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Study of Multiple Half Blades Effect on the Performance of Savonius Rotor: Experimental Study and Artificial Neural Network (ANN) Model

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Abstract

Objectives: To estimate and compare the performance in terms of torque and mechanical power of a new configuration of Savonius rotors with the conventional one. **Methods/Statistical Analysis**: New configuration comprises multiple half blades added to conventional configuration. Two different new configurations with different half blade geometries and locations were designed. The torque and mechanical power of the rotor was measured experimentally at various wind speeds and rotor positions. The tests were done 4-6 times for each measurement and the results were averaged. Moreover, the measured data were predicted using Artificial Neural Network (ANN). **Findings:** The location of half blades effect the performance of the rotor. Additionally, both new configurations of Savonius rotors are associated with above 45% increase in mechanical power compared to the conventional Savonius wind turbine. Based on the simulated results, it is found that the R^2 value within a range of 0.902-0.99, which indicated a very good fit of the measured data with the calculated data. **Application/Improvements:** ANN technique can be applied as a powerful tool and effective way in predicting and assessing the performance of the rotor (torque and mechanical power).

Keywords: ANN, Experimental Study, Multiple Half Blades, Performance, Savonius Rotor

1. Introduction

Renewable energies are considered as important sources for generating electricity because of their advantages such as reducing global warming, air pollution and fossils fuels[1,2]. Wind energy is one of the critical available sources that can be used for generating electricity via wind turbines.

Sigurd Savonius in[3] developed the vertical axis wind rotor. Savonius wind rotor is considered as one of a kind of wind rotors which consists of two vertical half cylinders[4]. Some of the benefits are: its simple structure, starting characteristics and its low speeds of operation and also the multi directional wind capturing ability[5]. It is most suited for local electricity which require low power[6,7].

Many researchers have studied the effect of blade geometries, blade shape and endplate on the performance of conventional Savonius rotor to increase the efficiency of conventional rotor[8-13].

In this present study, we experimentally investigate the multiple half blades (adding to the conventional Savonius rotor) effect on the performance of new configuration of Savonius rotor. This is the first study to conduct such an investigation. The goals of this study are: 1. To investigate the effects of multiple half blades on the torque and mechanical power of the newly configured rotors at various wind speeds and rotor positions, 2. To examine the impact of geometry of multiple half blades on torque and mechanical power at various wind speed and 3. To compare the mechanical power of the new rotor

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configurations with the conventional Savonius rotor. Moreover, Artificial Neural Networks (ANN) has used to predict the mechanical and torque characteristics of the new design rotor configuration.

2. Experimental Method

2.1 Design Blade Turbine

New configuration of rotors consist of multiple half blades which are added to the conventional configuration were studied using different geometries for an improved efficiency. New configurations and design parameters are shown in Figure 1 and the dimensions of models are listed in Table 1. Two new configurations are designed with various locations for multiple half blades. In the first configuration, the multiple half blades are attached along the main shaft center. While, in the second one, the multiple half blades are attached to the center of main blade of the rotor, i.e. the center of all blades (main blade and half blade) is the same as shown in Figure 1.

Table 1. New Savonius turbine design geometric parameters

Design parameter	Value	Design parameter	Value
D_1	160 mm	L	200, 300, 400 mm
D_2	140mm	h	200, 300, 400 mm
D_3	120mm	e_1	4 mm
H	600 mm	e_2	3 mm
D_{shaft}	20mm		

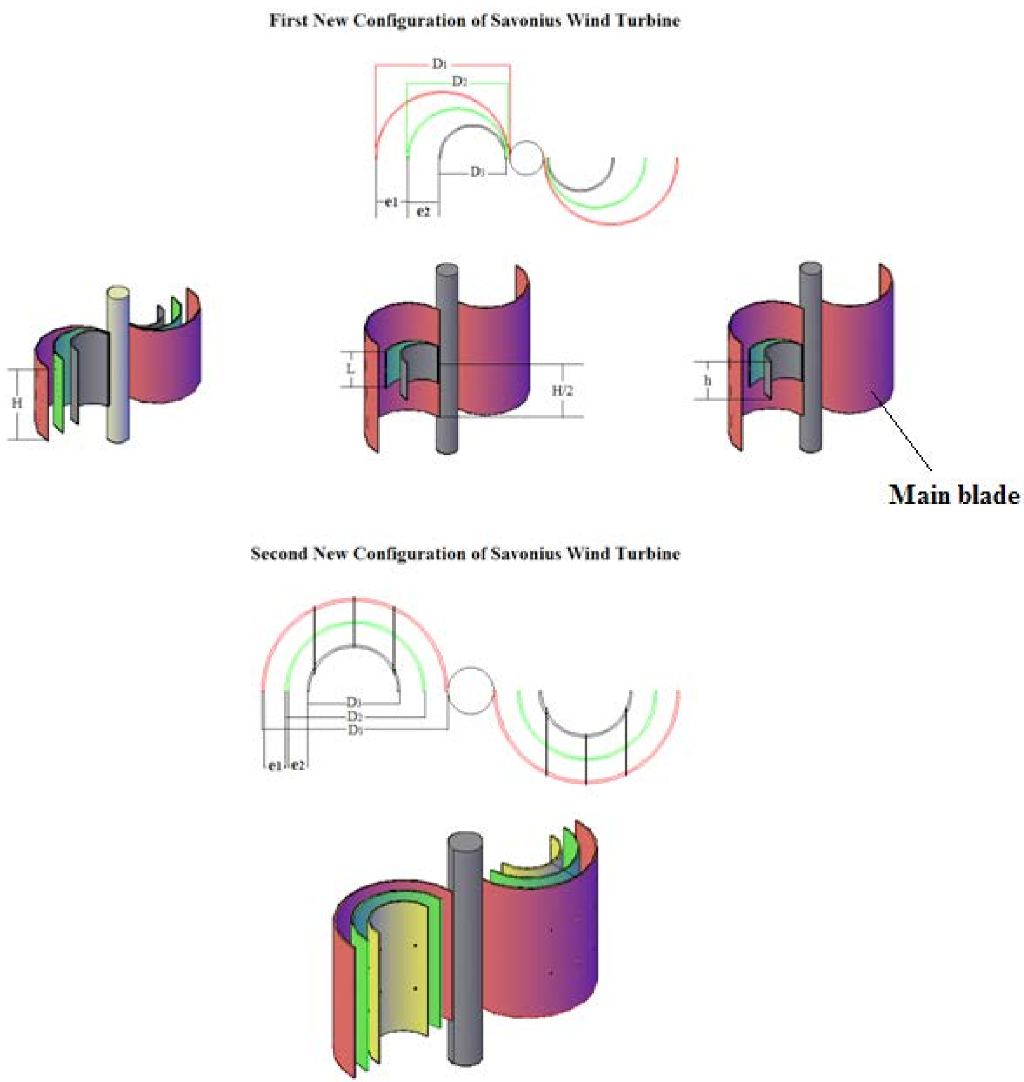

Figure 1. Geometries of two new configuration of Savonius rotor.

2.2 Experimental Setup

The experimental set up diagram for measuring the mechanical power and torque of the rotors are shown in Figure 2. Few of the components used in the set up are wind tunnel, measurement devices and also a Savonius wind rotor. An open circuit wind tunnel is used which has a power capacity of 5.7 kW and a squared exit of (800 mm x 800 mm). Rotor blades were made from PVC tubes because they can be easily cut and build in comparison to other type of materials. In addition, the rotor shaft was made from galvanized steel. The drive shaft carried the foremost stresses in this system because of the torque created by the blades and therefore, the Savonius rotor had to be placed on a wooden table. The rotor shaft has been supported close to the top and bottom by a really low friction bearing to attenuate the friction force. Pitot tube with an accuracy of 0.1 m/s and RPM reader were used to measure the wind speed and RPM of the rotors, respectively. For a wind source, centrifugal fan with the assistance of a Variac (for changing the output voltage and hence RPM rate of the fan) was used. The support eliminates any kind of vibration and ensures a decent stability of the setup throughout the experimental tests structure.

The measurement of torque were done at different rotor position using the brake drum measuring device (from 0 to 360° in step of 30°) and wind speeds were varied a range of 3 to 13m/s in step of 2 m/s. At a given wind speed and rotor position, the rotors static torque is determined. The static torque of the rotor was calculated at each 30° of the rotor angle. The values of load and spring balance reading were recorded to calculate the static torque at a best-known rotor angle.

2.3 Measurements and Instrumentation

As shown in Figure 2, the experimental setup consists of a pulley system, nylon string of 1mm diameter, weighing pan and spring scale. The wind speed is measured by a propeller type Pitot tube. Whereas spring scale and the weighing pan the shaft rotational speed is measured using RPM reader. The torque and mechanical power of the rotor can be estimated using Equation (1) and (2), respectively[14-16].

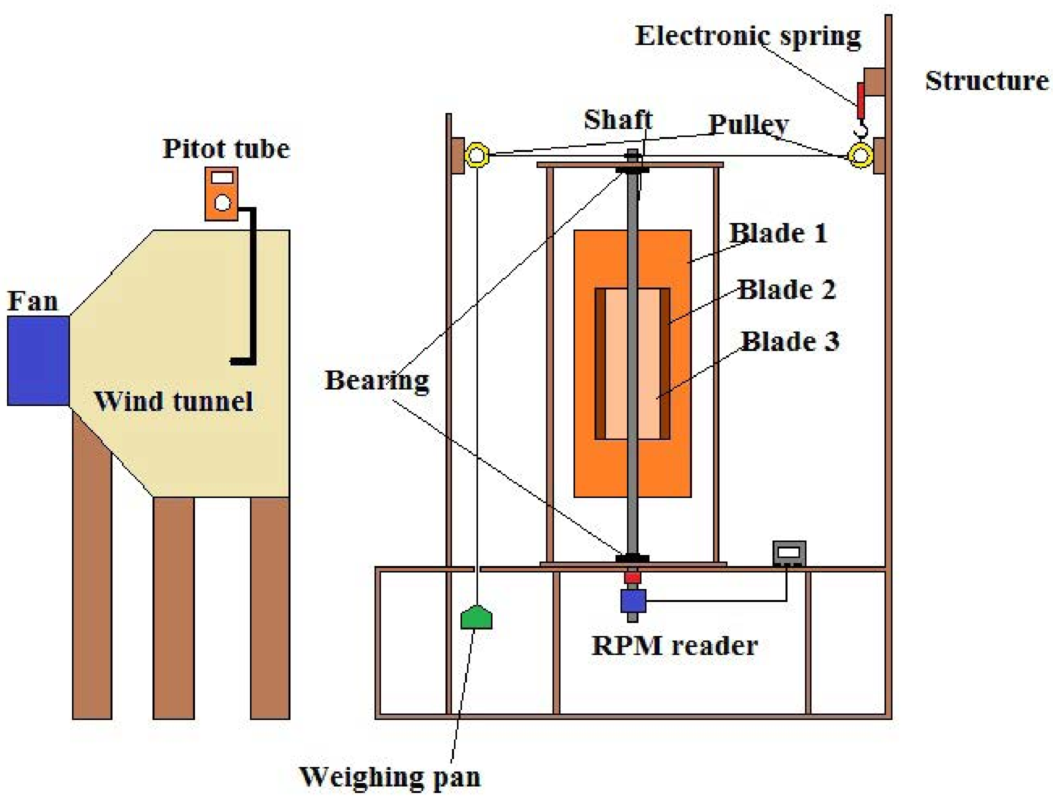

Figure 2. Experimental setup schematis.

$$T = F.r \tag{1}$$

$$P_m = T.\omega \tag{2}$$

Where T is used for the torque in N.m, the angular speed is denoted by ω in Rad/s, r is the radius of the rotor shaft and F is the force which is acting on the rotor shaft, which is obtained in N by:

$$F = (m - s)g \tag{3}$$

Where m represents the mass which is loaded in the pan in kg, s denotes the spring balance readings in kg and gravitational acceleration is denoted by g.

3. Results and Discussions

In this section, the dynamic and static torque and mechanical power of the 13 models were measured at various wind speed and rotor positions. Table 2 shows the geometries of each model used in the current study.

Table 2. Model of new design of Savonius wind rotor

	Model	H [mm]	L [mm]	h [mm]
Conventional Rotor	Model 1	600	-	-
First configuration of savonius rotors	Model 2 Model 3 Model 4 Model 5 Model 6 Model 7	600 600 600 600 600 600	200 300 400 400 400 300	200 300 400 200 300 200
Second Configuration of Savonius Rotors	Model 8 Model 9 Model 10 Model 11 Model 12 Model 13	600 600 600 600 600 600	200 300 400 400 400 300	200 300 400 200 300 200

3.1 Static Torque of the Rotors of the New Configuration of Savonius Rotors

Figure 3 shows the static torque of first configuration rotor at different wind speed and position angle. It had been noticed that the static torque of the first configuration rotors increases from 0° to 60° to reach the maximum value and then decreases from 30º to 120º to reach the minimum value in the wind velocity range of 3-13m/s. The values of static torque are marginally increased from 120º to 240º to get the highest value. The static torque has varied from 240º to 360º. Additionally, it had been noticed that model 1 had the lowest values of the static torque compared to the other models. Furthermore, the blade elevations directly affected the static torque of the rotors.

Figure 4 shows the static torque of the second design of rotors with variations of rotor location at various wind velocity The second configuration rotors static torque begins to rise from 0° to 60° to achieve the maximum value after that it is decreased from 60° to 120° and reaches the lowest value, and a slight increase occurs from 120° to 180°, then it is rapidly increased to reach the highest value at 240°. Whilst, the lowest value of static torque occurred at 300°...

Figure 4 also demonstrates that the multiple half blades geometry (L and h) has a minor effect on the static torque value of the second configuration, which can be neglected in comparison to the first configuration shown in Figure 3. Furthermore, Figure 3 confirms a gain of 10% to 25% in maximum static torque with the first newly configured rotor especially when the geometries of multiple half blades are not equal (L≠h).

3.2 Comparative study between 13 Savonius Models

An in depth study was carried out for the thirteen new models of Savonius wind rotors at numerous wind velocities are shown in Figures 5 and 6. Figures 5 and 6 shows the static torque of thirteen rotors with various rotor positions. Once the wind velocity increases, the static torque of the rotors will also increase. The standard rotors have a lowest static torque in comparison to the new rotors according to the figures.

For initial configuration Savonius rotor, the Model seven features a greater static torque from the different designs and also the static torque for model 2 and 6 are almost equal as shown in Figure 5. Moreover, consistent with the comparative study (Figure 6), model eight has the highest static torque in comparison to the models (1, 9, 10, 12 and 13).

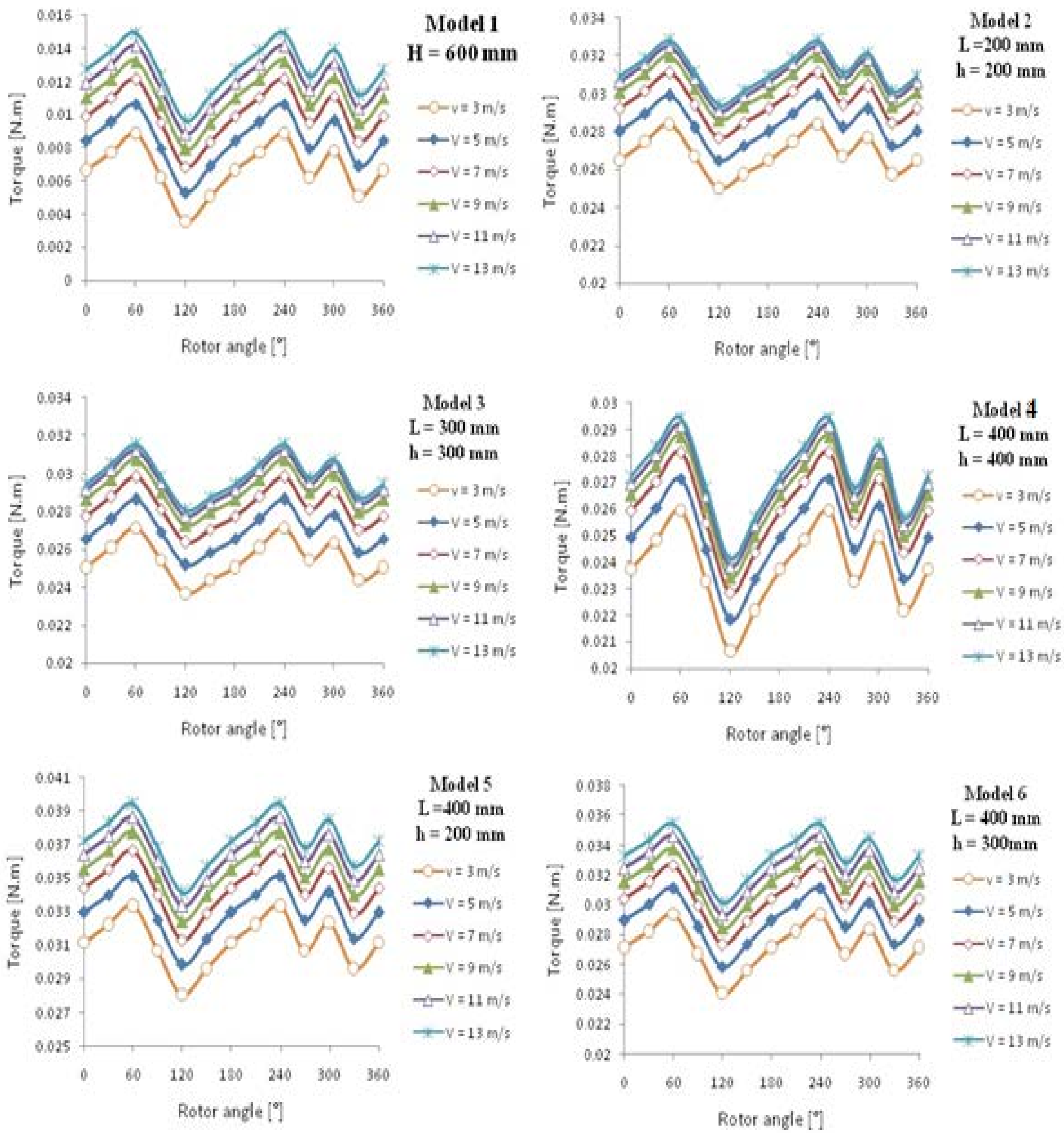

Figure 3. Static torque vs. angle of rotation for first configuration of Savonius rotors at various wind speed.

3.3 Dynamic Torque of the New Configuration of Savonius Rotors

Figures 7 and 8 illustrate the dynamic torque and mechanical power created by the thirteen designs of Savonius rotor at various wind velocities. It can be noticed that the dynamic torque and mechanical power rapidly increase as the wind velocity also increases. The conventional Savonius rotor (Model 1) encompasses a low dynamic torque in comparison to new designs. All the figures show that as the wind speed increases the dynamic torque and power of the new configuration of Savonius rotors will increase in a

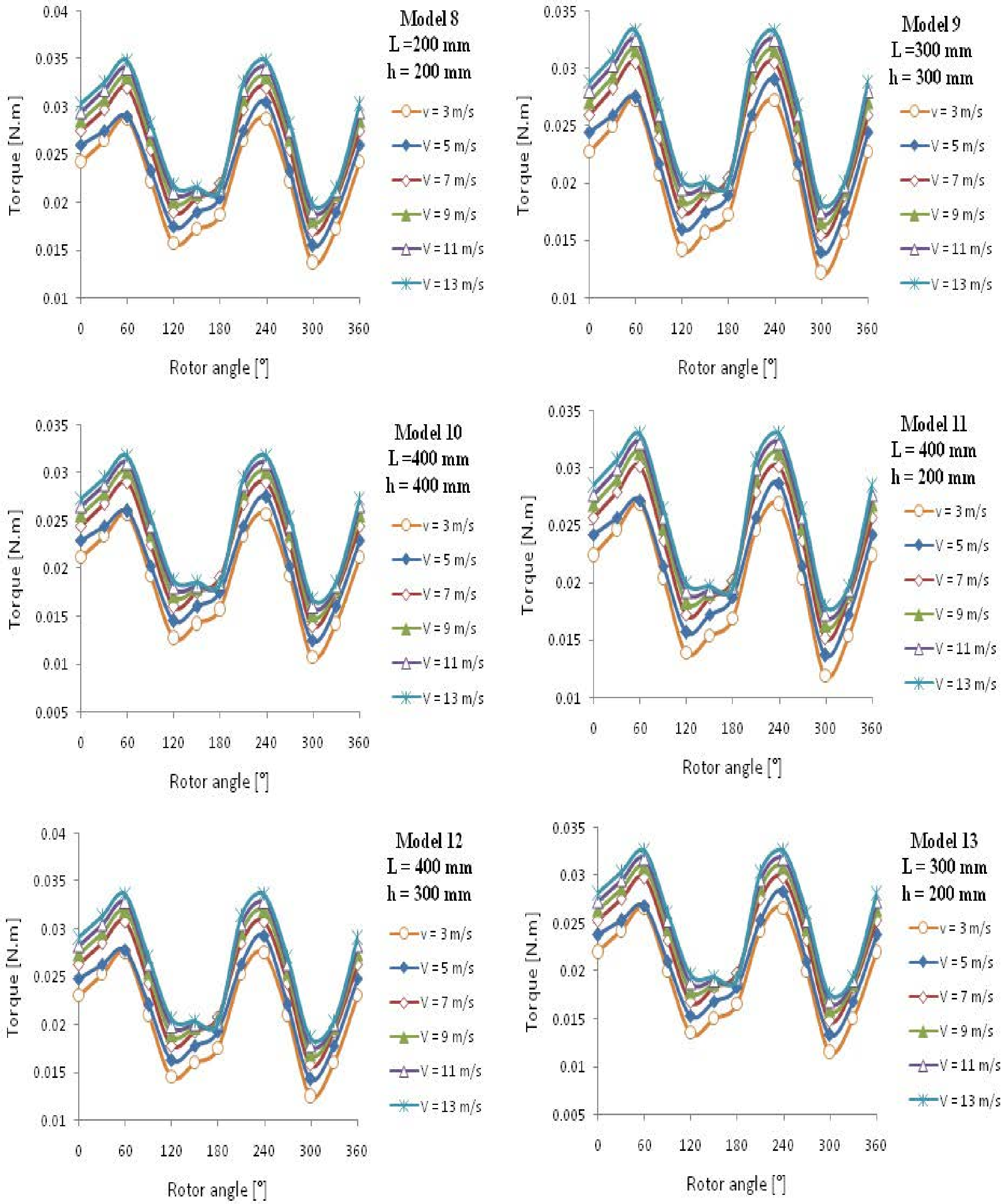

Figure 4. Static torque vs. angle of rotation for second configuration of Savonius rotors at various wind speed.

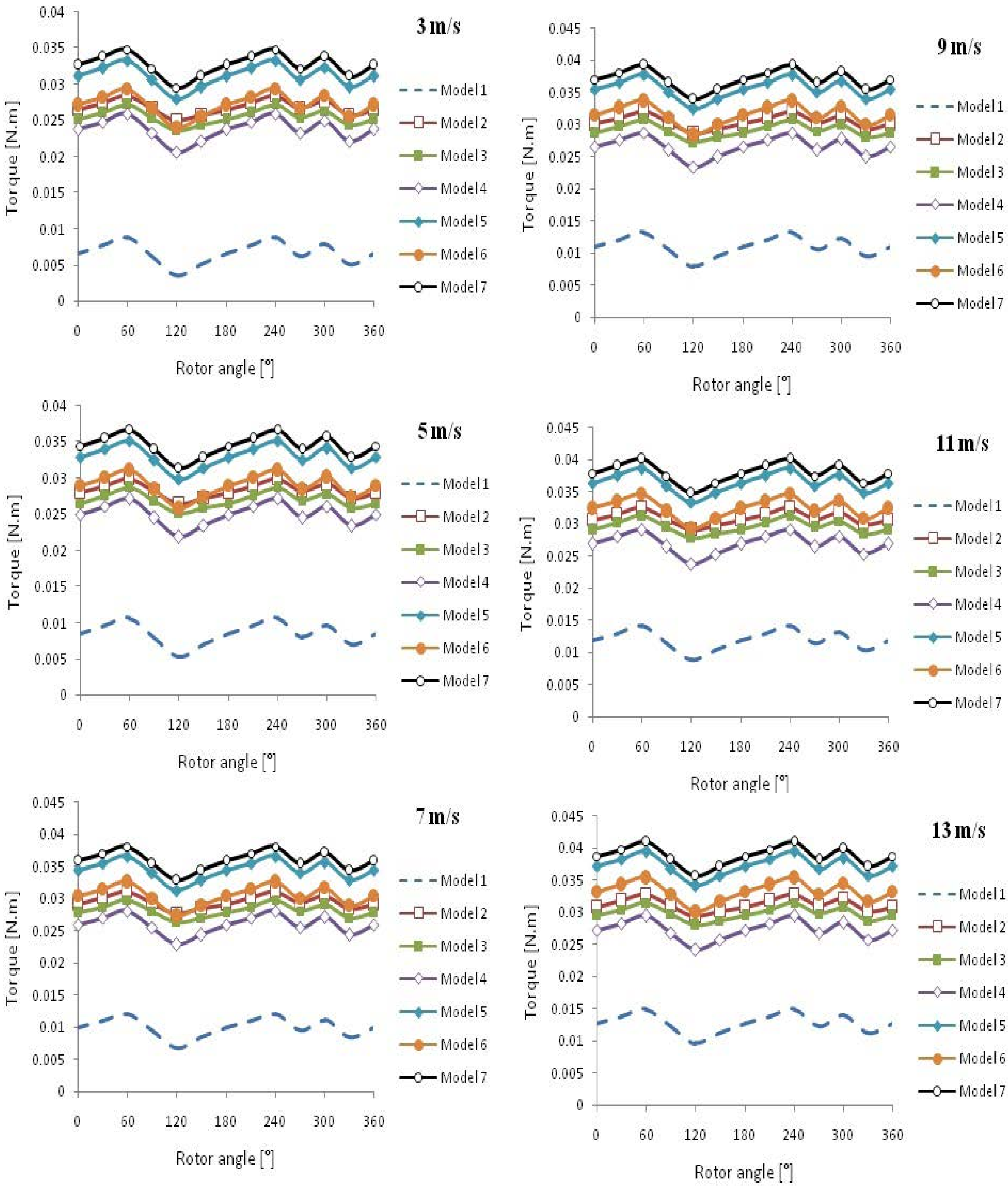

Figure 5. Static torque vs. angle of rotation for first configuration models.

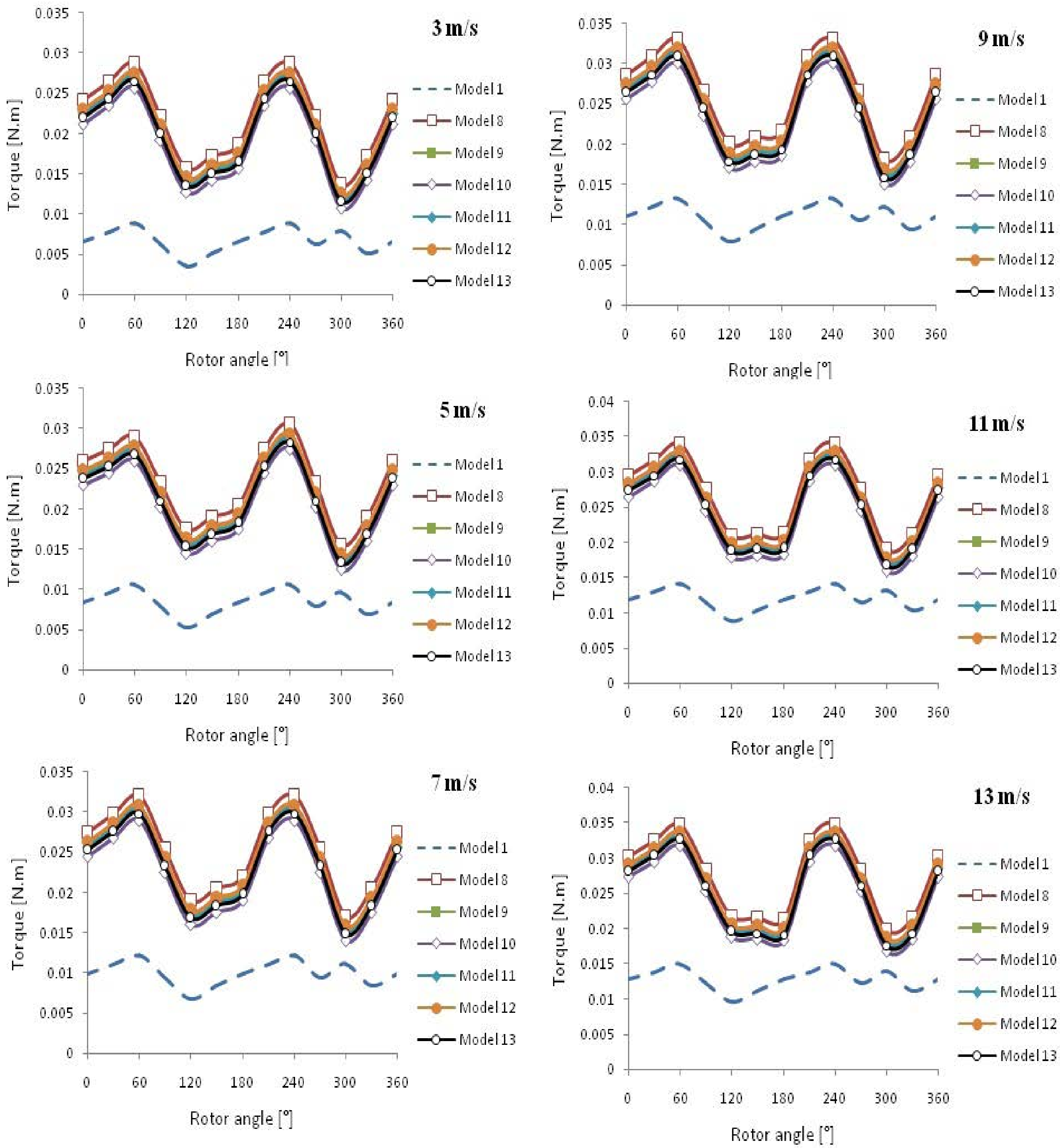

Figure 6. Static torque vs. angle of rotation for second configuration models.

non-linear way. Moreover, the impact of rotating velocity (RPM) on the dynamic torque and mechanical power of the rotors is shown in Figures 7 and 8.

It is noticed that Models 7 and 8 have the highest dynamic torque and mechanical power compared to other models.

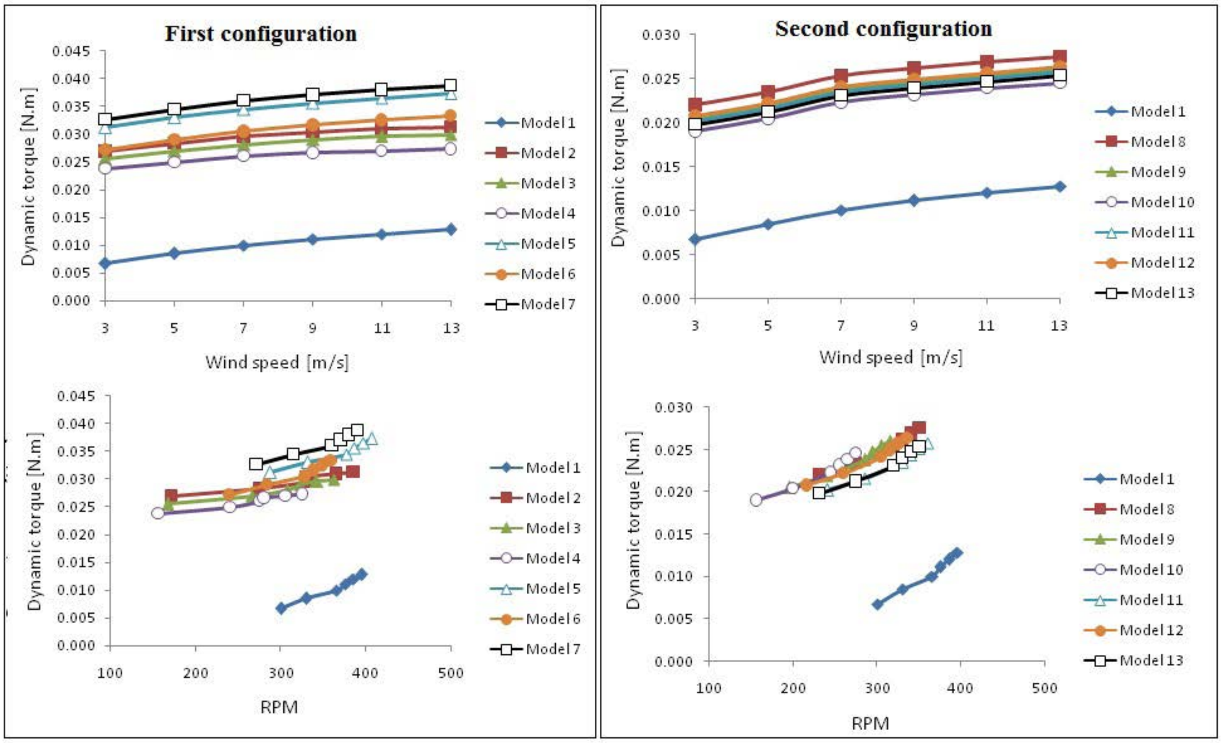

Figure 7. Dynamic torque vs. wind speed and RPM.

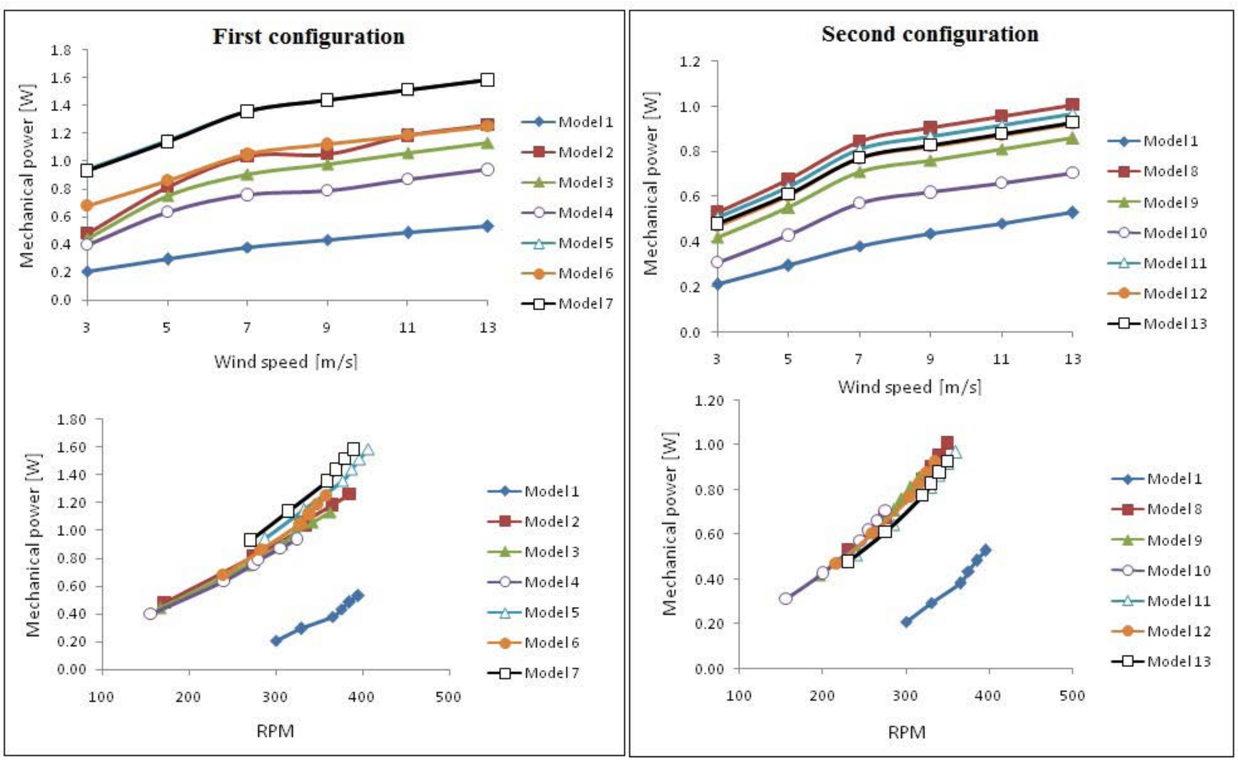

Figure 8. Mechanical power vs. wind speed and RPM.

The first configuration is observed to have a greater mechanical power and torque than the second configuration within the range of 3-13 m/s wind speeds. Moreover, they both demonstrated to have a greater torque and power as compared to the conventional rotor.

4. Ann Model Analysis

The developed ANN models (feed forward propagation network) were used for predicting the torque and mechanical power of the rotors are shown in Figure 9. The experimental measurement data of 468 experiments were separated into five inputs and two outputs as shown in Table 3. Thus, the data were divided randomly as 60% of the data were used for training, 20% for validations, while the remaining data 20% were reserved for testing. MATLAB R2015a was used to develop ANN models in this study.

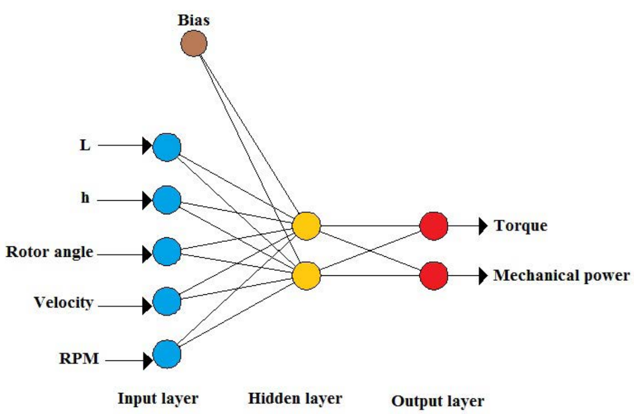

Figure 9. The structure of the ANN architecture for Savonius rotors.

The optimal network topology was determined using only two hidden layer while the number of neurons in this layer and the transfer function of hidden and output layers were determined iteratively by developing several networks. Each ANN was trained using a default stopping criteria of 10000 iterations. Thus, various ANN learning algorithms and transfer functions effects were studied by successful training of the neural network models. A series of topologies was examined in order to decide the highest quality range of neurons inside the hidden layer and these values had been varied from 2 to 20. Moreover, R^2 and mean squared error (MSE) were used as a measure of predictive capability of the network. Hence, the best topology i.e. 5:2:2, which has 15 neurons as the optimum, was chosen due to the values of R^2 of both the training and testing sets, which are approximately ranging from 0.902 to 0.990. Figure 9 shows the structure of the ANN that used to predict the torque and mechanical power.

The regression coefficients R^2 for torque and mechanical power of the rotors are represented in Figure 10. Confirmed that the experimental statistics for torque and mechanical power have a very good correlation with the models for all rotors. Therefore, R-squared values, which are close to unity, highlight the proper fitting of the calculated values.

5. Conclusions

In the present study, 13 new models are designed to improve the performance of classical Savonius rotor. The torque and mechanical power of the rotor are estimated experimentally at different half blade geometries, positions and wind speeds. Furthermore, ANN method is used to predict the torque and mechanical power of the rotors to show their accuracy of this method. The analysis has yielded the following conclusions:

- The study showed that the torque and mechanical power increase with increasing wind speed.
- It is observed that the torque and mechanical power of the model 7 was the highest compared to other models.

Table 3. Limit values for the input and output variables on ANN model

Configuration		Input					Output	
		L [m]	h [m]	Rotor angle [°]	Velocity [m/s]	RPM	Torque [N.m]	Mechanical power [W]
First	Min.	200	200	0	3	156	0.0206	0.344
	Max.	400	400	360	13	407	0.0409	1.678
Second	Min.	200	200	0	3	156	0.0107	0.175
	Max.	400	400	360	13	360	0.0348	1.275

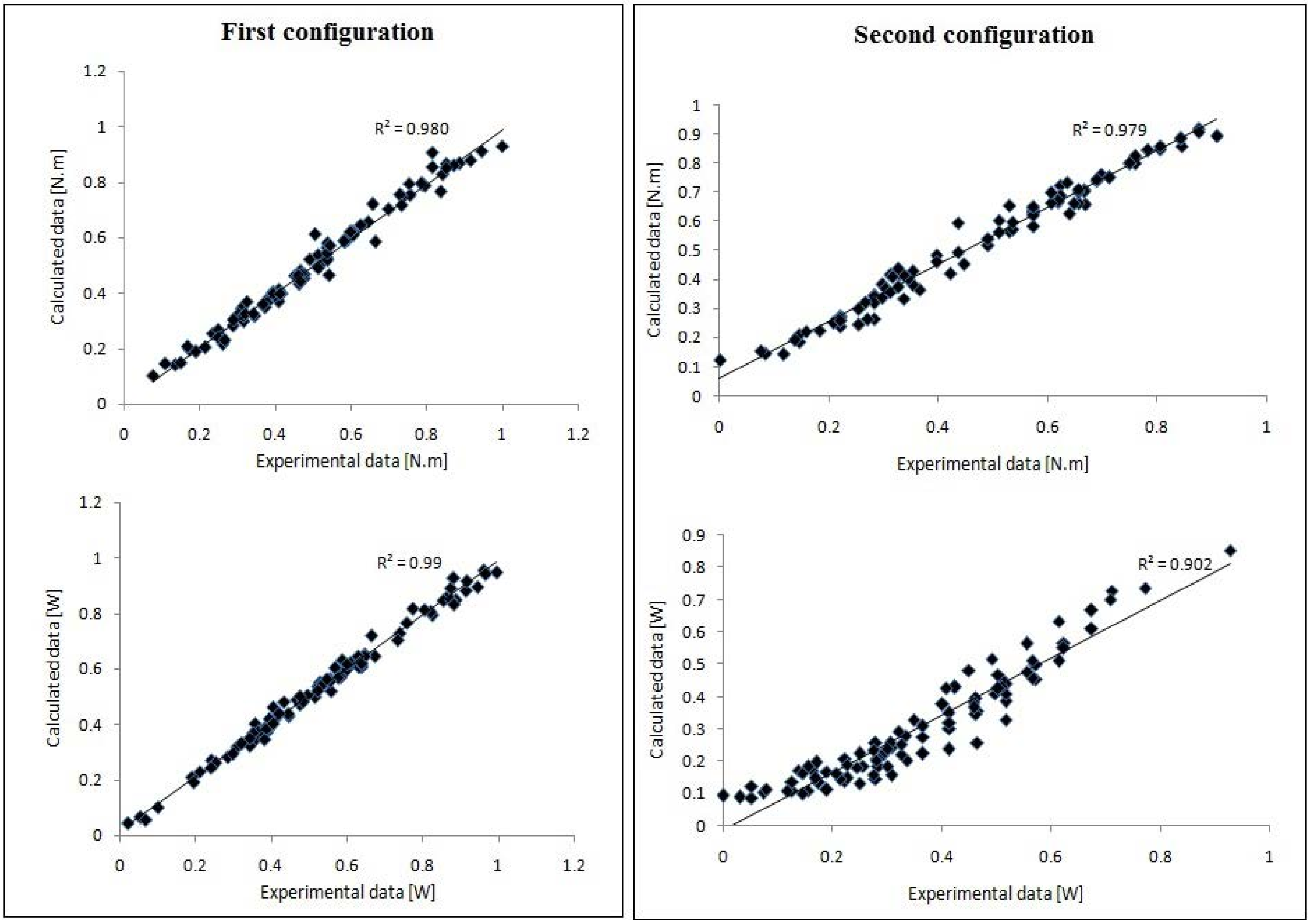

Figure 10. Correlations between experimental values and predicted torque and mechanical power by ANN.

- It is found that mechanical power of the rotors decreases as the height of half blades increases because of the weight of the rotors, which related to blade geometries of the half blades.
- For all the rotors, the static torque values at different rotor positions were positive.
- First configuration of Savonius rotor has the highest mechanical power in comparison to the second configuration and conventional rotors.
- It was also found that the largest half-bladed turbine vibrated violently during testing. This shows that at high wind speeds, turbines with larger blades are unstable. This may reduce the performance of the rotor.
- Based on the R-squared value, ANN method has a high accuracy to predict the torque and mechanical power of the rotors.

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