Experimental Study Of Counter Rotating Wind Turbine (Full Scale, R = 1.5 M) With Single Generator Using Gearbox

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Abstract: These Wind turbines are media used to convert wind energy into electrical energy. Counter Rotating type Wind Turbine is a type of wind turbine that has a double rotor. This type of wind turbine was developed because it is very suitable for high-speed wind, in this study the length of the blade is 1.5 m. Therefore the counter-rotating type wind turbine is made with full scale and tested with the wind in nature, especially the coastal area so that it can be seen the counter-rotating type wind turbine performance when using the natural wind in Indonesia. This performance is known by measuring the amount of electric power, torque and radial speed of the front and rear rotors based on high wind speeds. In the end, the performance of the wind turbine can be known at wind speeds of more than 5 m / s where the higher the wind speed the greater the front and rear rotor radial speed. This is directly proportional to the electrical power produced and inversely proportional to torque, where the greater the speed of the second radial rotor, the smaller the torque produced. Based on data obtained at wind speeds of 5.01 m / s, the front and rear radial speeds of the motor are 25 rpm, 12 Nm Torque, and 0.0072 Watt electric power respectively. Whereas the wind speed of 8.17 m / s obtained the values of front and rear radial speeds of 428 rpm, the torque and also electric power respectively 0.70934 Nm and 4.7034 watts.

Index Terms: Wind Turbine, Counter Rotating Wind Turbine, and Wind Turbine Performance

1 Introduction
To Electrical energy is one of the energies needed by mankind. The influence of technological developments causes humans to become increasingly dependent on electric energy, but fossil fuels which are one of the energy generations of electricity are currently limited. In addition, Indonesia is an archipelago that has the longest coastline number two in the world (after Canada) which is ± 99,093 km, and its location on the equator which actually has the potential of alternative energy from nature that can be used to generate electricity. Therefore wind turbines are used as a medium to utilize wind energy to become electrical energy. Counter Rotating Wind Turbine (CRWT) is one of the newest developments of horizontal axis wind turbines, consisting of two rotors that have different diameters or distances, and have rotor turns that are in opposite directions. The efficiency of this double rotor wind turbine energy conversion is theoretically better than a single rotor. Based on momentum theory (Betz limit), the maximum power coefficient for a single rotor is 16/27 (59.3%) with an axial wind speed ratio of 1/3 of incoming wind speed, according to Newman (1983) the maximum power coefficient of a double rotor wind turbine (double rotor) ideally through the disk actuator theory is 16/25 (64%). Therefore this study designed a wind turbine Counter. Rotating (Full Scale, R = 1.5 m) model with a generator using a transmission mechanism (gearbox), then tested its performance through measurement of the front and rear rotor radial velocity (rpm), electricity (watt), and torque (Nm) based on the existing wind speed.

2 Research Methods

2.1 Research Material
In this study, a counter-rotating type wind turbine was formed with several components, including blade, gearbox, and generator. The blade on the front and rear are formed with glass fiber material, here are the specifications of the blade used by counter-rotating type wind turbines in testing:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Front Rotor</th>
<th>Rear Rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>1.5 m</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Number of Blade</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Airfoil</td>
<td>NACA 4415</td>
<td>NACA 4415</td>
</tr>
<tr>
<td>Angle Of Attack</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Round Direction</td>
<td>Counter-clockwise</td>
<td>Clockwise</td>
</tr>
</tbody>
</table>

Furthermore, the other components are gearboxes. The gearbox is one of the components in the design of this wind turbine which functions to regulate the movement of both rotors, so that in moving counter-rotating with each other. Then, another other components used are gearboxes. The gearbox is one component in the design of this wind turbine which functions to regulate the movement of both rotors, so that counter-rotating moves with each other. The research material is a DC current generator. The DC generator used in this study is a mini induction motor that has been modified with the following specifications:
- Brand: RAE Corporation
- Maximum power: 500 watt
- Maximum voltage: 28 V
- Maximum current: 18 A
- Optimal rotation: 468 rpm

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The several tools used in this study are cameras, multimeters, anemometers, and lights. Here phone cameras are used for their blade movements from wind turbines, then after being recorded, the blade rotation of the wind turbine is calculated through the video obtained, the video is slowed down and counted the number of turns of the two blades of each rotor in 1 minute. Next is the multimeter, where it is used to measure the electrical voltage and electric current generated by the wind turbine itself. Then, as for the anemometer, it functions to measure the speed of the wind and the lights that function as the load of the wind turbine. Counter rotating wind turbine (CRWT) were carried out at the Hybrid Power Plant located at Pandansimo Baru Beach, Bantul, Yogyakarta.

2.2 Research Steps
The steps used in this research are to conduct literature studies in advance to obtain information sources both for the applied design concepts and the results of previous studies to help determine additional parameters used in this study. Furthermore, the design of this research is carried out, while the equation used begins to calculate the appropriate blade length when the power produced is around 400 watts, the following equation is used:

\[ r = \sqrt{\frac{P}{\frac{1}{2} \rho r^3}} \]  

(1)

Known :

\begin{align*}
P &= \text{Power (watt)} \\
\rho &= \text{Air density (1,145 kg/m3)} \\
r &= \text{length of blade (m)} \\
v &= \text{Wind Velocity (m/s)}
\end{align*}

Then, the equation used to calculate losses to find out the actual output power of wind turbines is :

\[ P_{\text{gearbox}} = \eta_{\text{gearbox}} \times P_{\text{gen}} \]  

(2)

\[ P_{\text{gen}} = \eta_{\text{generator}} \times P_{\text{gearbox}} \]  

(3)

Known :

\begin{align*}
P_{\text{gearbox}} &= \text{Power after losses in Gearbox (watt)} \\
P_{\text{gen}} &= \text{Power after losses occur in the Generator (watt)} \\
\eta_{\text{gearbox}} &= \text{Efficiency in Gearbox (%) (assuming 75%)} \\
\eta_{\text{generator}} &= \text{Efficiency on Generator (%) (assuming 80%)}
\end{align*}

After getting the value from \( P_{\text{gen}} \), it can calculate the overall efficiency of the wind turbine using the equation :

\[ \eta_{\text{system}} = \frac{P_{\text{gen}}}{P} \times 100\% \]  

(4)

Known :

\[ \eta_{\text{system}} = \text{System Efficiency in Wind Turbines (%)} \]

The design includes the design of a blade that is owned by a wind turbine. This functions so that the blade can capture wind properly so that it can rotate the rotor so that it can generate electricity and note the type of airfoil on the blade used is NACA 4115. Blade design includes the design of the chord width and twists angle of the blade, where the width of the chord can get from the following equation :

\[ C_{\text{opt}} = \frac{2\pi r}{N} \frac{V_{\text{wd}}}{L_{\text{C}} \lambda} \text{ where, } V_{\text{C}} = \sqrt{V_{\text{wd}}^2 + v^2} \]  

(5)

Known :

\begin{align*}
C_{\text{opt}} &= \text{Optimal Chord of HAWT wind turbine (m)} \\
N &= \text{radius (m)} \\
C_{\lambda} &= \text{Number of blades} \\
C_{L} &= \text{Lift coefficient (C_{L} value on L/Dmax on the type of airfoil used)} \\
\lambda &= \text{Tip Speed Ratio} \\
V_{\text{r}} &= \text{Relative air velocity (m/s)} \\
v &= \text{Air velocity (m/s)} \\
V_{\text{wd}} &= \text{Design air velocity (m/s)}
\end{align*}

Furthermore, the twist angle in blade design is sought by using the following equation :

\[ \beta = \tan^{-1}\left(\frac{\pi r}{n} \right) + \alpha \]  

(6)

Known :

\begin{align*}
v &= \text{Wind velocity (m/s)} \\
n &= \text{Rotation Velocity (rad/s)} \\
r &= \text{Radius (m)} \\
\alpha &= \text{angle of attack (°) (Assumption = 6°)}
\end{align*}

After doing the theoretical design, the data collection process is carried out, following the steps :

1. The manufacturing stage for several components such as generators, gearboxes, blades.
2. Assembly of all components to form a counter-rotating wind turbine (CRWT), making sure all components are installed properly installed.
3. After the assembly process is going well, a wind turbine is on a pole that has been provided by a Hybrid Power Plant at Pandansimo Baru Beach, Bantul, Yogyakarta.
4. Run the wind turbine, then measure the tension and the electric current generated using a multimeter, wind speed is measured using an anemometer and carried out at an altitude of 8 meters, while the measurement of rpm rotor produced using camera.
5. Then calculate the electrical power and torque generated from the data obtained.
3 RESULT AND DISCUSSION
The tested wind turbines are counter rotating type wind turbines using a gearbox with one generator, where the wind turbine has a 1.5 m blade length. In this study, wind turbines were tested to find a performance by measuring the front and rear rotor radial velocity, electric power, and torque with the existing wind speed. Some things that need to be considered in the results of this study are the radial speed of the front and rear rotors are the same, this is because the gear rotation of the front rotor shaft is followed by a gear rotation connected directly from the rear axle. Furthermore, the torque in the counter-rotating wind turbine can be obtained from the results of the front and rear axle, which is taken the average rotation from the front and rear axle, then the torque uses equation 7, then for the electric power data obtained using equation 8. By therefore the following are the results and discussion of the research:
3.1 Testing of Wind Speed for the Second Radial Speed of the Rotor

Based on Figure 3 and Figure 4, it can be seen that at 4.87 m/s wind speed, the radial speed of the front and rear rotors do not yet exist or 0, but at wind speed 5.01 m/s, the radial speed of the front rotor and rear rotor there is already but it tends to be small, which is 25 rpm for each rotor. At 6.97 m/s wind speed, the radial speed of the front and rear rotors are 104 rpm, where the radial velocity of the two rotors starts high and will develop if the wind speed is higher. This proves that the greater the wind speed, the higher the radial speed is generated from the front and rear rotors and the same radial speed of the front and rear rotors is same.

3.2 Testing of Wind Speed on Electric Power

In Figure 5 it can be seen that, for wind speeds of 4.87 m/s the electric power produced does not yet exist and for wind speeds of 5.01 m/s electric power starts to be produced even though it is not large, which is 0.0072 watts. Then at 7.13 m/s wind speed, the electrical power produced tends to be large at 3.4528 watts, this is because the electrical power generated depends on the rotation of the rotor, the greater the radial speed of the front and rear rotors, the greater electric power produced, while to increase the radial speed of the two rotors, a large wind speed is needed, therefore the greater the wind speed received by the counter rotating wind turbine, the greater the electric power produced because the radial velocity of both rotors is greater.

3.3 Testing of Wind Speed against Torque

In accordance in Figure 6, where the graph describes the wind speed of 4.87 m/s, the resulting torque does not yet exist or 0, while the wind speed of 5.01 m/s the torque produced reaches the maximum torque value in this study, which is 12 Nm. Because a wind speed of 4.87 m/s the rotor cannot rotate so that the torque value produced does not yet exist. Furthermore, for wind speeds of 5.01, the rotors have started to rotate but it needs a large force to rotate the shaft connected directly to the gearbox so that the torque produced is greater. In addition, after the maximum torque is reached and followed by the increasing wind speed, the force needed to rotate the rotor is getting smaller, so that the torque produced after reaching the maximum torque value will decrease.

3.3 Testing of the Rotor’s Second Radial Rotational Speed against Torque

In this test, there are 2 graphs derived from the rotating speed of the front and rear rotors. In addition, the shape of the graph displayed is the same, because the radial speed in the two rotors is the same, here is the graph:
As stated earlier, it can be noted that in figure 7 and figure 8 have the same graph because the radial velocity of the two rotors is the same so that the torque produced from the front rotor and rear rotor is the same. Therefore at the radial speed of 25 m/s, the torque produced reaches 12 Nm, this is because at the beginning of the rotor rotation, the force required is large, but when passing through the initial rotation phase and the radial speed is higher the torque is generated by the two rotors the smaller the force needed to rotate the two rotors.

4 CONCLUSION
1. Counter-rotating wind turbines with a single generator using a full-scale gearbox have been successfully made and tested. From the tests conducted, it was shown that the wind speed needed to apply this type of turbine was 5.01 m / s. In addition, the wind speed is directly proportional to the radial velocity of the two rotors, where the greater the wind speed, the greater the radial speed produced by the two rotors.
2. The radial speed of the two rotors is equal because the gear rotation of the front rotor shaft is followed by a gear rotation connected directly from the rear axle.
3. The production of electrical power produced is influenced by the existing wind speed, because the greater the wind speed is, the radial speed produced by the two rotors will increase, so the rotation that enters the generator gets bigger, at the end the greater the electrical power produced also. Therefore the electrical power produced is directly proportional to the amount of wind speed that exists.
4. In the rotor rotation for the first time on a counter-rotating wind turbine system, the torque required tends to be large, because the force needed to rotate the gearbox and generator is also large, but after the rotating speed increases due to the increased wind speed, the torque produced after the initial rotation phase of the rotor tends to decrease, because the force needed to rotate the gearbox and generator is no longer large.

REFERENCES
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