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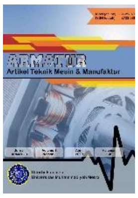

Laboratory tests of blade radius variation on vertical shaft savonius turbine performance

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A R T I C L E I N F O

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A B S T R A C T

Wind turbines are one of the machines that are currently still used to convert wind kinetic energy so that they can be used by humans such as to drive pumps in agriculture and produce electrical energy. Savonius turbine is a vertical axis turbine that is currently widely used as an electrical energy generator, this wind turbine is a type of drag type wind turbine that has a simple design that is in the form of a semicircular curved blade side. Therefore, the author is interested in researching the resulting performance including turbine rotational speed, power generated, and wind turbine efficiency against the variation of the blade radius. The method used is experimental, the stages of this research are in the form of literature studies, making savonius turbines, testing savonius turbines with variations in blade radius as well as data retrieval, data processing, and analysis. Based on the data obtained, the rotating speed of the turbine is influenced by variations in the radius of the blade. The larger the blade radius, the smaller the turbine rotational speed. The maximum turbine rotation speed at blade radius 63 is 173 rpm, while at blade radius, 88 is 118 rpm and at blade radius 113 is 115 rpm. So the highest turbine rotating speed at a radius of 63.

Introduction

The use of fossil-derived energy sources is still very dominant compared to the use of other energy sources. Even though the availability of fossil energy is predicted to run out in the next few decades. Thus the need for energy will be even greater. This excessive use of fossil energy has had an impact on the greenhouse effect and global warming [1].

The use of wind energy began to be developed in the early 1970s along with the energy crisis. One of the energies developed is wind energy, where the energy generated is mechanical energy and electrical energy. The energy has been developed and refined in Europe and America. The development continues and is now an alternative energy source that is applied independently to obtain energy [2].

Wind turbines are one of the machines that are currently still used to convert wind kinetic energy so that they can be used by humans such as to drive pumps in agriculture and produce electrical energy. The types of wind turbines are also

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increasingly diverse, based on the axis there are 2 types, namely the vertical axis (TASV) and the horizontal axis (TASH). The rapid development of wind energy utilization has made engineers compete to improve the efficiency of wind turbines such as creating lightweight materials for turbine *blades*, adding transmission systems to increase rotation in generators, and various other things.

Savonius turbines are vertical axis turbines that are currently widely used as electrical energy plants. This wind turbine is a type of *drag* that has a simple design and is in the shape of a semicircular curved blade side. The performance of the Savonius wind turbine can be influenced by several things, one of which is the blade radius on the turbine, the greater the radius, the greater the cross-sectional area, based on the theory the wider the cross-section on the turbine blade, the greater the ability of the savonius turbine to absorb wind kinetic energy. Therefore, this study discusses the effect of blade radius variation on savonius turbines on the resulting performance [3]. In addition, the resulting performance includes the acceleration of rotation and turbine power produced as well as efficiency against the variation of the blade radius.

Bibliography Review

Wind Energy. Wind can produce energy in terms of two main factors, namely [4] :

1. The presence of heat in atmospheric air that causes convection currents
2. The earth's rotation results in the wind moving in atmospheric air.

To calculate wind power (Pa) mathematically can be calculated using the formula [5]:

$$P_a = \tfrac{1}{2} \rho A v^3 \qquad (1)$$

Information:

ρ = Density of air (kg/m^3)
A = Cross-sectional area (m^2)
v = Wind acceleration (m/s)
P_a = Wind power (*Watts*)

Wind Turbines. It is a collection of tools and components utilizing the kinetic energy of the wind and converted into the form of motion energy, which moves the rotor and generator shaft so that it produces electrical energy adjusted to its rotor axis [6].

Wind turbines are the interaction of wind blades or blades, rotor axes on the ground and towers /towers (against the wind, or following the wind direction), and innovative engine types. The interaction of the blade with the wind includes dragging, lifting, or a combination of both. In the towing device, the wind pushes against the blade or sail, thereby making the rotor rotate its axis. Another problem is that drag devices have a lot of material on the blade. Although the number of towing devices is different, there are basically no commercial (economical) drag devices in production for power generation.

The lifting device uses an airfoil for the blade, similar to a propeller. However, other concepts with Magnus (rotating cylinders) and Savonius wind turbines. The Savonius rotor is not entirely a drag device, but it has the same thing as a large blade area for tapping the area. The advantage of the Savonius wind turbine is the ease of construction. Using lifts, the blade can move faster and more efficiently in terms of aerodynamics and material use and has the advantage of receiving wind from all directions [7].

Wind turbines have two types, namely, horizontal axis and vertical axis.

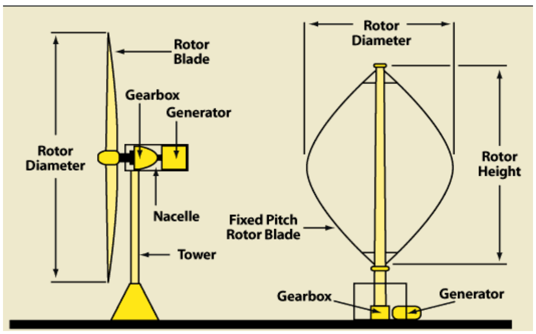

Figure 1. Horizontal and vertical axis wind turbines [6]

Horizontal wind **turbines.** is a type of turbine where the main shaft moves or rotates according to the wind direction. Therefore, the wind direction must be parallel to the turbine shaft as well as perpendicular to the direction of rotation of the *rotor*. Usually, this type of turbine has an *airfoil-shaped* blade. Generally, the more the number of blades, the higher the turbine rotation. The advantage of this type of turbine is that it has a fairly high efficiency. The drawback, though, is that it has a more complicated design because it can only capture wind from one direction from the rotor, so a wind direction is needed [8].

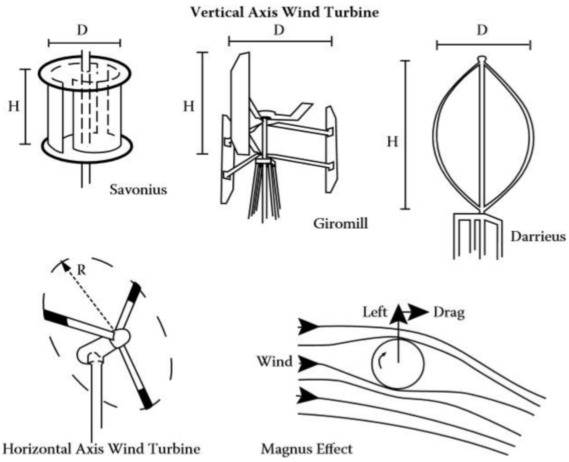

Figure 2. Horizontal wind turbines [7]

Vertical Wind Turbines. The vertical axis is a wind turbine where the blade movement is parallel to the wind direction. Based on the principle of differential action of vertical axis *rotors* that already existed since ancient times Finnish engineer *Sigurd Savonius* the name for the *rotor* he invented in 1921 and patented it eight years later [5]. Vertical wind turbines are used in wind acceleration that changes in different directions. Vertical wind turbines are known to several including Darrieus turbines, Savonius turbines, and H turbines [9].

Savonius Wind Turbine. Savonius wind turbine is a type of wind turbine that is driven using drag force. This turbine consists of two to three buckets or blades arranged in such a way that when viewed from above it will look like it forms the letter S. Savonius wind turbines have a simple appearance so that even in the manufacturing process it does not require expensive costs [9,10]. To see the performance of the *savonius* wind turbine can be determined as follows:

Sweep Area. In *Savonius* wind turbines the cross-sectional area of the turbine is the length of the diameter (*D*) times the turbine height (*h*), or mathematically it can be described in equation [9]:

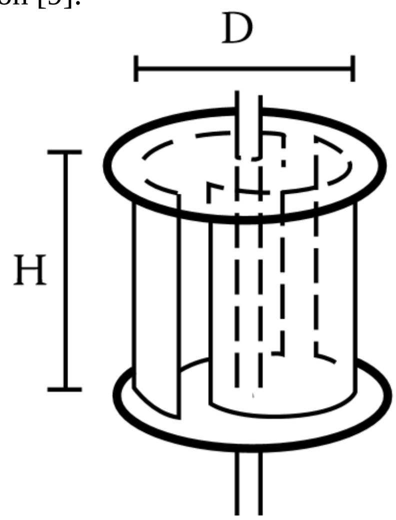

Figure 3. Turbine Sweep Area [7]

$$A = D \cdot h \qquad (2)$$

Information:
A = Area of rotor sweep area (m²)
D = Turbine diameter (m)
H = Height from the turbine blade (m)

Wind power. From the acceleration variation, we can calculate the power possessed by the wind before it is converted or before passing through a wind turbine. In the tests carried out, namely with variations in wind acceleration.

Power generated. The power generated is the power that has been converted from the power possessed by wind energy to the power produced. So that it can calculate the power produced, namely by using the formula:

$$P_{air} = Cp \cdot ½ \cdot \rho \cdot A \cdot v^3 \qquad (3)$$

System Efficiency. Cp is a comparison between and in the form of output produced by turbines (Electrical

Energy From Generators) and power generated by wind.

$$Cp = \frac{P_{out}}{P_{int}} \times 100\ \% \qquad (4)$$

Information:
P_{out} = power generated by the turbine
P_{int} = absorbed wind power

Power. Turbine power is the power generated by a wind turbine, in this study the power measured in the form of generator output power is formulated as follows:

$$Pe = v \times I \qquad (5)$$

Information:
v = voltage
I = current

Savonius turbine working system. Converting wind kinetic energy into electrical energy through a very sequential work system process between turbine components. The energy of wind gusts produces wind acceleration that changes every time, and at any given moment wind energy has a large wind acceleration. The wind energy can move the cross-section of the turbine blade and rotate and produce a moment of turbine inertia. Due to the movement of the turbine shaft, the rotating pulley drives the DC motor and generates electricity [4].

Radius. Radius is the distance between the center point of the circle and the surface of the circle, the radius of the circle has a diameter. If the radius increases then the diameter of the circle will increase, then if the radius on the turbine blade is enlarged, the dimensions of the turbine will change.

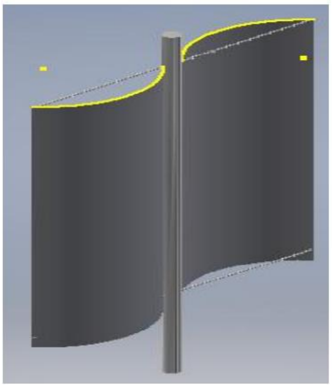

Figure 4. Blade radius

Research Methods

Research using methods experimental by making variations of blades and making test equipment. The following is a drawing of the flow chart of this research method:

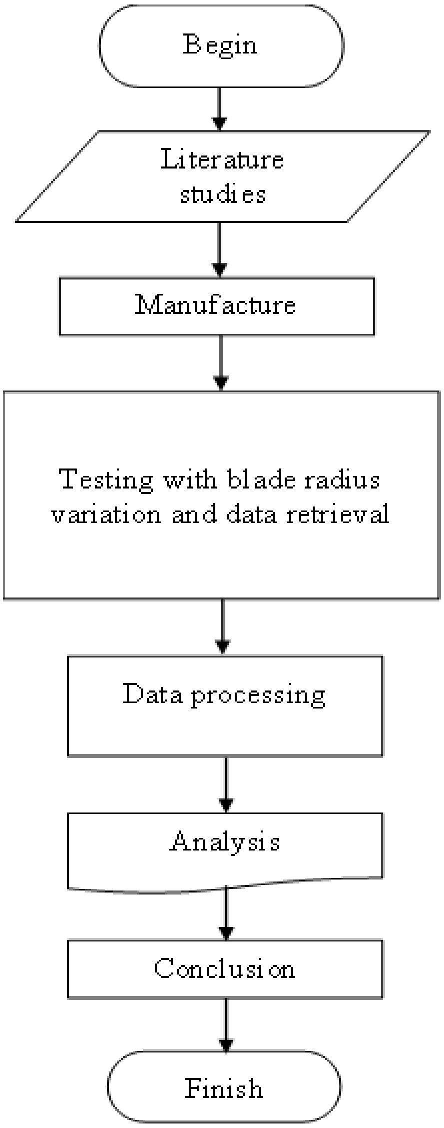

Figure 5. Research flowchart

Table 1. Equipment and Materials

No.	Equipment & Materials	Component
1	Equipment in the performance of savonius turbines	- Tunnel
		- Fan
		- Generator
		- Transmission system
		- Couples
		- Bearing
2	Equipment in the replacement of blades (radius of blades)	- Wrench + ring (8 mm)
		- Screwdriver
3	Equipment in the manufacture and assembly of blades	- Steel crossbar
		- Meter
		- Hand Grinding
		- Roll Machine
4	Materials in the manufacture and assembly of blades	- Aluminium plate
		- Galvanized pipe 12 mm
		- Bolts and nuts 8

Manufacture of turbine blades with variations in the radius of the blade. Prepare the necessary tools and materials. Take measurements on plates with an area of 197.82 mm x 500 mm as shown in Figure 6.

Figure 6. Measurement process

Measurements have been completed followed by cutting aluminum plates using cut burrs such as in Figure 7.

Figure 7. Cutting process

Then the drilling stage is 4 holes on the edge of the plate using an 8 mm drill bit as Figure 8.

Figure 8. Blade drilling process

The drilling has been completed, followed by forming a plate that has been cut with a variation in radius using a roller machine such as in Figure 9.

Figure 9. Plate rolling process

The dimensions of the tools used in the measurements are shown in Figure 10.

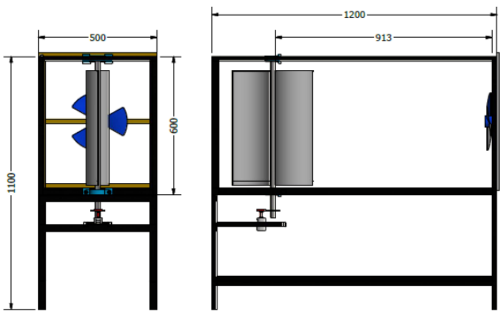

Figure 10. Dimensions of the media used

Data processing. The calculation of the rotor sweep area (*A*) is known as turbine height (*H*) 500 mm and respectively the turbine diameter (D) 262, 328, and 356 mm seen from the variations in the radius of blades 63, 88, and 113 obtained the following calculations:

$Ar_{63} \quad = H \text{ x } D$

$= 500 \text{ mm x } 262 \text{ mm}$

$= 131 \text{ mm}^2$

$= 0{,}131 \text{ m}^2$

The calculation of the variations of blades 88 and 113 is the same as the calculation of the swept area of the variations of blade 63 with results of 0.164 m 2 and 0.178 m^2.

Wind acceleration range of 2 m / s, 3 m / second, and 4 m / second obtained the following calculations:

$P_{air} \quad = ½ \rho \ A \ v^3$

$= ½ \text{ x } 1{,}225 \text{ x } 0{,}131 \text{ x } 2^3$

$= 0{,}872$ *watt*

The calculation of the variations of blades 88 and 113 is the same as the calculation of wind power of the variation of acceleration v_1 = 2 m / s.

The power generated from a wind turbine can only receive wind energy into mechanical energy of no more than 59.3% then the calculation of the power generated from the turbine with wind acceleration V_1 = 2 m / second variation in radius 63 is obtained as follows:

Pr $\quad = 0{,}593 \text{ x } 0{,}64 = 0{,}380$ *watt*

Results and Discussion

The effect of the blade radius on the acceleration of turbine rotation. Graph of the effect of the blade radius on the acceleration of wind turbine rotation in Figure 11 shows that at a radius blade of 63 wind acceleration of 2 m/s acceleration of turbine rotation produced at 120 rpm, wind acceleration of 3 m/s acceleration of turbine rotation produced at 159 rpm, and wind acceleration of 4 m/s acceleration of turbine rotation produced at 173 rpm. At a radius of 88 wind acceleration of 2 m/s acceleration of the resulting turbine rotation 86, wind acceleration of 3 m/s acceleration of the resulting turbine rotation of 100 rpm, and at wind acceleration of 4 m/second acceleration of the resulting turbine rotation of 118 rpm. And at a radius of 113 wind acceleration of 2 m / s acceleration of the resulting turbine rotation is 75 rpm, wind acceleration is 3 m / second the acceleration of the resulting turbine rotation is 93 rpm, and at wind acceleration of 4m / second the acceleration of the resulting turbine rotation is 115 rpm.

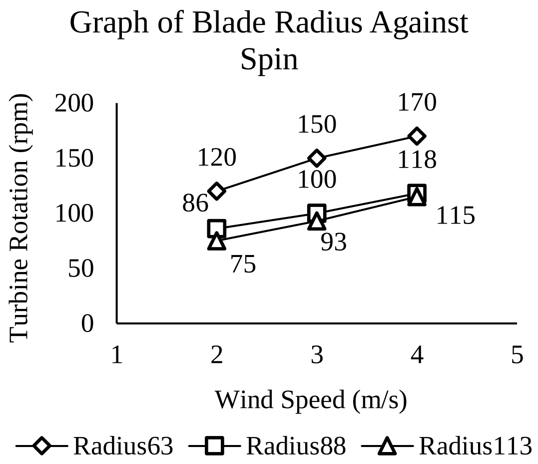

Figure 11. Effect of blade radius on turbine rotation

Based on the results of the graph above, the greater the wind acceleration, the higher the rotational acceleration of the turbine produced. Based on the influence of radius variations on the rotation produced, the larger the radius of the turbine blade, the smaller the turbine rotation, at a radius of 63 accelerations the maximum turbine rotation is 170 rpm, while at a radius of 88, the maximum turbine rotation acceleration is 118 rpm, and at a radius of 113 the maximum turbine rotation acceleration is 115 rpm.

The effect of the blade radius on the resulting voltage. The graph of the effect of the blade radius on the voltage generated in Figure 12 shows that at a radius blade of 63 wind acceleration of 2 m/s the voltage generator is 2.00 Volts, the wind acceleration is 3m/s the voltage generator is 2.2 Volts, and at the acceleration of the wind 4 m/second the voltage generator is 2.5 Volts. At a radius of 88 wind acceleration of 2 m/s, the voltage generated by the generator is 1.23 Volts, the wind acceleration is 3 m/s the voltage generator is 1.30 Volts, and at the wind acceleration of 4 m/s, the voltage generator is 1.56 Volts. And at a radius of 113 wind acceleration of 2 m / s the voltage generator is 1.00 Volts, the wind acceleration is 3 m / second the voltage produced by the generator is 1.28 Volts, and at the wind acceleration of 4 m / second the voltage produced by the generator is 1.31 Volts. Based on the results of the graph above, the greater the wind acceleration, the greater the voltage generated. Based on the influence of radius variations on the voltage produced, the greater the radius, the smaller the voltage produced, at a radius of 63 the maximum voltage is 2.5 Volts, while at a radius of 88, the maximum voltage is 1.56 Volts, and at a radius of 113 the maximum voltage is 1.31 *Volts*.

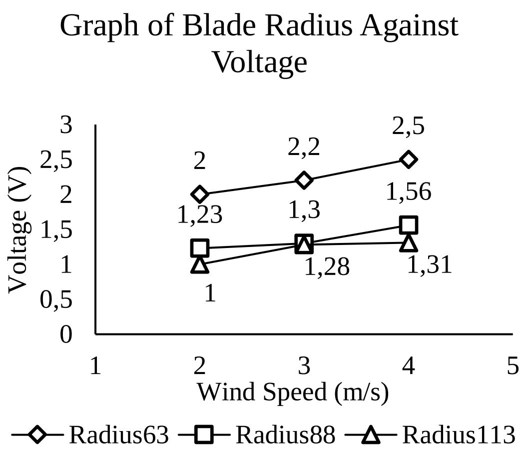

Figure 12. The effect of the blade radius on the voltage

The influence of the radius of the blade on the resulting current. The graph of the effect of the blade radius on the current generated in Figure 13 shows that at a blade radius of 63 wind acceleration of 2 m/s the current generated by the generator is 136 mA, the wind acceleration is 3 m/s the current generated by the generator is 159 mA, and the wind acceleration is 4 m/s the current generated by the generator is 173 mA. At a radius of 88 wind acceleration of 2 m/s the current generated by the generator is 111 mA, the wind speed is 3 m/s the current generated by the generator is 127 mA, and the wind acceleration is 4 m/second the current generated by the generator is 145 mA. At a radius of 113 wind acceleration is 2 m/s the current generated by the generator is 94 mA, the wind acceleration is 3 m/s the current generated by the generator is 105 mA, and the wind acceleration is 4 m/s the current generated by the generator is 126 mA.

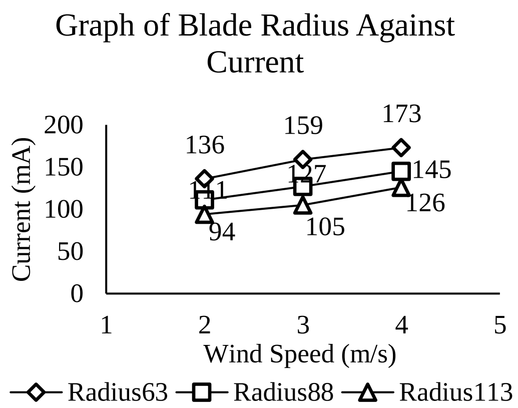

Figure 13. The effect of the blade radius on the current

Based on the results of the graph above, the greater the wind acceleration, the greater the current generated. Based on the influence of radius variations on the current produced, the greater the radius, the smaller the current produced, at a radius of 63 the maximum current generated is 173 mA, while at a radius of 88, the maximum current is 145 mA, and at a radius of 113 the maximum current is 126 mA.

The effect of the blade radius on the power generated. The graph of the effect of the blade radius on the power generated in Figure 14 shows that the output power produced at the blade radius 63 with a wind acceleration of 2 m / second is 0.272 W, the output power produced with a wind acceleration of 3 m / second is 0.342 W and the output power produced by wind acceleration of 4 m / s is 0.432 W. Output power produced on radius blades of 88 with wind acceleration of 2 m / s is 0.136 W, the output power generated by wind acceleration of 3 m/s is 0.165 W and the output power generated by wind acceleration of 4 m/sec is 0.226 W. The output power produced by radius blade 113 with wind acceleration of 2 m/s is 0.094 W, the output power generated by wind acceleration of 3 m/s is 0.134 W and the output power generated with wind acceleration of 4 m/sec is 0.165 W.

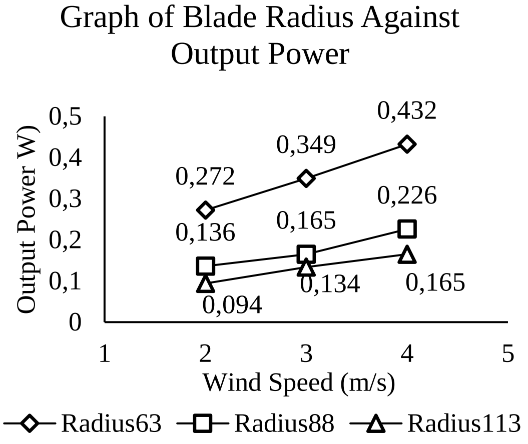

Figure 14. The effect of radius on power

The effect of blade radius on the efficiency of savonius wind turbines. The graph of the effect of the blade radius on the efficiency of the savonius wind turbine in Figure 15 shows that the efficiency of the savonius wind turbine at the blade radius 63 wind acceleration 2 m/s efficiency value is 40.7%, wind acceleration is 3 m/s efficiency value is 15.1% and wind acceleration is 4 m/s the efficiency value 8.0 %. At a radius of 88 wind acceleration of 2 m/s t, the efficiency value is 15.9%, the wind acceleration is 3 m/s the efficiency value is 5.9% and the wind acceleration is 4 m/s, and the efficiency value is 3.4 %. At radius 113 wind acceleration is 2 m/s the efficiency value is 10.4%, wind acceleration is 3 m/s the efficiency value is 4.4% and at wind acceleration of 4 m/s the efficiency value is 2.2 %.

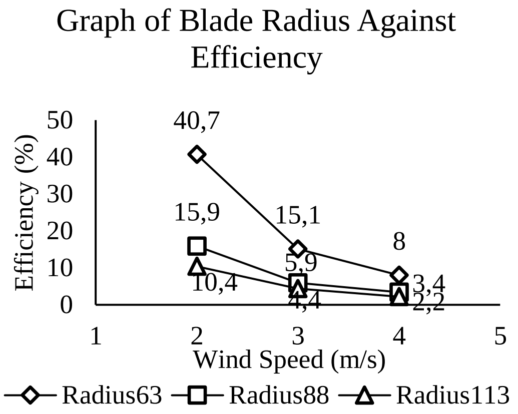

Figure 15. The efficiency of savonius wind turbines

From the results of this test, a graph of the effect of the blade radius on the power and efficiency of the savonius wind turbine was obtained, with the highest power and efficiency resulting from 3 blade radius variations, namely at a radius of 63 wind acceleration of 4 m / second and the resulting power of 0.432 *watts*, and the lowest power value was found in a radius of 113 wind acceleration of 2 m / second and the power produced by 0.094 *watts*. This can happen because the power generated is greatly influenced by the acceleration of turbine rotation and the radius on the turbine blade, the larger the radius on the blade, the smaller the output power produced this can be caused because when the position of the turbine is perpendicular to the wind that hits the turbine is very little because the larger the radius.

Conclusion

The results of the tests carried out can be drawn to the conclusion of turbine rotation acceleration is influenced by variations in the radius of the blade. The larger the blade radius, the smaller the acceleration of the turbine rotation. The maximum turbine rotation acceleration at radius 63 blades is 173 rpm, while at blades radius 88 is 118 rpm and at blades radius 113 is 115 rpm. So the acceleration of the highest turbine rotation at a radius of 63. The *output* power is influenced by variations in the radius of the blade. The larger the blade radius, the smaller the output power produced by the turbine. The maximum power on blade radius 63 is 0.432 Watts, while on the radius of blade 88 is 0.226 Watts and on the radius of blade 113 is 0.165 *Watts*. So the output power is highest at a radius of 63. The magnitude of the efficiency of the system is influenced by variations in the radius of the blade. The maximum efficiency on the 63-radius blade is 40.7%, while on the 88-radius blade is 15.9% and on the 113-radius blade is 10.4%. So the highest system efficiency at a radius of 63 blades.

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