

Dynamic VAWT Darrieus by changing angle of attack to reach maximum efficiency

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Abstract. Vertical Axis Wind Turbine is one of the most widely developed Renewable Energy. Many experiments and research are conducted to obtain maximum power efficiency. To get the maximum energy conversion efficiency required TSR (Tip Speed Ratio) is constant. To have the efficiency controller to change the Angle of Attack is required to maintain maximum efficiency at any wind speed. The method is applying controlled blades (aileron), the blades represent the value of Angle of Attack. In accordance with the changing of wind speed. In the VAWT Darrieus TSR reference value of 6, this value becomes the reference to obtain maximum efficiency against changes of wind speed. PID method is used to control the blades to form an Angle of Attack corresponding to the dynamic changes in wind speed. So that the VAWT speed is used as feedback into control. The shape of the blade affects the efficiency of the resulting spin, therefore the most efficient blade of the blades is the thin airfoil family in order to obtain the maximum flow of wind to rotate the generator. From the simulation done by using VAWT, it can be shown that the power efficiency obtained up to 28% in any wind speed.

1. Introduction

In recent years, research on wind energy has increased significantly as an alternative to main electricity [1]. This is based on the use of non-renewable energy sources such as petroleum, natural gas and coal which continue to be used as the main source in meeting national energy needs. In the world scope, petroleum reserves will be exhausted within a period of 40 years, natural gas 60 years and coal 200 years [2,3]. This condition makes the search for alternative energy more massive by countries so that in the future there will be no energy crisis. Renewable energy is the solution to the problem of depleting oil and gas reserves for future energy needs so that research, development and commercial use of renewable energy continues. Renewable energy can be defined as energy that can quickly be reproduced through natural processes. Renewable energy includes water, geothermal, solar, wind, biogas, bio mass and ocean waves. Some of the advantages of renewable energy include: The source is relatively easy to obtain; can be obtained free of charge; low waste, does not affect global temperature, and is not affected by rising fuel prices [4]. The inevitable impact of the influence of the use of fossil fuels is the use of fossil fuels resulting in global warming and air pollution so that the need for environmentally friendly and renewable energy sources such as wind, solar, geothermal, biomass, oceans. Wind energy is an energy source that has been used for a long time by several countries.

Wind is air that moves from high pressure to low pressure and the difference in air pressure is caused by differences in air temperature due to uneven heating by sunlight [5]. Moving winds contain



kinetic energy that can be converted to mechanical or electrical energy through windmills or wind turbines. So windmills or wind turbines are often referred to as Wind Energy Conversion Systems. Wind speeds in Indonesia range between 2 m / s - 6 m / s and with these conditions Indonesia is considered suitable for building small (10 kW) and medium-scale wind power plants (10 - 100 kW) [6]. Areas suitable for wind power generation in Indonesia are in coastal or mountainous areas. Based on data obtained from the Meteorological, Climatological, and Geophysical Agency (MCGA), it shows more than 50 locations that have wind speeds of around 3-5 m/s making it suitable for building small and medium scale wind power plants and to get a greater wind speed it is necessary to increase the height so that a greater amount of electric power is obtained [7].

Indonesia is one of the countries facing a fairly high electricity crisis. The need for each year continues to increase over time. Indonesia as the largest archipelago country has the potential to develop renewable energy. Table 1 shows the potential for renewable energy in Indonesia.

Table 1. The success rate of recognition [8]

Energy type	Resource	Equals	Installed capacity
Water	845 x 10 ⁶ BOE	75.7 GW	4200.0 MW
Geothermal	219 x 10 ⁶ BOE	27.0 GW	800.0 MW
Mini / Micro hydro	458 MW	458.0 MW	84.0 MW
Solar Biomass	49.81 GW	49.8 GW	302.4 MW
Sun	4.8 kWh/m ² /day		8.0 MW
Wind	9.29 GW	9.3 GW	0.5 MW

Based on Table 1, the utilization of wind energy in Indonesia is still not optimal, that is, it has only been installed at 0.5 MW from 9.29 GW of existing potential. This makes researchers challenged to continue to conduct research in increasing the productivity of wind power. Wind turbines are an important component in wind power plants that function to convert mechanical energy from the wind into rotary energy on the windmill, then the windmill spin is used to turn the generator, which will eventually produce electricity. In principle, wind turbines can be divided into two types of turbines based on the direction of rotation. Wind turbines that rotate on a horizontal shaft are called horizontal shaft wind turbines or Horizontal Axis Wind Turbine (HAWT), while rotating on a vertical shaft is called a vertical shaft wind turbine or Vertical Axis Wind Turbine (VAWT) [9]. Both of these models have their respective characteristics namely VAWT weight is heavier than HAWT. This is a factor that greatly influences VAWT performance because more wind speed is needed to drive heavier parts of the blade. Efficiency between the two with changing wind direction conditions, VAWT is more efficient than HAWT because the wind direction is far from the HAWT blade direction, while VAWT is able to maintain stability with changes in wind direction and VAWT flourishes in turbulent also sporadic wind patterns [10,11]. This research we will examine about VAWT (Vertical Axis Wind Turbine) or Wind turbine with vertical axis. Because considering from the side of a fairly efficient advantage that is in terms of research areas in areas with wind development is very varied and unstable it creates a wind direction is always different so it is very advantageous if using Vertical Axis Wind Turbine.

2. Related work

This research on VAWT has been developed by several researchers. Researchers Qasim propose the design of VAWT wind turbines [12]. The proposed design allows wind power to close the left side propeller and simultaneously opening the right side propeller which allows the wind to move freely. The proposed design is claimed to be able to be used throughout the world having high efficiency and simple construction. Researchers Qasim and Ionescu analyzed the VAWT design that was applied to the port and beach areas [12,13]. This was done in order to find the best technique in minimizing load and helping the self-starting ability of wind turbines. The results of research conducted found that for

coastal and turbine port applications must be stationary and without vibration, with good self-starting capability. Requirements achieved by a relatively low tip speed ratio (blade speed divided by wind speed) and at least 3 blades.

Researchers Liang also propose a straight-line vertical axis wind turbine (S-VAWT) design that is claimed to provide solutions to climate change and wind. In designing this S-VAWT, it is necessary to pay attention to several aspects, namely the selection of the blade by considering its aerodynamics and thickness, leading / trailing edge, and roughness as well as supporting arm, swept area, and solidity. Researchers in maximizing the power coefficient of the right rotor selection [14]. Researchers also propose a reduction in roughness on the blade surface, this contributes greatly to the dynamic stall. The results of the study are the out-offset blade incidence angle of degrees 4 degrees is preferred to improve the overall performance of S-VAWT.

3. Modelling of the system

The method used in this research is the experimental method. Activities undertaken in this study include designing a H-shaped Darrius turbine comprising variations of turbine angles with the same height, turbine manufacture, device set up, and data retrieval. Data collection is done by measuring the number of turbine rotations (rotation per minute, rpm) for each variation of the turbine angle at various wind speed variations. Flowchart of the proposed system is shown in Figure 1.

Wind is a moving air due to the difference in pressure. The air will flow from the high pressure area to the lower pressure area. Differences in air pressure are affected by sunlight. Areas that are exposed to sun exposure will have a higher temperature than areas that are less exposed to sun exposure. Under ideal gas law, the temperature is inversely proportional to pressure, where high temperatures will have low pressure, and vice versa. Air having mass m and velocity v will yield kinetic energy of:

$$E = mv \quad (1)$$

The volume of air per unit of time (discharge) moving with velocity v and passing through an area of A is:

$$V = vA \quad (2)$$

This will affect the wind pressure on each blade that produces a thrust force. The greater the air mass the greater the thrust it generates. Air mass moving in units of time with density ρ is:

$$m = \rho V = \rho Va \quad (3)$$

So the wind kinetic energy that blows in time unit (wind power) is:

$$P_w = \frac{1}{2}(\rho Av)(v^2) = \frac{1}{2}\rho Av^3 \quad (4)$$

Where, P_w = wind power (watts)
 ρ = density of air ($\rho = 1,225 \text{ kg/m}^3$)
 A = turbine cross section area (m^2)
 v = air velocity (m/s)

Since each type of wind turbine has different characteristics, the power factor as a function of the TSR is also different as shown in the following Figure 2.

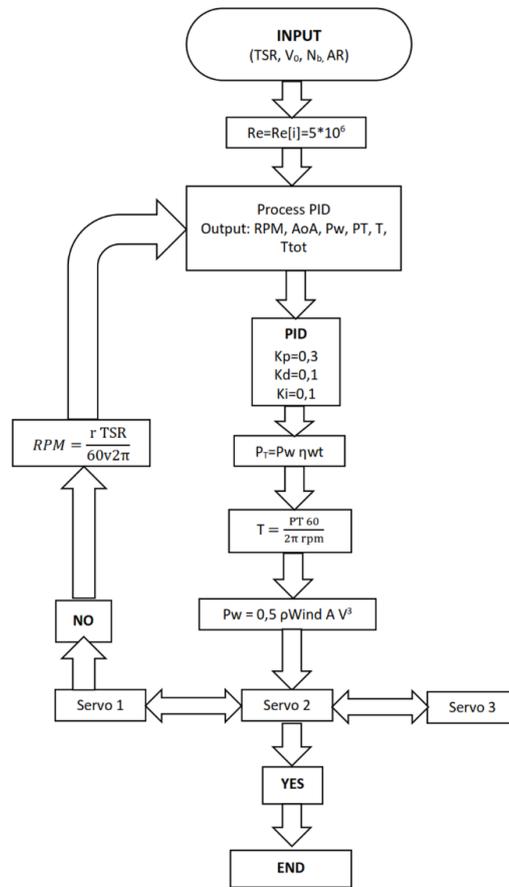


Figure 1. Proposed system.

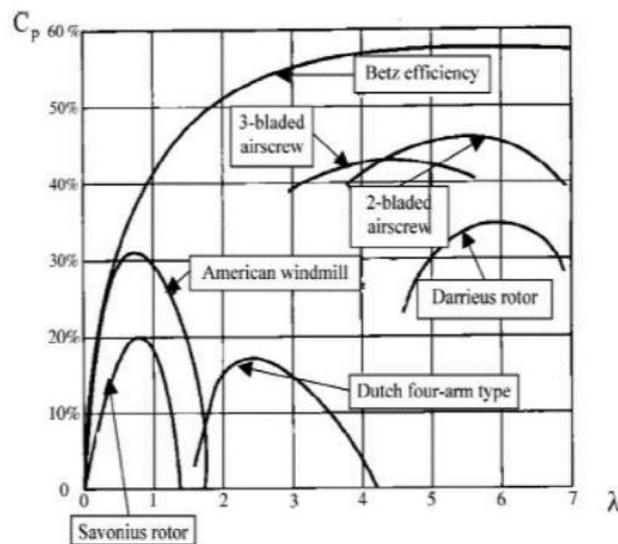


Figure 2. The optimal TSR value of Darrieus rotor.

Angle of attack is the term used in flow dynamics to explain the angle between the guiding line of the lifter (often the chord line in an airfoil) and the vector representing movement relative to the lifter and

the flow to which it is moving. The angle of attack is the angle between the guiding line of the lifter and the coming stream. The tip speed ratio, λ , or TSR for wind turbines is the ratio between blade tangential speed and actual wind speed v . The final speed ratio in related to efficiency, is certainly different from the blade design. Higher tip speeds produce higher noise levels and require blades with strong material due to the large centrifugal force too.

$$\lambda = \frac{\text{Tip Speed of Blade}}{\text{Wind Speed}} \quad (5)$$

The tip end speed can be calculated as ωR , where ω is the rotational speed of the rotor in radians / sec, and R is the radius of the rotor in meters. Therefore, it can also be written:

$$\lambda = \frac{\omega R}{v} \quad (6)$$

In this control will use arduino as microcontrol system. That will work to control the servo motor on VAWT to get the TSR value 3. In this case it will require 3 servo motors which will all be located on each VAWT blade. In this research will make VAWT with the amount of 3 blades, which in previous research that using 3 blades can produce maximum power than using more or less than 3 blades.

3.1. Aileron control electronics method

In this method will be used electronic control that can be used to change and adjust the aileron to get the appropriate angle of attack. By changing the gearbox motor that is connected to the 3 blades, so that it can adjust the angle so that according to TSR ayng needed. The description of aileron design that will be used in this wind turbine looks like the picture below.

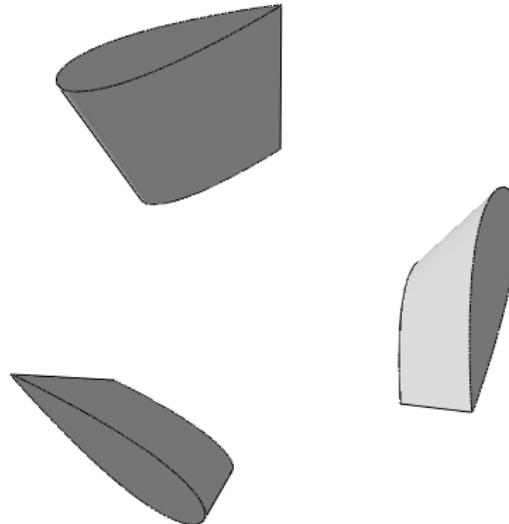


Figure 3. Aileron image on wind turbine NACA 0018.

3.2. Aileron control electronics method

By providing the initial set point the aileron will form an angle. After running process then by using arduino microcontroller will give feedback which will become reference program to give next command. This PID control is used to provide the aileron control to always form and maintain an angle corresponding to the set point.

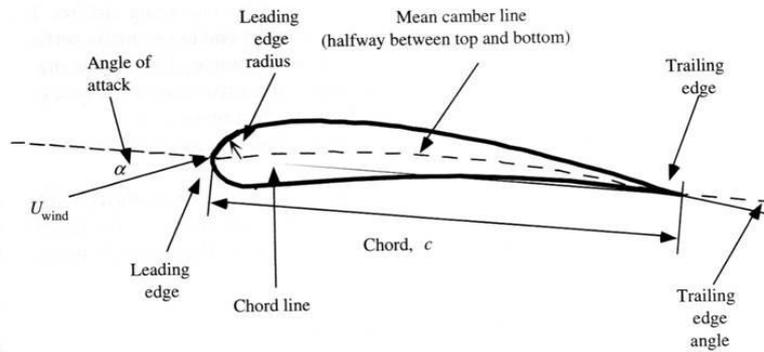


Figure 4. Flap design and slot design.

In this research will be used blade that is shaped more or less like the picture above which is classified thin airfoil family type root airfoil region. NACA (National Advisory Committee for Aeronautics) is a standard in designing an airfoil. Airfoil design is basically special and made according to taste and according to requirement. This type is used because the appropriate shape is used on vertical axis wind turbines. In previous research mentioned that the shape or design of the blade and aileron that serves to determine the Angle of Attack is very influential. This is because of the push force in the direction of the wind.

4. Results and discussion

Tests carried out on the proposed VAWT design is to calculate the power obtained and this is done 4 times. The starting point given TSR 6 values constantly so as to determine the appropriate angle of Attack so that the rotor can rotate and produce maximum initial torque. With brush method then servo that serves to move the blade in set the angle of attack can be placed under the blade. But the control panel is placed separately so that it does not come spinning with wind turbines. This will also be demonstrated when the VAWT has been rotated and TSR values are stable by changing wind speed, and the control reads the wind speed sensor that changes so as to feed the servo on the blade to provide an appropriate angle of attack so that the turbine can be controlled by rotation. So there is no free rotation without the control, which in case of resulting in a decreased torque and also power will decrease. The results of each testing are averaged and displayed each testing in Table 2. The overall results of each test are displayed in the graph shown in Figure 5.

Table 2. Testing result

Testing Number	V (m/s)	AoA (degree)	Rpm	Pw (Watt)	PT (%)	P (Watt)
1	4,4	9,79	25,5	35,2	17,1	10,7
2	3,8	4,997	21,9	23,3	17,0	6,4
3	4,5	4,30	21,7	45,0	32,8	28,96
4	5,5	7,9	33	60,9	44,4	35,0

In table 2 shows the average results of each test. The fourth testing produces the highest power (P) namely 35 Watt. The factor that makes this P value high is the average received wind speed namely 5.5 m / s, this makes the rpm at the rotor movement high. The other side of the angle of attack (AoA) in this test produced only 7.9 degrees, this is small compared to the first test that got an AoA of 9.79 degrees. The lowest P value obtained at a speed of 4.4 m / s also makes Rpm in the measured motor movement obtained 25.5 and the AoA measured in this test is 9.79.

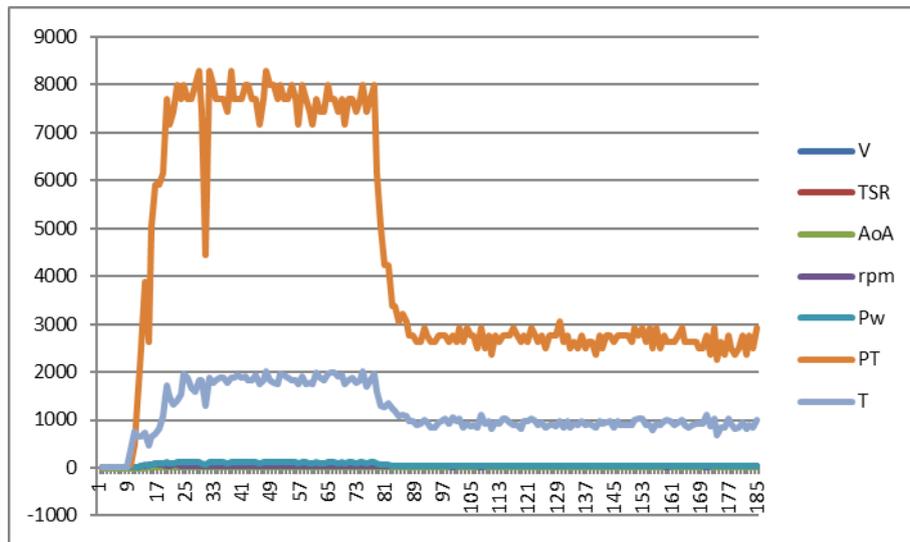


Figure 5. The results of power testing generated from the proposed VAWT with dynamic wind speeds.

In Figure 5 shows the overall test from beginning to end. The speed in this test starts from 0 m / s to 7 m / s. Changes in speed give effect to AoA, P and torque. As we can see, when we controlled the AoA to change the speed, for maintain the TSR value. When we controlled the speed of wind turbine, so there are no free spin. Its mean we know that VAWT more stable and riskless. Fortunately also give more efficiency and more torque.

5. Conclusion

The conclusion of this study is that the proposed VAWT is capable of producing an average Power (P) of up to 35.0 Watt with a speed of 5.5 m / s with a measured rpm of 33 and an Angle of Attack (AoA) of 7.9 degrees. As for the smallest power (P) of 6.4 Watt obtained at a speed of 3.8 m / s and the measured AoA at this stage is 4.997 degrees and the measured rpm of 21.9. Every change in wind speed influences the power generated from VAWT.

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