

DESIGN AND CONSTRUCTION OF H-TYPE VERTICAL AXIS WIND TURBINE

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ABSTRACT

The measurement of the wind velocity acting on the wind turbine is important for the development of wind turbine technology. The power produced by the wind turbine is influenced by its two major part, wind power and belt power transmission system. The blade and the drag area system are used to determine the powers of the wind that can be converted into electric power as well as the belt power transmission system. A set of blade and drag devices have been designed for the wind turbine prototype at the Thermal Laboratory of Faculty of Engineering, Universiti Industri Selangor (UNISEL). Test has been carried out on the wind turbine with the different velocities of 5.89m/s, 6.08m/s and 7.02m/s. From the calculation, the wind power has been obtained as 132.19 Watt, 145.40 Watt and 223.80 Watt. Experimental results show that wind power of the turbine increases with the increase of wind velocity.

Keywords: Wind Turbine, Wind Power, Belt Power Transmission System.

1. INTRODUCTION

Wind turbine is a machine that converts the wind's kinetic energy into rotary mechanical energy, which is then used to do work. In more advanced models, the rotational energy is converted into electricity, the most versatile form of energy, by using a generator [1]. For thousands of years people have used windmills to pump water or grind grain. Even into the twentieth century tall, slender, multi-vaned wind turbines made entirely of metal were used in American homes and ranches to pump water into the house's plumbing system or into the cattle's watering trough. After World War I, work was begun to develop wind turbines that could produce electricity. Marcellus Jacobs invented a prototype in 1927 that could provide power for a radio and a few lamps but little else [2]. When demand for electricity increased later, Jacobs's small, inadequate wind turbines fell out of use. The first large-scale wind turbine built in the United States was conceived by Palmer Cosslett Putnam in 1934; he completed it in 1941. The machine was huge. The tower was 36.6 yards (33.5 meters) high, and its two stainless steel blades had diameters of 58 yards (53 meters). Putnam's wind turbine could produce 1,250 kilowatts of electricity, or enough to meet the needs of a small town [3]. It was, however, abandoned in 1945 because of mechanical failure. With the 1970s oil embargo, the United States began once more to consider the feasibility of producing cheap electricity from wind turbines. In 1975 the prototype Mod-O was in operation.

This was a 100 kilowatt turbine with two 21-yard (19-meter) blades. More prototypes followed (Mod-OA, Mod-1, Mod-2, etc.), each larger and more powerful than

the one before. Currently, the United States Department of Energy is aiming to go beyond 3,200 kilowatts per machine. Many different models of wind turbines exist, the most striking being the vertical-axis Darrieus, which is shaped like an egg beater [1]. The model most supported by commercial manufacturers, however, is a horizontal-axis turbine, with a capacity of around 100 kilowatts and three blades not more than 33 yards (30 meters) in length. Wind turbines with three blades spin more smoothly and are easier to balance than those with two blades. Also, while larger wind turbines produce more energy, the smaller models are less likely to undergo major mechanical failure, and thus are more economical to maintain. Wind farms have sprung up all over the United States, most notably in California. Wind farms are huge arrays of wind turbines set in areas of favorable wind production. The great number of interconnected wind turbines is necessary in order to produce enough electricity to meet the needs of a sizable population. Currently, 17,000 wind turbines on wind farms owned by several wind energy companies produce 3.7 billion kilowatt-hours of electricity annually, enough to meet the energy needs of 500,000 homes.

The future can only get better for wind turbines. The potential for wind energy is largely untapped. The United States Department of Energy estimates that ten times the amount of electricity currently being produced can be achieved by 1995 [4]. By 2005, seventy times current production is possible. If this is accomplished, wind turbines would account for 10 percent of the United States' electricity production. Research is now being done to increase the knowledge of wind resources. This

involves the testing of more and more areas for the possibility of placing wind farms where the wind is reliable and strong. Plans are in effect to increase the life span of the machine from five years to 20 to 30 years, improve the efficiency of the blades, provide better controls, develop drive trains that last longer, and allow for better surge protection and grounding. The United States Department of Energy has recently set up a schedule to implement the latest research in order to build wind turbines with a higher efficiency rating than is now possible. The efficiency of an ideal wind turbine is 59.3 percent [5]. Turbines in actual use are about 30 percent efficient. The United States Department of Energy has also contracted with three corporations to research ways to reduce mechanical failure.

Even the wind turbines can categories to some of types like horizontal and vertical axis but it still had the own the disadvantages due to some effective reasons. For example HAWTs have difficulty operating in near ground, turbulent winds because their yaw and blade bearing need smoother, more laminar wind flows, difficult to install needing very tall and expensive cranes and skilled operators, downwind variants suffer from fatigue and structural failure caused by the turbulence and height can be a safety hazard for low-altitude aircraft. Other than that, the aerodynamics of a horizontal-axis wind turbine is complex. The air flow at the blades is not the same as the airflow far away from the turbine. The very nature of the way in which energy is extracted from the air also causes air to be deflected by the turbine. In addition, the aerodynamics of a wind turbine at the rotor surface includes effects that are rarely seen in other aerodynamic fields. The Darrius vertical type wind turbine has some problems, because VAWTs produce energy at only 50% of the efficiency of HAWTs in large part due to the additional drag that they have as their blades rotate into the wind. From the investigation of this wind turbine background, an H-type, vertical axis wind turbine has been designed and built at thermal Laboratory in Universiti Industri Selangor that has the capability to self-start. In addition, this turbine has been designed to allow a variety of modifications such as blade profile and pitching to be tested.

These studies have been concentrated on design and built an H-type, vertical axis wind turbine that has the capability to self-start due to the wind flow and efficient performance of the VAWT that could lead to a change in the standard thinking of how wind energy is harnessed, and may spur future VAWT design and research. Wind power calculation has been established and documented.

2. METHODOLOGY

2.1 Experimental Design

The main components that involved in this study to develop the vertical axis wind turbine have been designed by using the CATIA software and then they are assembled together to predict how the actual product is look like before producing the real product. The model of wind turbine to be tested at open hall has H-type shape with blade height of 1066.80mm. The Corner Sharpe has been used as aerofoil for the wind turbine blade with

function of producing a controllable aerodynamic force by its motion through the wind flow (Figure 1). The top

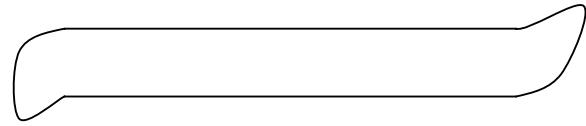


Fig 1: The Shape of Airfoils with 139.7mm

and bottom of each blade is a 1066.8mm x 139.7mm x 50.8mm deep rectangular section to allow for easier connections to the radial arms and passive pitching system. In this study the corner sharp has been selected as the shape of the blade for its very high capability to face the resistance of wind flow and faster rotation during the wind flow.

The base has been made with mild steel material which stands 6096.00mm high and weighs 15 kg, and on its own the base will not support the torque and moments produced from the wind turbine, so a base extension and a connecting bracket have been designed. To connect the 4 sheets of mild steel bracket to the mild steel base a bottom bracket made of 38.10mm x 762.00mm steel has been used. This bottom bracket is bolted from the bottom up through the sheets of steel and up through the steel base. These 38.10mm x 38.10mm structures provide quick assembly and disassembly of the turbine base structure. The bottom bracket requires 4 simple corner welds and flat head bolts welded in position that encourage quick assembly. To modify the base, 4 sheets of 1219.20mm x 2438.40mm x 19.05mm mild steel have been used to construct a base extension that give a larger footprint on which to place weights. The main sheet is oriented with 2 sheets side-by-side, with 2 other sheets on top at 90 degrees rotation to the bottom 2 sheets. This creates a base table of 2438.40mm x 2438.40mm width.

The shaft used this wind turbine design is the type of polishaft and its weight is 14kg and it is made from the mild steel. The diameter of the shaft is 30mm and its length is 2133.6mm and its surfaces are very soft and its makes the shaft rotate very smooth when attracted into bearing. Minimizing required start-up torque is essential for the wind turbine to self-start and thus, the success of the project. The bearings that are used in the wind turbine design projects are inferior units that are not salvageable. For the particular setup 2 roller bearings have been required that is to primarily centralize the shaft, and a turntable bearing to take the majority of the weight. This combination provides the least amount of friction, while maximizing bearing life and maintaining safe operating conditions. The diameters of the bearing are 88 mm and weights 300 gram each. Mild steel has been used for the three support arms to maintain a lightweight assembly with minimal inertial, moment, and centrifugal forces. The connecting arms provide a means to mount the blades to the center shaft. The arms are used as 1066.8mm lengths.

A drag device has been made from a lightweight plastic (casting plastic) and mounted to the main shaft. The height of the drag device is about 762.00mm and the

circular depth of the plastic is 182.88mm. Selecting appropriate airfoils for the 3-bladed vertical axis wind turbine is one of the most important design decisions. Different profiles provide various advantages and disadvantages that are considered. The estimated weight of each wood airfoil is 400 gram and this light weight woods construct with the proper aerodynamic shape to face the maximum wind flow.

The final assembly of the wind turbine design has been set at thermal Laboratory in Universiti Industri Selangor carrying out the experiments and is shown in figure 2 and there are 18 parts and 15 screws are combined together in the assembly process. The shaft is connected with the main parts and with the alternator during the full assembly of this vertical axis wind turbine.

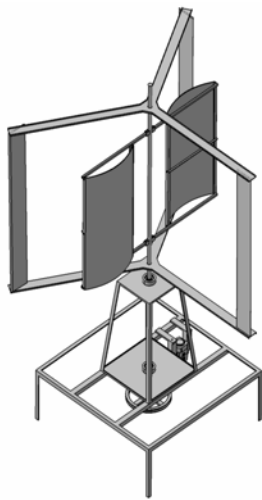


Fig 2: The final assembly of wind turbine

2.2 Experimental Procedure

The prototype wind turbine is mounted properly in the ground where the turbine is located and the four stands of the table are also make sure in flexible and balance with the ground portion. After that, the battery terminal and alternator terminal are checked properly connected with the lamp and switch. Then the wind turbine is allowed to rotate. Due to the rotation voltage is produced and the connected lamps are turned on. The produced voltage readings and the respective turbine rotations are recorded.

The ambient pressure and temperature are recorded using the manometer and thermometer for the evaluation of air density in the Laboratory environment of Universiti Industri Selangor. The power produced by the wind speed is also calculated which is shown in the specimen calculation section. The main test is performed at open hall in the Thermal Laboratory of Faculty of Engineering, UNISEL, where wind speeds are measured between 4 and 6 m/s, with gusts up to 7 m/s. During the test, the turbine has been run based on the design, then the blades are opened and the wind has been propelled, and finally it has been checked about sufficient production of lift when the blades are closed. It has been seemed as though the turbine would slow down too much

in the regions where lift is not produced thus the blades are kept opening up just to allow rotation. Next the blades have been opened to check the maximum attainable rotational speed in the drag position. In this position it is observed that there is plenty of windswept area to rotate the turbine. A rotational speed of 175 rpm is achieved and it has been obtained from approximate counting of the rotation of drag devices, whether the self-start of turbine is needed only the speed of 174 rpm.

2.3 Specimen Calculation

Absolute Pressure, $p = 760\text{mmHg} = 1.01 \times 10^5 \text{N/m}^2$

[Obtained from lab manometer]

Temperature, $T = 38.5^\circ \text{C} = 311.5 \text{K}$

Using equations of state for perfect gas the air density, ρ_∞ is 1.13 kg/m^3 and is defined as [6]

$$\rho_\infty = \frac{P}{RT} \quad (1)$$

Where, pressure P is $1.01 \times 10^5 \text{N/m}^2$, temperature T is 311.5 K, and gas constant of air R is $287.05 \text{ Nm/(kg)(K)}$.

The air viscosity, μ_∞ is determined using the Sutherland's equation [6] described below

$$\mu_\infty = 1.458 \times 10^{-6} \frac{T^{1.5}}{T + 110.4} \quad (2)$$

Where μ_∞ is dynamic viscosity.

At T is 311.5 K, equation (2) gives value of μ_∞ is $1.90 \times 10^{-5} \text{ kg/(m)(s)}$

Reynolds number based on the chord length is defined as [7]

$$\text{Re} = \frac{\rho_\infty v_\infty c}{\mu_\infty} \quad (3)$$

Where, air density ρ_∞ is 1.13 kg/m^3 , free stream velocity v_∞ is 5.89 m/s ; viscosity μ_∞ is $1.90 \times 10^{-5} \text{ kg/(m)(s)}$ and chord length $c = 5.5 \text{ in} = 0.1397 \text{ m}$.

Putting the values in equation (3), we have

$$\text{Re} = \frac{1.13 \times 5.89 \times 0.1397}{1.90 \times 10^{-5}} \left[\frac{\frac{\text{kg}}{\text{m}^3} \times \frac{\text{m}}{\text{s}} \times \text{m}}{\frac{\text{kg}}{\text{m} \times \text{s}}} \right]$$

$$\text{Re} = 0.49 \times 10^5$$

For the remaining velocities corresponding Reynolds number are given in table 1

Table 1: Free Stream velocity and corresponding Reynolds Number

Serial No.	Free Stream Velocity (m/s)	Reynolds number
1	5.89	0.49×10^5
2	6.08	0.51×10^5
3	7.02	0.58×10^5

For a rectangular blade, frontal surface area for three surface $(S_1)_T$ is $0.4482 m^2$ and is defined as

$$(S_1)_T = 3(S_1) \quad (5)$$

Where, frontal area for single surface of blade S_1 is $0.1494 m^2$.

For a rectangular drag surface, frontal surface area for single surface S_2 is $0.3484 m^2$ and is defined as [6]

$$S_2 = b_2 \times c_2 \quad (6)$$

Where, drag height b_2 is $0.762m$ and drag width c_2 is $0.4572m$.

For a rectangular drag surface, frontal surface area for two surface $(S_2)_T$ is $0.6968 m^2$ and is defined as

$$(S_2)_T = 3(S_2) \quad (7)$$

Where, frontal area for single surface of drag S_2 is $0.6968 m^2$.

For a wind turbine, total frontal surface area S_T is $1.145 m^2$ and is defined as [6]

$$S_T = (S_1)_T + (S_2)_T \quad (8)$$

Where, total frontal area for blade $(S_1)_T$ is $0.4482 m^2$ and total frontal of drag $(S_2)_T$ is $0.6968 m^2$.

Wind power of turbine is defined as [8]

$$P_{wind} = \frac{1}{2} \rho_{\infty} S_T v_{\infty}^3 \quad (9)$$

Where, density of air ρ_{∞} is $1.130 kg/m^3$, total frontal area S_T is $1.145 m^2$, and wind velocity v_{∞} is $5.89 m/s$.

Putting the values in equation (9), we have

$$P_{wind} = \frac{1}{2} \times 1.130 \times 1.145 \times 5.89^3 \left[\frac{kg}{m^3} \times m^2 \times \left(\frac{m}{s} \right)^3 \right]$$

$$P_{wind} = 132.19 \text{ Watt}$$

3. RESULTS AND DISCUSSION

Tests have been conducted on the wind turbine at open hall UNISEL at the three different velocity $5.89 m/s$, $6.08 m/s$ and $7.02 m/s$. Based on the measurement of velocity the wind power for this prototype is calculated at the previous section and is given in table 2. The calculated values for the Reynolds number in table 1 have been explained in the previous section. The further understanding of the relationship between the variables

measured as velocity as well as calculated wind power and Reynolds number from the test conducted has been discussed in term of graphs.

3.1 Reynolds Number

The Reynolds number characteristics of the wind turbine under the different velocity test are shown in term of graph in figure 3 for all Reynolds number. The Reynolds number increases with the increase in wind velocity. This is occurred due to the Reynolds number and wind velocity has proportionally linear relationship

$$\text{where its function is defined as } Re = \frac{\rho_{\infty} v_{\infty} c}{\mu_{\infty}}$$

According to the figure 3, the maximum Reynolds number obtained is 0.58×10^5 with the corresponding values of wind velocity $7.02 m/s$ and the minimum Reynolds number obtained is 0.49×10^5 with the corresponding values of the wind velocity $5.89 m/s$. The higher values in Reynolds number indicate the wind turbine has ability to produced more power due to increase in value of the wind velocity and this value is calculated and recorded in tests conducted at the wind velocity of $7.02 m/s$.

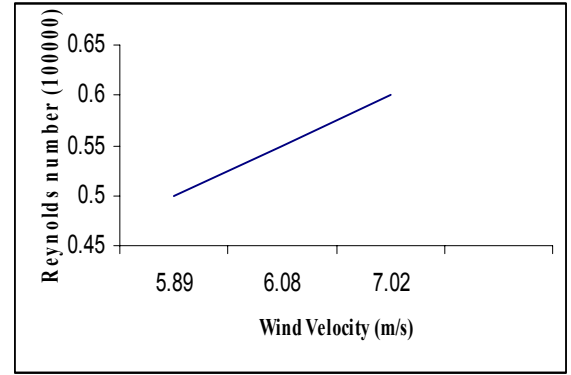


Fig 3: Reynolds number for wind as function of the wind velocity

3.2 Power of the Wind

The calculated wind power at the previous section for all the measured wind velocities are shown in table 2 and the corresponding graphs for this date has been shown in figure 4. From the graph it is observed that the value of the wind power increases very high with the increase in the value of wind velocity. This is occurred due to the wind power and wind velocity has proportionally tripled relationships where its function is defined as

$$P_{wind} = \frac{1}{2} \rho_{\infty} S_T v_{\infty}^3$$

The characteristics between the wind power and velocities has been shown in the figure 4 where the graph line has been bent to upward with the centered of bending occurred at point where the wind power 145.40 Watt and the corresponding velocity values is $6.08 m/s$. According to the graph, the maximum wind power obtained is 223.80 W when the corresponding value of wind velocity is $7.02 m/s$ and the minimum wind power obtained is

132.19 W when the corresponding values of the wind velocity is 5.89 m/s. The test conducted shows the wind turbine model needs very high wind velocity to rotate the blade and drag devices as well as to produce the maximum amount of wind power.

Table 2: Velocities and the corresponding wind power

Serial No	Velocities (m/s)	Wind Power (Watt)
1	5.89	132.19
2	6.08	145.40
3	7.02	223.80

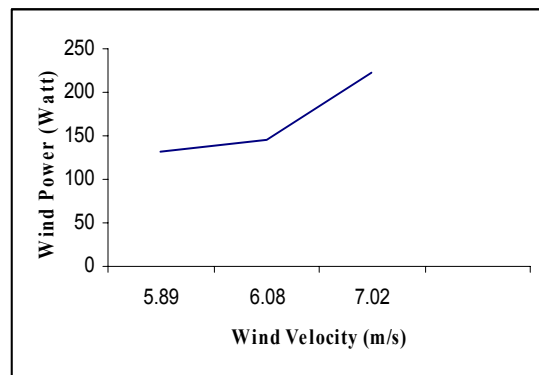


Fig 4: Wind Power as function of wind velocity

3.3 The Effect of Geometry

The prototype is considered two parts as the main factor to the turbine system rotate which the drag devices and airfoil geometry. The field test conducted on this Vertical Axis Wind Turbine give opportunities to evaluate and analyze the affections of the prototype with respect to the wind flow. The further explanations of this affection have been described more specific in the section 3.3.1 and 3.3.2.

3.3.1 The Airfoil Geometry

Selecting appropriate airfoils to a 3-bladed vertical axis wind turbine is one of the most important design decisions. Different profiles provide various advantages and disadvantages that must be considered. The prototype testing results provide information to choose the optimal blade profile for a self-starting application. The shape of the prototype blades is not considered 100% design in airfoil shapes and this is because that there is several wind affection to the blades in opposite direction from the wind flow direction. Since the affection of this wind flow due to airfoils or blades is very small and the amount of the force depends on the blade during the rotation has been ignored. Even the blade has been designed and used in this model is not considered as NACA 0012 or NACA 0015, but the shapes selected in current project still response and act with a very high durability and efficient functional to the shaft to rotate during the wind flow.

3.3.2 The Drag Devices Geometry

The drags devices have been used in current project provide external support to the blade by collecting the maximum amount of wind flow and initializing the rotation of the blade and the shafts. The drag devices are very sense to small amount of the wind flow and it always causes the blades and shaft rotate even the wind velocity passes away is very small in magnitude at the considered location. During the test conducted on this model the wind has been obstacle by one of the open drag, and diverted around the other. This is factorizing the net torque which drives the open drag around the shaft and induces rotation of the turbine, which leads to centrifugal forces. The rotational speed is increased until a critical point at which the turbine is moving fast enough to be driven by the lift forces. The opening/closing of drag mechanism is designed such that the centrifugal forces is overcome the inertial forces and direct forces at this critical speed.

3.4 Turbine Feasibility Comparisons

The calculated wind power from the current prototype and the overall comparisons of the existing turbine according to the type of connection used and the estimated costs are shown in table 3. The University of Wollongong project has produced the maximum wind power which is 700 W using the gearing system and Griffith University has produced 550 W using the similar

Table 3: Feasibility comparison of different projects.

Project	Type of Connection	Wind Velocity (m/s)	Power (Watt)	Cost (US\$)
University Wollongong	Gearing System	25	700	820
Griffith University	Gearing System	20	550	673
Unisel	Belt & Pulley	5.89	167.08	253

system [9,10]. The tested prototype in current project has been produced 167.08 W using the belt and pulley system. According to the ratio evaluation, the current model can exceed the existing model if the wind velocity is increased. The calculated forecast of ratio has been explained, the current prototype is capable to produce 567.33 W when the wind velocity increase to 20 m/s and 709.17 W when the wind velocity increase to 25 m/s. The overall comparison has been proved that, the current prototype which uses the pulley and belt system is more feasible than the others model such the gearing system in term of cost and to produce the power.

4. CONCLUSIONS

Followings are the conclusions drawn from this investigation:

Wind power produced by the prototype increases more with the increase of the wind velocity from the surrounding. Reynolds number becomes larger with the increase of wind velocity.

From the investigation it is observed that the current prototype is capable to produce 567.33 W when the wind velocity increases to 20 m/s and 709.17 W when the wind velocity increases to 25 m/s.

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7. NOMENCLATURE

Symbol	Meaning	Unit
P	Absolute pressure	(N/m ²)
T	Temperature	(K)
R	Gas constant	(Nm/kg.K)
ρ_{∞}	Air density	(kg/m ³)
μ_{∞}	Air viscosity	(kg/m.s)
v_{∞}	Free stream velocity	(m/s)
c	Chord length	(m)
Re	Reynolds number	(Dimensionless)
b_1	Blade height	(m)
c_1	Blade width	(m)
S_1	Blade frontal surface area	(m ²)
b_2	Drag height	(m)
c_2	Drag width	(m)
S_2	Drag device frontal surface area	(m ²)
S_T	Total frontal area of wind turbine	(m ²)
P_{wind}	Wind power	(W)