between mechanical power and wind speed for the tested overlap ratios. It can be noticed here that the rotor without overlap gives higher mechanical power than rotors with overlap. Different rotors with aspect ratios from 0.5 to 5 are studied experimentally at constant values of the other studied parameters. Fig. 9 confirms that there is an increase in power coefficient with the rise in aspect ratio. Fig. 10 shows that the rotors with end plates give higher mechanical power than rotors without end plates. This is because the existence of end plates increases the amount of air which strikes the blades of Savonius rotor [4]. Fig.11 shows that with the increase of twist angles, the stalling angle shifts further. Moreover, the twisted blade shows a maximum peak torque and a lesser falling slope, and hence a greater area than the semicircular blades. Fig. 12 compares the performance of the Savonius rotor with different twist angles at various airspeeds. From the performance view point, α = 15^0 is superior at lower wind velocities, whereas α = 12.5^0 is suitable at higher velocities. Maximum coefficient of performance, $C_p = 13.99$ is found at tip speed ratio of $\lambda = 0.65$ (V = 8.23 m/s) and for semicircular bladed rotor is giving C_p= 11.04 at the same velocity [5].

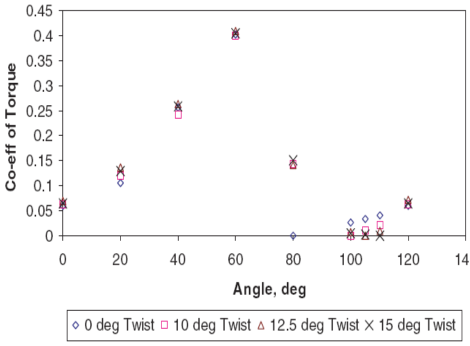

Fig. 11 Static torque coefficient for various twisted bladed Savonius rotor at V = 10 m/s [5]

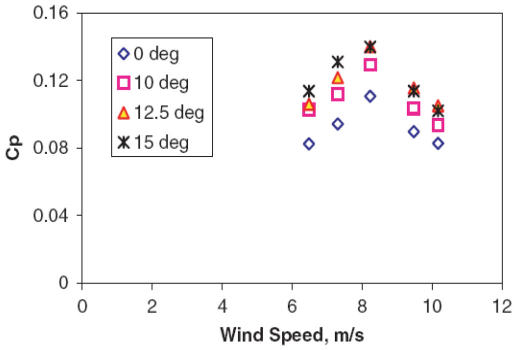

Fig. 12. Variation of coefficient of performance with velocity for various twisted bladed rotors [5]

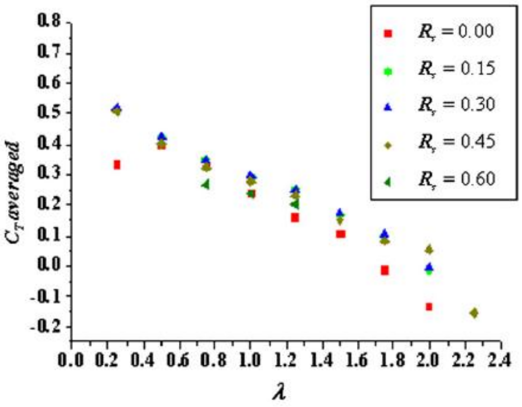

Fig. 13 Averaged moment coefficient versus tip speed ratio [9]

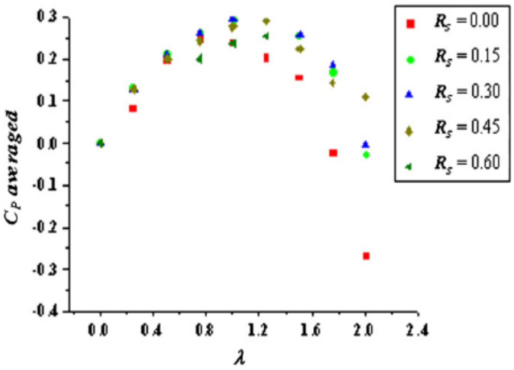

Fig. 14 Averaged power coefficient versus tip speed ratio [9]

Akwa studied the influence of various overlap ratios on performance coefficients of a Savonius wind rotor with using computational fluid dynamics. In the Figs. 13 and 14, the obtained values for the averaged moment and power coefficients for other buckets overlap ratios are shown. Through these figures, it can be observed that the rotor has the best performance for (R_s = e) values of 0.15, with averaged power coefficient equals to 0.3161 for the tip speed ratio 1.25. One can also observe that the high starting moment (for low values of λ) of a Savonius wind rotor increases while values of R_s grow until a certain value where the moment and performance of the rotor fall dramatically due to the decreased incidence of air on the concave side of the rotor buckets. Also it appears that the averaged moment coefficient of the rotor decays with the increase of tip speed ratio [9].

V. 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 (α). 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 fulfil the need of power at domestic level.

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