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Design and development of integrated savonius and darrieus small scale vertical axis wind turbine for power generation

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Abstract. The study focuses on the integration of the darrieus and savonius wind turbine to a vertical axis wind turbine for power generation. The material used for darrieus was fiber glass with three blades and diameter of 350 mm, and polyvinyl chloride (PVC) for the savonius with four blades and diameter of 100 mm. The evaluation was conducted using a controlled wind source to vary its linear wind velocity. The actual power generated was compared to the theoretical power generated to identify the efficiency of the system. With the lowest linear wind velocity of 2.63 meters per second, the actual power output of the system (combination of the darrieus and savonius power output) was 3.79 watts and the theoretical power output is 6.03 watt. This made the system to be 62.85% efficient with low wind velocity. With the highest wind velocity of 12.52 meters per second, the output of the system was 408.80 watts and the theoretical output is 650.61 watts. This made the system to be 62.83% efficient. In an overall performance of the system with varying linear wind velocity, the efficiency of the system is close to 63%.

1. Introduction

The acceptance of the recent technologies is an indication of the economic development and the measurement of the efficiency of the production. The acceptance of this technologies should take into consideration the substantial pressure to address environmental issues. The acceptance should be extensive and should provide public good. In case of environmental issues, public good leads to the absence of pollution. The absence of pollution is the adoption of the green technology. A green technology imparts benefits to consumers but additional costs to the producer [1-4].

The utilization of renewable energy has drawn much attention nowadays because of the excessive use of fossil fuel, energy depletion, and environment pollution. Alternative to fossil fuels is commonly the topic in research and development as this is evident by annual average growth rate of the consumption of the renewable energy as fuel in the generation of electricity. The capacity of wind energy has increased drastically over the other forms of renewable energy. In the context of wind energy, the horizontal axis wind turbine (HAWT) has been the center of exploration during the recent years. But, the vertical axis wind turbine (VAWT) has an essential advantages over the previous. VAWT can generate power even with relatively low cut-in wind speed, being omni-directional, and less noise. VAWT can be classified into two classes, the Darrieus (a turbine using the lift force) and Savonius (a turbine using the drag force). These two produce less noise, have a simple shape, and capable of maintaining stable performance with low wind speed [5-9].

The design of the darrieus and savonius wind turbine has different specifications. The savonius wind turbine can be applied in power generation but the self-starting mechanism might be a problem. On the other hand, the darrieus wind turbine compromises the efficiency if the blade rotates, the angle of attack is changed. The integration of the savonius and darrieus wind turbine can aid one another in addressing their flaws and help to increase their efficiencies. The proponents thought of a low cost design of a small-scale vertical axis wind turbine by integrating the savonius and darrieus wind turbine with a newer design of the blade architecture for a much higher efficiency than the conventional vertical axis wind turbine [10-15].

2. Design aspects

Figure 1 presents the design of the integrated savonius and darrieus small-scale vertical axis wind turbine. The combination of the savonius and darrieus wind turbine is intended to reduce the space for installation and thus, to increase the efficiency of the power output of a VAWT with the reduced production cost but with larger volume of electricity. The material used in the fabrication of darrieus blade is fiber glass and 80mm-diameter polyvinyl chloride (PVC) pipe for the savonius blade.

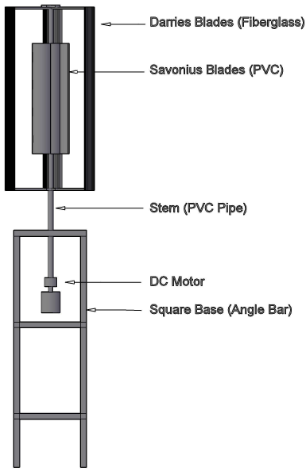

Figure 1. Design of the integrated savonius and darrieus small-scale vertical axis wind turbine

The researchers have come up with the design of the rotor blades for the darrieus with NACA 4415 because it has a better performance than the other airfoils design. The swept area, tip speed ratio, blade chord, number of blades, and, angle of attack were considered in the final design of the blade.

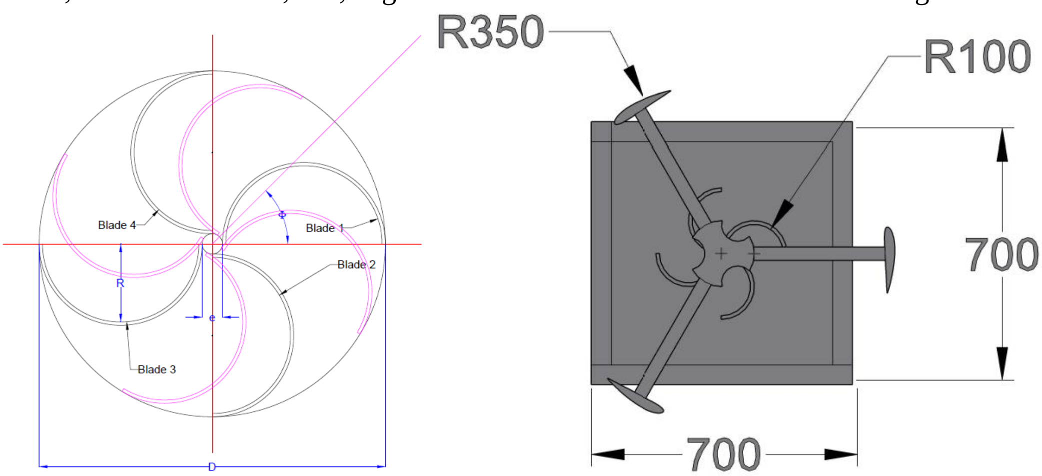

Figure 2. Design and dimensions of the savonius blade *(top view)*

The design utilized four blades of savonius (figure 2) and three blades for darrieus (figure 3) to achieve maximum power extraction since the power generation depends on how fast the blade can capture the wind and how fast these blades will rotate. The four and three blades combination increases the output efficiency with smoother rotation and most efficient design in the environment [13][14][15]. This combination of number of blades also helps in the quick start of the rotor as this is designed to rotate with higher rpm and more torque. With lower wind speed, the combination also allows the increase of the thrust and centrifugal force on the blade . The fiberglass and pvc pipe were used for the strength and stiffness of the blade. Figure 2 presents the radius of the savonius which is 100 mm and this is attached to a square base with side measuring 700 mm.

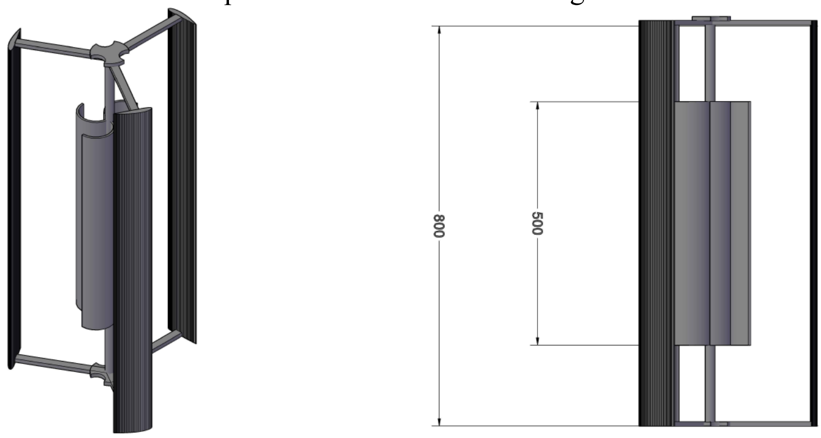

Figure 3. Design and dimensions of the integrated savonius and darrieus blade

Figure 3 shows the integration of the savonius and darrieus blade with the intention of reducing the space for installation. The length of the savonius blade is 500 mm and that of the darrieus blade is 800 mm.

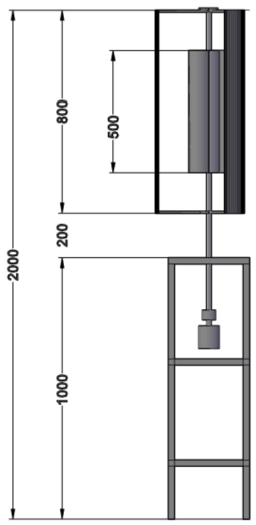

Figure 4. Dimensions of the integrated savonius and darrieus small-scale vertical axis wind turbine

Figure 4 presents the design and dimensions of the integrated savonius and darrieus small-scale vertical axis wind turbine. The height of the prototype is 2000 mm with its base height of 1000 mm.

The base (700 mm by 700 mm) was constructed using an angle steel bar to maintain its stability and it houses the dc motor.

3. Development of the system

The system combines the savonius and darrieus types of blades for a small-scale vertical axis wind turbine. The blades work in any wind direction and do not require any mechanism to change their angles. Figure 5 shows the constructed integration of the savonius and darrieus wind turbine. The design is intended to be integrated to an urban setting as this produces less noise and present no danger to anyone. As the wind blows, the mechanism starts with the rotation of the darrieus blades. With the fixed stem, clutch bearings, and the spaces between the three blades of the darrieus, the wind reaches the savonius that drives the blades to rotate also at the same time as the darrieus blades are rotating. The lower portion of the stem accumulates the generated rotation of the blades and this serves as the prime mover of the DC motor. The DC motor is connected to a battery for power storage with an inverter to match the required output voltage for consumption.

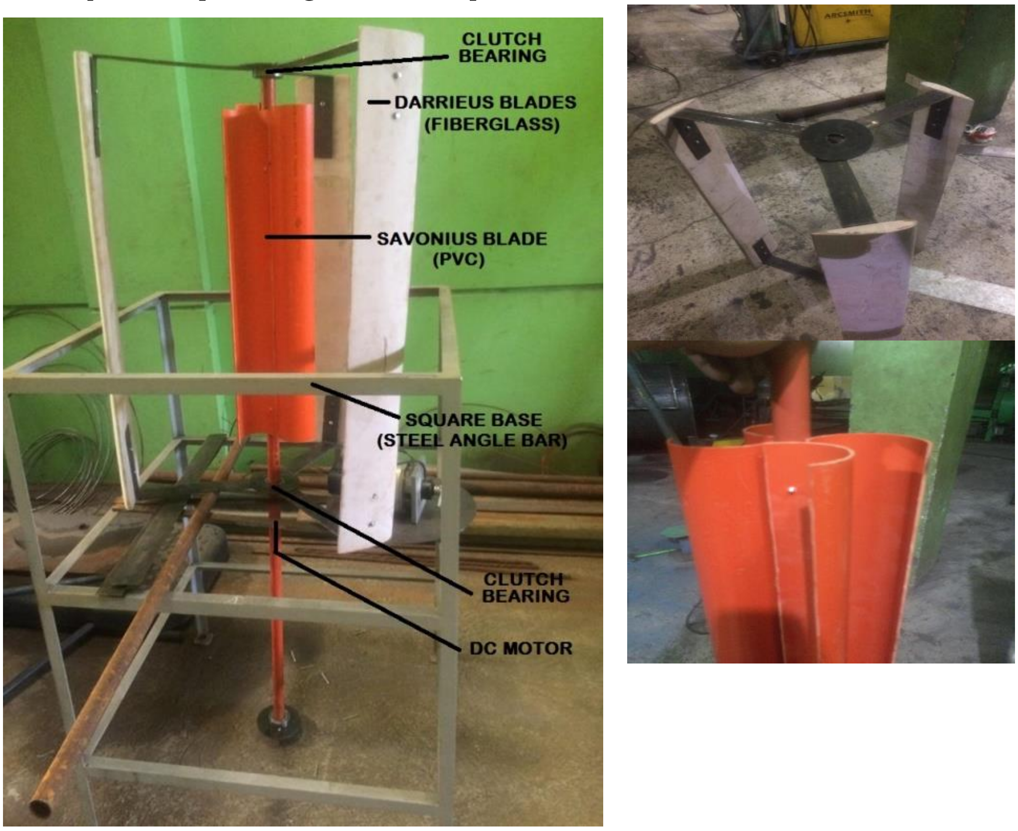

Figure 5. Development of integrated savonius and darrieus small-scale vertical axis wind turbine

4. Data and results

The evaluation of the system was conducted using a wind tunnel with varying speed as the source of wind energy. The linear velocity of the wind was varied from 2.63 meters per second to 12.52 meters per second. The result of the individual performance of the darrieus and savonius clearly shows that darrieus is more efficient in converting electrical energy from wind energy. Though, savonius is still capable of providing electrical energy from the available wind energy.

Figure 6 compares the result of the system (combining the savonius and darrieus wind turbine output) to the theoretical power output. The theoretical power output was computed using the formula $P = (\rho A V^3)/2$ where V is the linear wind velocity (in meters per second), ρ is the wind density (in kilogram per cubic meter), and A is the swept area considering the diameter of the wind turbine. Figure 7 shows the comparison of the actual power output of the system versus the theoretical power output. Table 1 shows the performance of the individual trial with varying wind characteristics, darrieus power output, savonius power output, system power output, and theoretical power output. Considering the lowest linear velocity of the wind which is 2.63 meters per second, the power output of the system was 3.79 watts and the theoretical output is 6.03 watts. The data show that the system is 62.85% efficient in the low wind speed. With the highest linear velocity of 12.52 meters per second, the generated output of the system was 408.40 watts and the theoretical output is 650.61 watts. The result shows an efficiency of 62.77% which is almost the same as that of the efficiency with the lowest linear velocity. With all ten different trials, the efficiency of each was close to 63%. The result clearly shows that the developed system will have the same efficiency regardless of the linear wind velocity.

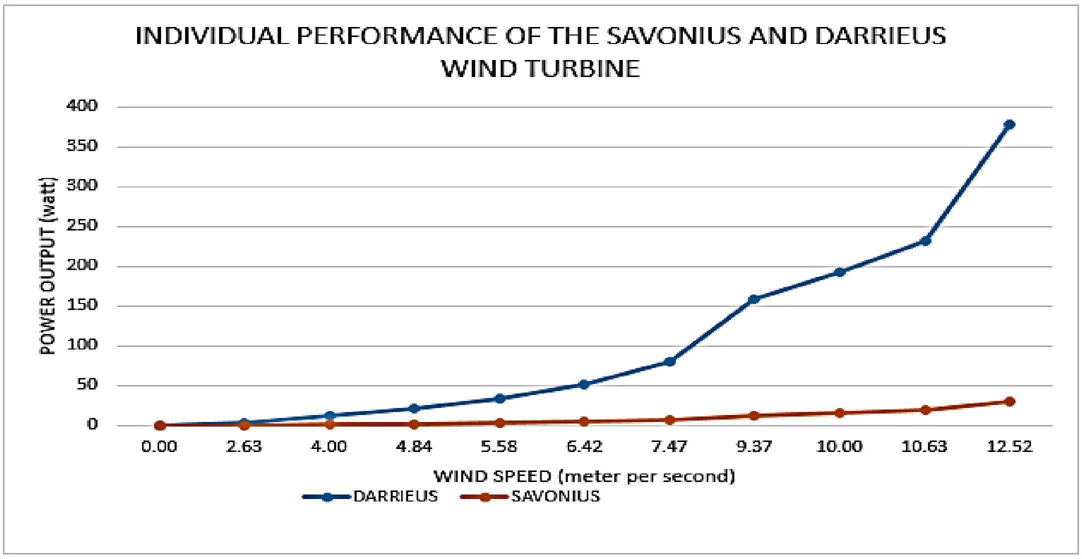

Figure 6. Performance of the savonius and darrieus wind turbine in watt versus the wind speed

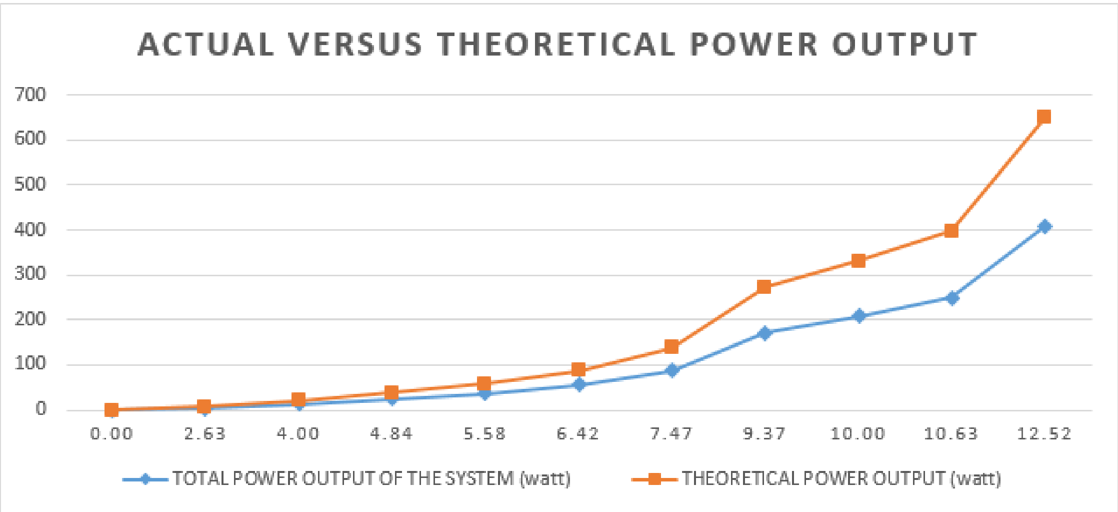

Figure 7. Actual power output of the system versus the theoretical power output in watt

Table 1. Performance of the individual trial with varying wind characteristics, darrieus power output, savonius power output, system power output, and theoretical power output.

WIND CHARACTERISTICS				DARRIEUS		SAVONIUS		SYSTEM (ACTUAL)	THEORETICAL	EVALUATION	
Linear Velocity (meter per second)	Temperature (°C)	Density (kg/m³)	Specific Weight (N/m³)	Area covered by the blade	Power output (watt)	Area covered by the blade	Power output (watt)	Power output (watt)	Power output (watt)	Power output difference (watt)	Percent Efficiency (actual / theoretical)
2.63	-20	1.395	13.68	0.38	3.50	0.03	0.29	3.79	6.03	2.24	62.852%
4.00	0	1.293	12.67	0.38	12.31	0.03	1.00	13.31	21.22	7.91	62.724%
4.84	5	1.269	12.45	0.38	21.83	0.03	1.78	23.611	37.59	13.98	62.812%
5.58	10	1.247	12.23	0.38	33.39	0.03	2.73	36.12	57.60	21.48	62.708%
6.42	15	1.225	12.01	0.38	50.91	0.03	4.16	55.06	87.72	32.66	62.768%
7.47	20	1.204	11.81	0.38	80.27	0.03	6.55	86.62	138.19	51.36	62.682%
9.37	25	1.184	11.61	0.38	158.11	0.03	12.91	171.02	272.73	101.71	62.707%
10	30	1.165	11.43	0.38	192.29	0.03	15.70	207.99	331.52	123.53	62.738%
10.63	40	1.127	11.06	0.38	231.07	0.03	18.86	249.94	398.21	148.27	62.766%
12.52	50	1.109	10.88	0.38	377.95	0.03	30.85	408.8	650.61	241.81	62.833%

5. Cost analysis

The intention of the study was to develop a VAWT that may be used in urban and rural area which is low-cost and all materials should be available in the local area. With the utilization of the fiber glass for darrieus and PVC for the savonius, the total expenses in the construction of this was PhP 12,215.00 or 231USD. Other related studies reflected their total expenses ranging from 600USD to 800USD. Table 2 presents the total breakdown of expenses of the prototype.

Table 2. Breakdown of components/materials and cost for the prototype

Components/Materials	Quantity	Cost	Function
Benetech GM816 Anemometer Wind Speed	1.0 unit	Php 870.00	wind speed reading
Bosca Charge Controller DC 12V/24V 5A	1.0 unit	Php 700.00	charging controller
Bosca Power Inverter 12V-220Vac (SA-10000AF)	1.0 unit	Php 1,200.00	power output converter
Reliance Electric DC Motor/Generator 24V	1.0 unit	Php 2,300.00	power generator
Darrieus Blade Fiberglass Fabrication	3.0 units	Php 2,000.00	blade material for darrieus
Clutch Bearing	2.0 units	Php 2,500.00	rotation shaft in one-direction configuration
Ordinary Bearing	1.0 unit	Php 100.00	rotation shaft in two-direction configuration
Wire	5.0 meters	Php 75.00	conductor
Disk Brakes	2.0 units	Php 600.00	brake system
Brake Caliper	2.0 units	Php 1,000.00	brake system
2600 Ah Battery	1.0 unit	Php 1,400.00	power storage
PVC Pipe 3	1.0 unit	Php 270.00	blade material for savonius
PVC Pipe 3/4	1.0 unit	Php 100.00	stem material
	TOTAL	Php 12,215.00	

6. Conclusion

There is a great advantage in the combination of the darrieus and savonius wind turbines in one vertical axis wind turbine over the horizontal axis wind turbine. With the use of the fiber glass and PVC as materials for the blades, these are light weight and produce less noise. These were able to answer the common issues facing the wind energy technology. Also, with all materials available to any end-user, the system may be constructed and developed in rural and urban areas. The system is capable of generating electrical energy even with low wind speed and the mechanism is less noisy with minimal vibration produced. The system is 63% efficient regardless of the linear wind velocity. Thus, there is a need to further improve the system to achieve higher efficiency. The mounting height, diameter of the system, materials to used, and other parameters may be considered for further exploration of the system.

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