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Portable Wind Turbine for Energy Recharging Device Applications

Joni Welman Simatupang and Kristiantho Sulistiohadi
Study Program Electrical Engineering, Faculty of Engineering, President University
Jl. Ki Hajar Dewantara, Cikarang Baru, Bekasi-17550, Indonesia
Corresponding author: joniwsmtp@president.ac.id

ABSTRACT

A new design of a portable, inexpensive, and easy to assemble horizontal axis wind turbine (HAWT) system for harnessing wind energy that can be reproduced by individuals in the need of electricity has been implemented. The design still follows the Betz' law theory to define the maximum electrical power that can be extracted from the wind in an open flow area. From our measurement data, the Betz Limit (C) of our design wind turbine is approximately 0.48, meaning it can capture not more than 48% of the incoming kinetic energy of the wind. It was found also that the system can generate a stable at least 5V and 1A of DC voltage and current, respectively. The wind speed is at least ranging from 35 to 55 km/h (~10 to 15 m/s). We conclude that this HAWT is still able to charge some rechargeable energy recharging devices, such as smart phone or power bank. This HAWT must be put outside to obtain a good amount of wind. But, actually it does not provide a waterproof protection system to make it usable in a rainy season. For further research, a new portable wind turbine can be designed to generate more electric power with waterproof ability system such like using PVC or acrylic which is modeled by this simple prototype.

Keywords: Betz Limit, energy recharging devices, harness, maximum power, portable.

I. INTRODUCTION

Wind turbine converts the kinetic energy of the wind into mechanical energy, which is in turn converted to be electrical power. Historically, the first electricity-generating wind turbine was a battery charging machine installed in July 1887 by Scottish academic James Blyth to light his holiday home [TJP04]. By 1930s, wind generators for electricity were common on farms, mostly in United States where distribution systems had not yet been installed. In this period, high-tensile steel was cheap, and generators were placed atop prefabricated open steel lattice towers. A forerunner of modern horizontal-axis wind generators was in service at Yalta, USSR in 1931. This was a 100 kW generator on a 30-meter tower, connected to the local 6.3 kV distribution system. It was reported to have an annual capacity factor of 32 percent, not much different from current wind machines [AW86].

Wind turbines can be grouped into one of two categories: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). The horizontal axis wind turbine (HAWT) can be visualized as a conventional box fan, in which a set of blades connected to a shaft that is parallel to the ground floor.

The rotor blades have to be connected to a horizontal shaft that is connected to a generator which will produce energy from the shaft work [OH05]. Fig. 1 shows the three main parts of a horizontal axis wind turbine (half part of our design also follows this pattern, another half follows the VAWT's design below), namely: rotor which includes the turbine blades, generator such as electrical generator, control electronics, and a gearbox, and structural support including the tower and yaw motor [WT], [MOO14].

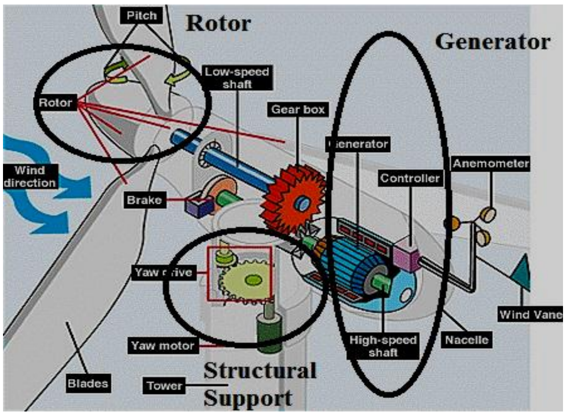

Fig. 1. A general pattern of a horizontal-axis wind turbine (HAWT) which emphasizing its three main parts: rotor, generator, and structural support [WT].

There are two kinds of HAWTs: the upwind wind turbine and the downwind wind turbine. An upwind rotor faces the wind while a downwind rotor enables the wind to pass the tower and nacelle before it hits the rotor [OH05], [MOO14]. Meanwhile, the vertical axis wind turbines (VAWT) operates on the same principle of converting rotational movement due to wind into shaft work, which is then converted into electricity through the use of a generator. A VAWT contains a shaft that is perpendicular to the ground (as opposed to the parallel shaft used by the HAWT) as illustrated in Fig. 2 [MOO14].

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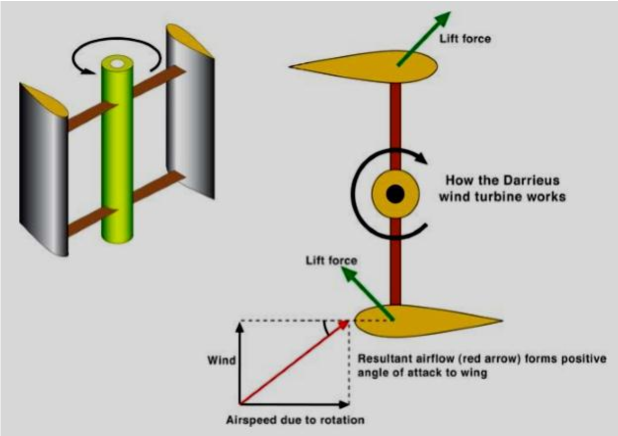

Fig. 2. Working principles of a lift-type vertical axis wind turbine (VAWT) [OH05].

In 2013, Small-scale Wind Energy Portable Turbine (SWEPT) from Virginia Polytechnic Institute and State University has been implemented [RAK13]. SWEPT operates in a very low wind speed range of 1 to 5 m/s, with extremely high power coefficient (32%), overall efficiency (21%), and power output (1 W) at its rated wind speed of 4 m/s. It has a very low cut-in speed of 1.7 m/s and is capable of producing power output up to 9.3 W at wind speed of 10 m/s.

Also, in 2013, a group of students from Northern Arizona University has constructed the prototype of portable wind turbine cost of about $195. Its final design can be disassembled into four pieces for ease of transportation. This prototype was constructed using mostly simple tools, but the system can generate 0.5 kWh of electricity per day, if provided with a wind speed of at least of 3.64 m/s for 10 hours per day [KC13].

A Dutch renewable energy start-up called *The Archimedes* has been proposed to solve the problems of a new class small-scale wind turbine. The company states that the Liam F1 turbine could generate 1,500 kWh of energy per year at wind speeds of 5 m/s, enough to cover half of an average household's energy used [ACH].

In this paper, a design of a horizontal axis wind turbine (HAWT) system to harness wind energy has been proposed and implemented. The rest of the paper is organized as follows: Section II describes the design and implementation of this portable device, Section III provides the results of experiment and discussion analysis. Lastly, section IV gives Conclusions.

II. Design Implementation

A. *Turbine Fabrication*

Common Personal Computer (PC) fan has been modified to fabricate the magnetic PC fan, including the blades. The fabrication steps of the magnetic fan will be explained in detail. First, the iron is taken out from the fan. Then, the lathe machine is used to cut the center of the fan (Fig. 3), also to process the iron inside become thinner by 3 mm in radius or 6 mm in diameter (Fig. 4). So, later on the magnet can be inserted without interrupting the spinning process of the fan blades (Fig. 5 and Fig. 6).

Fig. 5 shows that the fan has enough room for the iron to be glued back to make a turbine. The magnet allocation can be seen in Fig. 6 (left). The magnet must be in different pole when it is adjacent to other magnet. The magnet is glued to the iron. After the magnet is glued, the iron is glued back to the fan using the strong glue. It creates a white circle in the middle as shown in Fig 6 (right).

The initial diameter of the iron is 2.9 cm and the authors use 3 types of the same magnet element. The first fan uses rectangular type of neodymium earth magnet. It is also known as NdFeB [WSM12], NIB, or Neo magnet, with dimension of 10 mm x 5 mm x 2 mm, while the second and third fans use 5 mm x 5 mm x 1 mm circle neodymium earth magnet. And the last fan uses 6 mm x 6 mm x 1.5 mm square type of neodymium earth magnet. The magnet is different in each fan because the rectangular type is out of stock. Therefore, authors bought different size and type of magnet, but with similar performance. But then we realized that 3 fans were not enough to obtain the magnet power we expected, so we improvise the 6 mm x 6 mm x 1.5 mm square type. Finally, four PC fans have been succesfully fabricated.

B. *Tower Design*

The tower has to rotate by following the direction of the wind. The tower also must not fall when the wind speed is strong/high. So, the base diameter and the height of the tower are designed about 40 and 50 cm, respectively. The tower use bearing to make it rotates freely. It also has something like tail to adjust the position to follow the direction of the wind. The material of the base and the tower is 3 cm hollow iron. It creates a strong base and tower without making it too heavy to carry on. The author chooses the square ones because it is easier to put a bolt inside it to attach the fan. The base of this tower is X-shaped to ensure that it has the same power in all direction. Fig. 7 shows the finished tower design.

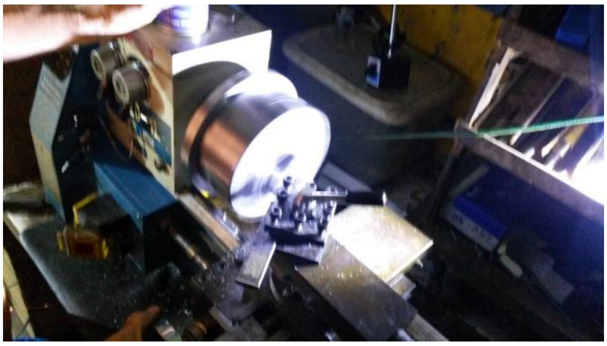

Fig. 3. The middle of the fan that close to the iron is cut with lathe machine.

Fig. 4. Iron inside the PC fan before (left) and after (right) process.

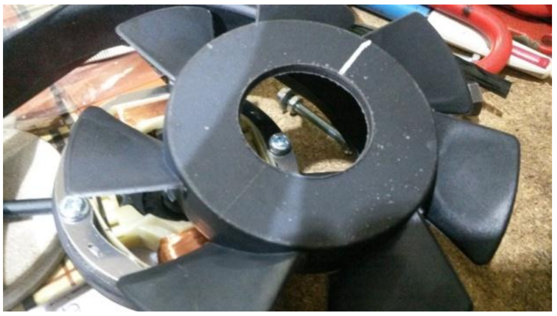

Fig. 5. PC fan blade after the iron was taken away.

Fig. 6. Placing magnet on the iron surface (left) and the finished PC fan (right).

Fig. 7. The tower consisted of four PC fans with multiblades.

C. Tail and Fin

This prototype could have a tail with fin to make it rotated by following the direction of the wind. The tail is created from ebonite because this material is light, but also strong. The fin for the tail is created from material of polyvinyl chloride (PVC). PVC is chosen because it is light, strong, and also pretty cheap. The finished tail and fin is shown in Fig. 8.

After all fabrication, then the turbine, tower, electrical circuit, tail and the fin must be assembled into a final form. The finished full-body assembly is shown in Fig. 9.

III. Experimental Measurement

The operation testing method/procedure to measure the output product of this simple portable wind turbine will be given here. Fig. 10 shows the testing method block diagram from beginning to the end. We just need to plug in the smartphone or power bank into the given socket, then to put the full-body tower to be explored in windy area. So, the wind will rotate the turbine, and the rotating turbine will produce power with AC voltage and current. After that, this power will be delivered to the rectifier, to be converted to DC voltage and current. This DC voltage will be delivered to 7806 voltage regulator. If the input voltage is below 6V, it will be immediately grounded. Although it is higher than 6V, only 6V will be delivered. The excess voltage will be stored for a moment and then also be grounded. When the output voltage is reaching 6V, it can be used to charge any smart phone or power bank. Testing process for charging a smart phone is shown in Fig. 10.

Fig. 8. Tail and fin of the turbine.

Fig. 9. Full-body of the portable VAWT system with tail and fin.

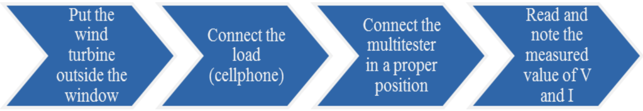

Fig. 10. Testing method block diagram.

Fig. 11. Testing process for charging the smart phone (*the blue one).

Usually, a normal wind will not reach the speed of 30 km/h. Therefore, measurement process was done in this way: by holding the device outside the car while the car moves by certain speed. The wind speed is approximated to be the same as the car speed by assuming that that there is no wind outside, meaning that the wind speed when the car stop is 0 km/h. The data was measured and then collected by two multi-meters: one for the output voltage, the other for the output current. Here, the tail is removed to ease the testing process as we can see in Fig. 11. In this process, the direction of the wind can be known by hand. The tail is an additional feature just if we want to use this device outside without touching the tower. From three measurements, we take the average value to be displayed in Table 4.1. Authors did not compare the output voltage with the speed because it will stay at around 6V due to the utility of voltage regulator.

IV. Result and Analysis

Three measurements have been conducted. All data were recorded at Table 1. The obtained maximum value of power coefficient is only 0.48. From the Betz's law [4], it should be 0.59. As we know, *C* is obtained by using Betz law, $P = 0.5\, \rho\, A\, v^3\, C$. So $C = 2P/\rho\, A\, v^3$, where P is V x I, ρ is 1.23 kg/m³ (wind density), A is 0.00589 m² (fan area), and ν is wind speed. This discrepancy happens due to the voltage regulator that creating a boundary to the output voltage (V). So, the power will saturate at some parts even if the wind becomes faster or the speed increases. But, this number is still good.

Figures 12 and 13 show the relations between wind speed vs coefficient of effectivity and output power, respectively. From the curves, we can see that there is no output from 5 km/h until 15 km/h. It is because the fan does not rotate at all. It starts rotating at 20 km/h, with a high coefficient because the voltage produced is still below 6V. The coefficient still increases due to the increasing of wind speed till the voltage is approximately regulated to 6V. It can be seen that the power generated is almost constant after 55 km/h. From all of data, the authors conclude that the portable wind turbine is able to recharge some electronic devices such as a smartphone.

V. Conclusion

In this paper, a portable, in expensive, and easy to assemble HAWT system has been introduced and discussed. This prototype was constructed from many simple tools and scrap materials in order to reduce the cost of fabrication and experiment. Furthermore, it is rugged and able to withstand in high wind speeds. For ease of measurements, the tail has been diassembled. The system can generate around 5V of electric voltage, if the wind speed provided is of at least 35 km/h (10 m/s). This measured voltage is able to recharge some electronic devices such as a smartphone/power bank for personal use.

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Tabel 1. Collected data of current and voltage from three measurements.

Speed (km/h)	V_1 (V)	V_2 (V)	V_3 (V)	V_{avg} (V)	I_1 (A)	I_2 (A)	I_3 (A)	I_{avg} (A)	P_{real} (W)	*C*	P_{ideal} (W)
5,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01
10,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05
15,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,16
20,00	2,41	2,39	2,40	2,40	0,12	0,10	0,10	0,11	0,26	0,41	0,37
25,00	2,87	2,94	2,90	2,90	0,17	0,21	0,18	0,19	0,54	0,45	0,72
30,00	4,29	4,22	4,25	4,25	0,24	0,25	0,22	0,24	1,01	0,48	1,24
35,00	5,14	5,20	5,17	5,17	0,33	0,34	0,30	0,32	1,67	0,50	1,97
40,00	6,00	5,98	6,00	5,99	0,45	0,39	0,40	0,41	2,48	0,50	2,95
45,00	6,10	6,00	6,10	6,07	0,54	0,58	0,59	0,57	3,46	0,49	4,20
50,00	6,10	6,00	6,10	6,07	0,80	0,77	0,82	0,80	4,83	0,50	5,76
55,00	6,10	6,10	6,10	6,10	1,20	1,20	1,10	1,17	7,12	0,55	7,66
60,00	6,10	6,10	6,10	6,10	1,20	1,20	1,20	1,20	7,32	0,44	9,94

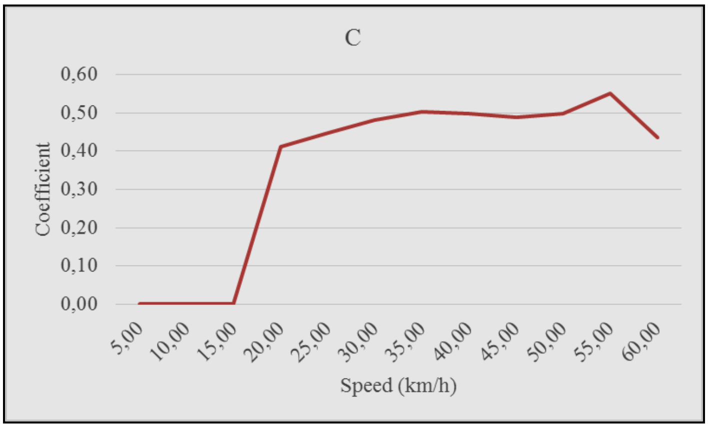

Fig. 12. Relation between coefficient of effectivity vs wind speed.

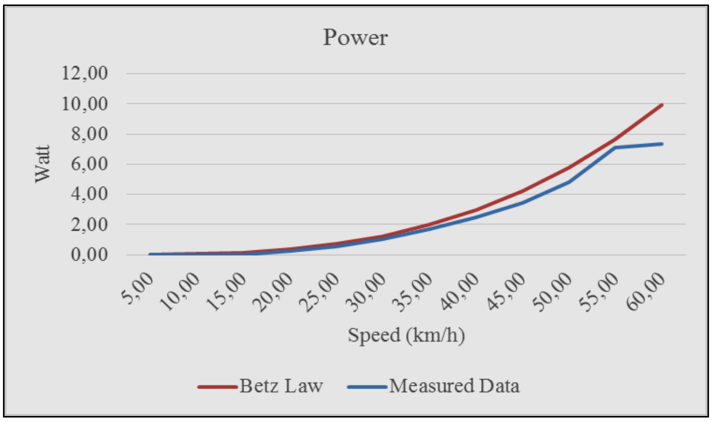

Fig. 13. Relation between output power vs wind speed.