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Paper title: Designing and Manufacturing of Miniature Savonius Wind Turbine

Paper abstract:

The main objective of this work is to develop a small-scale VAWT that can be installed on bikes to charge low power devices such as smart phone. To achieve this objective, a small Savonius vertical axis wind turbine is designed with three helical blades of 45o using solid works. Then, the Additive manufacturing technique (3D printing) was used for the fabrication of the blades and the other parts of the turbine by generating g-codes for solid works files by using Cure software program. The height and the diameter of the blades are equal to 100 mm while the length of the turbine shaft is equal to 160 mm. The experimental result for efficiency of this turbine is compared with the literature efficiency of two blades Savonius vertical axis wind turbine with a height to diameter ratio of 1.67 for validation.

Designing and Manufacturing of Miniature Savonius Wind Turbine

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Abstract

The main objective of this work is to develop a small-scale VAWT that can be installed on bikes to charge low power devices such as smartphones. To achieve this objective, a small Savonius vertical axis wind turbine is designed with three helical blades of 45^o using SolidWorks. Then, the additive manufacturing technique (3D printing) was used for the fabrication of the blades and the other parts of the turbine. This was done through the generation of g-codes for the SolidWorks files by using Cura software program. The experimental results showed that the performance of the designed turbine was satisfactory.

Key Words: Savonius turbine, VAWT, Additive manufacturing, 3D printing, Renewable energy.

1. Introduction

A way to meet the electricity demand without burning oil products using some alternative source must be found. This alternative source must have the potential to meet most of the demand in a short time, and in the same time, it must be economically feasible such as the wind turbines. Wind turbines can be categorized by the orientation of their axis of rotation into two groups: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). By using a shaft to transfer the torque, VAWTs can have the generator and other key parts located at ground level which enables designing them focusing on performance and economy rather than size and weight. Furthermore, maintenance and modifications are made easier with these parts placed on the easily accessible tower base. VAWTs are omnidirectional which allows for a design with essentially only one moving part, which is made up of the rotor, shaft and generator rotor which are all joined. Also, the concept has shown potential for lower noise emissions [1]. Furthermore, in [2] it has been shown that the concept is more suitable for up-scaling than the HAWT concept. However, torque ripple on the shaft and bending moments on the blades due to the constantly changing angle of attack are issues that are only addressed for VAWTs, making dimensioning for fatigue more complex [1, 3, 4].

Throughout the last decades, the HAWT concept has derived by far the most interest and financial support which has led to the development of the large and economically feasible wind turbines of today [1]. However, VAWTs have some advantages as mentioned above that have led to a renewed interest in the concept. Also, the research of VAWTs is not nearly as comprehensive as for HAWTs which by itself can motivate further studies.

Savonius wind turbines are a type of VAWTs. Savonius wind turbine was invented by the Finnish engineer Sigurd Savonius in 1922 [5]. Kummbernuss et al. [6] studied experimentally the performance of vertical axis wind turbines (Savonius type) with different overlap ratios and shift angle. Each wind turbine was tested with different speed. This study presents the effect of the shape of the blades, a number of the blades, overlap ratio and the phase shift angle on the performance of the wind turbine. The overlap ratios used were 0, 0.16, and 0.32 while the shifted phase angles were 0, 15, 30, 45, and 60 and the air velocities were 4 m/s, 6 m/s, 8 m/s, and 10 m/s. The results show the overlap ratio has a big effect on the performance of the Savonius wind turbine and must be carefully determined when designing this type of turbines. Also, shift angle effect on the performance of the wind turbine depending on the air speed. Larger phase shift angle with low air speed will produce high performance. Smaller phase shift angle with high air speed will produce high performance.

Yao et al. [7] presented a new design of vertical axis wind turbine. It contains a tower cowling to increase the performance of wind turbine. The wind turbine was put inside the tower cowling. This tower cowling will increase the air force on the inner parts of the blades which produce positive torque. It also prevents air from forcing the outer parts of the blades which produce negative torque. According to this study, the tower will reduce the cost of maintenance and has long service life. Also, they study the effect of the number of the blades. According to this study, the optimal number of the blades for this design is two blades.

Kharudin et al. [8] presented a design for a small vertical axis wind turbine. This wind used to convert wind energy to electrical energy. This act as a mobile charger, so by using this wind turbine anyone can charge his mobiles while traveling from one place to another.The designed wind turbine has four blades with a length of 60 mm, the height of 25 mm and thickness of 2 mm. It was found that the produced voltage is 7.68 Vdc at 100 km/hr (31.6 m/sec).

Jae et al. [9] studied the effect of twist angles on the performance of drag based VAWT. The effect was studied experimentally and theoretically using CFD. For angle values of 0, 45, 90 and 135 degrees, and for tip speed ratio ranging from 0 to 1.2, the results showed that a twist angle of 45 degrees produces optimum performance coefficient of 13% at a tip speed ratio of 0.5.

Kamoji et al. [10] tested helical Savonius rotors in an open jet wind tunnel and described that the power coefficient of the helical Savoinus rotor was greater than that of the conventional Savonius rotor.

Shankar [11] examined the performance of both rotors with two blades and three blades geometries. He also established that two blades Savonius rotor have almost 50% greater peak power output than the three blades rotor.

Burcin et al. [12] suggested a modification to the typical design of the Savonius wind turbine by using straight blades with a longer length. The power coefficient of the modified turbine was found to be 20% greater than that of a typical Savonius wind turbine.

Frederikus et al. [13] conducted an experimental study to investigate the effect of the number of blades on the performance of Savonius wind turbine. The study investigated turbines with 2,3 and 4 blades. The results showed that four blade design has high torque and good performance at low tip speed ratio, but at higher tip speed ratios the three-blade design is superior.

It worth mentioning that not all wind turbines can be used in rooftop application. For example, horizontal axis wind turbines cannot be used in low altitude because they require very high wind speed with low turbulence. Therefore, in this work, we propose a new design of a small-scale VAWT that can be installed on bikes to charge low power devices such as smartphone. The procedure of designing and manufacturing the proposed wind turbine is documented in this work. Moreover, the performance of the designed turbine was validated experimentally.

The paper is organized as follows, the design procedure for the proposed wind turbine is shown in section (2), the manufacturing process is described in section (3), the experimental setup and the results are illustrated in section (4) while results are discussed in section (5). Section (6) concludes the work.

2. VAWT Design

The main objective of this work is to develop a miniature VAWT that can be installed on bikes to charge low power devices such as smartphone. To achieve this objective, a small Savonius vertical axis wind turbine is designed with three helical blades of 45^o using SolidWorks. The Savonius wind turbine is a drag based vertical axis wind turbine that utilizes the kinetic power of the wind to create torque on the turbine rotor. The wind hits the surface of the turbine blades creating a force that leads to the creation of torque on the turbine rotor. The Savonius turbine usually has two to three blades, at any given moment some blades contribute to the rotation of the rotor creating positive torque, and some restrict the rotation of the rotor creating negative torque. Some specific design inputs have been chosen before starting the design process.

The input power (P_{in}) to the Savonius wind turbine can be determined from the following equations:

$$P_{in} = \frac{1}{2}\rho V^3 A C_p \qquad \text{Eq. 1}$$

Where:

ρ is the air density
V is the wind velocity.
C_p is the power coefficient (= 40 %, [10])
A is the turbine swept area which is given by

$$A = 2R*H \qquad \text{Eq. 2}$$

Where:-

R is the radius of the blade (= 50 mm).
H is the blade Height (= 100 mm).

The height and the diameter of the blades are equal to 100 mm while the length of the turbine shaft is equal to 160 mm.

3. Manufacturing Process

The proposed VAWT is modeled by using SolidWorks. The turbine has four main elements, which are the shaft, the blades, the base, and the pulley. Firstly, SolidWorks was used to draw the blades and the other parts of Savonius VAWT (

Figure **2**, and

Figure **2**). Then, additive manufacturing technique (3D printing) was used for the fabrication of the blades and the other parts of the turbine by generating g-codes for SolidWorks files by using Cura software program [14]; shown in

Figure **3**. Figure 4 displays the 3D printer which was used in the manufacturing of the Savonius VAWT parts.

The results obtained were very satisfactory. The 3D printed parts were of high quality and the fits were very good.

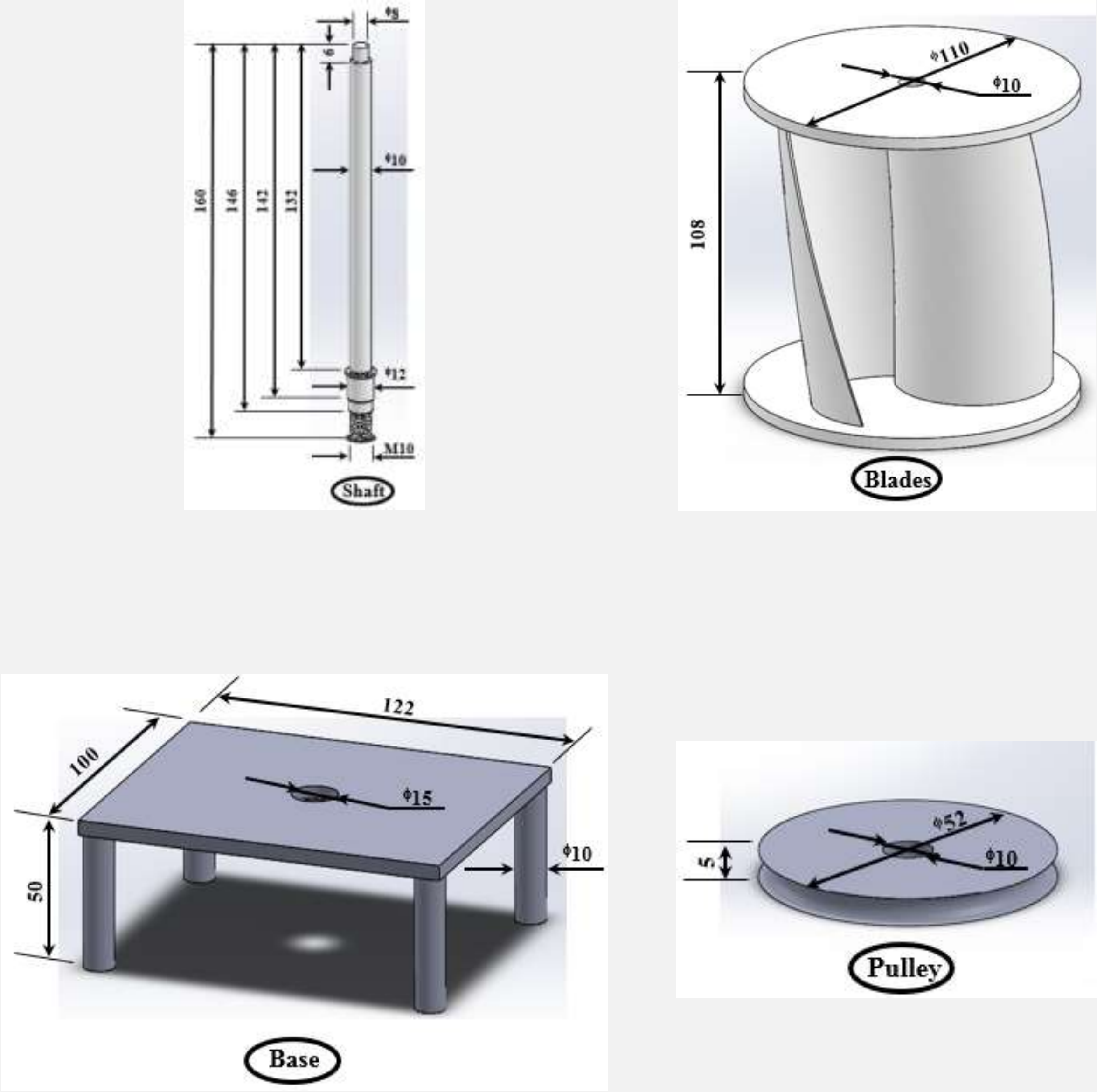


Figure 1: 3D Modeling of the all turbine parts orientation and main dimensions (all dimensions in mm).

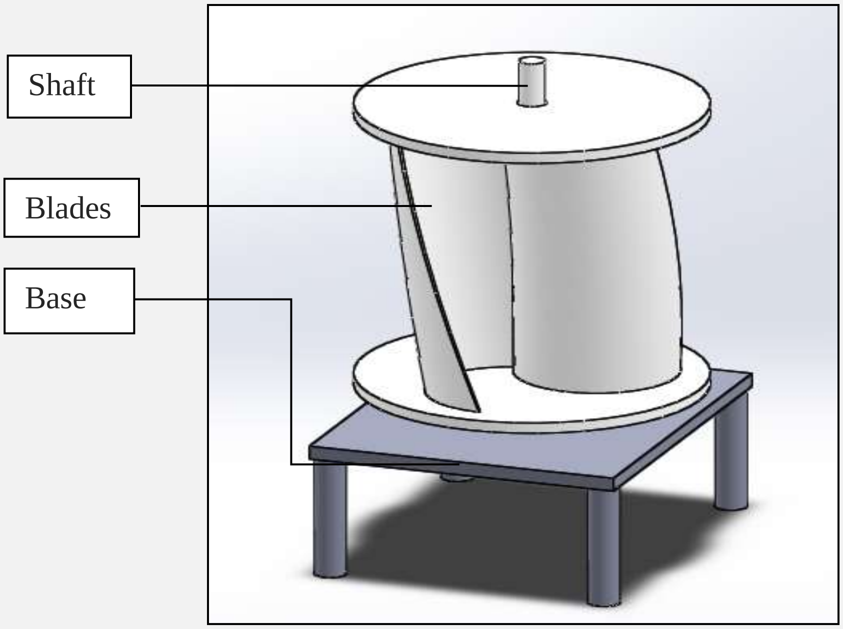
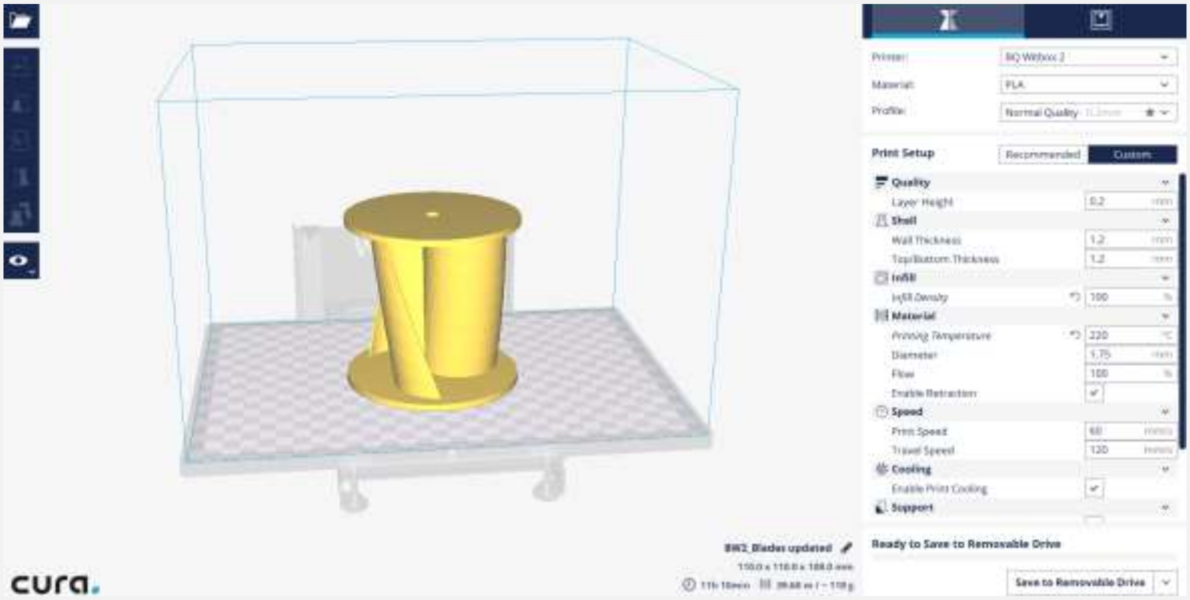


Figure 2: Solidworks model of the Proposed Minature VAWT (Assembly drawing).



Printer: BQ Witbox 2
Material: PLA
Profile: Normal Quality

Print Setup

Quality
Layer Height 0.2 mm

Shell
Wall Thickness 1.2 mm
Top/Bottom Thickness 1.2 mm

Infill
Infill Density 100 %

Material
Printing Temperature 220 °C
Diameter 1.75 mm
Flow 100 %
Enable Retraction ☑

Speed
Print Speed 60 mm/s
Travel Speed 120 mm/s

Cooling
Enable Print Cooling ☑

Support

Ready to Save to Removable Drive

Figure 3: Generating g-codes for the three blades in Cura program software.

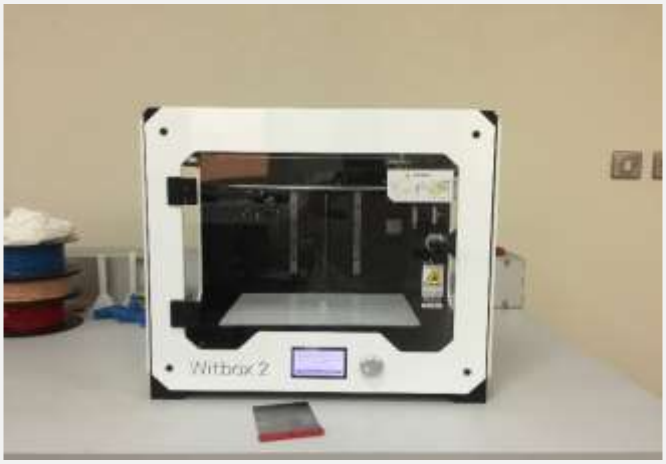


Figure 4: The 3D printer.

The used material in printing is polylactic acid (PLA) and has following properties, shown in Table 1.

Table 1: The properties of the printing material

Melt temperature	170 °C
Tensile strength	(61 – 66) MPa
Flexural Strength	(48 – 110) MPa
Heat Deflection Temperature	(49 - 52) °C

4. The Experimental Setup

The turbine was tested using different wind speeds using a variable speed blower, Figure 5. The blower flow rate was given in the blower manual and divided into 7 levels, then the air velocities calculated by the following equation.

$$V = \frac{Q}{A} \qquad \text{Eq. 3}$$

Where:

V is the air velocity.
Q is the flow rate of the blower
A is the cross-section of the blower nozzle.

Figure 5: Variable Speed Blower.

The velocities of the air which comes from the blower for its different several levels are shown in Table 2 .

Table 2: Blower air velocities.

Level	1	2	3	4	5	6	7
Wind speed (m/sec)	4	8	12	15	20	24	28

A tachometer is used to measure the angular velocity of a rotating shaft, shown in Figure 6. The tachometer utilizes the reflection of light from a small chip mounted on the shaft to determine the angular speed of the rotating blades.

Figure 6: Tachometer used for measuring the blades rotational speed.

The setup used to test the designed VAWT is shown in Figure 7.

Figure 7: The experimental setup.

5. Results and Discussion

The measured rotational speed of the turbine shaft under different wind speeds is shown in Table 3.

Table 3: The rotational speed of the turbine shaft in rev./min (r.p.m.).

Wind speed (m/sec)	The rotating speed of the shaft (r.p.m.)
4	500
8	550
12	620

The recorded high rotational speeds (500 - 600 r.p.m) proved that the turbine is able to withstand high speeds without failing. A significant decrease in rpm was noticed after coupling the turbine with the generator. The turbine and generator were assembled together using a belt and two pulleys to find the produced power. Figure displays the miniature Savonius vertical axis wind turbine and the generator assembly.

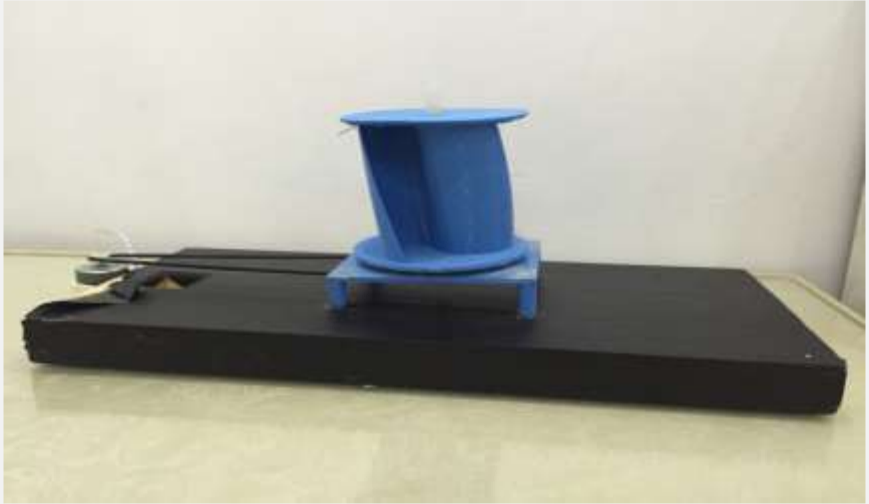


Figure 8: Assembly of the miniature Savonius VAWT with the generator.

The input power for the VAWT is calculated from Eq. 1. The output power (P_{out}) is calculated from the following equation:

$$P_{out} = IV \qquad \text{Eq. 4}$$

Where:

I is the current in Amper.
V is the voltage in Volt.

The turbine efficiency (η) is computed from the following equation:

$$\eta = \frac{P_{out}}{P_{in}} \qquad \text{Eq. 5}$$

Table 4 shows the results of the input power, the output power, and the turbine efficiency with different wind speeds. It worth mentioning that the input power is calculated based on a value of $C_p = 0.4$ [10]. It show be noted that the bicycle speed can reach 10 m/sec (36 km/h). At this speed, the designed wind turbine can produce 2.5 watt, which is equivalent to the amount of power from PC USB that can be used to charge smart phones.

Table 4: The Power and efficiency results

Wind speed (m/sec)	Input Power (Watt)	Voltage (V)	Current (A)	Output Power (Watt)	Turbine Efficiency (%)
12	4.23	2.5	0.010	0.025	0.591
15	6.75	8	0.03	0.24	3.5

These results show that the efficiencies of the system at the given velocities are low. These results due to a loss in the system due to friction in the turbine-belt assembly.

6. Conclusion

A VAWT turbine of Savonius type was designed and manufacturing successfully using SolidWorks and the additive manufacturing (3D printing) technique. The turbine has 3 blades and has a small size that can be mounted on small moving vehicles like bikes or mounted on any flat surface to capture wind energy. So, the turbine can be used in different places and people. So it can be used in open areas such as camping places and especially at night. By using this product, we can produce clean, non-polluting and sustainable energy.

The designed turbine was able to withstand high speeds without failure. The rotational speed of the shaft is very high without the coupling to the generator. This speed reduces dramatically after attaching the shaft to the generator. Therefore, the shaft-generating assemble needs more attention to reduce the power loss that results from this coupling. This issue will be considered in the future work.

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