CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In this section, all of the data collected from all the testing conducted throughout this research were recorded and tabulated. The results including the wind speed values produced when using and without using the wind concentrator, the voltages and currents generated by the DC motor and also, the rotational speed and torque of blade rotors. The results were analyzed and the performances of the blade rotors on each types of testing were discussed in terms of its angular speed (ω), tip speed ratio (TSR), power coefficient (C_P) and torque coefficient (C_T).

5.2 Comparisons of wind speed at different positions

The wind speeds produced by the air compressor were being measured at different positions and the results were tabulated in Table 5.1 below.

Table 5.1: Results of the wind speeds at different positions

Type of testing / No. of measurement	Without wind concentrator at 0 cm distance	Without wind concentrator at 30 cm distance	With wind concentrator
1	0.64	0.86	0.93
2	1.16	0.78	1.04
3	1.24	0.68	1.35
4	1.04	0.58	1.26
5	0.58	0.56	1.37
6	0.60	0.80	0.84
7	1.51	0.76	0.91
8	0.87	0.67	0.84
9	0.76	0.74	0.85
10	0.92	0.66	0.90
Average	**0.932**	**0.709**	**1.029**

The wind speeds were measured before the testing on the blade rotors being conducted. So, there will be no blade rotors used when determining the value of the wind speeds. Based on Table 5.1, when comparing the wind speed produced without using the wind concentrator, it can be observed that the wind speed will decrease as the distance increased which was from 0.932 m/s to 0.709 m/s. However, using the wind concentrator had caused the wind speed to increase approximately 10.41 % from 0.932 m/s to 1.029 m/s compared to the wind speed produced without using the wind concentrator at 0 cm.

5.3 Comparisons of Savonius VAWT blade rotors on different types of testing

5.3.1 Conventional Savonius VAWT

The data collected during the testing on conventional Savonius VAWT were recorded and tabulated in Table 5.2. The data collected during the testing were the measurements of voltage, current, torque and rotational speed (RPM). There are three (3) types of testing conducted; without using wind concentrator at 0 cm and 30 cm distance and also using wind concentrator at concave-blade and center-blade position. The analysis of efficiency of power performance (η), angular speed (ω), tip speed ratio (TSR), power coefficient (C_P) and torque coefficient (C_T) can be done after the measuring of voltage, current, torque and RPM were completed.

Table 5.2: The data collected on the performances of conventional Savonius VAWT at different types of testing

No.	Type of testing	Wind speed, v (m/s)	Voltage, V (mV)	Current, I (mA)	Electrical power, P_E (mW)	Torque, T (mNm)	Rotational speed (RPM)	Angular speed, ω (rad/s)	Mechanical power, P_M (mW)	Efficiency, $\eta = P_E/P_M$	Tip speed ratio, TSR	Power coefficient, C_P	Torque coefficient, C_T
1	Without concentrator at 0 cm distance	0.932	128.300	48.600	6.235	0.283	853.200	89.347	25.264	0.247	8.944	0.680	0.075
2	Without concentrator at 30 cm distance	0.709	105.000	44.800	4.704	0.231	608.800	63.753	14.697	0.320	8.390	0.520	0.070
3	With concentrator at concave-blade position	1.029	134.800	69.700	9.396	0.262	1061.000	111.108	29.124	0.323	10.074	0.710	0.077
4	With concentrator at center-blade position	1.029	117.300	66.800	7.836	0.284	951.600	99.651	28.303	0.277	9.035	0.690	0.076

The bar chart diagram shows the comparison of the electrical power (P_E), mechanical power (P_M), efficiency of power performance (η) and performances produced by the conventional Savonius VAWT in terms of the angular speed (ω), power coefficient (C_P), torque coefficient (C_T) and tip speed ratio (TSR) are shown in Figure 5.1, Figure 5.2, Figure 5.3 and Figure 5.4 respectively.

Based on Figure 5.1, the electrical power can be calculated by using the formula in Equation 2.3. The electrical powers generated by the conventional Savonius VAWT produced the highest which was 9.396 mW at highest wind speed when tested with the wind concentrator at concave-blade position. The voltages and currents generated by the highest electrical power were 134.800 mV and 69.700 mA correspondingly. Meanwhile, the lowest electrical power generated was 4.704 mW when being tested without using the wind concentrator at 30 cm distance at the lowest wind speed. The voltages and currents generated by the lowest electrical power were 105.000 mV and 44.800 mA respectively.

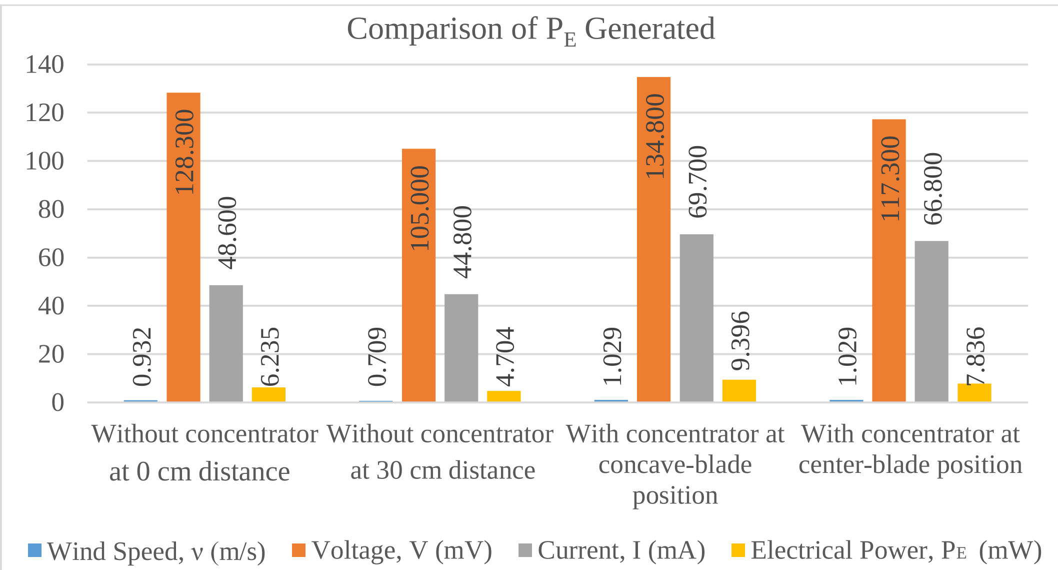

Figure 5.1: Bar chart on the comparisons of electrical power (P_E) generated on conventional Savonius at different types of testing

Based on Figure 5.2, the mechanical power can be calculated by using the formula in Equation 2.7 while the angular speed can be calculated by converting the RPM values into rad/s. The mechanical power generated by the conventional Savonius VAWT produced was the highest which at 29.124 mW at highest wind speed when tested with the wind concentrator at concave-blade position. Although the torque produced on this testing was the second highest among others, the angular speed produced had caused the mechanical power to be generated the uppermost. The torque and angular speed obtained were 0.262 mNm and 111.108 rad/s correspondingly. In the meantime, the lowest mechanical power generated among all four (4) of the testing conducted was 14.607 mW as the torque and angular speed being produced were also the lowest at only 0.231 mNm and 63.743 rad/s. The readings were achieved when tested without the wind concentrator at 30 cm distance at the lowest wind speed.

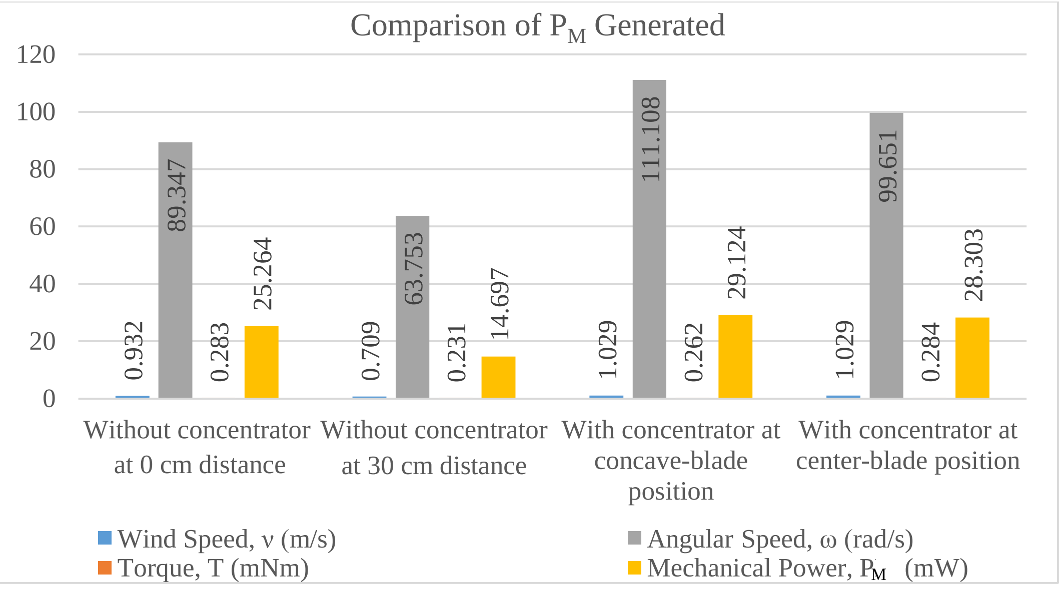

Figure 5.2: Bar chart on the comparisons of mechanical power (P_M) generated on conventional Savonius at different types of testing

The efficiency of the power generated was basically to determine the capability of generating some electrical powers from a mechanical power input to the DC motor. Based on Figure 4.3, the maximum efficiency that can be achieved was 0.323 (32.2%) when tested with the wind concentrator at concave-blade position and the minimum was 0.247 (24.7%) when tested without the wind concentrator at 0 cm distance.

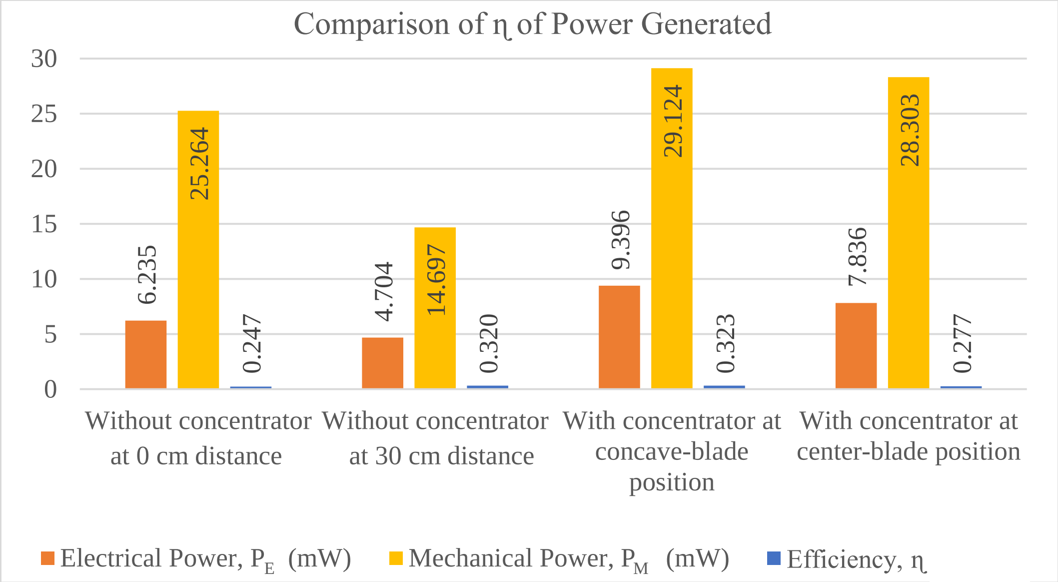

Figure 5.3: Bar chart on the comparisons of efficiency (η) of the power generated on conventional Savonius at different types of testing

The C_p, C_T and TSR were calculated and determined by using Equation 2.4, Equation 2.8 and Equation 2.9. The lowest angular speed produced as can be observed in Figure 5.4 was from the lowest wind speed where it produced TSR at 8.390. The C_p and C_T calculated from the TSR produced were 0.520 and 0.070. Since the wind speed was higher when being tested by using the wind concentrator, the angular speed produced was the highest when it was tested at concave-blade position and the TSR was 10.074. Thus, the C_p and C_T calculated were 0.7011 and 0.077

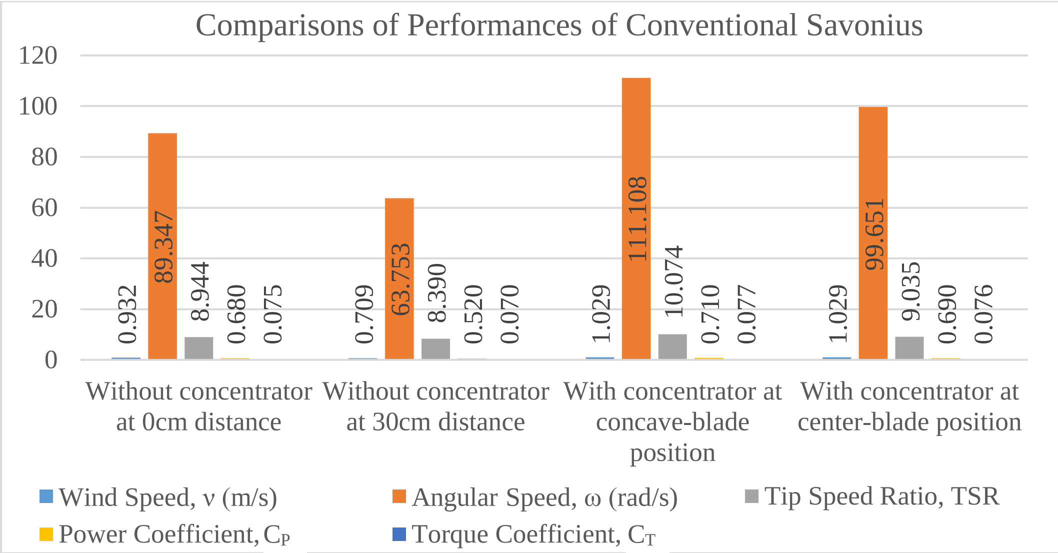

Figure 5.4: Bar chart on the comparisons of performances of the conventional Savonius in terms of angular speed (ω), tip speed ratio (TSR), power coefficient (C_P), torque coefficient (C_T) at different types of testing

5.3.2 Helical Savonius VAWT

The data collected during the testing on helical Savonius VAWT were recorded and tabulated in Table 5.3. The data collected during the testing were the measurements of voltage, current, torque and rotational speed (RPM). There are three (3) types of testing conducted; without using wind concentrator at 0 cm and 30 cm distance and also using wind concentrator at concave-blade and center-blade position. The analysis of efficiency of power performance (η), angular speed (ω), tip speed ratio (TSR), power coefficient (C_P) and torque coefficient (C_T) can be done after the measuring of voltage, current, torque and RPM were completed.

Table 5.3: The data of performances of helical Savonius VAWT at different types of testing

No.	Type of testing	Wind speed, v (m/s)	Voltage, V (mV)	Current, I (mA)	Electrical power, P_E (mW)	Torque, T (mNm)	Rotational speed (RPM)	Angular speed, ω (rad/s)	Mechanical power, P_M (mW)	Efficiency, $\eta = P_E/P_M$	Tip speed ratio, TSR	Power coefficient, C_P	Torque coefficient, C_T
1	Without concentrator at 0 cm distance	0.932	121.200	25.100	3.042	0.195	382.400	40.045	7.802	0.390	4.009	0.210	0.075
2	Without concentrator at 30 cm distance	0.709	86.500	21.800	1.886	0.185	270.500	28.327	5.229	0.361	3.728	0.185	0.070
3	With concentrator at concave-blade position	1.029	152.800	27.400	4.187	0.217	649.600	68.026	14.767	0.284	6.168	0.360	0.077
4	With concentrator at center-blade position	1.029	139.400	28.500	3.973	0.214	623.500	65.293	13.947	0.285	5.920	0.340	0.076

The bar chart diagram of the comparison of the electrical power (P_E), mechanical power (P_M), efficiency of power performance (η) and performances produced by the helical Savonius VAWT in terms of angular speed (ω), power coefficient (C_P), torque coefficient (C_T) and tip speed ratio (TSR) are shown in Figure 5.5, Figure 5.6, Figure 5.7 and Figure 5.8 respectively.

Based on Figure 5.5, the electrical power can be calculated by using the formula in Equation 2.3. The highest electrical power generated by the helical Savonius VAWT was 4.187 mW at the highest wind speed when being tested with the wind concentrator at concave-blade position. The voltages and currents generated by the highest electrical power were 152.800 mV and 27.400 mA correspondingly. Meanwhile, the lowest electrical power generated was 1.886 mW when tested without the wind concentrator at 30 cm distance at the lowest wind speed. The voltages and currents generated by the lowest electrical power were 86.500 mV and 21.800 mA.

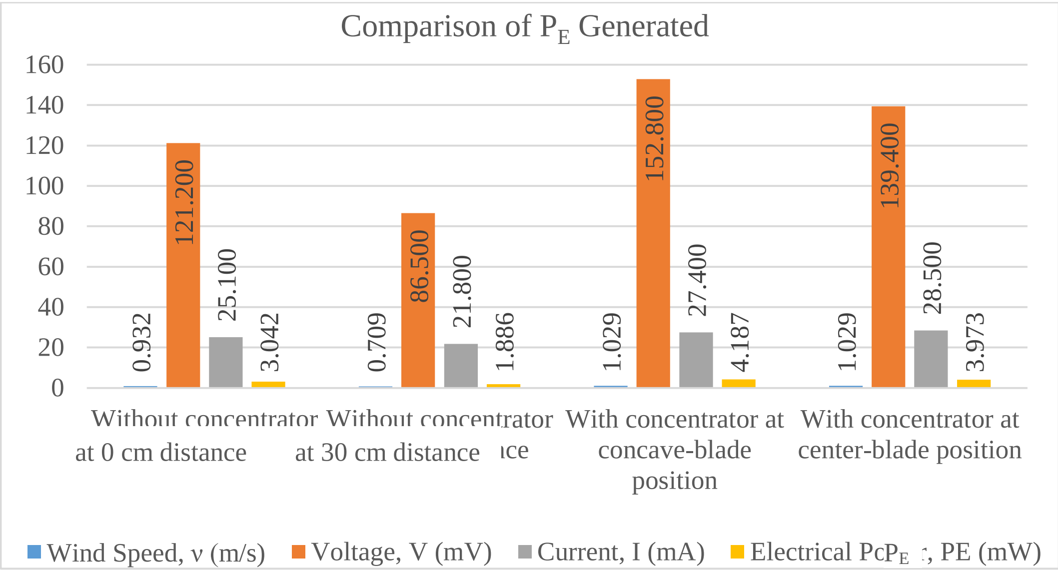

Figure 5.5: Bar chart on the comparison of electrical power (P_E) generated on helical Savonius at different types of testing

Based on Figure 5.6, the mechanical power can be calculated by using the formula in Equation 2.7 while the angular speed can be calculated by converting the RPM value into rad/s. The highest mechanical power was generated by helical Savonius VAWT which was 14.767 mW at the highest wind speed when being tested with the concentrator at concave-blade position. As the torque and the angular speed produced was also the highest, it subsequently had caused the mechanical power to be generated at the uppermost. The torque and angular speed obtained were 0.217 mNm and 68.026 rad/s correspondingly. On the other hand, the lowest mechanical power generated was 5.229 mW as the torque and angular speed being produced were also the lowest only at 0.185 mNm and 28.257 rad/s respectively when the rotor was tested without using the concentrator at 30 cm distance at the lowest wind speed.

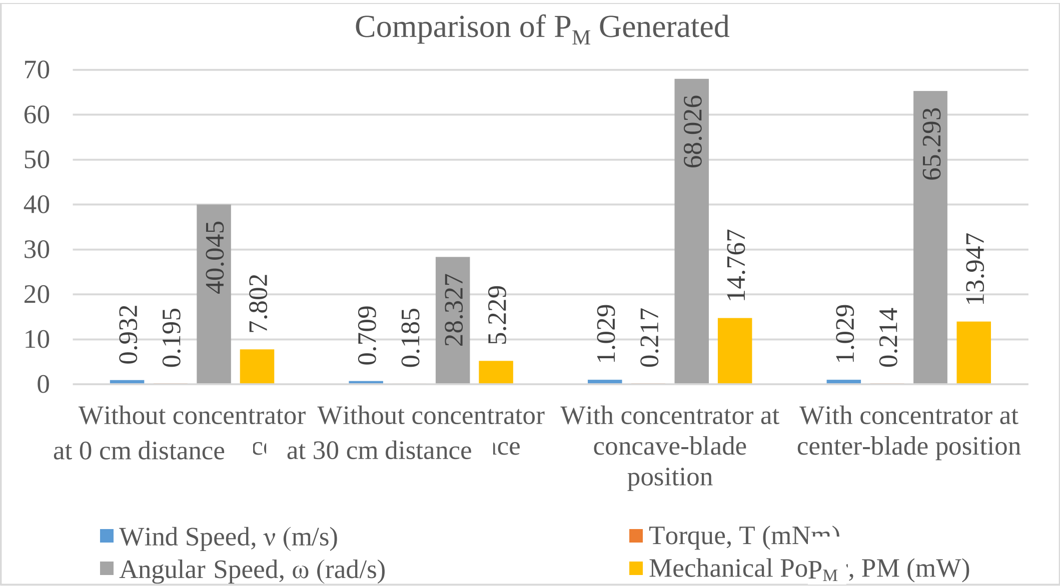

Figure 5.6: Bar chart on the comparison of mechanical power (P_M) generated on helical Savonius at different types of testing

The efficiency of the power generated was basically to determine the capability of generating some electrical powers from a mechanical power input to the DC motor. Based on Figure 5.7, the maximum efficiency that can be achieved was 0.390 (39.0%) when being tested without the wind concentrator at 0cm distance and the minimum was 0.284 (28.4%) when tested with the wind concentrator at concave-blade position.

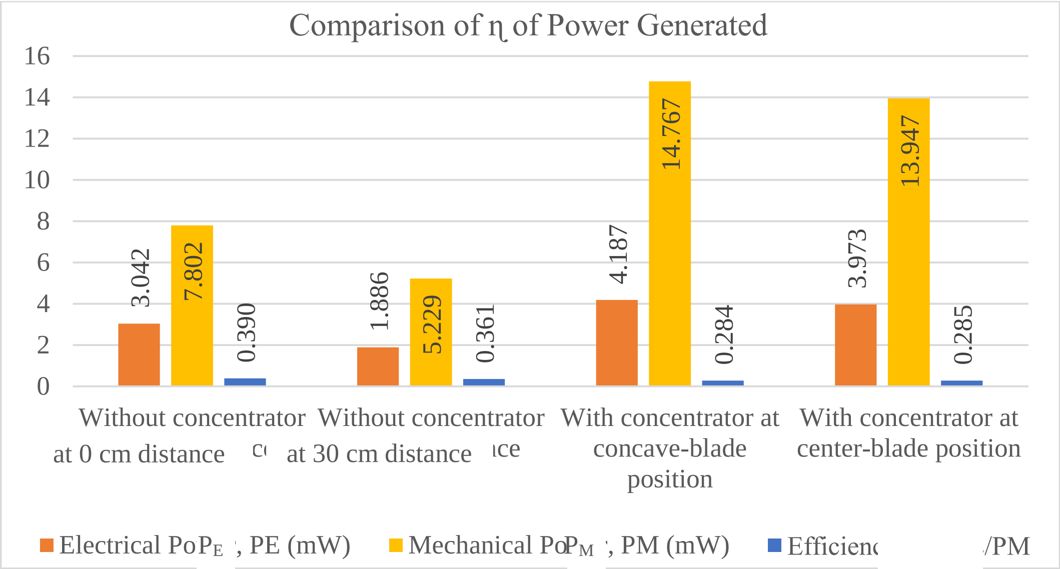

Figure 5.7: Bar chart on the comparisons of efficiency (η) of the power generated on helical Savonius at different types of testing

The C_P, C_T and TSR were calculated by using Equation 2.4, Equation 2.8 and Equation 2.9 respectively. The lowest angular speed achieved based on Figure 5.8 was from the lowest wind speed where it had produced TSR at 3.728. The C_p and C_T obtained from this TSR were 0.185 and 0.070. Since the wind speed was higher when being tested by using the wind concentrator, the angular speed produced was the highest when it was tested at concave-blade position and the TSR was 6.168. Thus, the C_p and C_T can be obtained were 0.360 and 0.070.

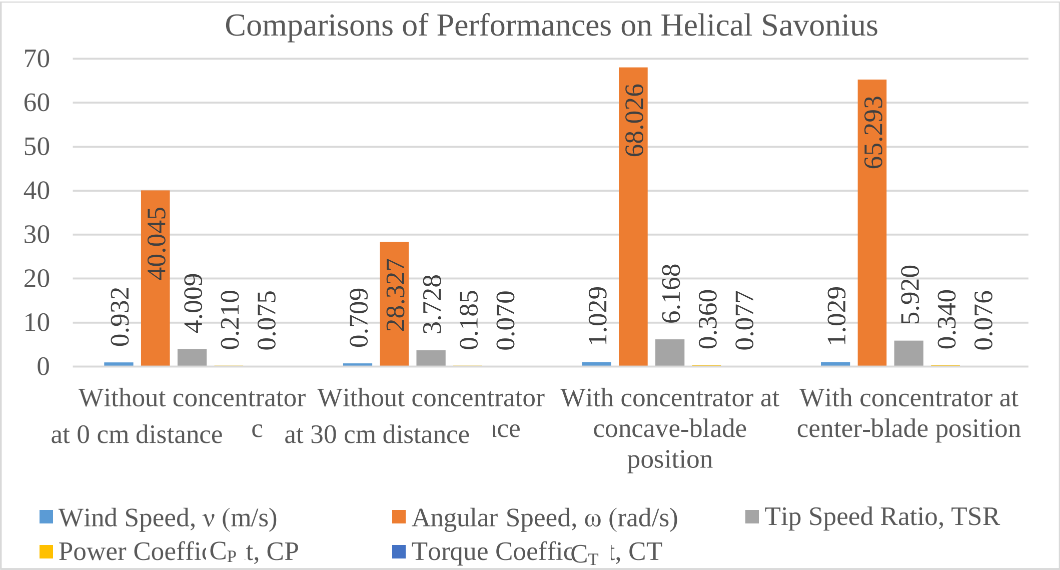

Figure 5.8: Bar chart on the comparisons of performances on the helical Savonius in terms of angular speed (ω), tip speed ratio (TSR), power coefficient (C_P), torque coefficient (C_T) at different types of testing

5.4 Comparisons of performances on Savonius VAWT blade rotors

In order to determine the best performances between the conventional and the helical Savonius VAWT blade rotors, both blade rotors were tested with different wind velocity in a wind tunnel at a range between 0.70m/s to 1.46m/s. The variations of wind speed will produce a different value of TSR, C_P and C_T. However, the maximum value of TSR, C_P and C_T will not be influenced by the wind velocity because of the dependency on the design of the wind turbine alone. The wind velocity will only affect the output power; the operating TSR, C_P and C_T are changing due to the changes in the wind velocity. The graph of C_P against TSR and the graph of C_T against TSR are shown in Figure 5.9 and 5.10 respectively.

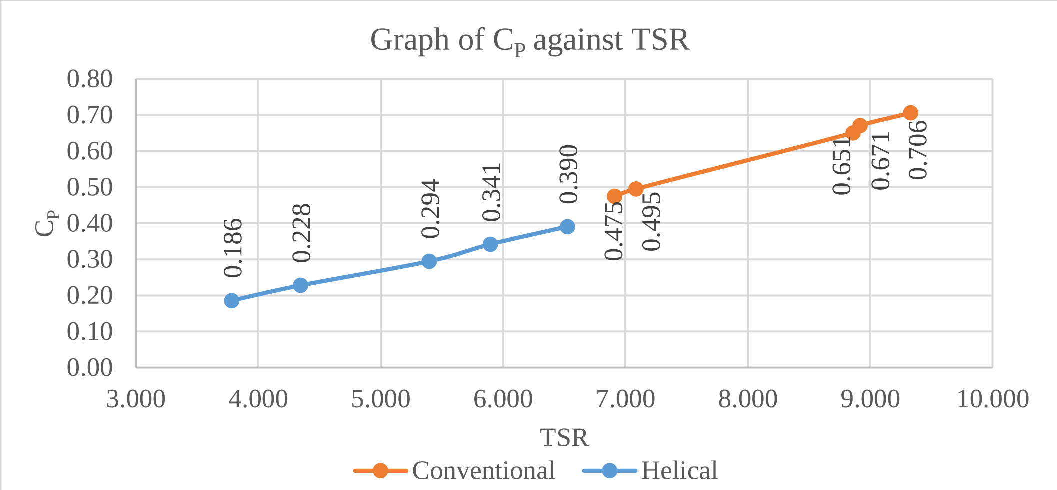

Figure 5.9: The graph of power coefficient (C_P) against tip speed ratio (TSR)

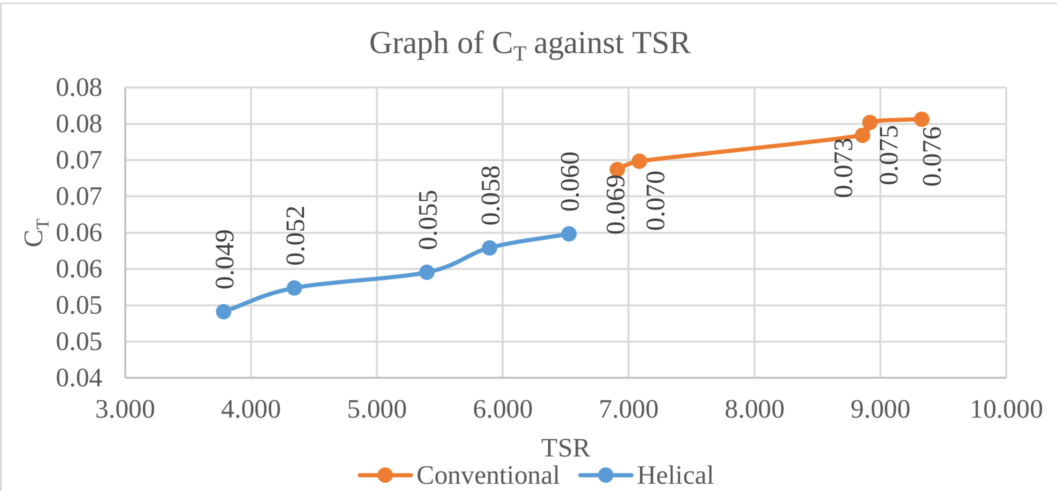

Figure 5.10: The graph of torque coefficient (C_T) against tip speed ratio (TSR)

Based on Figure 5.9 and Figure 5.10, it shows that the value of C_P and C_T increases as the TSR was also increased. The highest performance produced when using the helical Savonius VAWT in terms of C_P and C_T were 0.390 and 0.060 at TSR equals to 6.525. Meanwhile, the conventional Savonius VAWT had produced a better performance compared to the helical Savonius VAWT. The highest C_P and C_T being produced were 0.706 and 0.076 at the highest TSR which equals to 9.329. In conclusion, the best performance was obtained by using the conventional Savonius VAWT as it can operates better at low wind potential compared to the helical Savonius VAWT.

5.5 Discussions

The average wind speed in Table 5.1 showed that the wind speed drops when the distance of the rotor increases from the wind energy source produced by the air compressor. The percentage of wind speed which dropped from 0.932 m/s to 0.709 m/s was approximately 23.93 %. Meanwhile, when using a wind concentrator, the wind speed had risen from 0.932 m/s to 0.709 m/s which made the percentage of wind speed increased for approximately 10.41 %. The chosen initial wind speed was 0.932 m/s because the wind concentrator was installed in front of the air compressor where the air flows out of it which also means that the distance was equals to 0 cm. Based on the Bernoulli's theory in Equation 2.10, the theoretical wind speed produced by the wind concentrator are:

$$\rho_{a1} A_1 v_1 = \rho_{a2} A_2 v_2,$$

where $\rho_{a1} = \rho_{a2}$ *assume the air density constant*

$$v_2 = \frac{A_1}{A_2} v_1 = \frac{0.600 \times 0.600}{0.375 \times 0.095} \times 0.932 = 9.418 m/s$$

When comparing the theoretical wind speed with the output wind speed, the different between both wind speeds is 10.93 %. Some large amount of wind potential lost can be explained as follows:

a. During the installation of the wind concentrator, it did not really in a static position as the wind from the air compressor might had forced the wind concentrator to be pushed for a little bit.

b. As the structure of the wind concentrator is angular-shaped, there are some edges at the wind concentrator which can act as the wind resistors which caused the wind speed to drop.

Based on the data tabulated in Figure 5.1, Figure 5.2, Figure 5.5 and Figure 5.6, the wind potential and angular speed had some effects on the generation of mechanical and electrical power. As the wind potential risen, it had influenced the angular speed to rotate the Savonius VAWT rotors and the shaft of the DC motor faster. Hence, it had caused more powers generated.

The efficiency of power was the ratio of the electrical power to the mechanical power. Generally, the highest mechanical and electrical power was the ones produced by the conventional Savonius VAWT and being tested by using the wind concentrator at concave-blade position which were 9.396 mW and 29.124 mW respectively. The efficiency at this condition was 0.323 (32.2%). It was the highest efficiency produced among the others. In Figure 5.3, it can be observed that the efficiency increases when the wind speed and angular speed was also increased. However, when the helical Savonius VAWT was tested with the same type of testing, the final results produced were vice versa. The increases in wind speed and angular speed had caused a decreasing in the power efficiency. Therefore, the highest efficiency produced by the helical Savonius VAWT was 0.323 (32.2%) when tested without using the wind concentrator at 0 cm distance.

As the TSR is related to the angular speed and the wind speed, this project had proved that the increasing of angular speed influenced the increment in TSR. The lowest angular speed was produced at the lowest wind speed when tested by without using a wind concentrator at 30 cm distance. Although the wind speed was higher when using wind concentrator, the difference in testing positions of the Savonius VAWT blade to the outlet of the wind concentrator had produced some different angular speeds. The highest angular speed produced was when being tested at the concave-blade position and it also had produced the highest TSR for both of the rotors. The TSR achieved by the conventional Savonius VAWT was 10.074 while for helical Savonius VAWT was 6.168.

Based on all types of testing being conducted on both of the Savonius VAWT rotors, the lowest performances were generated during the testing without using the wind concentrator at 30 cm distance. The wind speed produced by the air compressor was the lowest at 30 cm distance. The wind speed reduces as the distance increases which may cause by the wind friction by the surrounding air as the wind energy with a higher pressure tends to diverge towards a lower pressure air. Besides, the air from the surroundings may also cause a negative torque produced on the Savonius VAWT rotors which will then reducing the angular speed and affecting all of the performances of the rotors.

The performances of Savonius VAWT rotors was proven to be improved when tested using the wind concentrator as the wind speed was amplified during the process. However, a different position of the blade can affect the performance. This project observed and analyzed that when the blade was placed at the concave-blade position from the outlet of the wind concentrator, the performance was higher compared to when the blade was placed at the center-blade position. It is because the wind concentrator was focused on the direct airflow only over the concave blade which will cancelled out the negative moments produced by the action of the wind on the convex part. It also offers the possibility of increasing the movement and efficiency of the rotor.

5.6 Summary

In conclusion, the best performances were produced by the conventional Savonius which gave some higher performances in every testing conducted compared to the helical Savonius. It also can be concluded that the increasing of wind speed will influence the performance on both Savonius VAWT blade rotors. As the air velocity increases, the voltage, current, angular speed and torque of the rotors will also increase. Therefore, the higher the value of these parameters will subsequently causing the performances in terms of TSR, C_P, and C_T also increases.