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Optimization of savonius turbine towards different inner blade positions to improve turbine performance

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Abstract

The purpose of this study is to examine the performance of the Savonius turbine on the inner blade position in order to improve turbine efficiency. The blades used are a simplification of the Savonius U/L and the Savonius 1:2 double blade model. This research begins by creating four blade models: a single-blade model, a double-blade model at the blade's tip, a double-blade model at the blade's base, a single-blade model, and a double-blade model along the blades against the wind. The four models are then fitted in the test system for generator performance. Next, the efficiency characteristics of the turbine will be tested against rotation. The test results of the four models were evaluated by comparing each model's efficiency. The results indicate that the Savonius double-blade 1:2 and Savonius U/L turbines achieve efficiencies of 2.42% and 2.1% at 5 m/s and 7 m/s, respectively. At speeds of 5 m/s and 7 m/s, the double-tip position inner blade model increased by 81% and 61%, respectively. The double-tip inner blade variant has the maximum efficiency at 9 m/s, at 3.71 percent. Therefore, the Savonius U/L type vertical axis wind turbine with a 1:2 double blade is the most suited blade model for usage at wind speeds less than 7 meters per second. While the Savonius model with innovations in the inner blade double tip position is suitable for operation at wind speeds greater than 9 meters per second, the Savonius model without such advances is not viable.

Keywords:
Inner blade position, double blade on tip, double blade on root, efficiency, Savonius turbine.

1. Introduction

The reliance on fossil fuels, such as oil and coal, to supply domestic energy demands is growing annually [1], [2]. This is due to the fact that energy supplies and reserves are not proportional to exponentially growing populations, economies, and energy consumption patterns. Meanwhile, fossil energy sources, which have been the primary energy sources, have extremely limited supply and continue to deplete [3], [4], [5]. In the meantime, oil reserves in Indonesia and other nations are projected to be drained within 20 years based on the ratio of reserves to production in 2007. Meanwhile, it is anticipated that natural gas would run out in 61 years and coal in 147 years [2], [6], [7], [8], [9].

Referring to Law Number 30 of 2007 regarding energy and in accordance with government policies on energy conservation (Keppres Number 43, 1991) and energy saving (Inpres Number 10, 2005), and supported by Minister of Energy and Mineral Resources number 02 of 2004 regarding policies for developing renewable energy and conservation of energy or the development of green energy, every citizen is encouraged to investigate the potentials of alternative energy sources in Indonesia, such as wind. Wind energy is one of the fastest-growing renewable energies in the world today. Wind energy can be used for a variety of reasons [10], [11], [12] such as generating electricity, pumping water for irrigation, drying or chopping crops, aerating fish/shrimp ponds, etc.

Wind turbines transform the kinetic energy of wind speed into mechanical energy in the turbine's propeller. The mechanical energy is then used to power devices such as water pumps, electric generators, and compressors [13], [14], [15], [16], [17]. France Patent No. 2522074, U.S. Patent No. 4,362,470, Japan Patent No. 2003293928, German Patent No. 821930, Danish Patent No. 37015, and Finland Patent No. 65940 have all been issued patents on the technology for converting wind energy through the Savonius turbine to variations in the inner blade position. Few individuals have examined the Savonius turbine's optimization for variations in the position of its inner blades in accordance with its specifications. For this reason, it is necessary to develop a Savonius turbine model for variations in the position of the inner blade (inner blade position) for the relatively low wind potential in Indonesia by employing galvalume plate blades that are inexpensive and simple to replicate, with optimal performance characteristics at different wind speeds.

Wind is a source of renewable energy. Wind is generated by natural law due to changes in air pressure in a given region [18], [19], [20], [21]. The difference in pressure is caused by the sun's heating of particular regions, which warms the surrounding atmosphere, or, in other words, raises the air temperature in the region. As the temperature rises, the air pressure in the region will rise. While there are still frigid regions in other locations, these regions have comparatively low air pressure. The difference in air pressure leads air to migrate from regions of high air pressure to regions of low air pressure. There are two components of aerodynamic force: [22], [23], [24], (Herlambang et al., 2020), [25]. First, a lift is the force component that is perpendicular to the wind's vector of attack on the blades. Second, thrust (drag) is the component of the wind force that acts in the direction of the blade. Typically, the performance of airfoil blades is measured in terms of the drag force coefficient (Cd) and lift force (Cl). The lift force [26], [27], [28] is a perpendicular force to the flow that strikes an airfoil form. The drag force is a force that is perpendicular to the fluid flow that strikes an airfoil. The coefficient of power (Cp) chart illustrates wind turbine efficiency. Betz restrictions of 59.3 percent, such as HAWTs [29], [30], [31], [32] restrict the power coefficient of Savonius rotors.

First, the Savonius Wind turbine with the inner blade position on the tip of the blade, double blade on the blade root, and single blade and double blade along the blades have an impact on the efficiency of the turbine. Second, the Savonius wind turbine with an inner blade position and a double blade model on the tip of the blade, a single blade on the root blade, and a double blade along the blade against wind flow has the most efficient turbine performance. The Savonius turbine with an inner blade position model consisting of double blades at the tip of the blade, double blades at the root of the blade, a single blade, and double blades along the blade provides the highest performance. This work intends to construct a Savonius rotor model for modifications in the inner blade position utilizing a galvalume blade by adjusting the ratio of the blade's inlet and outlet sides. This study's novelty is a Savonius rotor for modifications in the inner blade position with the following dimensions: height x diameter = 800 mm x 560 mm, yielding 5 Savonius rotors. This study intends to design and build Savonius turbine models for variations in the inner blade position, including double blades at the tip of the blade, double blades at the root of the blade, a single blade, and double blades down the length of the blade. Second, evaluating the Savonius turbine for variations in the inner blade position at wind speeds of 5, 6, 7, 8, and 9 meters per second. Third, analyze the optimization of the five Savonius models for the effect of modifications in the inner blade location on turbine performance parameters.

2. Materials and methods

2.1. Materials

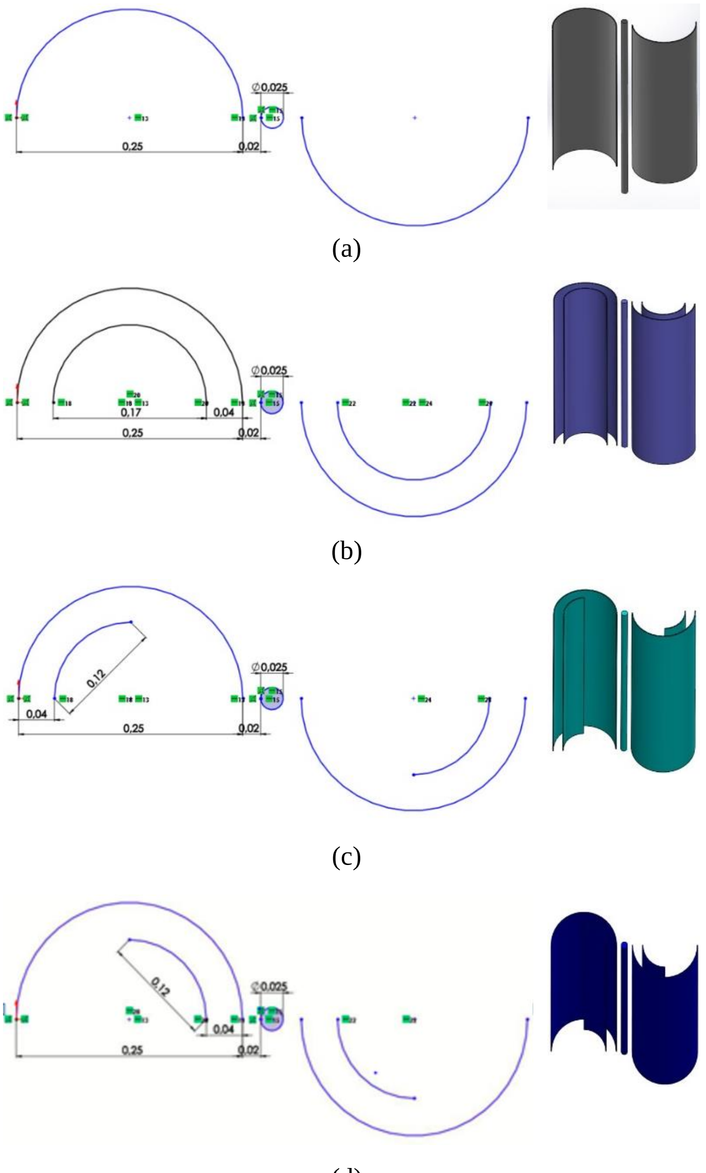
The essential components of the VAWT Savonius wind rotor with regard to variations in the inner blade position are a turbine rotor, a blade holding disc, and a shaft. The turbine rotor converts the kinetic energy of the wind into mechanical energy in the form of the shaft's rotation. There will be five variants of 3-blade rotors, each with a unique inner blade position at the rotor tip, root, and middle. The turbine blades are built from galvalume with a 20 mm thickness and are mounted on a disc/blade holder. The choice of blade material is galvalume plate material with light and strong considerations for the blade-rotating shaft's duty. 560 millimeters is the diameter of the Savonius rotor in relation to variations in the inner blade position. This turbine blade is positioned on a disc that serves as its support. The blade holding plate is constructed from a galvalume plate with a thickness of 20 mm, and its diameter is 650 mm. This blade holding plate is intended to reduce the burden of the rotating turbine propeller shaft. The turbine rotor is fitted with a 50 mm-diameter solid shaft manufactured of St 37 iron. When the blade rotates, axial and tangential forces are applied to the turbine shaft, which is attached to the blade holding plate and strengthened by two bearings. The disc-brake system measures the amount of torque created by the rotating turbine. Torque is measured by noting the amount of force created and multiplying it by the distance to the center of the turbine shaft. The frame is manufactured from St 37 steel, the L profile is 50 mm x 50 mm x 50 mm, and it is constructed to be robust to reduce vibrations. The frame's legs are equipped with 4-inch wheels that serve to resist the wind's force.

2.2. Methods

The design of the Savonius turbine blade for variations in the inner blade position uses the Solidworks 2014 software precisely and accurately. This step is done by designing a single-blade Savonius wind turbine model and single-stage double blade with variations in the ratio of the inlet and outlet sides (1:1, 1:2, 1:3, 1:4) to the wind flow to improve performance. The proposed rotor is shown in Fig. 1.

The manufacturing process is one in which all planned components are produced in phases, beginning with the production of the turbine blades, the hub linking the blades, the main frame, and the testing load on the turbine, and concluding with the development of the overall tool. In gathering this data, the metrics measured include generator efficiency and mechanical efficiency, which are comprised of three experiments with varying inlet-to-outlet ratios.

Data analysis based on the graph of the best performance characteristics of the Savonius turbine. The analysis is done by comparing the variations in the ratio of the inlet and outlet sides. The test data are processed to obtain wind speed, shaft rotation, wind power, turbine torque, turbine power, and turbine efficiency. The results of the processing are then displayed in the form of a turbine characteristic graph. The performance of each Savonius turbine on the variation of the inner blade position was studied and analyzed. So that it will produce conclusions on the Savonius turbine on variations in the inner blade position with variations in the ratio of the inlet and outlet blades that have the best performance



(a)

(b)

(c)

(d)

Fig 1. Proposed rotor (a) Single-blade Savonius turbine, (b) sDouble blade center Savonius turbine, (c) Double blade root Savonius turbine, and (d) Double blade tip Savonius turbine.

.In this instance, mechanics require a rotation, wind, voltage, and current meter to test the generator's efficiency, as shown in Fig. 2. With so many variables, it will be easy to determine the optimal generator efficiency and turbine mechanics. The data gathered from the performance results of the Savonius turbine model modifications in the position of the inner blade (inner blade position) to the wind flow upon completion of all tests. Fig. 5, to get a comprehensive understanding of this research, the linkages between the research aspects are drawn up in a flow chart of the research stages.

3. Results and discussion.

The data for the test results were collected from the Energy Conversion Engineering Laboratory, Department of Mechanical Engineering, Semarang State Polytechnic. A blower is an instrument used to generate wind velocity. The collected data is necessary for analyzing the performance of the wind turbine. The information consists of wind velocity (v), air density (ρ), generator rotation (n), wind sweep area (A), voltage (V), current (I), and torque value. It can be observed from Fig. 3 that turbine power will be greater as the turbine rotation increases.

The influence of turbine rotation on turbine power can be examined as follows: a single blade with a wind speed of 5 m/s produces an average turbine rpm of 269 and an average turbine power of 4.56 W

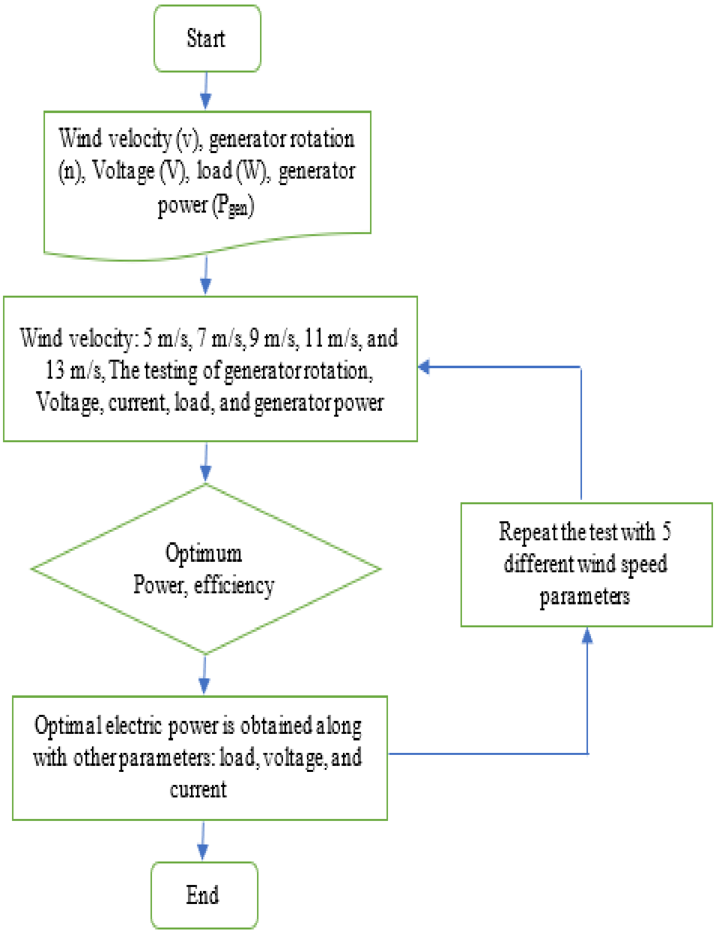


Fig 2. Flowchart of research stages to obtain optimum electric power and system efficiency

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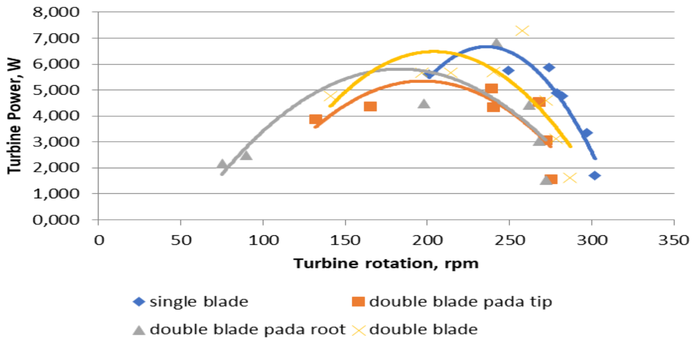

Fig 3. Turbine power (Pt) towards turbine rotation (n) at a wind velocity of 5 m/s

Then it can be determined that the double blade at the tip of the blade provides an average turbine speed of 227.28 rpm and an average turbine power of 3.82 W, when the wind speed is 5 m/s. Then it can be determined that the double blade on the root blade provides an average turbine speed of 201 and an average turbine power of 3.56 W when the wind speed is 5 m/s. Then it can be determined that the double-bladed turbine with a wind speed of 5 m/s generates an average rpm of 249.42 and an average power of 4.8 W.

Due to its lesser weight than other types of blades, the single-bladed turbine type has the highest rotational speed and power of all turbine types.

The characteristics demonstrated that the turbine torque and rpm have an effect on the turbine power, in Fig.4**.** The higher the turbine torque, the higher the turbine power, and the higher the turbine rpm, the higher the turbine power. the rotation of the single blade is more than the rotation of the double blade on the tip, hence the turbine power of the single-blade model on the tip is greater than the turbine power of the double-blade model on the tip.

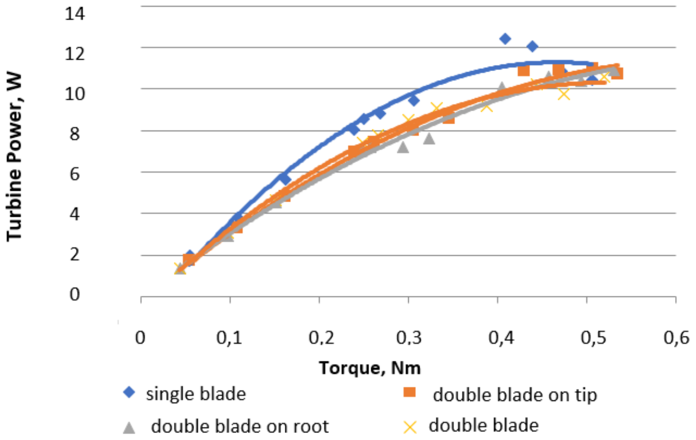

Fig 4. Turbine power toward the torque

The type of single blade which is averaged occupies the first position among other types of blades because the type of single blade has a larger rotation than other types of blades; consequently, rotation will affect the mechanics (turbine power); if the P-mechanics with the same wind speed, the Cp will be even greater, as shown in Fig. 5. The TSR is also controlled by rotation; if the rotation is high, the TSR obtained will be high as well. The rpm value for the single-blade kind of blade is high due to the blade's light weight; hence, the blade weight also influences the 13 m/s turbine rotation speed. Fig. 6, showed that the voltage is inversely proportional to the current, if the voltage drops, the current will increase.

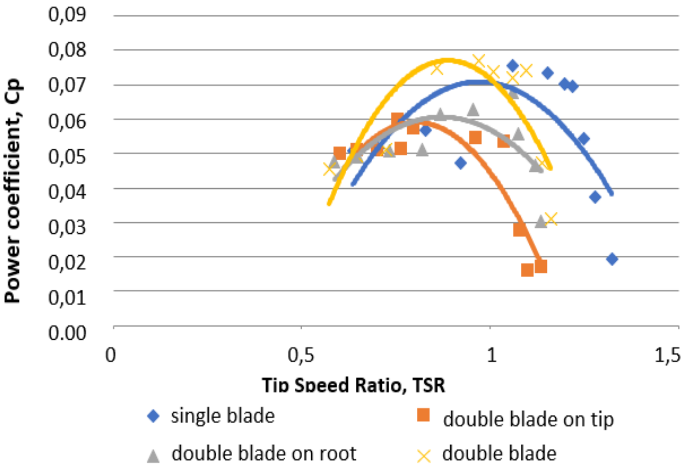

Fig 5. Power coefficient (Cp) towards tip speed ratio (TSR)

While the generator power is influenced by the generator current and voltage, if the load increases, the generator voltage will decrease. And the generator current will increase, in Fig. 7.

The influence of generator rotation on electrical power, revealed that a single blade with wind speeds of 5, 7, 9, 11, and 13 m/s at a load of 5 W generates an average generator rpm of 442 and an average generator power of 5.03 W. It can be observed from Fig. 8 that generator power will be greater as the generator rotation increases. Then it can be determined that the double blade at the tip of the blade with wind speeds of 5, 7, 9, 11, and 13 m/s and a load of 5 W generates an average generator speed of 389 and an average generator power of 3.67 W.

Then it can be determined that the Double blade on the root blade provides an average generator speed of 384 and an average generator power of 3.43 W with wind speeds of 5, 7, 9, 11, and 13 m/s and a load of 5 W. Then it can be determined that double blades with wind speeds of 5, 7, 9, 11, and 13 m/s at a load of 5 W create an average generator speed of 430 rpm and an average generator power of 5.45 W.

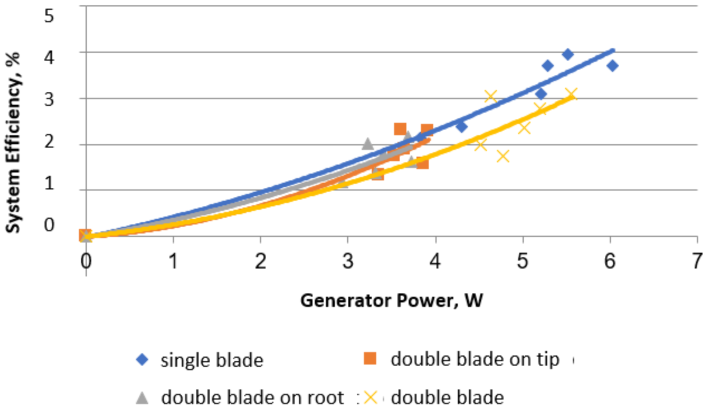

Fig 6. Generator voltage (Vdc) toward current (Idc)

Due to its lesser weight than other types of blades, the single-bladed turbine type has the greatest rotational speed and tension among the other turbine types.

Fig. 9, explained that the comparison of generator power to system efficiency at average speed, it can be analyzed that single-blade blades with wind speeds of 5 m/s, 7 m/s, 9 m/s, 11 m/s, and 13 m/s produce an average generator power of 5.03 W and produce a system efficiency of 3.15%. Then it can be analyzed that the double blade on the tip with wind speeds of 5 m/s, 7 m/s, 9 m/s, 11 m/s, and 13 m/s produces an average generator power of 3.67 W and produces a system efficiency of 1.85%.

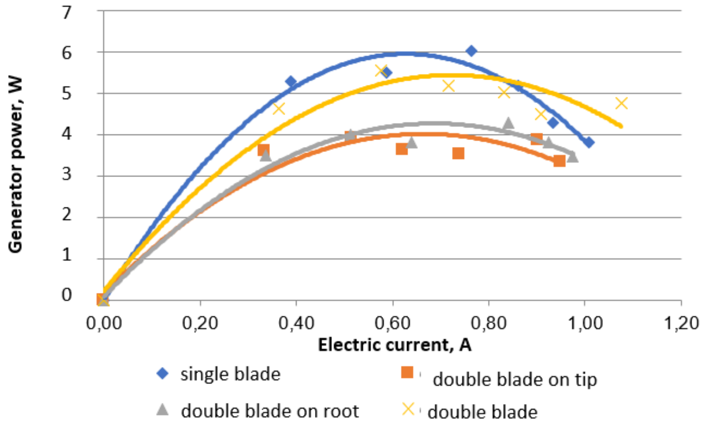

Fig 7. Generator power (Pg) toward electric current (Idc)

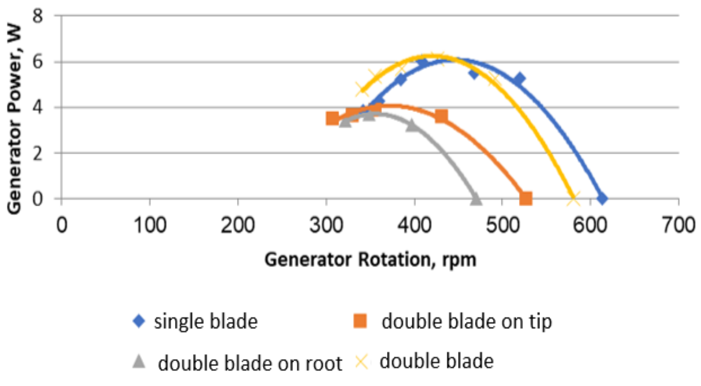

Fig 8. Power coefficient towards generator rotation

Then it can be analyzed that the double blade on the tip with wind speeds of 5 m/s, 7 m/s, 9 m/s, 11 m/s, and 13 m/s produces an average generator power of 3.43 W and produces a system efficiency of 1.69%. Then it can be analyzed that the double-blade blades with wind speeds of 5 m/s, 7 m/s, 9 m/s, 11 m/s, and 13 m/s produce an average generator power of 5.45 W and produce a system efficiency of 2.5%.

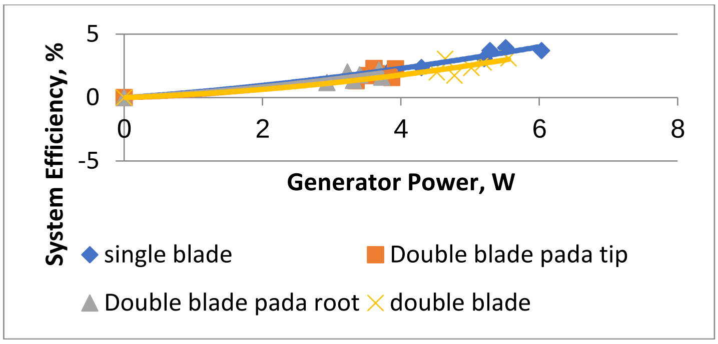

Fig 9. System efficiency towards power generator

This study produces measurable outcomes after verification of the results of previous studies to provide a clear explanation for further research. Where the blades used are a simplification of the Savonius U/L double-blade model developed by Herlambang et al [1] and the Savonius 1:2 double-blade model which was also developed by Herlambang et al [2]. The test results of the four models were reviewed by comparing the efficiency of each model. The results show that the Savonius double blade 1:2 and Savonius U/L turbine produce efficiency at speeds of 5 m/s and 7 m/s, which are 2.42% and 2.1%, respectively. There was an increase from the double tip position inner blade model at speeds of 5 m/s and 7 m/s by 81% and 61%, respectively. At a speed of 9 m/s the double tip position inner blade model has the highest efficiency, which is 3.71%. Therefore, the application of the Savonius U/L type vertical axis wind turbine and the 1:2 double blade is the most suitable blade model for use at wind speeds of less than 7 m/s. While the Savonius model with innovations in the inner blade double tip position is suitable for use at wind speeds of more than 9 m/s.

4. Conclusions.

This study concludes that the single-stage Savonius double-blade wind turbine model has a diameter of 600 mm, a turbine height of 700 mm, and blade variants of a semicircle, an outer quarter circle, and an inner quarter circle, with a blade gap of 40mm. Variations in wind speeds of 5 m/s, 7 m/s, 9 m/s, 11 m/s, and 13 m/s were used during the experiments. According to the criteria of the Savonius wind turbine performance test, the optimal efficiency of the Savonius turbine type is determined as follows, from highest to lowest: Single Blade = 12.04%, Double Blade = 6.22%, Double blade at tip = 3.97%, Double blade at root = 3.36%. Double blade = 0.231%, Double blade at root = 0.217%, Single Blade = 0.186%, and Double blade at tip = 0.161%.

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