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Experimental Evaluation of Multiple Savonius Turbines in Oblique and Cluster Configurations

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ABSTRACT

Majority of the published literature on the performance of multiple straight bladed Savonius turbines arrays is purely based on numerical simulation analysis using CFD solvers. Thus this paper attempts to validate some of those results via experimental study by using a low-speed wind tunnel. However, helical Savonius turbines with 90□twist angle are used in the later. Multiple turbines configurations of interest are two-turbines oblique and three-turbine clusters. Despite having different geometry and size, the overall increased in power enhancement as predicted by CFD and experimental data are almost the same i.e., 20-30%. This improved in power enhancement is directly attributed to the positive flow interaction between turbine in the configuration. Other factors influencing this phenomenon includes gap distance, relative phase angle position, and direction of angular rotation.

Key words: Turbine cluster, Oblique configuration, Savonius turbines.

1. INTRODUCTION

The main advantage of Vertical Axis Wind Turbines (VAWT) over its contemporary Horizontal Axis Wind Turbines (HAWT) is that when the former is placed in close proximity its power density is increased [1]. In the case of VAWT, the increase in power density is, as a result, a flow interaction between turbines resulting in a coupling effect [2]. However, an investigation on two Savonius turbines by using PIV and CFD has shown the power enhancement is due to two factors: first by the Magnus effect and second by the periodic flow between turbines [3]. Further investigation by [4]-[7] has established parameters affecting the power enhancement such as gap distances, relative angular position, turbines configurations, and rotor blade rotational direction.

For two Savonius rotors placed in parallel rotating in contra direction, the gap distance and relative phase angle between them influence the total power enhancement [2]. The best power improvement achieved is 37%. A similar concept can be extended to 11 turbines with a gap distance of 0.7 Diameter resulted in 60% in power improved when compared to a single turbine [4]. Whereas in an oblique configuration when the second turbine is located either on the left or the right of the upstream turbine, again the relative phase angle plays an important role. An optimum layout of five turbines in oblique array using the concept of wake energy reuse produced power enhancement of the downstream turbine by 23% [5]. In this case, the gap distance is between 4.7 to 5 Diameter. Three turbines cluster arrangement yielded about the same power enhancement. A rather extensive numerical investigation on three turbines clusters and a wind farm is reported by [6]. This work is later supported by others [7]-[9].

In general, all papers cited to date involved numerical simulation analysis by using CFD solvers. Therefore, the main objective of this paper is to verify those findings particularly by [6] via experimental study. The performance of a single turbine was first investigated and used as a reference for power enhancement. The power generated by two and three helical Savonius turbines with 90° twist angles with load was computed by measuring its voltage and currents at a wind speed 5m/s.

2. MATERIAL AND MODELS

This section describes in detail the turbine physical model configuration and experimental setup used in the wind tunnel testing. Furthermore, the fundamental relation for turbine performance is presented in this section.

2.1 Savonius Physical Model

The helical Savonius rotor design is chosen over the straight blade design due its superior performance [10] of the former in terms of starting capability and power coefficient. The PLA 3D printed Savonius wind turbine prototype is tested in this study as shown in Figure 1. It has different cross-section throughout its complete revolution due to twist angle parameter. Both ends are attached by acrylic endplates. The details of the turbine geometry are given in Table 1.

(a) (b)

Figure 1: Helical Savonius turbine (a) Swept area (b) Top view

Table 1: Turbine configuration

Parameter	Description
Turbine group	Vertical axis wind turbine
Diameter	0.27 m
Height	0.5 m
End plate diameter	0.297 m
Blade twist angle	90º
Overlap ratio	0.242
No. of bucket	2
Weight	1.4 kg

2.2 Wind Tunnel Setup Procedure

The whole experimental studies were carried out using an open circuit wind tunnel powered by 75KW axial fan. Wind flow uniformity is about +-0.1m/s within its 2m x 2m test section. The turbine and its fixture assembly are located 1m from the tunnel test section.

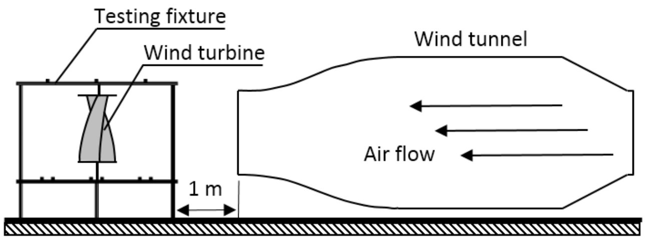

Figure 2: Testing equipment's setup

Each turbine is connected to a 12V axial flux permanent magnet (AFPM) generator as shown in Figure 3. The output voltage and current were measured manually by a digital Voltmeter/Ammeter. A 3-watt bulb acted as a load. This method is an alternative to the use of an expensive torque sensor and encoder as advocated by [11], [12]. Load conditions testing was performed for different wind velocities. However, results for 5m/s wind speed are reported in this paper. The oblique and clusters configurations with gap distances of 1 Diameter implemented by [6] were adopted as a baseline system. Two types of oblique and one type three turbine cluster configuration were evaluated as shown in Figure 4 and Figure 5.

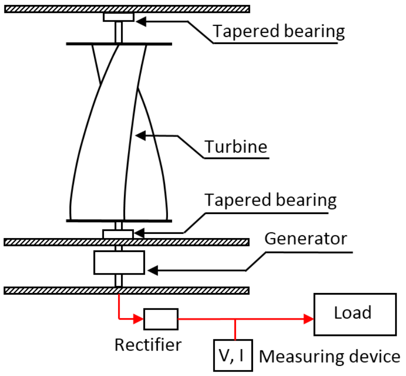

Figure 3: Wind tunnel test setup for single helical Savonius turbine

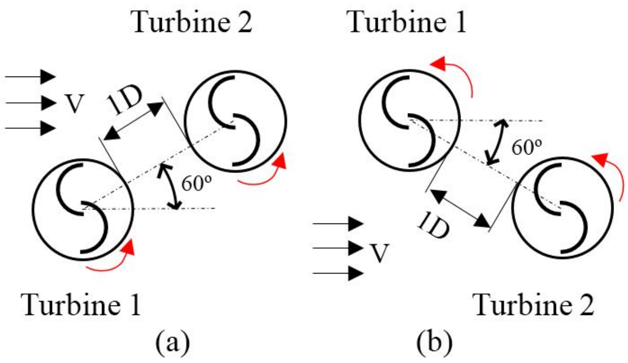

Figure 4: Oblique layout: (a) Configuration I and (b) Configuration II layout for CCW rotation direction

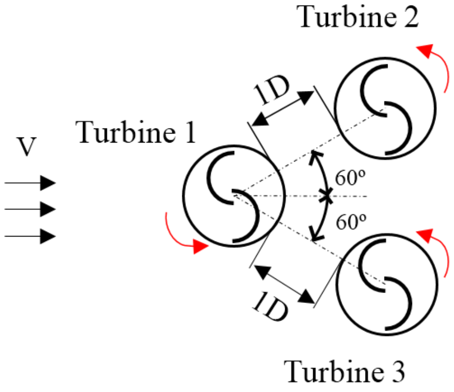

Figure 5: Three turbine cluster configuration for CCW rotation direction

The performance of a Savonius wind turbine was usually denoted as power efficiency or overall turbine performance. The turbine power efficiency, C_p is computed by using (1) to (3).

$$C_p = P_e / P_{th} \tag{1}$$

$$P_e = IV \tag{2}$$

$$P_{th} = 0.5\rho(DH)v^3 \tag{3}$$

where P_e is the actual power, V is the turbine voltage, I is the current generated, P_{th} is theoretical power available for a given swept area (DH) at the wind speed (v) of interest.

3. RESULTS AND DISCUSSION

Performance analysis of the helical Savonius turbine with 90º twist angle has been analyzed through wind tunnel testing.

3.1 Single Turbine

The result of a single turbine would be used as reference performance throughout the study. Table 2 shows the turbine performance for single turbine testing when the turbine was set to rotate in clockwise (CW) direction and counter-clockwise (CCW) direction at wind speed of 5 m/s.

Table 2: Single turbine performance data

Rotation	Voltage, V	Current, A	C_p
CW	9.1	0.09	0.062
CCW	9.1	0.09	0.062

This shows that for an isolated turbine, the direction of rotation has no effect on the turbine performance.

3.2 Oblique Configuration

Figure 6 shows the results of performance data of two turbines in oblique configuration I with both turbine rotating in clockwise (case 1) and counterclockwise (case 2) directions. The power coefficients are compared with the single isolated turbine. The overall turbine performances are increased by 1% and 10% for CCW and CW turbine rotation respectively. Similar performance improvement observed for the oblique configuration I, case 2 with CW turbine rotation as numerically predicted by [6] which is 9% compared to the isolated turbine.

The oblique configuration II performance data can be seen in Figure 7. The overall performance drastically improved by 17% for CW turbine rotation while 26% for the CCW turbine rotation. However, the improved CFD predicted performance of same configuration with CW turbine rotation is only 8% [6].

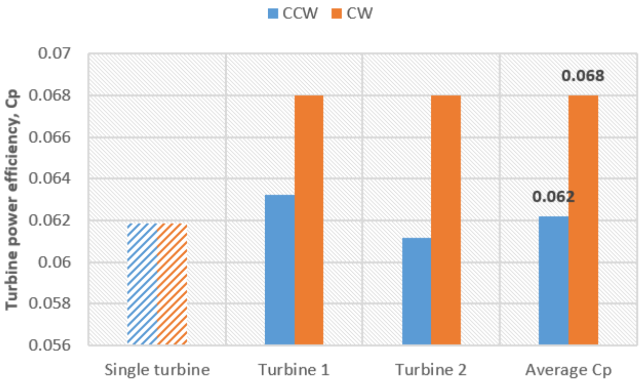

Figure 6: Individual turbine performance: Oblique configuration I

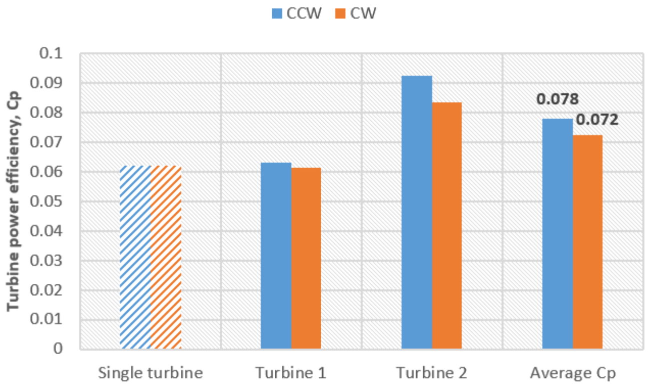

Figure 7: Individual turbine performance in oblique configuration II

3.3 Cluster Configuration

The cluster configuration studied by [6] consists of two types. Type A is where one turbine placed at upstream and two turbines at the downstream. On the other hand, type B consists of two turbines at the upstream and one turbine at the downstream. However, in this study only type A is considered as shown in Figure 8 due to space limitation. Analysis through numerical simulation shows improvement of overall turbine performance by 22% and 34% respectively. The highest overall performance achieved at gap distance of 1 turbine diameter distance [6].

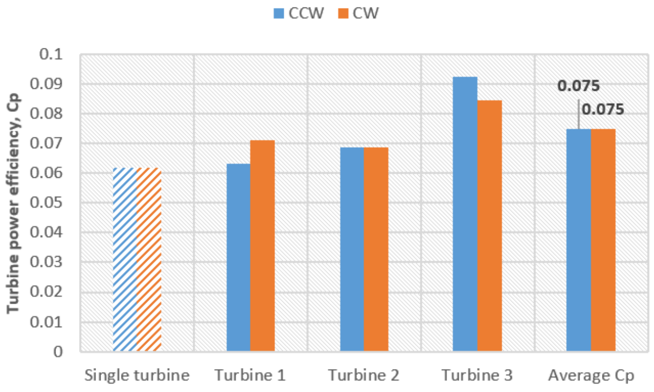

Figure 8: (a) Cluster configuration at one turbine diameter gap distance and 60^0setting angle (b) Turbine performance data

The implementation of the cluster configuration has demonstrated an improvement of individual turbine performance. Turbine 3 is observed to have outperformed the two turbines regardless rotational direction. Similar pattern improvement observed as in the oblique configuration II was applied to the turbine 3 position. The overall performance of this configuration shows improvement by 21% compared to the single helical Savonius turbine. Thus verifying the published data [6] on similar configuration. The turbine placed on the advancing blade region provides higher power efficiency compared to the turbine placed on the returning blade region [8]. The positive interaction between turbine in cluster arrangement can be observed via numerical study. The placement of turbine 2 at low velocity region of turbine 1 reduces the negative torque exerted on the turbine 2 while the placement of the turbine 3 at high velocity region increases the positive torque on the turbine 3 as reported in [13]. Hence, the performance of the downstream turbines shows improvement at the optimal position either placed on the advancing region or returning region of the upstream turbine.

5. CONCLUSION

In this study, the performances of multiples helical Savonius turbine with 90° twist angle are compared with the straight bladed Savonius of similar configurations. The former was carried out by actual experimentation while the later was obtained by numerical study. The conclusions are as follows:

1. Despite the differences in geometry and size, power performance enhancement for both studies are the same with exception of the oblique configuration type II.
2. The oblique configuration II shows highest performance improvement in CCW direction with 26% higher than isolated turbine.
3. The cluster turbine shows improvement performance up to 21% regardless of turbine rotation direction.
4. Power enhancement is largely due to the flow interaction between turbines as cited by others [3], [5]

A current study is now being undertaken to improve the performances of multiple helical Savonius turbine further by optimizing the gap distance and other parameters.

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