# Experimental Study of Combined Blade Savonius Wind Turbine

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**Abstract –** Many modifications have been made on **c**onventional Savonius wind turbine's rotor blades have been made to improve the performances. The rotor blade modification in this research is a blade combination where the circle-shaped conventional model is combined with the one of a concave elliptical model. The combined blade will not affect the simplicity of construction and cost of manufacture of turbine rotors. The aim is to analyze the influence of the blade combination towards the performance of Savonius turbine. The research includes experimental method using open-jet-type wind tunnel of rotor's prototype with three different blade models of the same dimension. The experiment shows, there are influences of the modification of the rotor blade to the performances of the turbine. The combined blade improves the performances of the power coefficient maximum ($Cp_{max}$) up to 11 % compared to the conventional blade at the tip speed ratio (TSR) of 0.79.

**Keywords -** Savonius turbine, combined blade, experimental, performance

## 1. Introduction

Recently, There requirement of fossil fuels energy are increasing, hence, it is necessary to develop an alternative energy to anticipate the lack of fossil energy sources. The wind energy is one of alternative energy which is environment friendly and have a good potential to be developed. The Savonius turbine is device used to convert wind energy into electricity. It is simply constructed with low cost and able to utilize winds from all directions. However, it has less efficient if compared with other turbines, Zhou and Rempfer [1].

Many types of research have been conducted on modification of geometry and rotor of Savonius turbine to increase its efficiency, Akwa et al. [2] declared that the performance of Savonius rotor is influenced by the flow parameter and turbine geometry, Saha et al. [3,4] investigated the effect of the number of blades and rotors stage on the Savonius turbine efficiency. Adding the blades to three blades decrease the power coefficient (Cp), due to the wind of the first blade is bounced back to the next blade. It results rotation in the opposite direction of the first blade [3].The number of optimal stages is two, further increasing of stages number decrease the turbine performance related to the increasing of inertia of rotor [4]. Another researcher, Kamoji et al. [5] indicates that the power coefficient tends to decrease due to the increasing of number of rotor stages

The performance of the Savonius turbine can be improved using additional types of equipment to the turbine. Mohamed et al. [6] have used an obstacle shielding at the returning blade side to optimize blade shape. Altan and Altigan [7] have added a curtain at rotor turbine. They have reported that the use of obstacle and curtain can improve the performance of Savonius turbine. Goleca et al. [8], reported that using deflector plate increased the turbine power coefficient (Cp) up to 50 % if compared to Savonius turbine without deflector plate. Irabu et al. [9] stated that the use of guide-box tunnel at the two blades Savonius turbine increases the power coefficient of the turbine up to 1,23 times if compared to the other one without guide-box. The increasing of performance using additional equipment will make Savonius turbine more complex, Sharma et al. [10], hence it is desirable to improve the turbine efficiency without any additional equipment

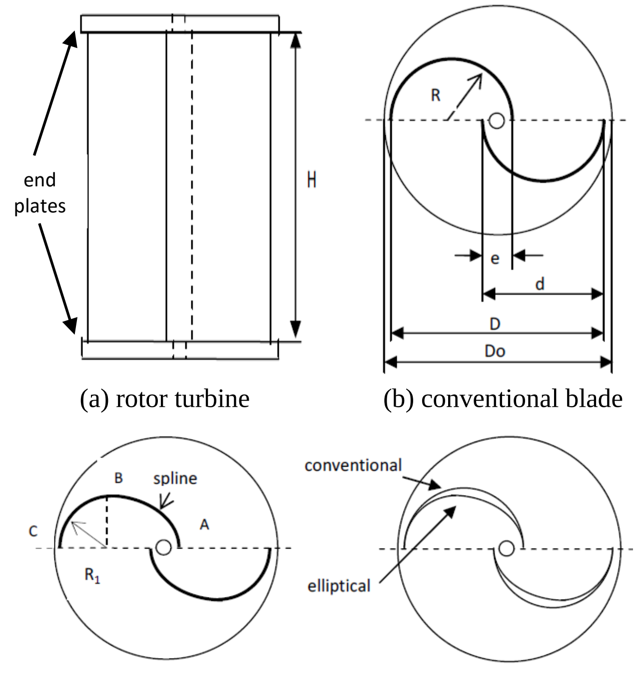
Saha and Rajkumar [3] investigated the effect of twist blade on turbine performance. They reported that the maximum power coefficient ($Cp_{max}$) of the turbine with twist blade was 13.99, this is a higher than $Cp_{max}$ of the turbine with conventional blade that has $Cp_{max}$ = 11.04 at the same wind speed. Then, Kamoji et al.[11] have investigated helical blade, where power coefficient (Cp) is the same with that of conventional blade without shaft and overlap ratio = 0. McTavish et al. [12] examined a novel vertical axis wind turbine (VAWT). They reported that the rotor shape at the concave and convex side should be a focus point of turbine development to increase the rotor torque so that it is more competitive with the existing design. At the rotor of Savonius turbine, mechanically, a speed of wind result positive torque ($Mr^{+}$) at the concave side and the power of negative wind in the form of negative torque ($Mr^{-}$) at the convex side, Altan and Altigan [13].

Kacprzak et al. [14] numerically compared the performance of turbine with the conventional and elliptical blade. The result showed that the elliptical blade has higher power coefficient than the conventional blade. Kamoji et al. [15] have investigated the use of shaft between end plate towards the performance of modified and not modified turbine. The used of shaft decreases the wind flow at the overlap. The maximum power coefficient of the modified turbine without and with the shaft between the end plates were 0.21 and 0.143, while the conventional blade without modification with the shaft has $Cp_{max}$ = 0.175 at TSR 0.69.

Based on the description above, the combination of the concave and convex side models needs a research and testing with an expectation that it can increase the performance of Savonius turbine than a simple and inexpensive wind energy conversion system. The improved performance of Savonius turbine would be one option as an alternative energy source, such as irrigation and water pumping.

## 2. Rotor configurations

For prototypes turbine rotor were made, each of which has conventional blade, elliptical blade and combination blade without shaft for end plates, while combination blade has shaft for the end plates. The dimension and size needed are referred to the rotor model that has been investigated. While the conventional model is referred to the research report by Kamoji et al. [15], and the elliptical model is by Kacprzak et al. [14]. Both models are chosen because they have the same dimension and suitable coordinate point.




(a) rotor turbine (b) conventional blade

(c) elliptical blade (d) combined blade

**Fig. 1.** Dimension model of rotor blade turbine Savonius.

The blade modification is made by conventional model Fig. 1b the concave side and the elliptical model Fig. 1c the half-circle-shaped side, to make a combined blade Fig 1d. The model and elliptical dimension blade is a curve line that links the coordinate point of axis -x that is A (- 15 mm ; 0) , B (50 mm ; 50 mm), C (- 100 mm ; 0), where the line that links the point A and B is a spline that links the points B and C, and points B dan C is a quarter-circle with radius of $R_1$ = 50 mm., Kacprzak et al. [14]. The conventional model as a concave side is a half-circle with radius of R = 57.5 mm., Kamoji et al. [15]. From the point, the turbine rotor is made with dimension of D = 200 mm, H = 200 mm, the ratio aspect (AR) = 1.0, diameter ratio end plate (Do/D) = 1.1, chord diameter d = 115 mm, overlap distance e = 30 mm, or ratio overlap (e/2R) = 0.15. All prototype models are made of ratio material with the same size. The rotor blade is made of aluminium plate of 0.6 mm thickness, and the end plates are made of an acrylic plate with the thickness of 5 mm.

The rotor prototype is formed by making slot (channel) of end plate with the depth of 3 mm by using CNC (Computer Numerical Control) machine that is appropriate or goes with the model and dimension of Fig. 1. The blade is formed with an axis of the end plates, where conventional and elliptical blade use aluminium plates of 2 x 0.6 mm, while the combined blade uses 1 x 0.6 mm at each of axis of blade side (conventional dan elliptical), so all prototypes of rotor blade have the same weight Fig. 2. Specifically, the test of prototype of combined blade with shaft between the end plates is made by placing the shaft at the diameter e’= 15 mm, so the ratio overlap becomes (e-e’/2R) = 0.075

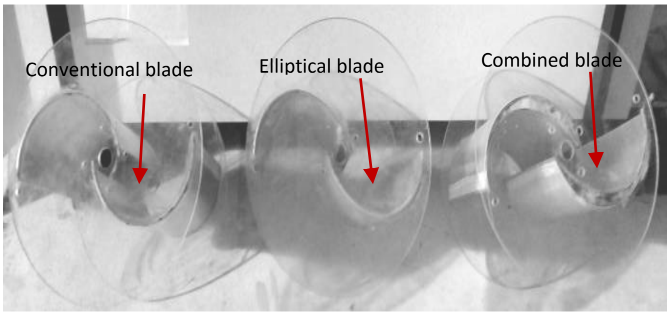



**Fig. 2.** Prototypes blade rotor conventional, elliptical and combined blade with end plates.

## 3. Experimental set-up

The experimental study is based on the prototypes testing by using open-jet-type wind tunnel with other supporting equipment Fig. 3. Wind tunnel uses blower Dayton Electric-type U71B1, power 1/6 hp. 1060 rpm with section area of 300 x 300 mm. The installation of the prototype is supported by rotor shaft of diameter 15 mm, pulley radius and rope for torque measurement of $R_{pulley}$ = 15 mm and $r_{rope}$ = 1.5 mm. Spring balance and load indicator use weighing tool of scale 1 : 1000 gram, and the measurement of rotor rotation tachometer model-type, KW06-563, at the accuracy of ± (0.05% + 1 digit). The rotor shaft is supported by bearing axial (30202R) at the lower part and bearing radial at the upper part (6902U) which is greased with multi- purpose oil at every the beginning of data obtaining (collection) in order to avoid friction. The load measurement ($F_1$) and spring balance ($F_2$) are done at every constant rotation by reducing 50 rpm, at the wind speed of 4 m/s. The torque shown at each rotation is given by :

$$T_T = \frac{(F_1 - F_2)(R_{pulley} + r_{rope})g}{1000} \qquad (1)$$

Meanwhile the power turbine power with the equation:

$$P_T = T_T\left(\frac{2\pi n}{60}\right) \qquad (2)$$

Kamoji et al. [11], Blockage Ratio, is the area comparison of rotor linear sweep and cross-section area wind tunnel as follow:

$$B = \frac{A_T}{A_W} = \frac{(2d - e)H}{H_W * W} \qquad (3)$$

Coefficient of power $$C_p = \frac{2P_T}{\rho_a A_T V^3} \qquad (4)$$

Coefficient of torque $$C_t = \frac{2T_T}{\rho_a A_T V^2 R} \qquad (5)$$

Tip Speed Ratio $$TSR\ (\lambda) = \frac{\omega . R}{V} \qquad (6)$$

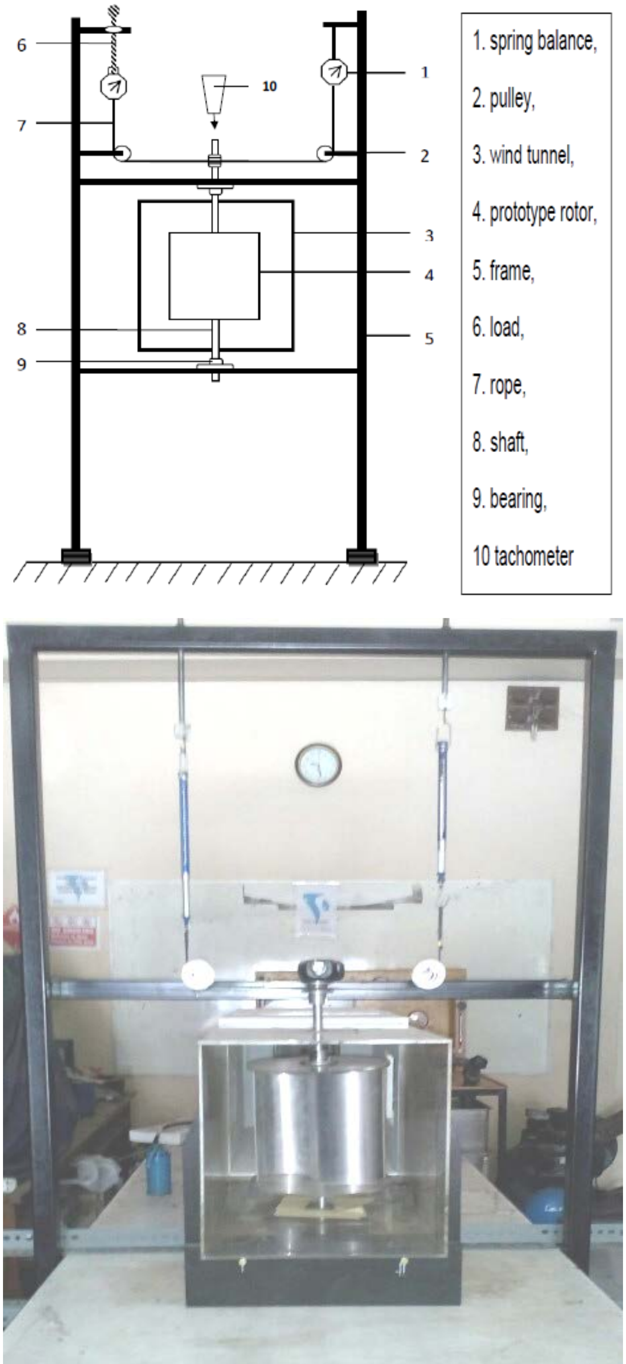



**Fig. 3**. Experimental set up.

## 4. Experimental Results

The experimental result is displayed by graphics between the coefficient of power (Cp) and coefficient of torque (Ct) towards tip speed ratio (TSR). All rotor blade models were tested, that are conventional blade, elliptical and combined blade show that the combined blade which is the combination of conventional and elliptical blades can increase performance of Savonius turbine as shown in the following figure:

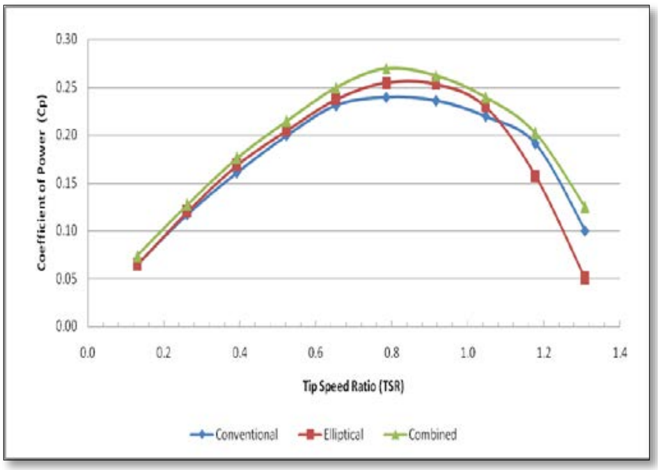



**Fig. 4.** Comparison Coefficient of Power (Cp) vs TSR, conventional, elliptical and combined blade rotors.

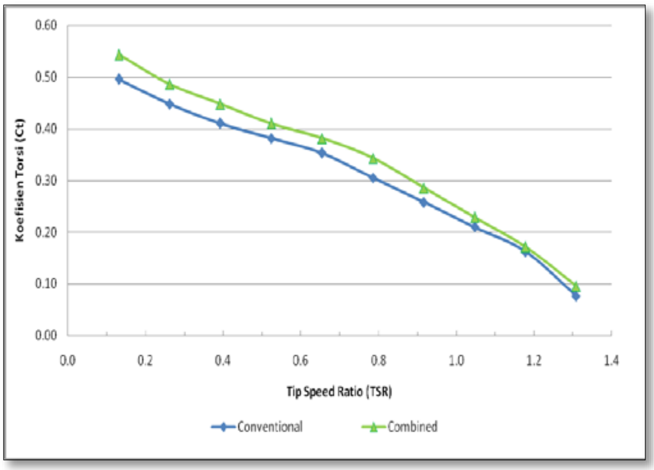



**Fig. 5.** Comparison Coefficient of Torque (Ct) vs TSR, conventional and combined blade rotors.

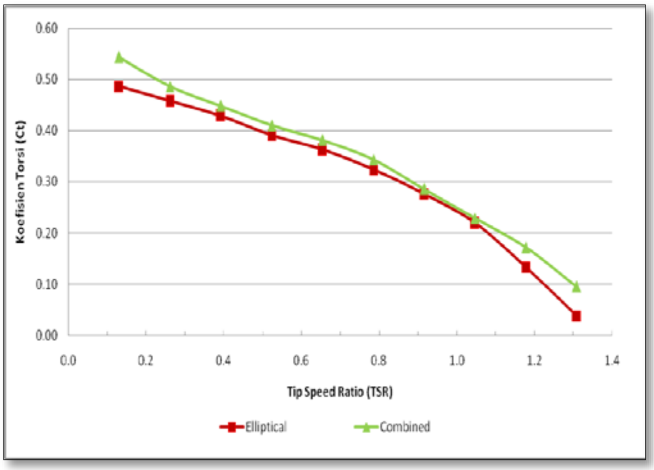



**Fig. 6.** Comparison Coefficient of Torque (Ct) vs TSR, elliptical and combined blade rotors.

Figure 4 shows graphic of coefficient of power (Cp) of the three blade rotors towards tip speed ratio (TSR). The combined blade produces Cp greater (higher) than that of conventional and elliptical blade towards the tip speed ratio. The three models of blade reaches maximum power coefficient ($Cp_{max}$) at TSR = 0.8. The combined model has the highest $Cp_{max}$ that is up to 5.5 % towards the elliptical model and 11 % towards conventional model. The increase of power coefficient up to TSR = 0.7 tend to show the same result, however after reaching the maximum coefficient, there is a difference. The elliptical blade tends to show the very low decrease compared to other models. The combined blade still shows the best coefficient power compared to other models. By showing the Cp towards the conventional and elliptical blade, including the obtained maximum power coefficient towards TSR, the experimental value (coefficient) obtained is similar to the simulation result done by Kacprzak et al. [14]

The comparison of torque coefficient between the three blade models shows that the combined model is higher than the conventional and elliptical one. Figure 5 shows the comparison of torque coefficient (Ct) of combined blade and conventional blade tend to show similar form of graphic. The low TSR shows a difference of coefficient (value) around 9 %, however, the high-TRS tends to have almost the same value. Figure 6 shows torque coefficient (Ct) of combined blade that shows a great difference between elliptical blade at the lowest and the highest TSR.

The wind that pushes the blade to the concave side of Savonius rotor (advancing blade) at a certain speed can produce a positive wind strength (power) which is a positive torque ( Mr+ ) and negative wind strength which is hindering convex blade at returning blade produces negative torque (Mr-). Because of the concave side (advancing blade) is higher than the torque of convex side (returning blade), cause rotative movement at the turbine rotor, Altan et al. [13].

The difference of big energy moment will produce bigger performance towards the turbine. The increase of distance from central rotation at the concave side (advancing blade) will increase the moment of positive rotor, and conversely, if the distance is decreased from rotation center at the convex side (returning blade) will decrease the negative moment. Such case goes with the combined model done towards the conventional and elliptical blade. The use of elliptical blade model at the concave side can increase the distance of energy catching point from the rotative center, meanwhile, the convex side that uses conventional model (of the half-circle) shows a distance of catching point of smaller obstacle energy towards the rotation center if compared with using elliptical model.

The pushing energy because of the wind speed is influenced by the coefficient of drag blade. The concave side has greater drag coefficient than that of convex side, so the pushing energy of the concave side is greater if compared to hindrance (blocking) energy of the convex side. The use of elliptical model at the concave side will produce greater drag coefficient than that of the conventional model, and conversely, the use of conventional model at the convex side can decrease the blocking energy of rotor blade. Making use the superiority (strength) of the conventional and elliptical blade to be a combined blade increases the performance of turbine. The result of testing the combined blade shows a certain constant performance along the value (coefficient) of tip speed ratio (TSR) compared with the conventional and elliptical blade.

The use of shaft between end plates affects the power coefficient (Cp) of Savonius turbine specifically of the combined blade based on the testing result as shown in Fig. 7. The testing result without using shaft between end plates has greater (higher) Cp compared with that of using shaft for the combined blade. The graphic of power coefficient (Cp) at the combined blade generally has similar form with using or without using shaft. The maximum power coefficient ($Cp_{max}$) happens at TSR = 6.5 with $Cp_{max}$ = 27 %. The difference between the use of shaft at combined blade will result with the decrease of average performance at 30% after reaching $Cp_{max}$ towards the testing without shaft. Figure 8 the shaft between end plate of combined blade can decrease the torque coefficient (Ct) of turbine up to 21 %. Generally, the graphic form of torque coefficient (Ct) towards TSR is the same, however at the TSR of 6.5 ($Cp_{max}$) there is a tendency showing that the torque coefficient (Ct) is different form of the other ones. The change of the Ct value deals with Cp value that directly experience very low decrease after reaching $Cp_{max}$ value. The use of shaft between end plates matches with the research report of Kamoji et al. [14] stating that $Cp_{max}$ Savonius rotor modification without shaft is higher than the Savonius rotor modification with the shaft.

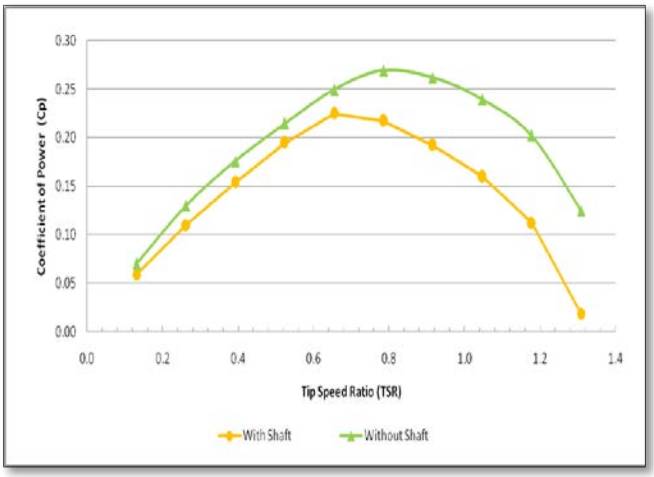



**Fig. 7** Comparison Coefficient of Power (Cp) vs TSR, combined blade rotors without and with shaft.

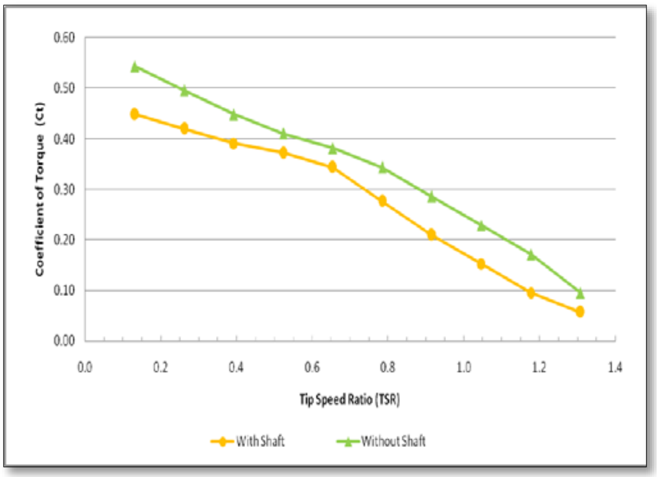



**Fig. 8** Comparison Coefficient of Torque (Ct) vs TSR, combined blade rotors without and with shaft.

Saha et al. [4] in their research, reports that the inertia of the rotor is influential to the decrease of turbine performance. Adding (fixing) the shaft can make the weight of rotor increase that leads to the increase of inertia energy. The used of the shaft between the end plates also decrease the flow of the wind at the overlap because of the block by central shaft. Fujisawa [16] states that the Savonius turbine rotor produces good performance at the ratio overlap of 0.15. The use of shaft will decrease the ratio overlap to 0.075 and causes the flow of wind decrease, and it is not focused on the concave side of returning blade so the performance of rotor will decrease if compared to not using shaft between the end plates.

## 5. Conclusion

Based on the result of experimental testing and the analysis of the blade model, conventional, elliptical and combined blade, it can be concluded that

- The coefficient of power (Cp) and coefficient of torque (Ct) of combined blade is more stable along the tip speed ratio (TSR) compared to that of conventional and elliptical blade
- The combined blade improve the performance of Savonius turbine, where $Cp_{max}$ increases at 11 % the conventional blade and at the 5.5 % towards the elliptical blade
- The increasing of performance using the combined blade will not make construction of the wind turbine more complex, and
- The use of shaft linking the end plates can decrease the performance of turbine due to the influence of inertia and the change of ratio overlap.

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