DESIGN AND CONSTRUCTION OF SAVONIUS ROTOR

Mirsad Hyder Shah
Student, Technische Universitat Dortmund.
Dortmund, (Germany).
E-mail: Itsmirsadhyder@yahoo.com ORCID: https://orcid.org/0000-0003-2476-5887

Sameer Ali Alsibiani
MD. Yanbu University College,
Yanbu Industrial City, (Kingdom of Saudi Arabia).
E-mail: Alsibianis@rcyci.edu.sa ORCID: https://orcid.org/0000-0003-1918-5175

Recepción: 04/09/2020 **Aceptación:** 07/10/2020 **Publicación:** 13/11/2020

Citación sugerida **Suggested citation**
Hyder, M., y Ali, S. (2020). Design and construction of Savonius rotor. *3C Tecnología. Glosas de innovación aplicadas a la pyme. Edición Especial, Noviembre 2020,* 65-77. https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

ABSTRACT

Renewable energy sources have been researched for more than a century now. Wind energy; which is often characterized as an unreliable source of energy, is not unreliable if placed at places with smooth wind currents. Savonius rotor as Vertical Axis Wind Turbine (VAWT) can be used as a standalone power generation device because of its low cost, low cut-in speed and the fact that it can accept wind from any direction. S-Rotors when compared to other types of rotors have a lower Power Coefficient but factors like Overlap ratio, Aspect Ratio, Number of Blades and Blade shapes can affect its efficiency. This paper discusses the Design and construction of a Savonius wind turbine by studying how the factors above influence the rotor's performance. Finally, a Single-stage, Two blade conventional Savonius rotor with an Overlap Ratio of 0.1 and Aspect Ratio of 3.3 has been constructed and discussed below. Studies for choosing the best material have also been conducted and PolyVinyl Chloride (PVC) has been selected to prepare the blades from. According to the study conducted, the voltage output recorded at 5.4 m/s wind speed was 19.1 Volts.

KEYWORDS

Savonius Rotor, Wind Turbine, S-Rotor, HAWT, VAWT.

1. INTRODUCTION

Wind turbines are classified into two categories: HAWT and VAWT. This classification refers to the position of rotor axis relative to wind direction. The Savonius rotor is thus used as vertical axis wind turbine like the other Darrieus rotor. S-Rotors or Savonius rotors have been employed as VAWT widely in the previous decades. The main reasons for which S- rotors are employed in residential areas are because they are self-starting, produce low noise and can accept wind energy from any directions. S-Rotors are also employed at places with low wind potential and where HAWTs cannot run. Since the C_p (Power Coefficient) of an S-Rotor is poor in large wind turbines, design parameters are altered as to improve the power coefficient by reducing the size of the rotor itself (Al-Kayiem, Bhayo, & Assadi, 2016).

The S-rotor was invented by Finnish engineer S. J. Savonius in 1925. As discussed earlier, S-Rotors are generally preferred over D-rotor because of low cut-in speeds and high torque, but their C_p is poor when compared with other wind turbines. In 1919, German physicist Albert Betz put forth what is known as the Betz theory. According to him, the theoretical maximum efficiency for a wind turbine is 59.3%. This value is generally known as the Betz limit for wind turbines (Al-Kayiem *et al.*, 2016).

Because of their superiority over other wind turbines, S-Rotors have been used to harness energy for various purposes; mainly power generation, to meet electricity demands (Al-Kayiem *et al.*, 2016).

2. RESEARCH DESIGN AND CONSTRUCTION

2.1. BLADES SHAFT AND COUPLING OF WIND TURBINE

For the design of blades and the selection of material for the wind turbine, following factors were taken into consideration:

- The blades of the windmill should not break if winds with high current cross the surface.
- The material should not decompose over time and not prone to rusting in harsh environment.

 https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

- The material should be easily accessible.
- The cost of the material should be low cost.
- The blades should be durable in the long run.

Considering all the reasons mentioned above, Polyvinyl Chloride (PVC) was the best choice available. After cutting the PVC to achieve the desired design the edges were smoothened with sandpaper.

Table 1. Parameters and Values of Blades Shaft and Coupling.

PARAMETERS	VALUES
Diameter of turbine	0.375 m
Volume of Blade	0.0395 m^3
Diameter of Single Blade	0.203 m
Overlap distance	0.0381 m
Density of PVC	1467 kg/m^3
Mass of PVC	3.8 kg
Blade angle	180º
Shaft Height	1.34 m
Shaft Diameter	0.036 m
Coupling Height	0.058 m
Bush size	0.02 m

The blades were weld to a shaft at an angle of 90 degrees, this enabled the blades to be rotated by wind currents. The shaft had to be strong enough to withstand strong gushes of wind and considering the work of Menet (2004); the shaft was made out of PVC.

Figure 1. AutoCAD vs Hardware of Blades and Shaft.

https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

2.2. BASE OF WIND TURBINE

For the construction of the base, mild steel bars were welded together to provide stability to the whole design. For maximum stability a four legged stand base was proposed and implemented.

Table 2. Parameters and values of base height and diameter.

PARAMETERS	VALUES
Base Height	0.36 m
Base Diameter	0.56 m

Figure 2. AutoCAD vs Hardware of Base of Turbine.

3. IMPORTANT DESIGN PARAMETERS OF SAVNOIUS ROTORS

- Overlap Ratio.
- Aspect Ratio.
- Number of Blades.
- Number of Stages.
- Blade Shapes.

3.1. OVERLAP RATIO

The overlap ratio is ratio of the overlap distance (the distance by which the inner edge of the blade overlaps the inner edge of the adjacent blade) by the diameter of the entire turbine. As shown below in figure (Al-Kayiem *et al.*, 2016).

 https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

$$Overlap\ Ratio = \beta = \frac{e}{D}$$

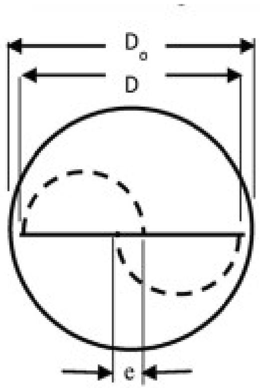

Figure 3. S-Rotor with Overlap ratio. **Source:** (Al-Kayiem *et al.*, 2016).

3.2. ASPECT RATIO

Aspect Ratio is the ratio of Rotor's height H to its Diameter D;

$$Aspect\ Ratio = \frac{H}{D}$$

Increasing Aspect ratio increases performance and angular speed of the rotor. Aspect ratio is adjusted to meet the torque and RPM requirements of the generator, which will produce electricity (Al-Kayiem *et al.*, 2016).

Blackwell, Sheldahl, and Feltz (1978), experimentally concluded that increasing aspect ratio increased the power coefficient (while keeping all other parameters constant).

3.3. NUMBER OF BLADES

With an increase in the number of blades the power coefficient decreases. This decrease is due to the fact that, as the number of blades is increased, more wind is deflected by a blade from entering into the concave side of its adjacent blades (Al-Kayiem *et al.*, 2016).

Al-Kayiem *et al.* (2016) in his work concluded that S-Rotors indeed do perform better at low wind currents. It is also compared and concluded that two blades perform better than

 https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

three blades as more drag is wasted in the three-blade system. The C_p of two blade design is much better than a three-blade system.

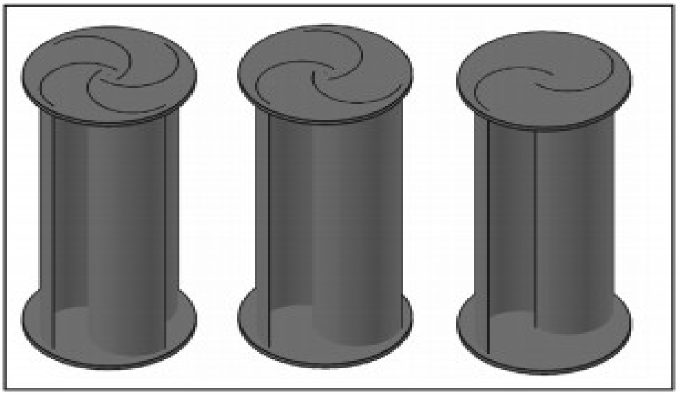

Figure 4. S-Rotor with various number of blades. **Source:** (Al-Kayiem *et al.*, 2016)

3.4. NUMBER OF STAGES

Number of stages mean one or more stages of an S-Rotor in a single design. This means that the wind currents will have more area to sweep through and better torque uniformity around 360 degrees. This eliminates the dead zones left by rotor's blades that are not rotating. Note that the stages of an S-Rotor are shifted at a specific phase shift angle.

In his paper, Al-Kayiem *et al.* (2016), debated that a Double staged S-Rotor may produce the best power coefficient as compared to a single or three staged S-Rotor. This explains the hypothesis that as the stages of an S-Rotor are increased it means if one of the stages of S-Rotor is rotating it must carry the inertia of the other stages since they are not producing any torque.

Saha, Thotla, and Maity (2008), in his experimental work, concluded that a single staged rotor gave a C_p of 0.18, a two-staged rotor gave a power coefficient of 0.29, while the three-staged demonstrated a C_p of only 0.23.

https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

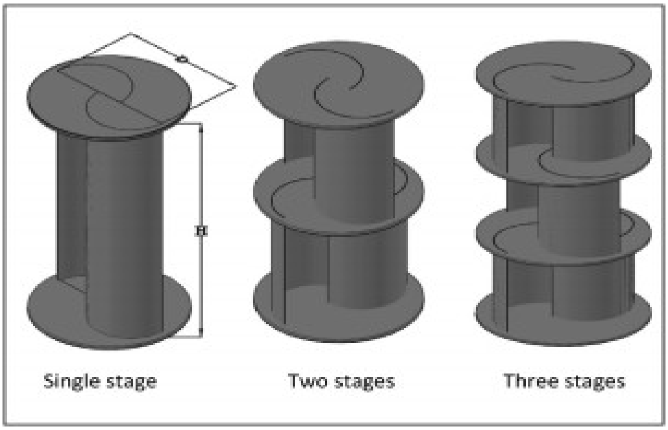

Figure 5. Single and Multistage S-rotors. **Source:** (Al-Kayiem *et al.*, 2016).

3.5. BLADE SHAPES

Although S-Rotors are generally similar S-shaped rotors, there have been few attempts to modify the blade shape in order to increase its aerodynamic property in order to increase the C_p.

Muscoloa and Molfinob (2014) simulated five different S-type VAWTs, including a simple S-Roto. In the four wind rotors, two were new models and two were proposed by Kyozuka (2008). The rotor named Bronzinus, performed the best and produced the highest power coefficient. But if the tip speed was crossed C_p of the wind rotor proposed by Menet (2004) was found to be superior.

4. FINAL DESIGN OF ROTOR AND ASSEMBLY

The Rotor assembly consisted of the following parts:

- Base:

The base was made up of mild steel. The purpose of the base was to hold the rotor in its place and provide a suitable height above the ground for the blades to face the wind. The PMDC motor was coupled under the base as well. To provide maximum strength Mild steel bars were welded in an L-shaped arrangement.

https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

- Bearing & Bearing Housing:

The purpose of the bearing was to support the shaft and lessen the friction for the shaft to rotate. The bearing housing protects the bearing from any damage and restricts the movement of the shaft.

- Motor Housing:

Motor housing consists of two horizontal plates made of Mild Steel which will have the motor sandwiched in the between. The top end of the motor was secured to the assembly by screws.

- Rotor Shaft:

The rotor shaft was made up of PVC. Due to its high strength, Polyvinyl Chloride was chosen to withstand bending forces exerted by the rotating blades. The shaft had to be strong enough to withstand strong gushes of wind and considering the work of Menet (2004); the shaft was made out of PVC.

5. RESULTS

The parameters and values for the final design have been presented in Table 3. As the factors discussed above have been carefully considered such that the power coefficient of the rotor never drops. According to Al-Kayiem *et al.* (2016), the average Power Coefficient of an S-rotors under open flow conditions ranges from 0.037 to 0.37. However, the Power Coefficient of S-rotors with external flow guides can reach up to 0.52.

Table 3. Parameters and values of Final Design.

PARAMETERS	VALUES
Model type	Two blade conventional Savonius rotor
Height	1.25 m
Diameter	0.375 m
Area	0.456 m^2
Aspect ratio	3.3
Overlap ratio	0.1
Number of stages	1
Number of Blades	2
Design of Blade	Conventional Blade

https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

In the Figure 6, the AutoCAD drawing and the actual hardware are shown. As the Savonius rotor has a conventional blade design and it is a two blade system. Furthermore, it uses minimal area and takes only 0.456 m^2 of area. The factors affecting the power coefficient of the S-rotor have also been calculated and presented.

Figure 6. AutoCAD vs Hardware of S-rotor.

In Table 4, the results for the wind turbine have been shown. The velocity of the wind was measured using an anemometer which was placed right in front of the rotor. The wind made the rotor move as intended. However, the maximum wind velocity that could be simulated was 5.4 m/s. On the Beaufort Scale, such a wind speed has a Beaufort number of 3 and is considered as a Gentle Breeze only. But due to the rotor being lightweight it was easily rotated, and enough Revolutions were generated. At a windspeed of 5.4 m/s, the generator under the S-Rotor generated 19.1 Volts.

Table 4. Results of Wind Turbine.

WIND SPEED m/s	RPM	VOLTAGES
4.1	200	14.91V
4.5	241	17.0V
4.9	253	18.17V
5.1	265	18.64V
5.4	302	19.1V

https://doi.org/10.17993/3ctecno.2020.specialissue6.65-77

6. CONCLUSION

This paper presented a study in which S-rotors have been employed as a power generation unit. The design and construction of a Savonius rotor has been carried out in this paper and S-rotors have been proved to be used in power generation units. S-Rotors are generally highly affected by varying geometric parameters and blade shapes. S-rotors produce high starting torques and low cut-in speeds. Furthermore, factors such as Overlap Ratio, Aspect ratio, number of blades and number of stages have been briefly discussed in this paper. It is also concluded that by increasing/decreasing the factors discussed above, the Power Coefficient of the wind turbine varies. For the design of blades and the selection of material for the wind turbine, Poly Vinyl Chloride (PVC) was chosen as the best material available. It was chosen mainly because of its low cost and durability. Furthermore, choosing the suitable Aspect and Overlap ratio is a difficult task but from the work of Blackwell *et al.* (1978) it can be inferred that keeping the Overlap ratio to a minimal and increasing the Overlap ratio; increased the power coefficient of the Savonius Rotor. Finally, for a better power coefficient, the authors predict a two blade two stage rotor will do a better job for conventional wind turbines but will prove ineffective if the wind currents are equally distributed from the top to the bottom on the whole blade design.

REFERENCES

Al-Kayiem, H. H., Bhayo, B. A., & Assadi, M. (2016). Comparative critique on the design parameters and their effect on the performance of S-rotors. *Renewable Energy*, *99*, 1306-1317. https://doi.org/10.1016/j.renene.2016.07.015

Blackwell, B. F., Sheldahl, R. E., & Feltz, L. V. (1978). Wind tunnel performance data for two-and three-bucket Savonius rotors. *Journal of Energy*, *2*(3), 160-164. https://pdfs.semanticscholar.org/9c43/b666ff48d4396dc6a42cb27eb9f6a6563c21.pdf

Kyozuka, Y. (2008). An experimental study on the Darrieus-Savonius turbine for the tidal current power generation. *Journal of Fluid Science and Technology*, *3*(3), 439-449. https://doi.org/10.1299/jfst.3.439

Menet, J. L. (2004). A double-step Savonius rotor for local production of electricity: a design study. *Renewable energy*, *29*(11), 1843-1862. https://doi.org/10.1016/j.renene.2004.02.011

Muscoloa, G. G., & Molfinob, R. (2014). From Savonius to Bronzinus: a comparison among vertical wind turbines. *Energy Procedia*, *50*, 10-18. https://doi.org/10.1016/j.egypro.2014.06.002

Saha, U. K., Thotla, S., & Maity, D. (2008). Optimum design configuration of Savonius rotor through wind tunnel experiments. *Journal of Wind Engineering and Industrial Aerodynamics*, *96*(8-9), 1359-1375. https://doi.org/10.1016/j.jweia.2008.03.005