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Performance of Combined Water Turbine Darrieus-Savonius with Two Stage Savonius Buckets and Single Deflector

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Abstract- The objective of this study is to show the effect of single deflector plate on the performance of combined Darrieus-Savonius water turbine. In order to overcome the disadvantages of low torque of solo Darrieus turbine, a plate deflector mounted in front of returning Savonius bucket of combined water turbine composing of Darrieus and Savonius rotor has been proposed in this study. Some configurations of combined turbines with two stage Savonius rotors were experimentally tested in a river of constant velocity 0.8 m/s. The angle of deflector with respect to current flow influences the turbine perfomanace characteristics. The torque and the power coefficient of combined turbine with deflector increase for Savonius rotor mounted on the outside of Darrieus rotor. The optimum deflector angle of 30^o gives a better performance of combined turbine.

Keywords- Turbine, performance, torque, power, Darrieus-Savonius

1. Introduction

Free flow of water from a river, a lake and an irrigation canal are sources of renewable energies among other sources like solar and wind energy. The waterfalls are often used for the benefit of nature tourism and it is the reason that the waterfall sources are not permitted by a government to be exploited to produce the electricity. The same thing like the canal flows of irrigation for agriculture which are not allowed for the permanent installation of electricity power since the hydropower will disturb the water flow. In case of free stream flow of a river, it is found almost everywhere in rural areas.

In application of water current turbines, these turbines generate power from the kinetic energy of a flowing stream of water without the use of a dam or barrage. These systems whether free stream or restricted flow can be installed as floating or bottom mounted units. Water current turbines can be installed in isolated or grid connected configurations, stand alone or as a supplement to existing generators, floating or fixed to the bottom of a water course. Since many remote communities in rural areas are situated near moving water these turbines represent a promising source of clean power. In general, the turbines can be applied to any application where a moving stream of water with sufficient volume exists. This can include industrial outflows, irrigation canals, rivers and tidal streams. In free stream applications water is allowed to move freely around the turbine so no potential head can be developed, however energy can be extracted from the kinetic head of the flow passing through the system. In fast moving flows the turbine is simply deployed with an open rotor, whereas in slower water a duct is required to accelerate the flow so that energy can be extracted more effectively. This allows consideration of a much larger number of sites for installation of this technology.

The suitable water turbines for the application of free flow are Darrieus, Gorlov and Savonius type. The Darrieus and the Gorlov type are the most common used in electric power generation. One of the differences of the turbines is found in the blade geometry in which the Darrieus turbine use a straight blade while the Gorlov use helical one. The advantage of

Darrieus blade is easy to be constructed as not the case for the Gorlov turbine but Gorlov turbine has uniform torque. The Savonius type is drag type turbine which has high starting torque at low speeds, but the efficiency is low. The three-dimensional hydraulic helical turbine develops an efficiency of about 35% in similar free flow conditions [1]. The maximum possible efficiency attainable is 59.3% and is known as the Betz limit.

The effect of some variables of turbine performance was studied by Shiono *et al.* [2] who give the influence of water velocity, turbine solidity and inclination of helical blades to the rotor performance of Darrieus turbine. They show that the higher velocity the higher efficiency of turbine. The solidity seems to be small influence on the turbine, but the smaller the solidity the higher the turbine speeds. The efficiency of Darrieus turbine can be influenced by a narrow canal [3], but there is little influence on the efficiency of turbine. The effect of geometry of blades that characterized by term NACA type gives the influence on the efficiency [4].

The disadvantage of Darrieus turbine that it has low starting torque so that the turbine cannot be started connecting to a load. Another type of water turbine is Savonius type. The Savonius turbine is one of the selfstarting vertical-axis turbine. It is drag-type device that consists of two or three buckets. For that reason, in order to improve the starting torque, Kyozuka [5] studied experimentally the hybrid turbine composed of Darrieus and Savonius turbine in which the Savonius mounted in the middle of Darriues turbine. The combined rotor consists two blades and two buckets. This configuration improves significantly the torque at low speed. Hybrid turbine is also called combined turbine of Darrieus-Savonius and it is used to improve the small starting torque of a solo Darrieus turbine since a Savonius rotor generates large torque in the low speed range, whereas the Darrieus turbine generates large torque primarily in the high speed range. Jahangir and Iqbal [6] studied the hybrid turbine to obtain the efficiency of turbine function of water current velocity. The efficiency is higher for higher velocity. The insertion of Savonius large buckets in the middle of Darrieus turbine will decrease the combined turbine efficiency because the buckets experience a large drag on the surface buckets [7]. The higher the bucket size, the lower the efficiency of the turbine rotor.

The Sovonius turbine composed of single stage, two stages and three stages were tested by Khan *et al.* [8] in water current flow. They reported that the efficiency of these rotor are small that is lower than 5%. Kailash *et al.* [9] mounted single deflector and two deflector plate in the upstream to the fluid flow. The efficiency increased for the configuration of turbine with deflector mounted upstream to the fluid flow on the returning blade side acts as an obstacle to the flow coming towards the returning blade. This condition reduces the negative or reverse torque on the returning blade side. This kind of rotor with deflector was also reported by Golecha *et al.* [10], in which the efficiency increased when the deflector is mounted in front of returning blade side. Saha *et al.* [11] showed the increase about 25% of the Savonius rotor using twisted buckets.

In this study, we propose the experimental observation of hybrid turbine composed of Darrieus and Savonius turbine in which the Savonius bucket mounted either in the middle and at the outside of the Darrieuss rotor, but it is attached at the same shaft. The purposes are to obtain higher torque at low speed and efficiency compared to the solo Darrieus turbine. Besides that, an experimental investigation is conducted to identify the appropriate position of the deflector plate on the returning bucket side of Savonius bucket to increase the power coefficient of the combined rotor.

2. Experimental Setup

Darrieus turbine vertical type shown in Figure 1. The blades of rotor composed of four airfoil NACA 0020 which were made by wood laminated by smooth plastic sheet. The diameter and height of turbines are respectively 400 mm and 500 mm. Chord length of blade is 63 mm and the solidity σ = 0.2 The solidity is calculated from the equation (1) as follows

$$\sigma = \frac{CB}{\pi D} \tag{1}$$

The semi-circular section is used as the bucket of the Savonius rotor and the schematic arrangement of two stage Savonius buckets is shown by Figure 2. The first and the second stage of buckets have the same dimensions where the diameter of semi-circular section with d = 40 mm and height h = 120 mm. The frontal area of Savonius is small compared to that of Darrieus rotor for the reason of overcoming the efficiency reduction. The buckets consists of a semi-circular cylinder mounted on the same shaft with Darrieus rotor. Buckets made of steel with a thickness of 0.6 mm.

Two main configurations of Darrieus-Savonius turbine are observed in this study. The first configuration is to place the two stages of Savonius bucket at the outside position of Darrieus rotor as shown by Figure 3. Another configuration is to place the Savonius bucket both in the middle and outside Darrieus rotor.

Power coefficient of Darreius-Savonius turbine is given by the following relationship

$$C_P = \frac{P_t}{1/2.\rho A_t V^3} \tag{2}$$

The dimensionless speed of rotor is represented by λ called Tip Speed Ratio (TSR) and given by

$$\lambda = \frac{U}{V} = \frac{\omega.R}{V} \tag{3}$$

Torque coefficient is calculated by

$$C_T = \frac{C_P}{\lambda} \tag{4}$$

The other parameter of Savonius turbine is called aspect ratio, which is defined as the ratio between height of bucket and total bucket diameter or

$$A_\alpha = \frac{h}{2d} \tag{5}$$

In this case, the $A_\alpha = 1.5$. Usually the aspect ratio is greater than unity to improve the efficiency Jahangir and Iqbal [6].

The turbine rotors shown in Figures 1, 2, 3.

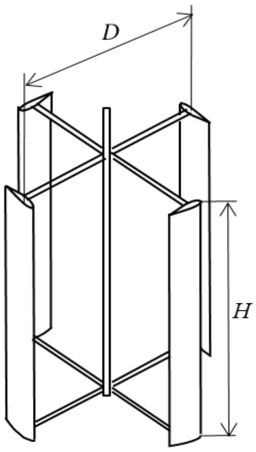

Fig. 1. Darrieus turbine

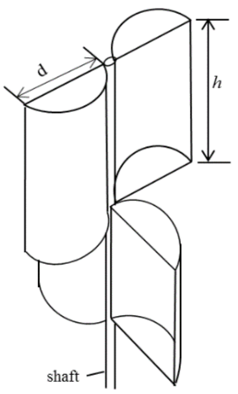

Fig. 2. Savonius turbine

Fig. 3. Darrieus turbine

In experimental measurement of combined turbine performance, we installed a deflector plate in upstream flow of two stage Savonius bucket with orientation some angles β (Figure 4) in front of returning side bucket. The purpose of deflector plate on the returning side is to reduce the negative torque of Savonius rotor.

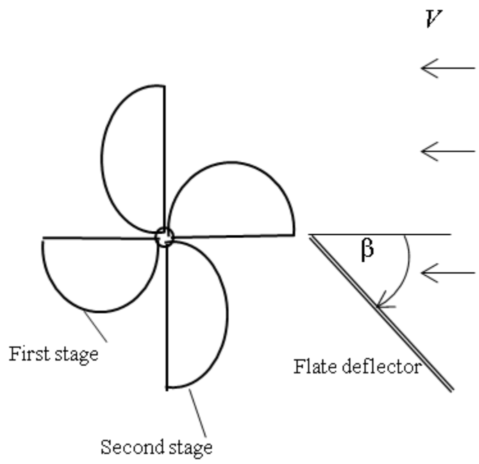

Fig. 4. Top view of Savonius rotor

The combined turbine was tested in Ogan's river located in Tabuhan Village, South Sumatera, Indonesia where the water flows with constant velocity 0.8 m/s. The Free stream velocity measured with current meter flowatch fl-03 with the measuring range of 0.1 to 18 m/s and accuracy ±2%. The River has a wide ± 50 m and 1.5 m in depth. The river provides the uniform flow. The Torques were measured by rope brake dynamometer. The extended shaft of rotor was installed a small drum wheel where the rope brakes the rotor. The one end of rope was loaded gradually and the other end was connected with digital spring scale (with accuracy 1%) where the force measured. The difference of these two forces were multiplied with wheel radius to obtain the torque or written by

$$T = \frac{(L-S).r_{wheel}.g}{1000} \tag{6}$$

Each addition of load, the rotor speed was measured by digital laser tachometer with the measuring range of 1 to 99,999 rpm and the accuracy of ± 0.02%.

3. Results and Discussion

A series of experiments were carried out with some position of the Savonius buckets in Darrieus rotor and with deflector plate. The results of these experiments are compared with the solo Darrieus turbine. Torque coefficients were shown by Figure 5 where C_T varies with λ. The left part of the curves for all turbine configurations has no data point because the rotor was overloaded when the load reached maximum and it stopped to run. For the solo Darrieus turbine, the operation speed ranges from λ = 1.75 to 2.62 and the maximum torque coefficient obtained C_T = 093. The solo Darrieus rotor was inserted by the Savonius bucket on the outside without deflector plate (β = 0°), the torque coefficient of the combined turbine decreases and operation speed range also decreases from λ = 1.6 to 2.56. The rotation Savonius is mainly the result of the different between the drag on the advancing bucket and the drag on the other one. This decrease in torque is due negative torque increases when the flow comes on the returning bucket. Altering the attaching angle on the returning side of Savonius bucket at angle β = 30°, the torque coefficient increases to 0.107, which is greater than solo Darrieus and combined rotor with deflector angle β = 0°. It is also observed that the speed of combined rotor increases. So the deflector is as the optimum plate arrangement under given conditions. For the deflector plate angle β = 60°, torque coefficient smaller than that rotor with deflector angle β = 30°. It seems that higher deflector angle, the flow direction does not fully concentrate to the advancing bucket side. However, the differences in torque values are small. So, we observe the improvement of torque at low speed for the turbine with deflector plate.

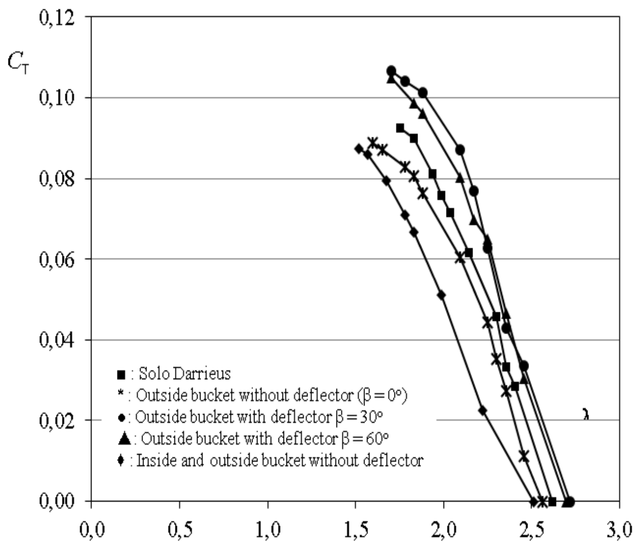

Fig. 5. Torque coeeficient

A good estimation of Darrieus rotor performance depends on the evaluation of lift and drag coefficient. These values may be obtained from airfoil data of a corresponding blade in a uniform steady flow. While for Savonius rotor, it is determined by difference in drag force between advancing and returning bucket. Figure 6 shows the comparison of the power coefficients of the combined turbine with several configurations. From all configurations of the rotor, the maximum power coefficient is attained to C_P = 0.19 for a combined turbine with β = 30° and Savonius stages mounted on the outside of Darrieus rotor. This coefficient is 18% higher than the solo Darrieus rotor which has a maximum coefficient of power C_P = 0.16. This combined rotor has the highest range of speed operation and it is more advantageous since the high rotation is preferable for the electricity generation. For the combined rotor with β = 60°, the performance is closed to rotor with β = 30° but we observe lower coefficient of power. The combined rotor where two stages Savonius bucket mounted only the outside of Darrieus rotor and without deflector (β = 0°), the power coefficient is smaller than the solo Darrieus rotor. Moreover, for the combined rotor without deflector and where the Savonius buckets are mounted both inside and outside the Darrieus rotor that this rotor has a lower power coefficient than solo Darrieus. The negative torque exists in turbine rotor without deflector due to the returning bucket side.

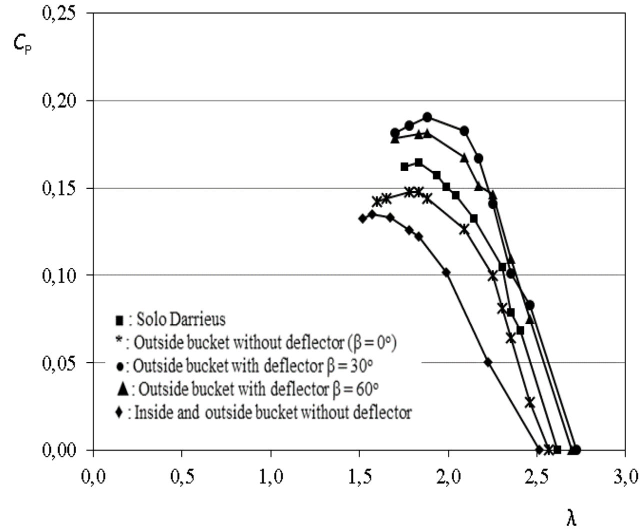

Fig. 6. Power coeeficient

4. Conclusion

The performance of combined turbine composing of Darrieus and two stages of Savonius rotor was experimentally investigated to obtain an optimum. This combined turbines with a set of two stages Savonius rotor mounted on the outside of the Darrieus rotor on the same shaft and with single deflector plate in front of returning side of the bucket have higher torque and power coefficient than the solo Darrieus turbine. The increase attains about 18% for power coefficient and about 16% for torque coefficient. We also observe the increase of turbine speed.

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Abbreviations

At Swept area of Darrieus and Savonius rotor or equal to (D x H) + 2x(h x d) (m2)

Aα Aspect ratio of Savonius bucket

B Number of blades

C Chord length of blade (m)

CP Power coefficient

CT Torque coefficient

D Diameter of Darrieus rotor (m)

d Diameter of semi-cylinder bucket (m)

g Gravitation (m/s2)

h height of bucket (m)

L load (kgf)

Pt Turbine power (W)

R Radius of Darrieus rotor (m)

rwheel Radius of the brake wheel (m)

S Load of Spring balance (kgf)

U Tangential velocity of rotor (m/s)

V Free Stream velocity of water (m/s)

T Torque (Nm)

β Deflector angle (o)

λ Tip Speed Ratio

σ Solidity

ω Angular velocity (rad-1)