Performance of a Two Bladed Savonius Wind Turbine –A pre-investigative experimental study, to decide over a horizontal axis machine

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Abstract: Given the scarce availability clubbed with the ill effect of conventional energy on the environment, renewable energy resources have taken the driver's seat. Of late, one such available way is harnessing wind energy because of its affordability and availability. Wind turbines generate electricity by using the power of the wind through a coupled electric generator. Of the two types of wind turbines available, viz. horizontal axis (HAWT) and vertical axis (VAWT) wind turbines, the Savonius rotor has a vertical axis characterized by the economy, simpler geometry generating power at low wind speed, which makes it suitable for efficiently generating mechanical energy. Their performances and efficiencies can be improved with modifications to conventional Savonius wind turbines and rotor blades. In this work Savonius wind turbine is designed and fabricated from a PVC pipe of specific dimensions cut into semi-cylindrical halve with no overlap. The Savonius wind turbine was evaluated at different wind velocities from 2.2 to 6.5m/sec. The output was measured by an electric device. The performances of the wind turbine at various wind velocities were estimated. The present work found that the Savonius wind turbine has good potential to extract wind power at low wind speeds within the tested range. The PVC rotor blades will have adequate strength; non-corrosive hence could be installed on the rooftop. The turbine efficiency could be increased by selecting more than two blades with the introduction of diffuser vanes.

Keywords: Renewable energy; VAWT; Drag type; Savonius; PVC blade; Power

I.INTRODUCTION

The wind can be visualized as an approximate large mass of air with horizontal movement caused by the heat gradient present on the earth. The air circulation is triggered by the uneven heating of the earth's surface due to Sun’s radiation. The buoyancy of the air in the vicinity of the warm area expands and is forced upward by the cool denser air. The factors that influence this process could be the nature of the terrain, the cloud cover, and the inclination degree of the sun, etc.

Renewable energy sources are and can be considered inexhaustible energy that is harnessed. Using proper technology, humans naturally can harness phenomena such as sunlight, wind, tides, water, bio-based processes, and geothermal heat. India occupied fourth place in the wind power installed capacity globally, and the Governments encourage entrepreneurs by giving subsidies on capital investments. India has a potential source in harnessing wind energy, and the Government Of India has an estimated 45000 MW of wind power throughout the year. The Government Of India initiated wing viz., MNRE is planning and formulating the policy framework for renewable energy, the wind energy policies by it being investor friendly.

The wind turbine converts the wind energy into mechanical energy and electrical energy. Wind turbines can be categorized based on the axis of rotation as horizontal or vertical, vertical axis turbines being not common. For running any wind turbine, the wind speed should be more than 3 m/sec at 10 m height. Wind loses its momentum at the earth's surface due to friction with the surface.Having a higher wind turbine tower, one can expect a higher annual average wind speed.

VAWT has a simpler structure easy to install compared to geometry and is HAWT. The generator can be installedon the ground, with the tower needing no support. VAWT also works wellat low wind speed areas. Some of the common VAWT are Savonius and Darrius rotors.

Savonius turbines are preferred owing to lower cost and higher reliability, sacrificing some efficiency. It needs little maintenance and a complicated mechanism for wind direction control and is self-starting. Savonius machines are good for high torque and low rpm applications and are not generally connected to power grids. Small VAWT is simple in structure and captures wind from any direction. They can also be mounted safely at the ground level. It is used for water pumping at a low suction head for agricultural purposes in rural areas. Other applications are decentralized electricity generation for remote areas, which can be stored in the battery. Earlier metallic sheets were used in fabricating the Savonius rotor. For that, solidity is more, and high drag force is needed to rotate the Savonius turbines. Though much literature is available, few selected research related to the current topic is highlighted here.

Mohammed Hadi Ali [1] studied the performance and comparison between two and three blades of Savonius wind turbine tested in a wind tunnel at low-speed conditions in their investigations. They saw that the two-bladed configuration was more efficient compared to three bladed version. They reasoned that increasing the number of the blade would increase the drag surface area leading to increase in the reverse torque, resulting in decreased net torque. Binyet Emmanuel et al. [2] carried out a numerical study of a six-bladed Savonius wind turbine and reported that the improvement of the efficiency of Savonius wind machines is possible by increasing the number of blades and by preventing the wind from impinging on the convex parts. N.H. Mahmoud et.al [3] investigated using different geometries of Savonius rotors to explore the most effective operation parameters. They found that the two-blade configuration is more efficient compared to three and four blades. Further investigation revealed that the rotor with end plates had higher efficiency compared to the one without endplates. Also, the performance was better with double stage rotors without overlap compared to single-stage rotors with overlap. They reported higher power coefficient with increased aspect ratio. Chatchai Promdeea et. al[4] investigated the effects of wind angles and wind speeds on voltage generation using a Savonius turbine with double wind tunnels. The turbine was designed to convert wind flows in opposite directions when a vehicle is moving, At higher wind speeds, voltage generated was higher and with double tunnels generated output voltage at almost all the wind angles (60 to -75 degrees) approximately a hike by 45-68%. Abdullah Al-Faruk et.al [5] carried out wind tunnel experiments on Savonius turbine geometry by changing several design parameters, to investigate the optimum configuration, at different wind velocities. The influence of geometry on the performance showed an increase in coefficient of power by 24.12%. Tom Harries et.al [6] investigated the optimization of a prototype novel drag-driven vertical axis tidal stream turbine. They reported many benefits of a drag turbine that included simplified blade design, deploy ability in shallow waters and scope for denser array spacing. Norzanah Rosmin et.al [7] worked on the performance of the single-stage and double-stage two-bladed micro-sized turbine as a typical Rainwater Harvesting (RWHS) System. Their study focused on the electrical power generating capability. The system was fabricated using an aluminum sheet of an aspect ratio (AR) = 1.8, Height =80 mm and Diameter = 45 mm. They found satisfactory performance in terms of constant voltage and current. The power generated by the single-stage rotor was almost double, at 1280 rpm, compared to the double-stage rotor. Firoz Alam et.al [8] tested microscale VAWT on a prototype and tested it in a wind tunnel under a range of wind speeds of 1.4m/s to 8.33m/s. The speed of the rotor with and without cowl was carried. It was seen that the speed was more than double while using the cowl. Abhishiktha Tummala [9]- made a study of the installation of large-scale wind farms considering a small-scale wind turbine of both horizontal and vertical axis type. The performance, blade design, control and manufacturing of horizontal axis wind turbines are carried out .They concluded that the impact on climate by such a system is considerably large. R. D. Maldonado et.al [10] conducted a study on optimal characteristics by using 3-d software model of rotor assembly, followed by a simulation of the air flow and blade interaction. The simulation indicated formations of vortices. Further studies were done using blades with different geometry and blade gap. Simulations results showed the geometry and blade gap increases the power coefficient by 20%.

Installing an air deflector in front of the Savonius rotor increased the velocity of the Savonius rotor by 32%.

Some more investigation worth mentioning here is Giovanni Gerardo Muscolo et. al[11] on a proposed a novel vertical wind turbine Bronzinus, the S blade and Tandem blade Savonius by Bagus Wahyudi et.al [12] that was used to produce "jet flow" in the narrow gap on the advancing blade, a horizontal configuration of a Savonius wind turbine mounted on the upstream edge of a building by P. Larin et. al[13] , using both experimental and CFD in 3-d domain, a study based on a combination of circle-shaped conventional model is combined with the one of a concave elliptical model by Arifin Sanusi et al.[14]. They used a conventional Savonius wind turbine rotor blade for performance enhancement. The combined blade had no effect on the constructional simplicity and manufacturing costs of turbine rotors. They reported an increase of 11 % compared to the conventional blade and the 5.5 % towards using analysis based on CFD. Hiren Tala et al. [15] analyzed the rotor performance focusing on an optimized the aspect ratio using CFD, without altering the frontal area. They found that a unit of Aspect ratio of 1 gives maximum torque and the torque decreases by increasing the aspect ratio beyond 1. O. S. Olaoye et al.[16] investigated numerically the aerodynamic characteristics of the Savonius rotor using the rotor configuration of that of a semicircular and segment of a circle and overlap ratio for optimization of Two Bladed Savonius Wind Turbine with and without splitters and found a beneficial outcome , through CFD. Burcin Deda Altan et al.[17] investigated the performance improvement of the Savonius wind turbine using wind deflecting plates , placed in front of the rotor, to minimize the negative torque that affected the convex surface. This arrangement served the purpose of increasing the wind speed entering the rotor. They reported increased rotor performance and power due to the prevention of the wind from escaping to the sides. Sobhi Frikha et al.[18]studied the effect of the incidence angle on the aerodynamic characteristics of the flow using a Savonius rotor. They used six different configurations of incidence angles equal to θ=0°- θ=150° with an increment of θ=30°.Results indicated that the variation of the incidence angle affects the local characteristics.

The above studies indicate that a two bladed rotor has always offered the benefit of low cost, simplicity and better performance. However, not many studies are focusing on the installation of a portable roof top mounted windmills for homes in remote location, using cheaper available resources, that could address the electricity problem in remote in accessible villages, where low speed wind is available during most of the time.This work makes such an attempt to address this problem by using a PVC irrigation pipe to fabricate Savonius rotors where the weight is less resulting in less drive force requirement to rotate the turbine, could be easily mounted in any convenient place like a rooftop for electricity generation.

II.WORKING PRINCIPLES OF SAVONIUS ROTOR

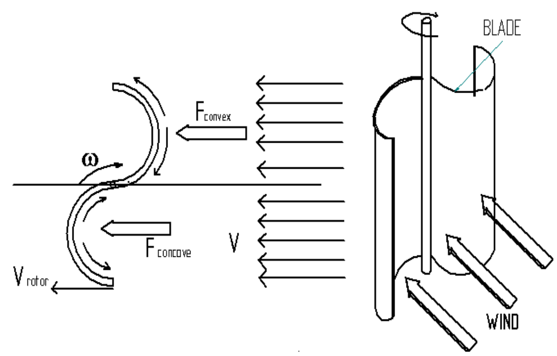


Fig 1. Schematic of wing the drag forces acting on two bladed Savonius rotor

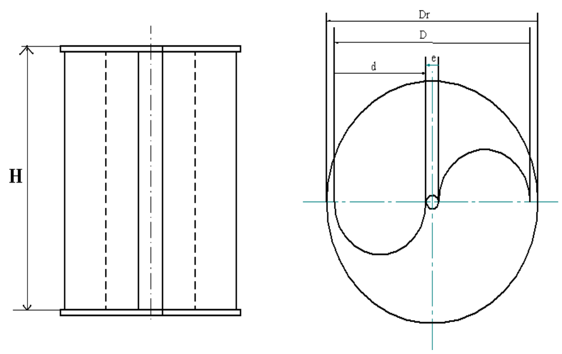
Savonius turbines are the drag–type with two or more fixed blades on to a central shaft in the opposite direction. Each vane catches the wind triggering the partial rotation of the shaft and thereby exposing the opposite vane to the upcoming wind, this process being continuous, causing the shaft to rotate continuously. The drag experienced in the concave part is of higher magnitude, compared to that on the convex part, due to which a torque T is generated., thus making the rotor to spin (angular velocity ω). This action generates mechanical power ω x T. This process continues as long as wind is accessible, and the resulting mechanical action could be used to drive a pump or a small generator & store electricity in a battery [20-22].

III.EXPERIMENTAL SETUP AND DATA REDUCTION

The dimension of the rotor depends upon the type of material. To construct the test set-up a PVC readymade high-pressure irrigation pipe was used; the cylindrical-shaped pipe was cut into two pieces in a longitudinal direction and these halved pieces were positioned on the central shaft by proper support.

The rotor assembly is positioned on a fabricated vertical stand. The gearbox and electrical measuring instruments are positioned at the bottom of the rotor. The fabricated Savonius rotor has the following dimension : Blade radius (d) = 188mm; rotor diameter (D) = 400 mm; rotor height (H) = 900 mm, shaft diameter(e) = 20mm and thickness of the blade (t) = 3 mm. The aspect ratio α = H/D= 2.5

The rotation of the rotor was measured by a tachometer at different wind velocities. Wind speed was measured by a digital anemometer. The results were analyzed for the wind speeds of 2.2, 3, 3.7, 4.9, 6, 6.5 m/sec. Both analytical and experimental results were obtained.



(a) (b)

Fig 2. Wind turbine model cross sections

Fig. 2 shows the schematic diagram of the Savonius rotor consisting of a steel shaft, ball bearing, supporting frame, gearbox assembly, upper frame and generator. The present experimental investigations were carried out on two blades without overlapping. The blades of rotors were made from PVC pipes of 3mm thickness. The pipe was cut at the center throughout its length and these halved pipes are positioned on the central shaft by proper support. The Savonius rotor shaft was mounted on a structure fabricated by a strong MS pipe. Two ball bearings were mounted on the bearing housing fitted to the endplate. The endplates support the rotor shaft. The rotor assembly was then mounted on a strong framework structure as shown in figure 3.

The endplates are stationary, and their purpose is only to accommodate bearing in position. Hence weight on the rotor assembly is reduced. Also, the existence of endplates increases the amount of air that strikes the blades of the Savonius rotor.

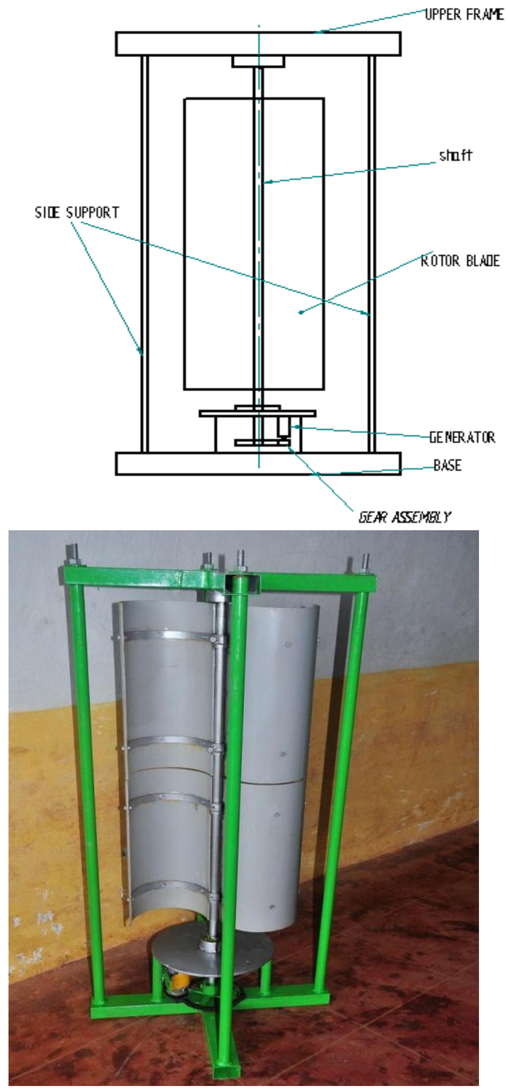


Fig 3(a): Schematic of assembly (b)Photograph of Fabricated model of single stage two blades Savonius wind turbine

Savonius wind turbine's performance can be expressed as function of torque coefficient (C_t), power coefficient (C_p) and the tip speed ratio (λ). The tip speed ratio, is expressed as (equation 1)

$$TSR = \lambda = \frac{V_{rotor}}{V} = \frac{\omega x d}{V} \qquad (1)$$

Where V_{rotor} = peripheral velocity of rotor (m/s)

d = diameter of the halved cylinder of rotor

V = wind speed m/s.

The coefficient of torque or C_t is determined by taking the ratio of actual torque from the rotor (T) and the theoretical torque available in the wind (T_w), and is expressed as (equation 2)

$$C_t = \frac{Ta}{Tw} = \frac{4Ta}{\rho x A S x d x\ V^2} \quad (2)$$

Where ρ = Air density atMSL taken as 1.225 kg/m^3
T = Torque generated(Nm)
A_s = Bladesswept area = Rotor height (H) ×Rotor diameter (D)

The power coefficient Cp is determined by taking the ratio of the max powers that could be utilized from the wind and the total power available in the wind.

$$Cp = \frac{Pw}{Pa} = \frac{Tx\omega}{½x\rho xHxDx\ V^3} \quad (3)$$

IV.UNCERTAINTY MEASUREMENT AND INSTRUMENTATION

The wind speed and the shaft rotational speed were mesured by using a digital anemometer and a digital tachometer. The mechanical power can be measured by using the dynamometer setup. However, in this present work, the output power of the turbine was measured by the available PMDC motor where voltage V and current I are measured at each wind speed. There are individual uncertainty in the measurement of wind speed, shaft rotational speed, volttge and current. The uncertainty[19] in all these mesurement taken together was found to be less than 2%

V.RESULTS AND DISCUSSION

The fabricated two bladed Savonius rotor performance was studied at different wind velocities ranging from 2.2 m/s to 6.5 m/s. The variation of rotor speed at different wind speeds is depicted in figure 5. From the results of the experiments, it was observed that ,as the wind speed increases from 0 m/s up to 2.2 m/s, the Savonius wind turbine was initiated, and the rotor started to move. This wind velocity where the wind turbine started to rotate is the cut-in speed. The rotor picked up momentum and increases its speed as the wind velocity increased. as the output ratio is considered 2.5 the rotor appears and works at a higher rotational speed with less torque.

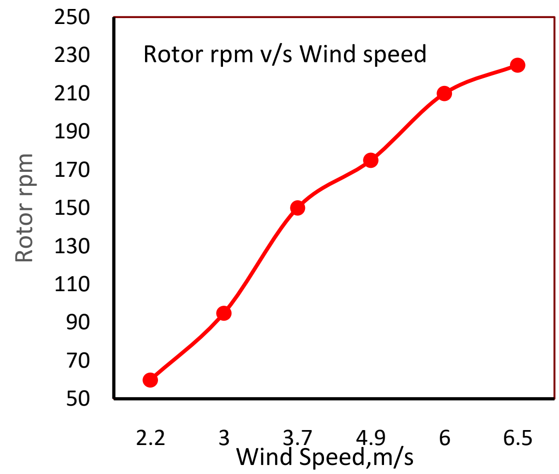


Fig 5: Rotor speed (rpm) related to wind speeds (m/s)

Fig 6 shows the relationship between actual torques of the shaft of wind turbine models for different wind speeds. The torque increases with wind velocity. The pressure on concave blades is higher than the pressure on convex blades which results that the difference in forces that will rotate the wind turbine. The torque development at the range of 0.638 N/m can be seen at a wind velocity of 6.5 m/s. However, the wind turbine can work even at high wind speed the torque development is more. The torque development can be enhanced by adopting more than two rotor blades.

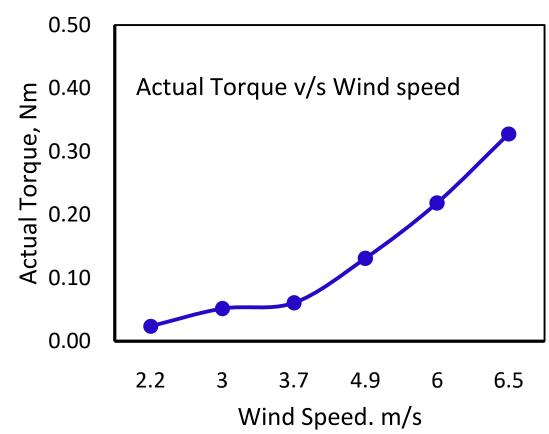


Fig 6: Actual torque of wind turbine rotor for different wind speeds (m/s).

Figs. 7, 8 and 9 represent the variation of power, power coefficient and tip speed ratio at different wind velocities. The power and power coefficient increase with wind velocities. The performance coefficient is the highest (0.12) when the TSR is 0.68.

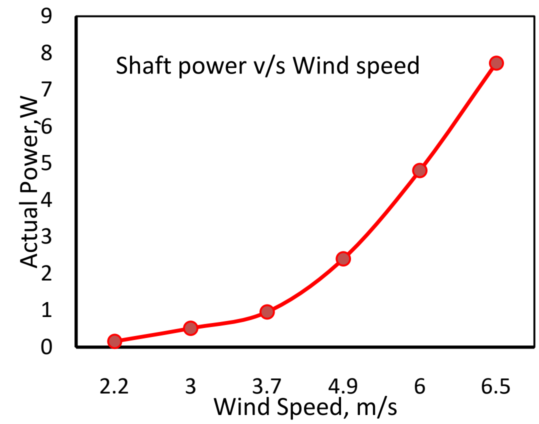


Fig 7: Actual power of wind turbine rotor for different wind speeds (m/s).

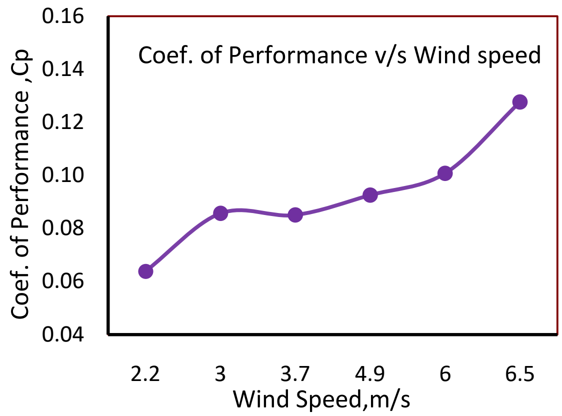


Fig 8: Power coefficient variation (Cp) with different wind speeds (m/s).

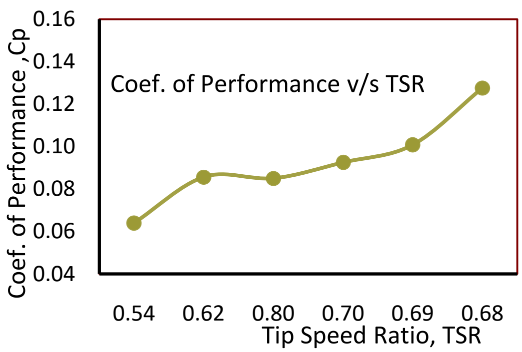


Fig 9: Power coefficient variation (Cp) with different Tip Speed Ratios

VI.CONCLUDING REMARKS

In this work,a two-bladed Savonius rotor in a single stage with no overlapping blades was fabricated using cheaply available PVC pipes , taking into consideration rural India and its easy availability . Investigations were done with the Savonius wind turbine at low wind speeds of 2.2, 3.0, 3.7, 4.9, 6.0, 6.5 m/s. The following conclusions are made based on the experimental investigations.

1. The PVC rotor blades offer adequate strength, non-corrosive in nature and can be easily installed on the rooftop making a Savonius turbine a viable low-cost power generating option in remove and space constraint areas.
2. The turbine efficiency can be increased by selecting more than two blades with the introduction of diffuser vanes. A double stage rotor can give higher performance than a single stage.
3. The Savonius wind turbine has a few drawbacks such as negative torque development by returning blades of the rotor and improper pressure distribution on advancing blades that could be addressed using a horizontal axis machine.

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