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An electric power generation improvement for small Savonius wind turbines under low-speed wind

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ABSTRACT

Savonius wind turbines have advantages of self-rotating at low speed wind, high starting torque, and less noise generation. However, they have low electric power generation capacity. This paper presents electric power generation improvement for small Savonius wind turbines when operating at low-speed wind of 1-6 m/s by using optimal Bach-type blades, twist blades and a wind tunnel. The turbine prototypes with the optimum diameter and height of 32 cm were developed with 3 different blade types: conventional semicircular blades, Bach-type blades and twisted 15° blades and a wind tunnel. The experimental results showed that the Savonius wind turbine with Bach-type generated highest electric voltage, which was 19.3% and 7.6% higher compared to conventional blades and twisted 15° blades. The additional wind tunnel could improve electric power generation efficiency by approximately 21.4% compared to the turbines without the tunnels.

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1. INTRODUCTION

Most winds that exist near-surface of the earth are inherently in the range of very low-low speed wind of 3-5 m/s, as shown in Figure 1 [1]. Therefore, designing high power conversion wind turbines that effectively convert wind energy to electricity at low wind speed would be a great challenge for researchers. There are several types of wind turbines currently available; some are shown in Figure 2 [2], [3]. It is seen that the wind turbines with high tip speed ratio (λ) would achieve higher power coefficient (C_p) but with a much larger in size. In fact, there is only the Savonius wind turbine type that could operate with the tip speed less than 1.5 well while having small size, by mean of self-rotating, high starting torque [4]-[7] and less noise [8] capacity; but unfortunately with the lowest C_p [9].

Many research publications have been proposed regarding efficiency improvement for the Savonius Wind turbines, which could be summarized in terms of the wind speed range and the investigation part(s) of the turbines as shown in Table 1 [10]-[25]. It could be seen that much research have been done on the blades since 1991 and some implementation on the additional guiding plates or tunnels and others. Bach-type blades and twist blades seem to provide significant efficiency improvement while adding the end plates or guiding plate/tunnel could also improve. However, all the proposed techniques were the results only at medium speed wind (5-11 m/s). In this research, the efficiency when they operate at low-speed wind range of 1-6 m/s is investigated, examined, and evaluated.

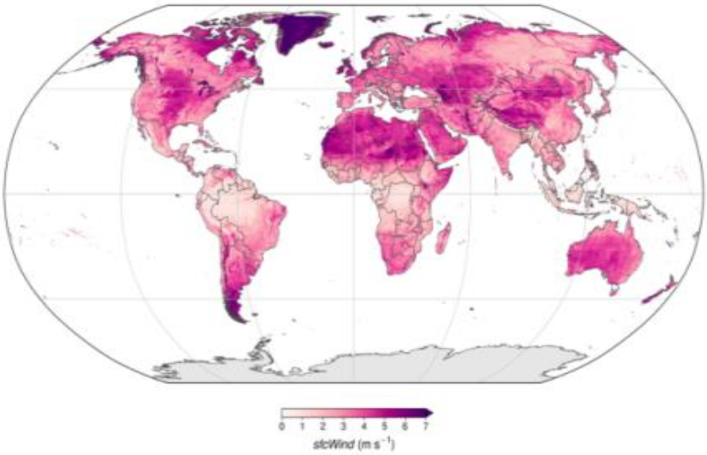

Figure 1. World map of near-surface wind speed [1]

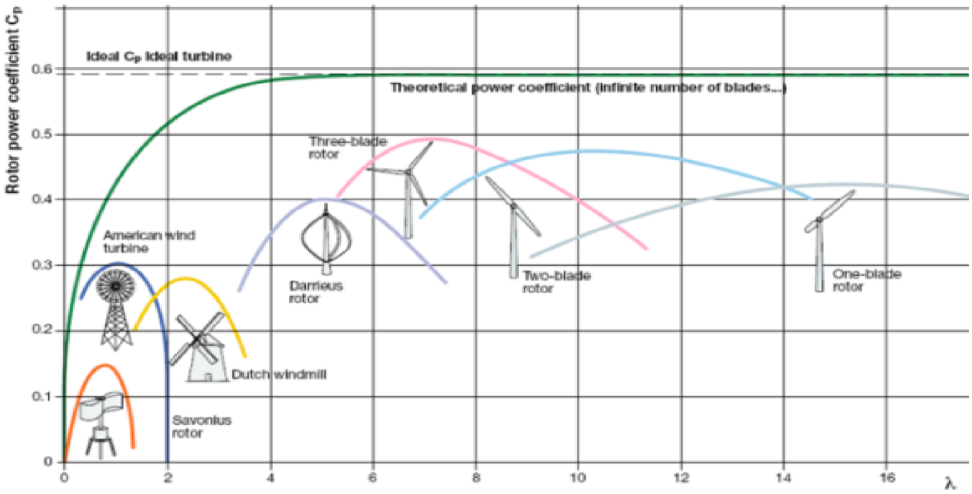

Figure 2. Power coefficient (Cp) of different types of wind turbines at different tip speed ratio (λ) [2], [3]

Table 1. Literature review on efficiency improvement for Savonius wind turbines

Investigated Part	Methodology	Efficiency Improvement	Publication Year	References
Blades	Effects of different angles of blade arcs	Affect to the efficiency	1991	[10]
	Number of blades (2,3 blades) Number of rotor (1,2,3 rotor stacks) Wind speed = 6-10 m/s	2-blade turbine is the best 2-stack is the best 2-blade,2-stack, 25 degrees give Cp=31%	2006	[11]
	Effect of blade curve	Affect to the efficiency	2008	[12]
	Bach-type	Cp=39.4% High starting torque	2010	[13]
	Twisted angle of blades between 0 and 25 degrees, wind speed 6-11 m/s	15 degrees at 6.5 m/s is the best Cp=13.99%	2012	[14]
	Effects of different angles of blade arcs	Affect to the efficiency	2015	[15]
	Effect of blade curve	Affect to the efficiency	2015	[16]
	2 blades	2-blade is the best performance at low wind speed	2019	[17]
	Reduce weight and increase airflow area	Increase efficiency	2019	[18]
Guiding Plate or End Plates or Tunnel(s)	Guiding plate	Improved mechanical efficiency	2013	[19]
	Double wind tunnels	Improved generated voltage	2016	[20]
	Add upper and lower end plates	40% increase torque	2017	[21]
	Wind concentrator	10.41% increase wind speed	2018	[22]
	Add upper and lower end plates	Increase tip speed ratio of 50%	2019	[23]
Others	Turbine aspect ratio (AR)	AR affects the efficiency	2015	[24]
	Optimum geometry	15% at a tip speed ratio of 1.2	2017	[25]

2. METHOD

2.1. Configurations and components of turbine prototypes under investigation

In this research, there are 3 types of blade styles: conventional semicircular, optimum twisted 15° and Bach-type blades. Figure 3 presents the configuration and components of the designed Savonius wind turbine test rig under this research. The turbine included of a wind tunnel, 3 different blade types of Savonius wind rotor (conventional, Twist-blade and Bach-type) and a direct current (DC) generator. Figure 4 illustrates the photographs of different type of the aforementioned blades: conventional semicircular blades (Figure 4(a)), twist 15° blades (Figure 4(b)), and Bach-type blades (Figure 4(c)). All the blades made by the same material (zinc) with thickness of 0.35 mm, diameter of 32 cm and height of 32 cm, end plates diameter of 35.2 cm (10% larger than one of the rotor).

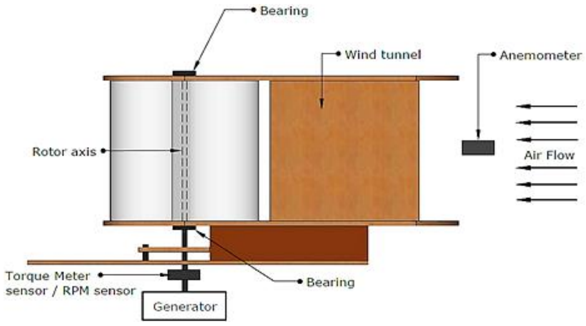

Figure 3. Configuration and components of the Savonius wind turbine under this research study

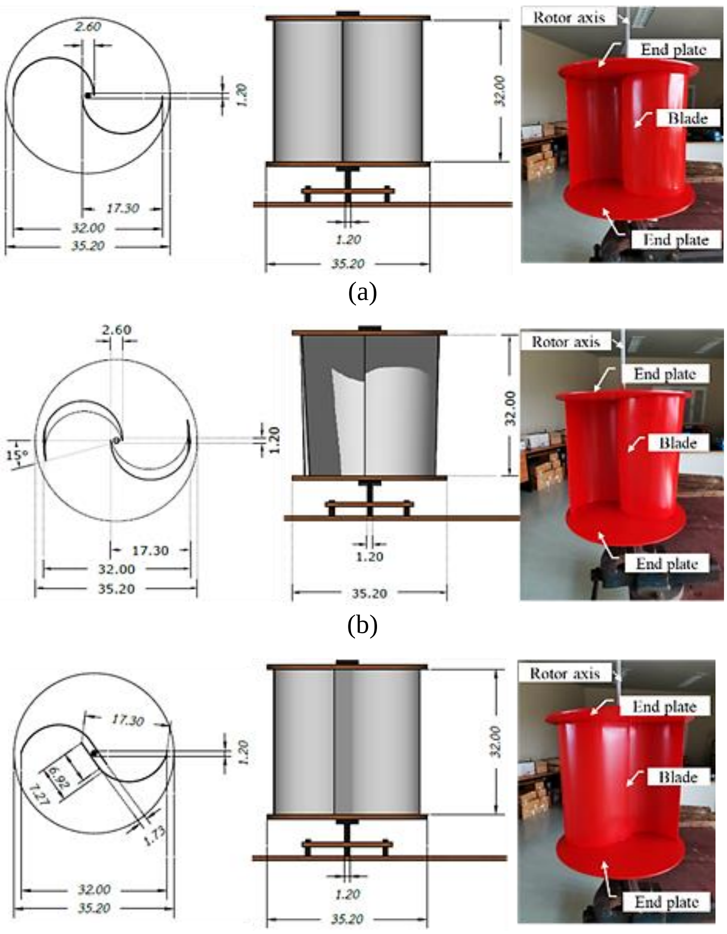

Figure 4. The different blade types of Savonius wind rotor; (a) conventional semicircular blades, (b) twist 15° blades, and (c) Bach-type blades

The turbine shaft has diameter of 1.2 cm. The wind tunnel arrangement with geometrical parameters is illustrated in Figure 5. This dimension is the optimum design proposed in [26]-[27], which has the length of the curtain blades (*l1*=45 cm and *l2*=52 cm) and the angles of the blades (α= 45° and β =15°). Construction of this deflecting tunnle is simple and cheap.

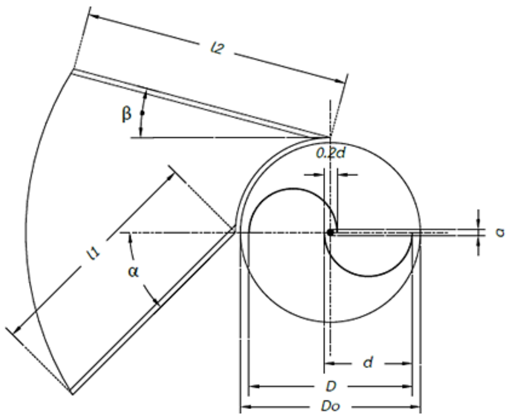

Figure 5. Geometrical parameters of the wind tunnel arrangement [26]

2.2. Experimental test setup

Figure 6 shows the experimental test setup for this research. The test setup consisted of the wind tunnel, 3 blade types of a Savonius wind rotor and a DC generator. The Savonius rotor shaft was supported the top and bottom by low friction bearing and connected by a flexible coupling to DC generator. And then measurements of wind velocity and the number of revolutions were measured by a torque meter sensor. An anemometer laser light source model EXTECH461920 with the measuring range of 0-30 m/s was used to measure the wind velocity and the accuracy of multifunctional anemometer is ±5%. The rotational speeds were measured on the tachometer equipment with the measuring range of 2.5-99999 rpm and the accuracy of tachometer equipment is ±0.02%.

The test scenarios were divided into 2 cases: with and without the tunnel. For each case, 3 types of blades (conventional, twisted 15° and Bach-type) were tested for observing the electrical characteristics in terms of performances and efficiency. The wind speed under the tests was in the range of 1-6 m/s. The shaft of the turbine prototype was connected to a commercial 30 W, 310 V DC generator. For the load test, the load was tested by supplying direct current from the DC generator to the light bulb LED 12 V 5 W for measuring voltage, current, and calculating energy for all wind speed values.

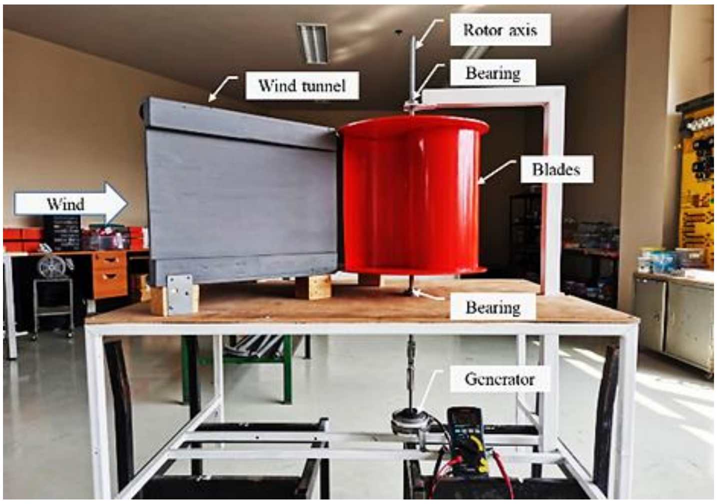

Figure 6. Photograph of the experimental test setup under this research investigation

3. RESULTS AND DISCUSSION

Figures 7 and 8 compares the generated voltages of the different blade types in the case of no-load for with and without a wind tunnel. The results showed that the Savonius wind turbine with Bach-type generated the highest electric voltage for all the wind speed range compared to the conventional and twist blades 15° Savonius turbine as shown in Figure 7 and the wind tunnel could achieve higher voltage compared to ones without the tunnels as shown in Figure 8. The Bach-type blades with a wind tunnel generated output voltages of 22.7 V, (i.e., at 3.5 m/s) whereas without a tunnel generated 27.5 V.

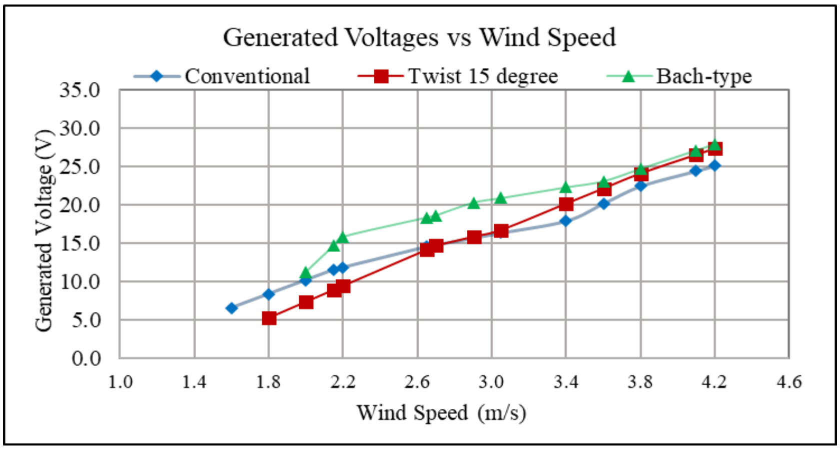

Figure 7. Experimental results: comparison of the generated voltage of the Savonius wind turbine with 3 different types of blades without the wind tunnel

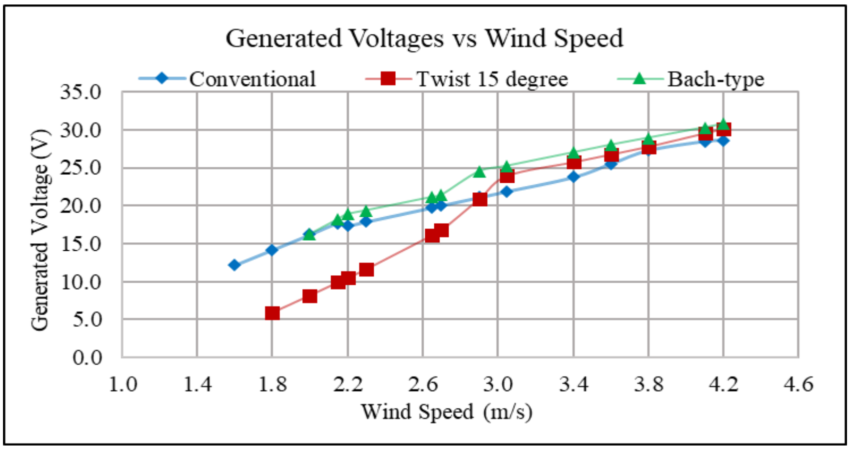

Figure 8. Experimental results: comparison of the generated voltage of the Savonius wind turbine with 3 different types of blades with the wind tunnel

Figures 9 and 10 compares the generated power of the different blade types in the case of load-tests for with and without a tunnel. The results showed that the Savonius wind turbine with the Bach-type generated higher electric power for over 3.0 m/s wind speed compared to the conventional and twisted 15° blades Savonius turbine as shown in Figure 9 and with the wind tunnel could achieve higher power compared to ones without the tunnel. In addition, the wind tunnel could reduce wind disturbance, as revealed by the linearly curves at higher wind speeds as shown in Figure 10.

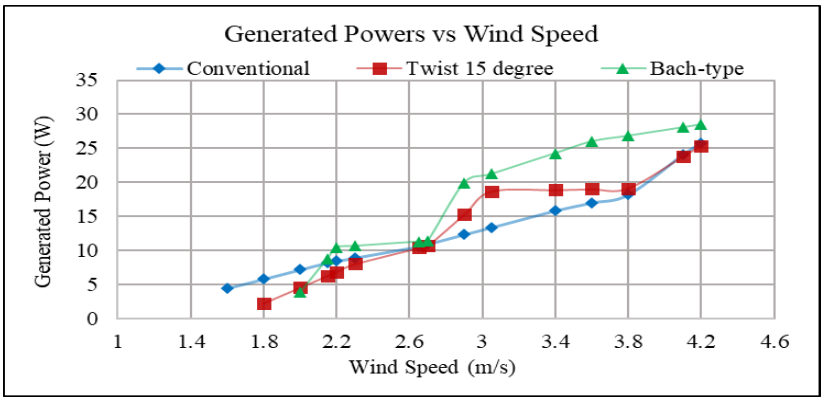

Figure 9. Experimental results: comparison of the generated power of the Savonius wind turbine with 3 different types of blades without the wind tunnel

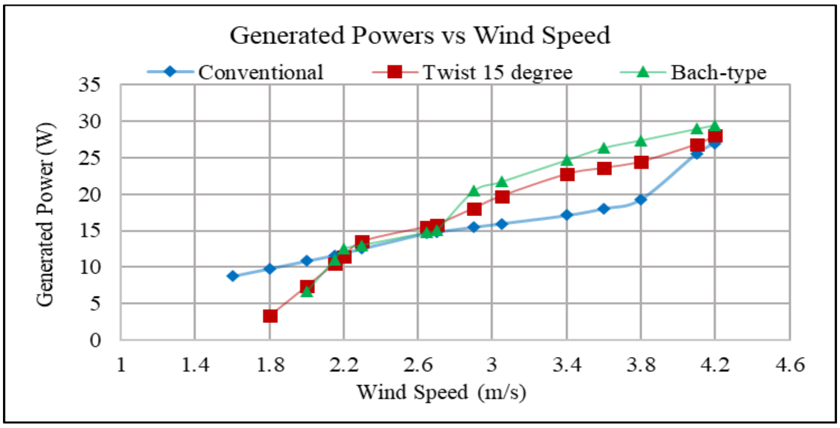

Figure 10. Experimental results: comparison of the generated power of the Savonius wind turbine with 3 different types of blades with the wind tunnel

Figures 11 and 12 compares the generated current of the different blade types in the case of load-tests for with and without a tunnel. The results showed that the Savonius wind turbine with the Bach-type generated higher electric current compared to the conventional and twisted 15°. Blades Savonius turbine and with the wind tunnel could achieve higher current for over 3.0 m/s wind speed compared to ones without the wind tunnel.

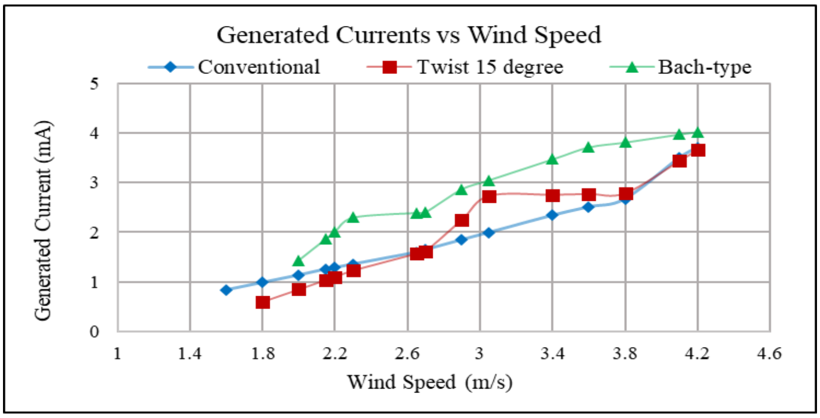

Figure 11. Experimental results: comparison of the generated current of the Savonius wind turbine with 3 different types of blades without the wind tunnel

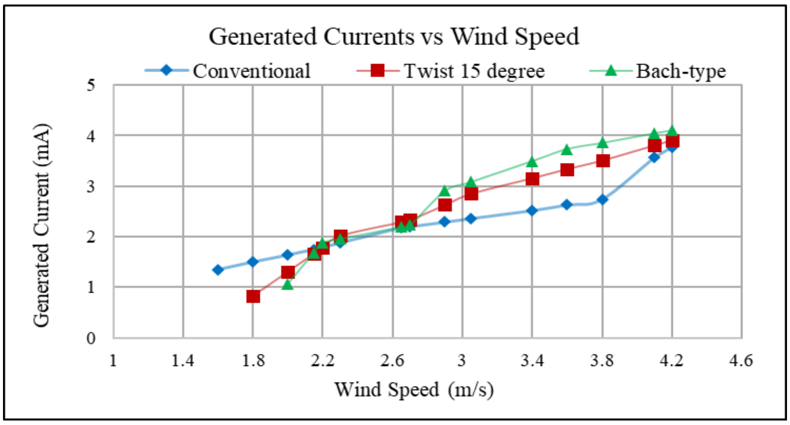

Figure 12. Experimental results: comparison of the generated current of the Savonius wind turbine with 3 different types of blades with the tunnel

4. CONCLUSIONS

This paper proposed effects of wind blades and wind tunnels on electric energy generation of the proposed Savonius wind turbines with 3 different types of blades: conventional blades, twisted 15° blades and Bach-type blades. The experimental results showed that the Savonius wind turbine with Bach-type generated highest electric voltage for all wind speed compared to the conventional and twisted 15° blades Savonius wind turbine. In addition, when implementing the wind tunnel for those turbines, their energy generation could achieve higher efficiency by 21.4% compared to ones without the tunnel.

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