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# Electronic control for optimizing power absorption of darrieus vertical axis wind turbine by adjusting angle of attack method

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**Abstract**. This paper presents a mechanical design and electronic control for the angle of attack on the Vertical Axis Wind Turbine (VAWT) darrieus type with NACA0015 and 3 blades. This research was conducted to obtain high-efficiency absorption power on various wind speeds. The VAWT mechanical design is based on systematic calculations with a height of 150cm and a diameter of 120cm. NACA0015 airfoil with calculations in the NACA airfoil database obtained blade length of 15.892cm and width of 1.905cm. The electronic control on this system, Arduino mega controller, has input from an anemometer sensor, and rotary encoder sensor. While, the output is servo motors for 3 blade. A microprocessor control unit is programmed to control the adjustment of blade angle of attack. The angle of attack is defined by wind speed, angular speed of VAWT, and a defined TSR (Tip Speed Ratio). The angle of attack control method is PID (Proportional-Integral-Derivative) algorithm. By setting the TSR value constantly at 3-4, the angle of attack will be adapted even on any various wind speed. Expected result, the maximum power absorption will be obtained on various wind speed. This system can increase power efficiency of VAWT up to 35-40%.

## 1. Introduction
Wind energy is one of the renewable energy sources as wind power plants [1]. Based on a map of energy wind published by the World Bank Group and the Department of Wind Energy, Indonesia is a potential area for developing wind power plants with wind speeds of 2 until 8 m/s [2], as in figure 1.

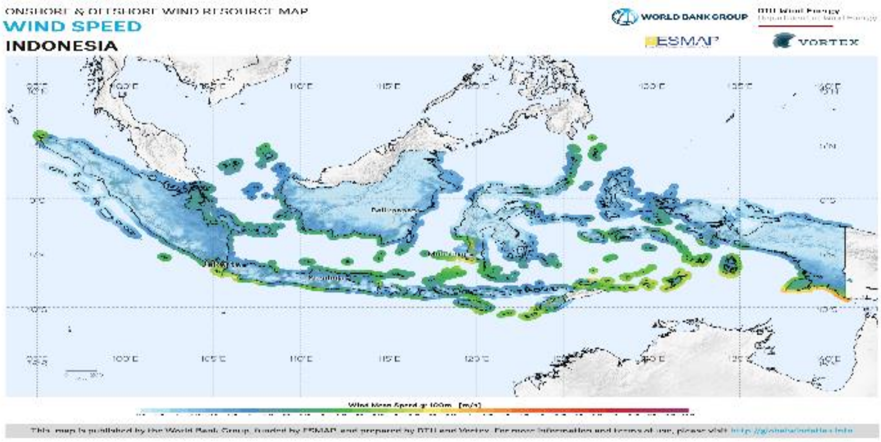


**Figure 1.** Indonesia's wind energy potential map [2].

The utilization of wind energy that is using wind turbines by converting the kinetic energy into mechanical energy [3]. There are two types of wind turbines that are often used, namely Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) [4-6]. Based on previous research, VAWT has several advantages over HAWT, namely lower production costs, easy installation, maintenance, can absorb wind energy from all directions, and has a relatively low rotational speed resulting in low noise [7]. While on the airfoil design with reference to previous research on airfoils for VAWT using ANSYS FLUENT software. The results of the analysis show that symmetrical airfoils such as naca 0012, naca 0015, naca 0018 and naca 0025 are well used for VAWT by considering the same characteristics between lift and drag [8].

Another problem when discussing wind energy, wind speed characteristics must be considered. Based on the conditions in the field the wind speed always changes at any time and the resulting power becomes fluctuations [9]. So there are some previous studies that discuss the effect of the VAWT pitch angle on TSR and wind speed. One such study uses Computational Fluid Dynamics (CFD) Simulation Software for Experimental and numerical VAWT investigations with variable pitch. The results obtained are that the coefficient power (Cp) of the variable pitch is greater than the fixed pitch with several variations in the value of TSR [10].

Therefore, it is necessary to make a mechanical design and electronic control for the angle of attack from wind turbines that will be applied in Indonesia using the Vertical Axis Wind Turbine(VAWT) Darrieus type with NACA 0015. The purpose of this research was to obtain high-efficiency absorption at various wind speeds with a control angle of attack. Another purpose of the control angle of attack is to avoid input power from winds that exceed the working ability of wind turbines which can cause damage to mechanical and electronic devices.

The scientific contribution of this study is to make VAWT darrieus type with an angle of attack control that can help in the scope of the utilization of wind energy conversion with the results of efficiency and power produced always optimal.

## 2. Method/ modelling of the system

### *2.1. Design calculation of vertical axis wind turbine*

*2.1.1. Design of turbine blade.* To determine the height of the Vertical axis wind turbine are as follows (can be written as) [10]:

$$H = 1.2 * D \tag{1}$$

Where, $H$ is Blade Height(m) and D is Diameter(m).

*2.1.2. Power calculations*

- Wind power, the amount of wind energy that can be converted into power can be searched using the equation [11]:

$$P = \tfrac{1}{2} A\rho v^3 \quad (2)$$

Where, $P$ is Power that can be produced by wind turbine (Watt), $A$ is swept area wind turbine ($m^2$), $\rho$ is air density (1.18 $kg/m^3$), $v$ is wind speed (m/s).

- Wind turbine power, turbine power is the turbine's ability to extract existing wind power using the following equation [11]:

$$Pt = T.\ \omega \quad (3)$$

Where, $Pt$ is Turbine Power (Watts), $T$ is torque (Nm), $\omega$ is angular velocity (rad/s). Angular velocity can be obtained from:

$$\omega = \frac{2\,.\pi.N}{60} \quad (4)$$

Where $N$ is Rotation per Minutes (RPM).

- Efficiency, in the Betz theory, the power coefficient is always greater than 16/27 (0.59) [12]. This characteristic can be used as a calculation of efficiency from VAWT. The value coefficient as [13]:

$$Cp = \frac{Pt}{P} \quad (5)$$

Where $Cp$ is Efficiency Power (%).

- Tip speed ratio (λ), TSR is a comparison between the speed of the tip of the wind turbine that rotates with the wind speed which is formulated in the following equation [14-15]:

$$\lambda = \frac{\omega.r}{V} \quad (6)$$

Where, $r$ is radius of wind turbine(m).

*2.2. Design airfoil profiles*

Symmetrical airfoil is commonly used for VAWT because it has the same characteristics of lift and drag on the upper and lower surfaces [8]. Therefore, the airfoil chosen analytically and numerically is NACA0015 as in figure 2.

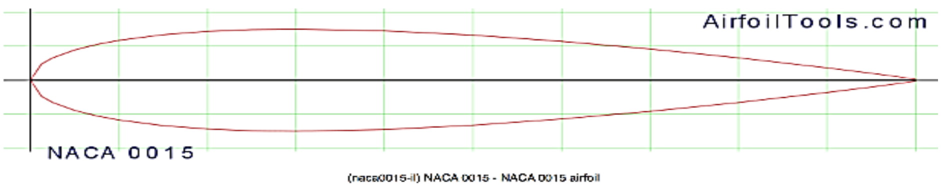


**Figure 2.** NACA 0015.

The airfoil used in this study was the NACA 0015 airfoil. This NACA 0015 airfoil has the following meanings 00 shows that this type of NACA does not have a chamber, and 15 shows that NACA has a maximum thickness of 15% of the length of the chord.

### *2.3. Electronic design and angle of attack control*

*2.3.1. Electronic design methods.* The electronic design of wind turbines uses several components such as the block diagram shown in Figure 3. In the input section using an anemometer sensor, rotary encoder sensor and TSR constant set is 3. While the output uses a servo motor. All of this is controlled using a microcontroller.

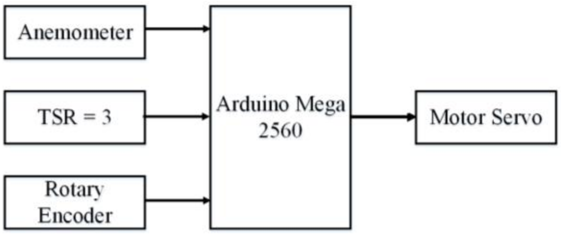


**Figure 3.** Block diagram electronic.

*2.3.2. Mechanism angle of attack.* To improve turbine efficiency and performance, one of them is by using the Angle of Attack mechanism in the form of blade movements and blade angle changes to improve turbine performance [16], as in figure 4.

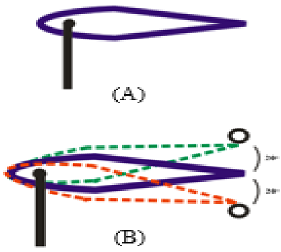


**Figure 4.** (A) Fixed pitch mechanism, (B) Variable pitch mechanism.

## 3. Results and discussion

### *3.1. Specification of wind turbine*

Based on the results of calculations, the 3D specifications and designs of wind turbines are obtained as described in table 1.

**Table 1.** Specification of wind turbine.

| No. | Specification | Detail |
|---|---|---|
| 1. | Wind Turbine Type | Vertical Axis Wind Turbine Darrieus Type |
| 3. | Diameter | 130 cm |
| 4. | Height | 200 cm |
| 5. | Material | Aluminum Pipe and Dural<br>stainless steel axles |

The design of the blade uses 3D software using a database from airfoil tools so that specifications such as table 2, designs are obtained as shown in figure 5, and the implementation of blade as shown in figure 6.

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**Table 2.** Specification of blade.

| No. | Specification | Detail |
|---|---|---|
| 1. | NACA Type | 0015 |
| 2. | Number Of Blade | 3 Pieces |
| 3. | Material | Balsa Wood |
| 4. | Blade Height | 150 cm |
| 5. | Blade Length | 16 cm |
| 6. | Blade Width | 1,9 cm |

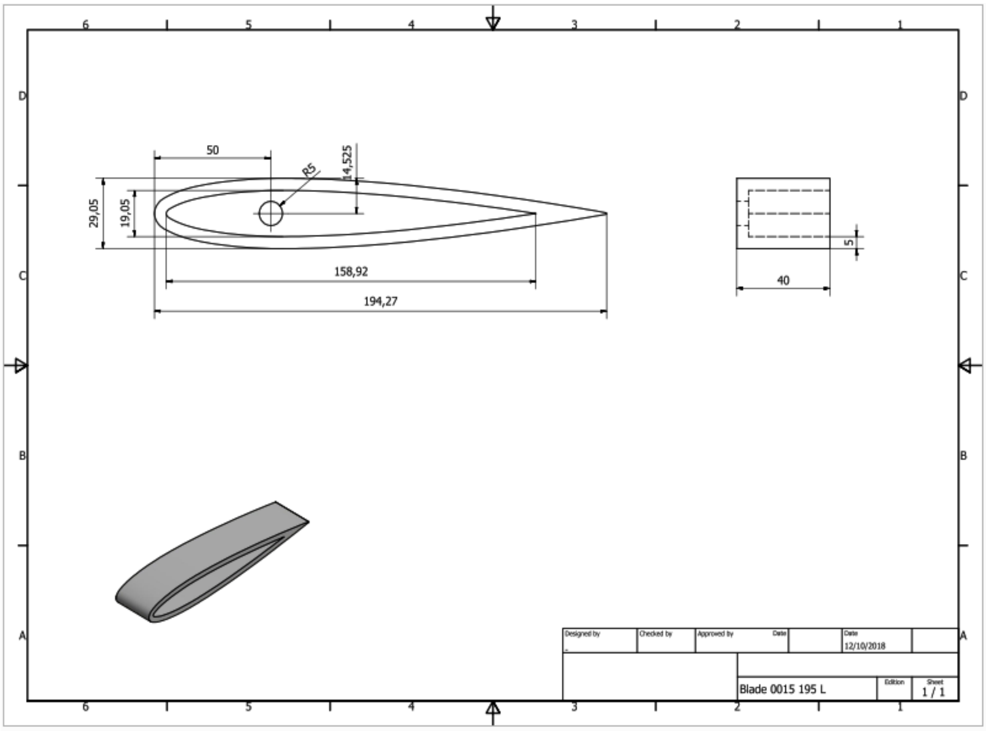


**Figure 5.** Design blade NACA 0015.

(a) (b)

**Figure 6.** (a) Front blade implementation, (b) Blade implementation appears above.

### *3.2. Electronic testing*

The results of the electronic testing data shown in the table 3.

**Table 3.** Electronic testing results.

| No. | Wind Speed (m/s) | RPM Desired (RPM) | RPM Actual (RPM) | Error RPM (%) | Servo Desired (°) | Servo Actual (°) | Error Servo (%) |
|---|---|---|---|---|---|---|---|
| 1. | 1 | 44,09603136 | 44,30853388 | 0,481908493 | 5,625 | 5,39 | 4,177777778 |
| 2. | 2 | 88,19206271 | 87,31260664 | 0,997205466 | 11,25 | 11,685 | 3,866666667 |
| 3. | 3 | 132,2880941 | 131,24834121 | 0,785976166 | 16,875 | 17,548 | 3,988148148 |
| 4. | 4 | 176,3841254 | 175,95071320 | 0,245720639 | 22,5 | 22,844 | 1,528888889 |
| 5. | 5 | 220,4801568 | 219,28264645 | 0,543137472 | 28,125 | 29,211 | 3,861333333 |
| 6. | 6 | 264,5761881 | 264,07321434 | 0,190105453 | 33,75 | 34,119 | 1,093333333 |
| 7. | 7 | 308,6722195 | 307,44753763 | 0,396758047 | 39,375 | 39,943 | 1,442539683 |
| 8. | 8 | 352,7682509 | 350,60025085 | 0,614567792 | 45 | 45,989 | 2,197777778 |
| | | **Average Error** | | **0,531922441** | | | **2,769558201** |

Based on Table 4, calculations and testing of electronic circuits are carried out with wind speeds of 1 to 8 m / s. So that the data obtained with desired RPM obtained from the calculation results using the TSR formula in equation 6, with the TSR value set 3. In testing the actual RPM data obtained which is different from the desired RPM with the average RPM error value is 0.531922441.

Whereas in testing servo angles, the desired servo is set at an angle of 0-45° divided by the wind speed of 1-8 m/s. The actual servo is obtained based on the actual RPM with an average error value of 2.769558201.

### *3.3. Control angle of attack*

The block control from the angle of attack is shown in figure 7.

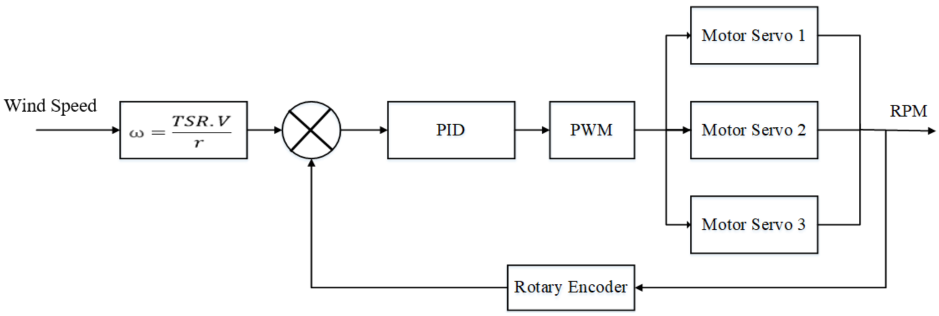


**Figure 7.** Block control angle of attack.

The first input is from wind speed data obtained from the sensor anemometer. After that wind speed data is used to calculate the value of angular speed as a set point. The setpoint data will be controlled by the PID for setting the PWM value. PWM will activate 3 servo motors connected to the blade to set the angle of attack. After a change in the angle of attack the value of angular speed is read by the rotary sensor to be compared with the set point whether it is appropriate or not. If not, the control will repeat again until the real value in the sensor matches the set point.

## 4. Conclusion

As the results, from the VAWT design type Darrieus NACA 0015 when implemented, the results that are in accordance with the 3D software design are obtained. In the electronic part, it can work in accordance with what is desired as shown in the test table that the RPM error is below 1% with an average error of 0.531922441 and a servo error below 5% with an average error of 2.769558201.

So from this result is expected maximum absorption power will be obtained at various wind speeds and this system can increase VAWT power efficiency up to 35-45% by setting TSR values constantly at 3-4 with the method from the angle of attack control.

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