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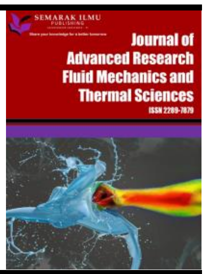

Experimental Study of Darrieus Water Turbine Two Blade Different Configuration and Hybrid Turbine for Application of an Irrigation Flow

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ABSTRACT

Rice fields are areas that have irrigation and rarely have lighting; this is dangerous at night because wild animals such as snakes are difficult to see. Irrigation has low-scale water energy with low-head conditions; hence the Darrieus and Savonius type water turbines are considered suitable for this condition. However, until now, there has been no comprehensive study of the feasibility of the two turbines for irrigation flow. Hence this study presents the experimental work to explore the performances of the Darrieus turbines Two Blade Different Configuration and hybrid Darrieus-Savonius turbine for irrigation flow. Accordingly, four configurations of the water turbines used in these investigations, i.e., Darrieus turbine with two different blades shape the aerofoil of NACA 0016 and NACA 0020, single Darrieus turbine with the aerofoil NACA 0016, single Savonius turbine, and hybrid Darrieus-Savonius turbine with the aerofoil NACA 0016. The mechanical power of the water turbines was measured using a rope brake dynamometer. The results show that the single Darrieus turbine with the aerofoil NACA 0016 has higher tip speed ratios but a lower torque coefficient than the single Savonius turbine. Then, hybrid Darrieus-Savonius turbine with the aerofoil NACA 0016, the maximum power coefficient lower than other. Furthermore, the single Savonius turbine has the highest power coefficient than the other. And the single Darrieus turbine with the aerofoil NACA 0016 shows that the turbine has higher torque than others. Thus, based on the results, a single Darrieus turbine with the aerofoil NACA 0016 is recommended for application.

1. Introduction

The water flow in irrigation generates electrical power besides its fundamental use for irrigation fields [1]. In converting the current into electrical energy, using a water turbine. The type of water turbine of Darrieus and Savonius is suitable for the water flow in irrigation [2]. Gharib-Yosry *et al.,* [3] apply a Darrieus turbine in water based on non-dimensional analysis, namely Reynolds number. Based on the results, a Darrieus turbine in water has higher performance than in air [3]. Patel *et al.,*

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[4] investigated the feasibility of the Darrieus turbine for water considering the number of blades and blade solidity. Based on the results, they showed an optimum number of blades and gave two types of symmetrical airfoils with similar power characteristics [4].

Furthermore, wind turbines' feasibility for water applications combines the Darrieus and Savonius turbines [5]. Saini and Saini [6] combine 3 Darrieus turbine blades with two Savonius turbine blades. Based on the results, the turbine combination resulting a higher performance coefficient than the single Darrieus turbine. Since the Darrieus turbine is suitable for converting the kinetic energy of free stream flow, the application is narrow due to the poor self-starting characteristics and lack of structural analysis [6]. Tunio *et al.,* [7] proved that by using the duct augmented system, the hydrokinetic Darrieus turbine performance increased significantly since the flow increased; then, a Darrieus water turbine performance can increase by using a blocking plate upstream of the rotor [8]. Then, Lust *et al.,* [9] investigated three blades Darrieus water turbine with setup conditions has waves and concluded the rotor degraded power production slightly compared to the current without the waves. Yagmur *et al.,* [10] examined single and double Darrieus water turbines in series. They showed that the numerical results are in good agreement with experimental findings, and the performance of the downstream turbine was lower than the upstream turbine [10]. Then, Mohamed *et al.,* [11] examine the solidity of the Darrieus turbine blade for water application which shows the thinner the airfoil, the greater the power coefficient characteristics.

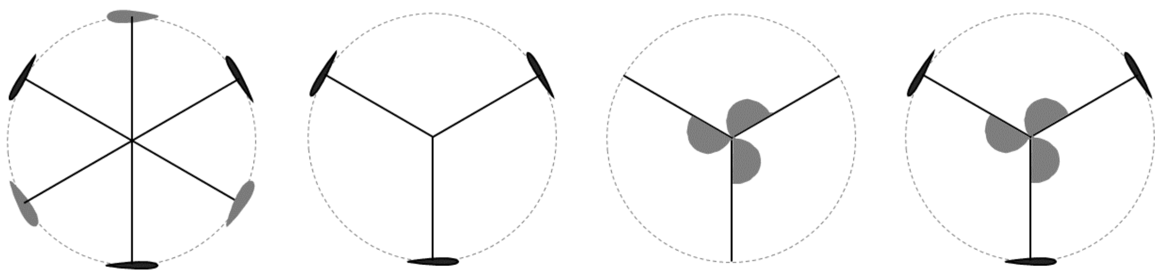
Another hydrokinetic is the Savonius turbine which is often used in power generation because it has high starting torque. A Savonius turbine with overlap has a higher power coefficient than that for a conventional shape of the same tip speed ratio [12, 13]. Commonly, the Savonius rotor has one stage for hydropower generation. Chen *et al.,* [14] performed two stages of Savonius rotor where the blade shape is straight combined with a curved blade using composite materials. A Savonius turbine V-type blade is investigated to determine the optimum condition. There is the optimum angle of V-blades, which gives an increase in the performance of the Savonius rotor [15]. Saini *et al.,* [16] presented the effect of attachment angle Savonius turbine U-type blades. Based on Golecha *et al.,* [17] and Salleh *et al.,* [18], Savonius turbine U-type blades can increase their performance by using a single flat deflector upstream of flow. The modification of the Savonius rotor by providing a dual splitter-like shape of the blade's concave side can improve the performance of the Savonius rotor [19]. At the Savonius rotor entrance, two-shield plates (as two deflector plates) are employed to enhance the turbine's performance significantly, as was conducted experimentally by Ramadan *et al.,* [20]. Shashikumar *et al.,* [21] developed a tapered type of Savonius blade and compared its performance with the conventional rotor. Then, Talukdar *et al.,* (2018) presented the feasibility of the Savonius turbine's elliptical blades type for water.

One type of hydrokinetic turbine is the combination of the Darrieus and Savonius turbine in which, commonly, the Savonius is inside of the Darrieus rotor. This hybrid rotor performance depends on the Savonius blades' attachment angle [23]. Kaprawi *et al.,* [24] investigate the performance characteristic of the two stages of the Savonius rotor attached outside to the Darrieus rotor. For the Savonius installed inside of the Darrieus rotor, the performance of the hybrid rotor can be enhanced [25]. A deflector of a straight plate can improve the hybrid water turbine performance [23]. Therefore, this aim is to investigate the hybrid system of the Darrieus and Savonius turbine for application in water, where the testing is under environmental conditions (irrigation of rice field). Tests in rice field irrigation to determine the real turbine performance so that its strength is known.

2. Methodology

2.1 Turbines and Irrigation

A comparison of a single Darrieus and single Savonius turbine is made separately to know their performance, and then these two turbines were combined to investigate their performance. Then, this study investigates the single Darrieus water turbine with two different airfoils. Therefore, four configurations of the water turbines used in these investigations, *i.e.,* Darrieus turbine with two different blades shape the aerofoil of NACA 0016 and NACA 0020, single Darrieus turbine with the aerofoil NACA 0016, single Savonius turbine, and hybrid Darrieus-Savonius turbine with the aerofoil NACA 0016. Figure 1 shows all configurations of the rotor.



(a) (b) (c) (d)

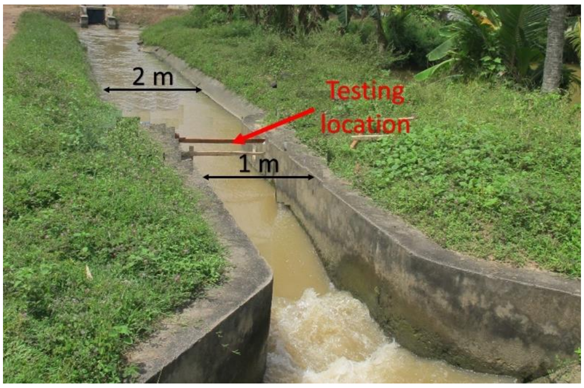
Fig. 1. Turbine configurations: (a) rotor Darrieus two blade different configuration (variation 1); (b) rotor Darrieus with aerofoil NACA 0016 (variation 2); (c) Savonius turbine (variation 3); and (d) hydrid Darrieus-Savonius turbine (variation 4)

Table 1 shows the dimensions of all rotors. The irrigation is the testing ground of all rotors. Figure 2 is the photograph of the irrigation. Based on Figure 2, the width of the upstream flow of 2 m, and the downstream of 1 m with a deep water level of 0.65 m.

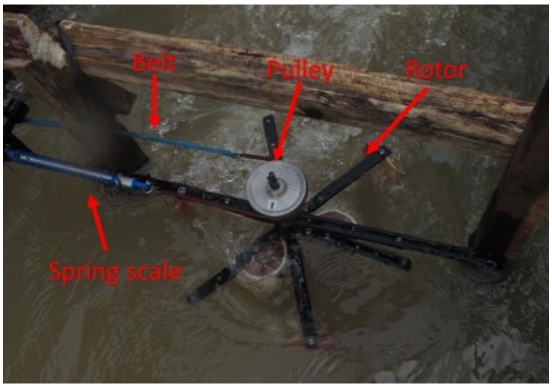
Table 1
Turbine rotor dimensions

Parameters	Darrieus 2 different blade configuration	Darrieus turbine	Savonius turbine	Hybrid
Blade type	NACA 0016 and NACA 0020	NACA 0016	Semi-circular cylinder	NACA 0016 – semi-circular cylinder
Thickness (mm)	10 and 12	10	1	Combination of Darrieus NACA 0016 and Savonius turbine
Number of blades	3 and 3	3	3	
Rotor diameter (mm)	300	300	15.2	
Blade diameter (mm)	-	-	70	
Rotor length	300	300	300	
Solidity	0.19 and 0.38	0.19	-	
Aspect ratio	1.0 and 1.0	1.0	1.97	
Blades material	Wood	Wood	the polymer of vinyl chloride	
Shaft diameter (mm)	8	8	10	

This study places all the rotors in the middle of the downstream flow at the irrigation's converging section. The velocity at turbine testing was 0.61 m/s which measuring with a current meter flowatch fl-03 having a precision of ± 2%; the system of the canalisation of the water flow, so the velocity was constant along the experimental investigations. The turbine is placed equal to the surface of the flow. Hence the distance between the turbine and the bottom of the irrigation of ± 35 cm.



(a)



(b)

Fig. 2. Photograph of the Irrigation: (a) Rice field irrigation; (b) Turbine experimental

2.2 Experimental Setup

Figure 3 shows the experimental setup of the turbine rotor—a rope brake dynamometer system to measure the turbine rotor's torque to determine its performance. Based on Figure 3, the turbine shaft (3) was supported by two ball bearings on the frame (1), one at the bottom and one at the top (4). The braking of the rotor shaft using by the nylon rope (8); the nylon rope has a diameter of 1.5 mm, through a pulley (5) attached to the shaft. One end of the nylon is tied with a tubular spring scale (6) model number ME505-1000 of the maximum capacity of 1 kg and the other end to the loads (9). The water current struck the blades (2) of the turbine rotor, so the rotor rotated. Rotation measurement using a non-contact digital tachometer. Adding the load on the bucket (9) reduces rotor rotation. After rotor rotation is stable, measurement of rotation and force on a spring scale. The turbine rotation slowed down due to increasing the bucket load, and the spring scale's force increased. The loads continued to increase and at a maximum load until the turbine experienced overload and stopped rotating.

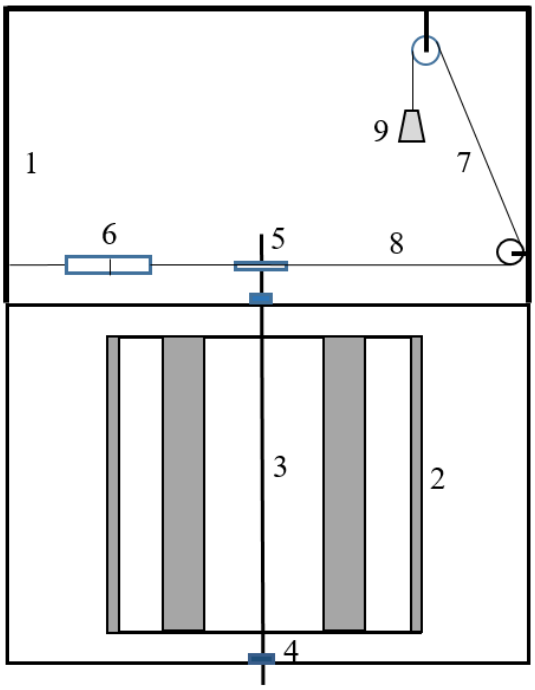


Fig. 3. Rope brake dynamometer system

2.3 Data Processing Analysis

The mechanical power (P_t) is function of torque (τ) and angular velocity of rotor (ω) become

$$P_t = \tau \cdot \omega \quad (1)$$

ω is function of the rotational of the rotor (n) is expressed with the following Eq. (1)

$$\omega = \frac{2 \cdot \pi \cdot n}{60} \quad (2)$$

The tip speed ratio (λ) is

$$\lambda = \frac{U_t}{V_w} \quad (3)$$

where U_t is tangential velocity of the rotor is

$$U_t = r \cdot \omega \quad (4)$$

Where r is radius rotor (r = rotor diameter/2). Then, the power coefficient (C_p) of the rotor is expressed using

$$C_p = \frac{P_t}{0.5 \cdot \rho \cdot A_t \cdot V_w} \quad (5)$$

where A_t is an area of the rotor perpendicular to the flow direction, and V_w is the water velocity. Further, the torque coefficient (C_t) calculates using

$$C_t = \frac{C_p}{\lambda} \quad (6)$$

3. Results and Discussion

The experimental results are plotted in terms of torque and power coefficient, representing the turbine rotor's performance characteristics. Figure 4 shows the torque coefficients of the four configurations of the turbines. The turbines operate maximum rotation (no-load condition).

For variation 1, the C_t characteristics seem to vary linearly from tip speed ratios. At lower speed, the torque coefficients appear slightly larger than variation 2. The solidity of Variation 1 changes; the torque curve characteristic changes due to the increase of the solidity.

For variation 2, the torque coefficient increases rapidly with decreasing rotor speed, and at about $\lambda \leq 1.9$, it seems to be constant before overloading. For variation 3, the single Savonius turbine has the highest torque coefficient than others, which attains a C_T of 0.35 at λ of 0.5. C_t for variation 3 decrease rapidly with the increase in the λ. Variation 4 has a lower torque coefficient than variation 3, and higher than Variations 1 and 2.

So, by adding the Savonius blades of the Darrieus rotor, the torque coefficient of the rotor becomes higher than the single Darrieus rotor; however, the tip speed ratios decrease to less than unity. The presence of the Savonius blades of a hybrid system is dominant in decreasing the tip speed ratios. Therefore, adding the Savonius blades to Darrieus rotor increases the C_t and decreases the λ. Hence, Variation 4 system is dominant in decreasing the λ.

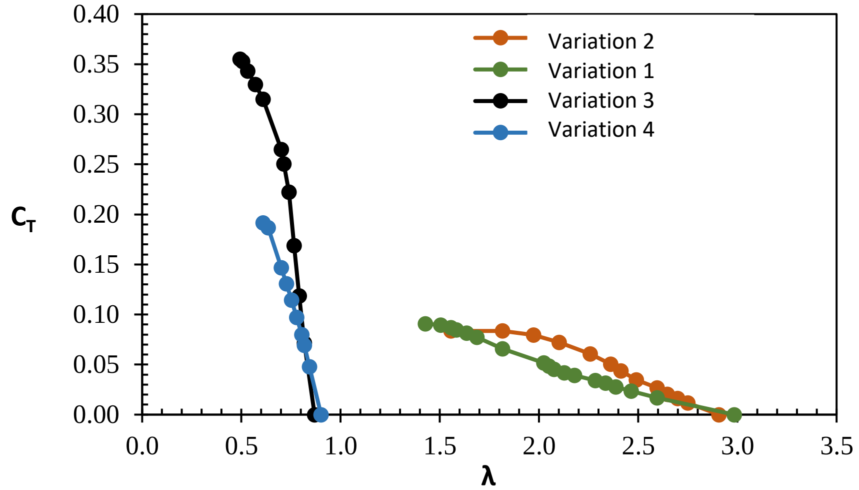


Fig. 4. Relation of C_t to λ

The C_t affects the C_p generated by the turbine rotor. Figure 5 shows the relation C_p to λ. Variation 3 provides higher C_p with wider λ than Variation 1, Variation 3, and Variation 4. Based on Figure 5, the relation of C_p to λ for variation 2 is parabolic. Variation 1 is lower than Variation 2 allegedly because different airfoils used in a single Darrieus rotor cause probably non-uniform forces on the rotor.

Further, using different symmetrical airfoils on a single rotor means the blade thickness is different. The increasing blade thickness means increasing the pressure gradient and the drag force along the airfoil. For variation 3, the maximum C_p has achieved 0.2 at λ of 0.6; this means the Savonius turbine is categorised as the drag type turbine because it operates between λ of 0.5 to 0.85. Variation 4 has lower C_p than Variation 1, Variation 2, and Variation 3.

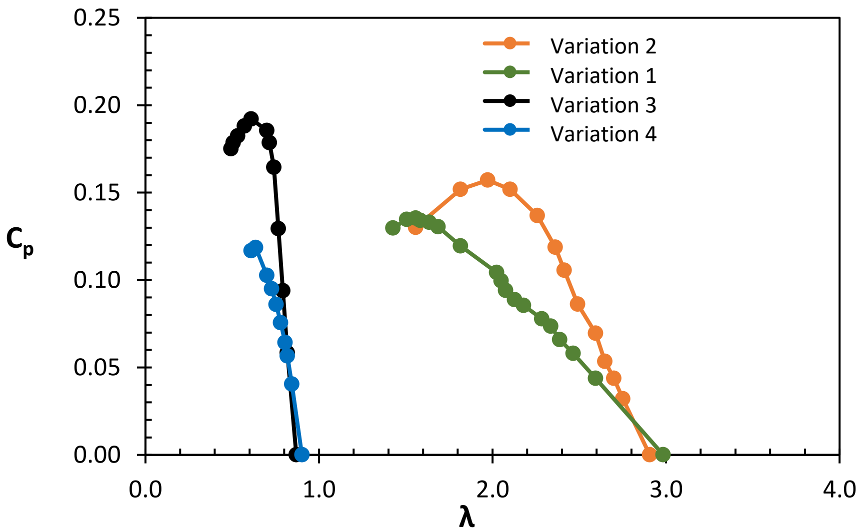


Fig. 5. Relation of C_p to λ

Figure 6 shows the relation of the P_t to λ. Based on Figure 6, Variation 2 generates a higher P_t than Variation 1, Variation 3, and Variation 4. Whereas, Variation 2 caused the highest P_t than Variation 1, Variation 3, and Variation 4. Meanwhile, Variation 4 is higher than Variation 3; this is allegedly because the area of the turbine is larger, so the power generate by Variation 4 is higher than Variation 3.

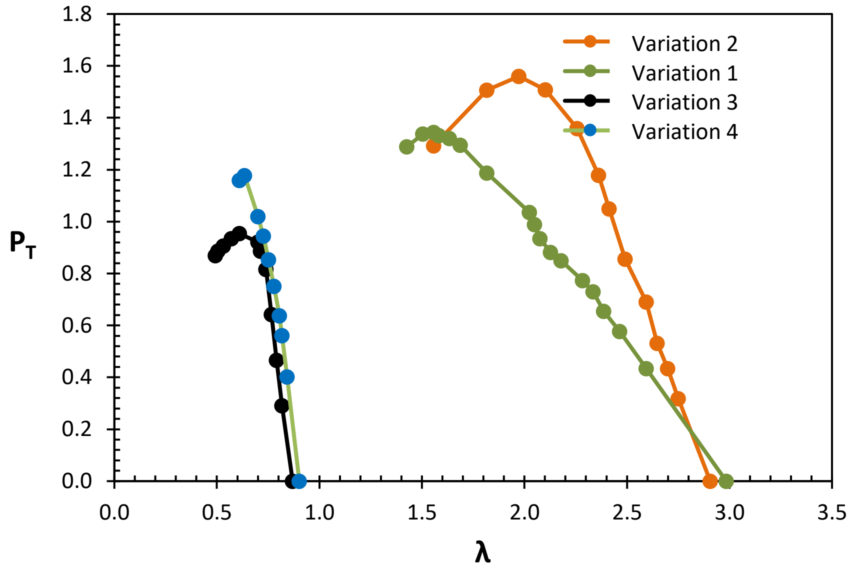


Fig. 6. Relation of P_t to λ

4. Conclusions

The Darrieus and Savonius turbine are two types of water turbines that generate electric power by utilising the flow in irrigation. Investigation of some configurations of both turbines by experimentally to enhance or to know their performance so that a wide range of tip speed ratio, high torque, and high efficiency are available. Based on the results, the single Savonius turbine (Variation 3) has the highest torque and power coefficient (Cp); however, Savonius turbine can operate at low speeds. The Darrieus turbine, either with three (Variation 2) or two different blade configurations (Variation 1), has a smaller torque coefficient (C_t) compared to the Savonius rotor (Variation 3) and the hybrid Darrieus-Savonius turbine (Variation 4). However, the operation of the Darrieus turbine is high speed. Furthermore, the Darrieus turbine's two blades different configuration (Variation 1) has a large range of characteristics in torque coefficient (C_t), power coefficient (C_p), and power generated (P_t). The maximum power coefficient of the hybrid Darrieus-Savonius turbine (Variation 4) can be considered the same order as the Darrieus turbine with two different configurations blades (Variation 1), and the power generated is larger than the Savonius type but lower in efficiency. Thus, based on the results, a single Darrieus turbine with the aerofoil NACA 0016 is recommended for application.

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