



Performance Investigation of Darrieus Wind Turbine with Adjustable Rotor Diameter

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Abstract: Wind energy is one of the popular sources of renewable energy that have largely been utilized around the globe. This energy converted kinetic energy into mechanical and electrical energy through application of wind turbine. Generally, wind turbines can be classified into two types which are horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). This paper is concerned with the performance of Darrieus wind turbine with adjustable rotor diameter. This research is conducted to investigate how the rotor diameter of the Darrieus wind turbine affected its performance by analyzing and comparing the power coefficient and torque coefficient produced. In this research, the Darrieus wind turbine has been designed for purposes of simulation process in QBlade software. The actual design of Darrieus wind turbine with adjustable rotor diameter is designed in Solidworks software while the simulation study in QBlade software experimented every 100 mm interval diameter from 500 mm to 1000 mm. The findings from this study shows that different tip speed ratio, TSR require different rotor diameter to produce the highest C_p and C_m . The lower value TSR mostly suited at 500 mm rotor diameter while at higher TSR, 1000 mm rotor diameter give the best performance for the Darrieus wind turbine. Even though the expected performance from simulation study shows positive value of C_p and C_m , there are also some parts of the graph especially from smaller rotor diameter simulation shows negative values of C_p and C_m at certain TSR. Thus, it is necessary to make some improvements to the design and simulation parameters so that it can produce positive and higher values of C_p and C_m to ensure the wind turbine has better performance.

Keywords: Performance Investigation, Darrieus Wind Turbine, Rotor Diameter

1. Introduction

The amount of energy consumption in modern civilization has become the symbol of development in industrialization and standard of living. Nowadays, the source of world's energy is almost ninety percent coming from the combustion of fuels such as petroleum oils, natural gas and coal. People use fossil fuels to nearly everything they needs, for examples, running factories, powering vehicles and also to produce electricity. However, the energy resources from earth's fossil energy are limited and the peak of the global production of petroleum will come in the next decades. By enhancing

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the renewable energy utilization technology, more cost-effective and reliable low carbon energy sources will contribute to fulfillment of the energy policies objectives in the world. It is a well-known fact that the renewable energy is safe and friendly to the environment as it can prevent the climate change because of the absence of emission detrimental to the environment. One example of renewable energy that is very useful and always presence in the surrounding is wind energy. The wind energy can be extracted using wind turbines by converting wind energy to mechanical energy. The mechanical energy is then converted to electrical energy wind turbines can be divided into two types, horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). Normally, HAWT is being used for heavy-duty commercial purposes and applied at large scales while VAWT is specifically installed near the ground and classified as a low altitude wind turbine. This makes the installation cost of VAWT is lower compare to the installation cost of HAWT. Basically, the wind turbine's operation depends on the velocity of the wind. Without wind, a wind turbine cannot be operated.

2. Methods

This study is done by simulation process that is conducted in QBlade software to evaluate the performance of the designed wind turbine. The aim is to find the highest power coefficient, C_p and torque coefficient, C_m produced from different rotor diameter at different tip speed ratio, TSR. Therefore, some steps have to be taken in this study to undergo the simulation process.

2.1 Vertical axis wind turbine (VAWT) Rotor blade Design

Table 1 explains the design Darrieus wind turbine that comes with three numbers of airfoils and NACA 0015 has been selected as the turbine's airfoil. Based on Figure 1, in the VAWT rotor blade design module in QBlade software, NACA 0015 airfoil is set at a height of 778 mm and each blade is divided into 6 segments for all three blades. Meanwhile, the diameter for actual or first simulation study is set at 500 mm rotor diameter. The simulation study is conducted by experimenting every 100 mm interval of rotor diameter from 500 mm to 1000 mm.

Table 1: Geometrical features of Darrieus vertical axis wind turbine.

Design	Orientation	Propulsion	Blades Airfoil	Number of blades airfoil
Darrieus	Vertical axis wind turbine (VAWT)	Lift and drag	NACA 0015	3

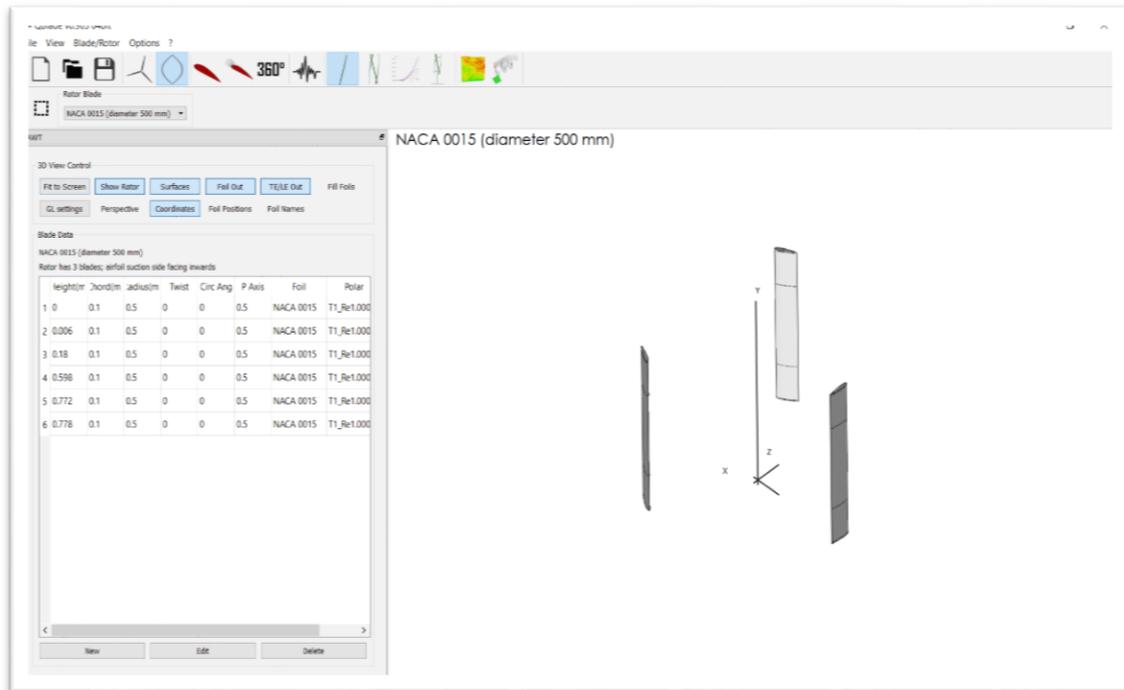


Figure 1: Darrieus VAWT rotor blade design in QBlade software interface

2.2 Rotor Double Multiple Streamtube (DMS) Simulation

Based on Figure 2, the parameters have to be set before starting the simulation process in rotor DMS module of QBlade software. In this case study, the default parameters have been applied and value of TSR been experimented from low to moderate TSR starting from 1 to 6. TSR Delta, which is the difference of TSR value is set at 0.5, that will bring in total of eleven points of TSR from 1 to 6 in each rotor diameter that been experimented. The same parameters have been set and applied for every rotor diameter in this simulation study.

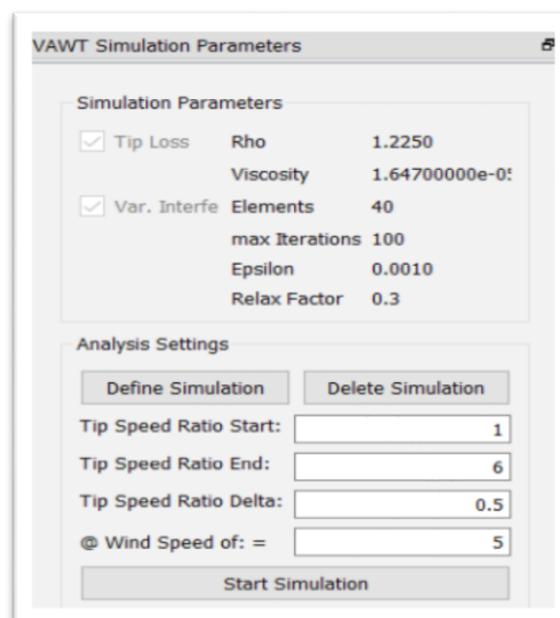


Figure 2: VAWT simulation parameters in rotor DMS simulation module QBlade software

2.3 Adjustable Diameter Darrieus Wind Turbine Design

The overall design of the Darrieus vertical axis wind turbine with adjustable rotor diameter is shown in Figure 3. The designed wind turbine is in isometric view of Solidworks software interface at its smallest diameter of 500 mm rotor diameter. The designed wind turbine consists of several parts including the stand, motor, connector, NACA 0015 airfoil and sets of rectangular shafts.

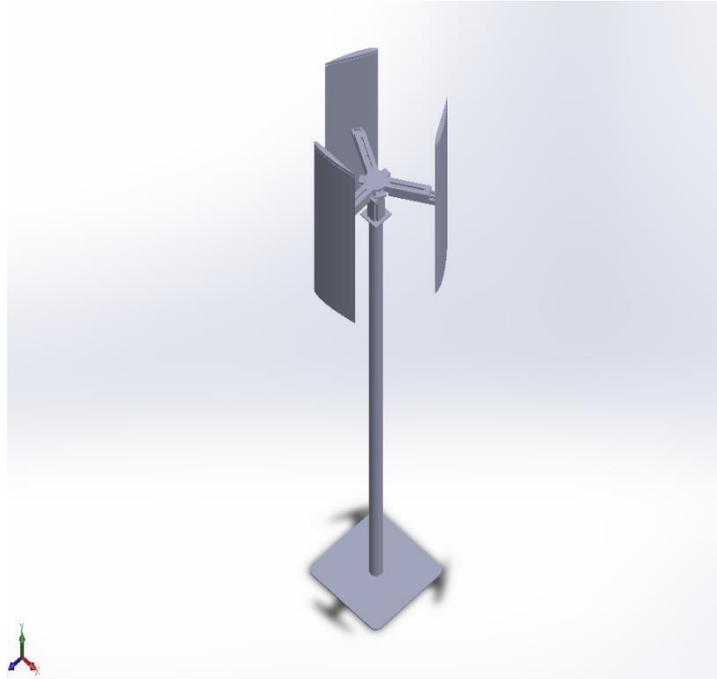


Figure 3: Adjustable wind turbine model designed in Solidworks software

The most important part of this wind turbine is the airfoil. The designed wind turbine is a three-bladed wind turbine that comes with NACA 0015 airfoil. The airfoil body resemble the symmetrical shape of NACA 0015 airfoil has been built to fit two mirror airfoils that are placed on both top and below of each three airfoil body. After that, the rectangular shape shaft is been slanted into the centre of airfoil body of wind turbine to hold the airfoil when the wind turbine is operating. The rectangular shafts are then connected to another set of rectangular shafts that were called the main shafts. This is an important part where the movement of increasing and decreasing the rotor diameter happen along these main rectangular shafts. All these main shafts are then been hold into a connector. A connector is a part where it has a rounded-shape at its centre and also consist of three rectangular shape shafts to connect each one of them to the main shafts. It also works to cover the motor that is placed below the connector. Lastly, the stand works to hold the wind turbine upright at a height and complete the assembly of Darrieus VAWT with adjustable rotor diameter. Figure 4 shows the parts of assembly for Darrieus wind turbine.

ITEM NO.	PART NUMBER	QTY.
1	Mirrorairfoil02-00	3
2	Motor Assembly	1
3	airfoil01-00	3
4	airfoil02-00	3
5	airfoil03-00	1
6	airfoil04-00	1
7	airfoil05-00	3

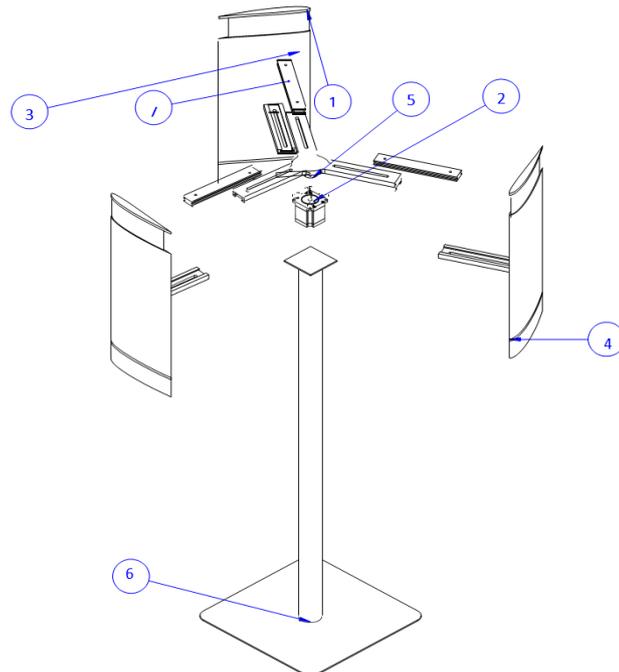


Figure 4: Parts of Assembly for Darrieus wind turbine

The mechanism of the wind turbine to change its diameter is by channelling the rectangular shape shaft built-with the airfoil body, along the groove or canal at the main shaft. This will either increase or decrease the rotor diameter based on the wind surrounding and its TSR value. The rectangular shafts will move towards the centre of wind turbine to become a smaller rotor diameter wind turbine, and moving further from the centre to make a bigger diameter wind turbine. Figure 5 shows the opening of rotor diameter and airfoils height of wind turbine.

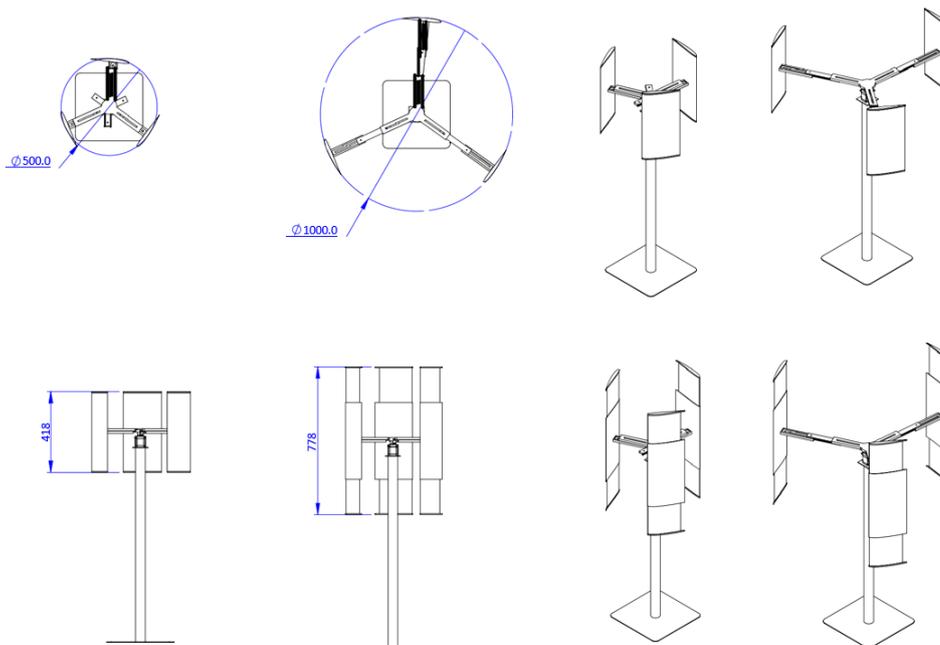


Figure 5: Opening of rotor diameter and airfoils height of wind turbine

3. Results and Discussion

Two graphs' findings for this study, TSR against power coefficient, C_p and also TSR against torque coefficient, C_m will be shown from the simulation process run in QBlade software. The findings and values of each C_p and C_m from every rotor diameter have been collected and analysed.

3.1 Validation

3.1.1 QBlade simulation results against experimental and numerical results (NACA 0021)

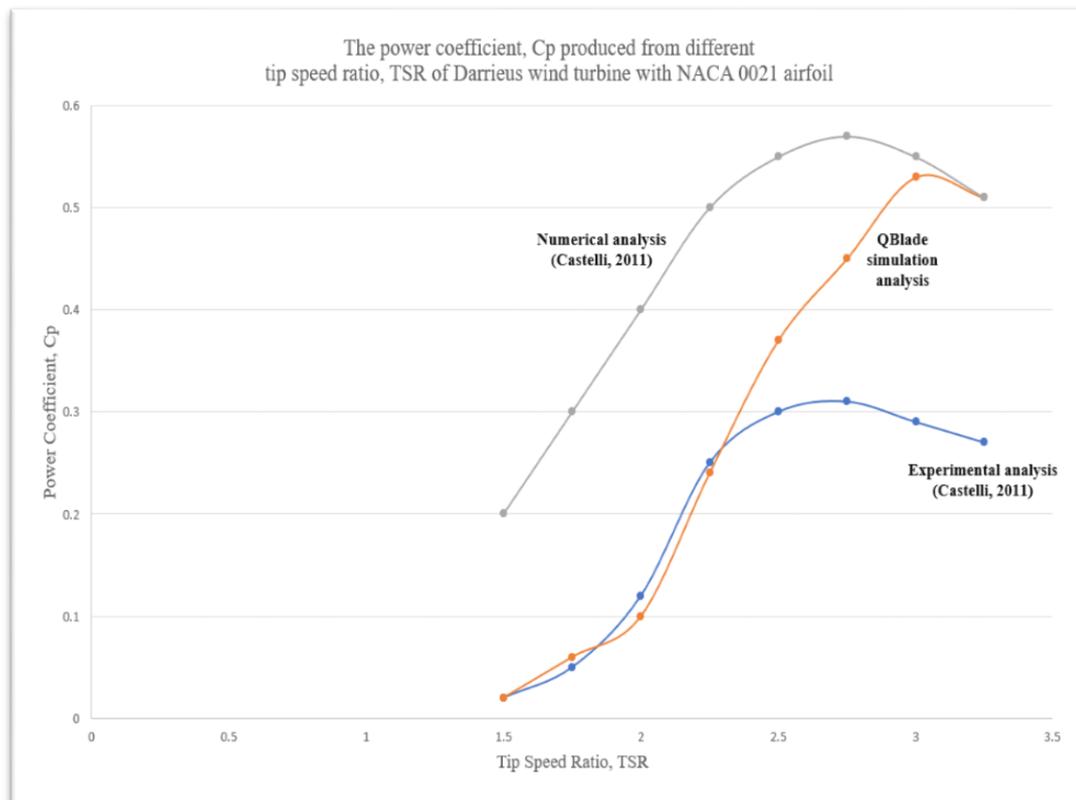


Figure 6: Comparison QBlade simulation analysis with experimental and numerical analysis

The graphs and results comparison between the experimental and numerical analysis by [21] with the QBlade software simulation analysis was shown in Figure 6. The graph curve of the QBlade simulation analysis able to replicate the shape from both numerical and experimental analysis. However, comparing QBlade simulation analysis with the experimental analysis, the graph and results shows they only match at low TSR and overshoot at higher TSR. There is an increasing difference between the value of power coefficient, C_p produced starting from TSR 2.5 until TSR 3.0, where the biggest difference in value of C_p is 0.2 at TSR equal to 3.0.

However, taking into considerations, the experimental results by [21] was an average number of C_p which means the experiment has been done in several sets or trials. Therefore, there might be some difference in actual value of C_p in those different sets or trials, that contributes to the shape of the experimental graph analysis. In conclusion, the differences are still acceptable as there is no bigger difference than 0.2 C_p for both graph and most importantly the shape for both graphs are more of the same.

On the other hand, comparing the QBlade simulation analysis with the numerical analysis, the graph and results shows otherwise, where both graphs have bigger difference of C_p value at low TSR

and the difference become smaller at higher TSR. The biggest difference in value of C_p between the QBlade simulation analysis and numerical analysis is 0.3 at TSR equal to 2.0.

3.1.2 QBlade simulation results against CFD computational results (NACA 0015)

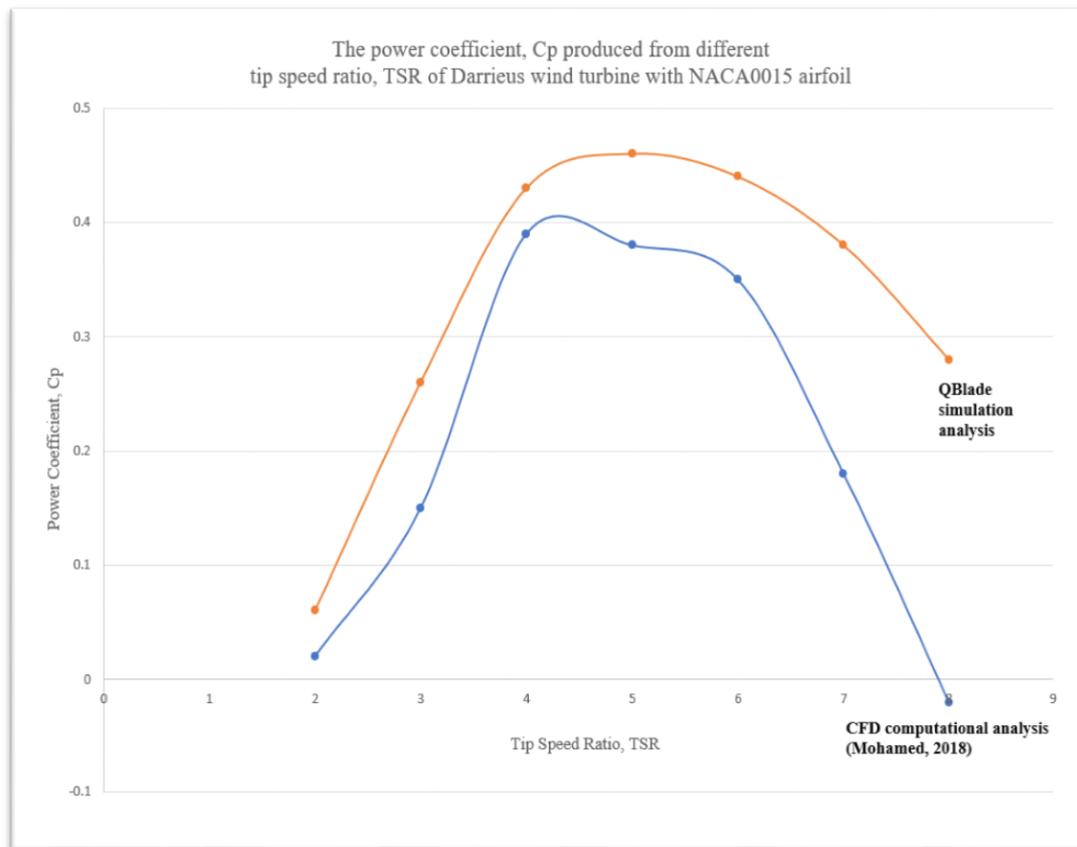


Figure 7: Comparison of QBlade simulation analysis with CFD computational analysis

The graph and results comparison between the CFD analysis in [13] and QBlade software simulation analysis was shown in Figure 7. The result obtained is appealing as both graphs has almost the same shape and curves. Both graphs peak between TSR 4 to 5 with the difference of 9.3% between the peak C_p . Plus, the differences in value of power coefficient, C_p between those two analyses are very little and neglectable. One difference between the two graphs is the wider operating range of TSR in QBlade simulation analysis compare to the CFD computational analysis. However, if the graph is expandable, there are not much difference in TSR value before both graphs reach zero (0) C_p which is around 2 TSR difference.

In conclusion, the simulation results of NACA 0015 airfoil in QBlade simulation analysis are in good agreement with other method of analysis from different published findings. This can ensure that the QBlade software provide a good and trusted result to evaluate the performance of Darrieus wind turbine with adjustable rotor diameter for this study.

3.2 Evaluation of wind turbine performance

The yellow-highlighted value in Table 2 and Table 3 show the highest value of C_p and C_m produced from different rotor diameter at different TSR. Meanwhile, Figure 8 and Figure 9 show the C_p and C_m graphs have been built or drawn using the data and values from their respective table. Each rotor diameter produces different graphs curves. In addition, the same rotor diameter is also producing different shape and curves of C_p and C_m graphs.

Table 2: Value of Cp produced from different rotor diameter of Darrieus VAWT

Tip Speed Ratio, TSR	Rotor Diameter, D (mm)					
	500	600	700	800	900	1000
1.0	0.008	0.008	0.007	0.006	0.005	0.005
1.5	0.085	0.065	0.054	0.047	0.041	0.037
2.0	0.320	0.283	0.240	0.200	0.172	0.152
2.5	0.503	0.486	0.488	0.468	0.433	0.395
3.0	0.499	0.491	0.468	0.464	0.478	0.481
3.5	0.252	0.490	0.468	0.445	0.438	0.442
4.0	0.109	0.238	0.384	0.427	0.412	0.410
4.5	-0.038	0.084	0.188	0.309	0.382	0.376
5.0	-0.198	-0.077	0.043	0.156	0.245	0.338
5.5	-0.368	-0.228	-0.112	0.009	0.105	0.200
6.0	-0.570	-0.403	-0.271	-0.150	-0.042	0.006

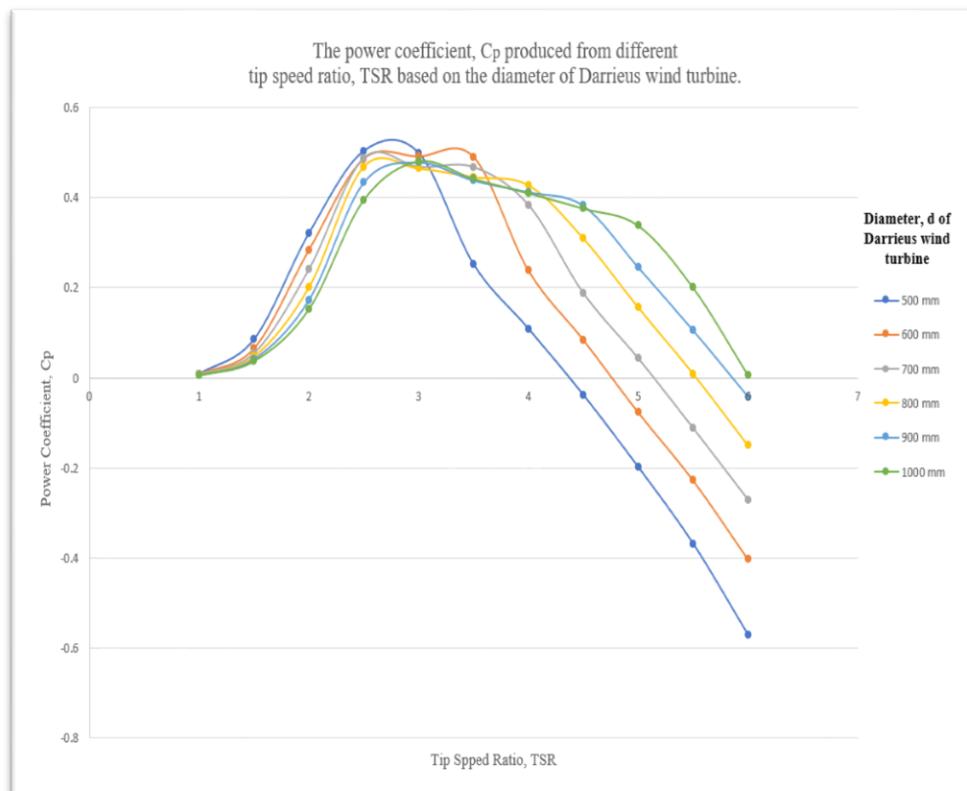


Figure 8: The graphs of Cp produced from different TSR based on the rotor diameter of Darrieus VAWT

Table 3: Value of C_m produced from different rotor diameter of Darrieus VAWT

Tip Speed Ratio, TSR	Rotor Diameter, D (mm)					
	500	600	700	800	900	1000
1.0	0.009	0.008	0.007	0.006	0.005	0.005
1.5	0.057	0.043	0.036	0.031	0.028	0.025
2.0	0.160	0.141	0.120	0.100	0.087	0.075
2.5	0.201	0.194	0.195	0.188	0.173	0.158
3.0	0.167	0.163	0.157	0.155	0.160	0.160
3.5	0.072	0.140	0.133	0.128	0.125	0.127
4.0	0.028	0.060	0.096	0.108	0.102	0.102
4.5	-0.009	0.019	0.042	0.069	0.085	0.083
5.0	-0.040	-0.016	0.010	0.031	0.050	0.068
5.5	-0.068	-0.042	-0.020	0.002	0.020	0.037
6.0	-0.095	-0.068	-0.045	-0.025	-0.008	0.010

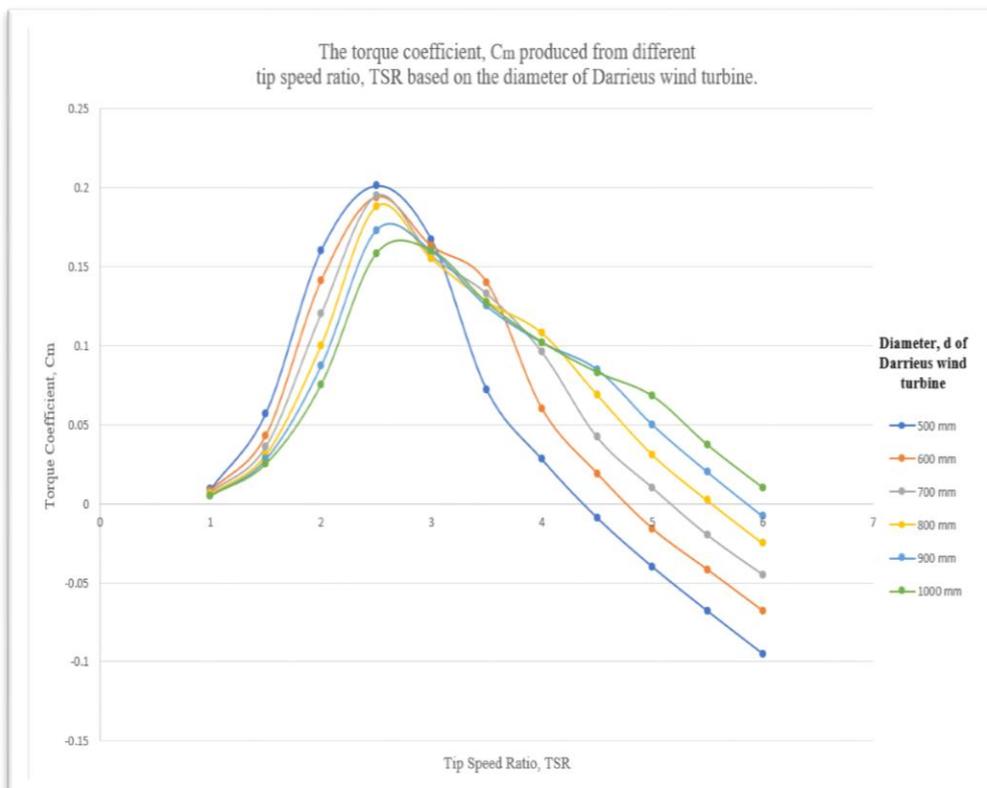


Figure 9: The graphs of C_m produced from different TSR based on the rotor diameter of Darrieus VAWT

3.3 Expected performance of adjustable wind turbine

Based on the findings from evaluation of wind turbine performance, the best efficient wind turbine that can operate at their best depending on the rotor diameter has been known. Different rotor diameter works the best in certain TSR to produce the highest value of power coefficient, C_p and torque coefficient, C_m . The graphs in Figure 10 and Figure 11 show the highest C_p and C_m produced from each TSR and their best rotor diameter.

The results for best rotor diameter at each TSR work the same for both C_p and C_m graphs. At low TSR from 1 until 3, the 500 mm rotor diameter produces the highest value of C_p and C_m . As the TSR increase to 3.5, the best suited rotor diameter is 600 mm. After that, the 800 mm and 900 mm rotor diameter work perfectly in producing highest C_p and C_m at TSR 4 and 4.5 respectively. Lastly, the biggest rotor diameter in this simulation study, which is 1000 mm is producing highest C_p and C_m values from TSR 5 to 6.

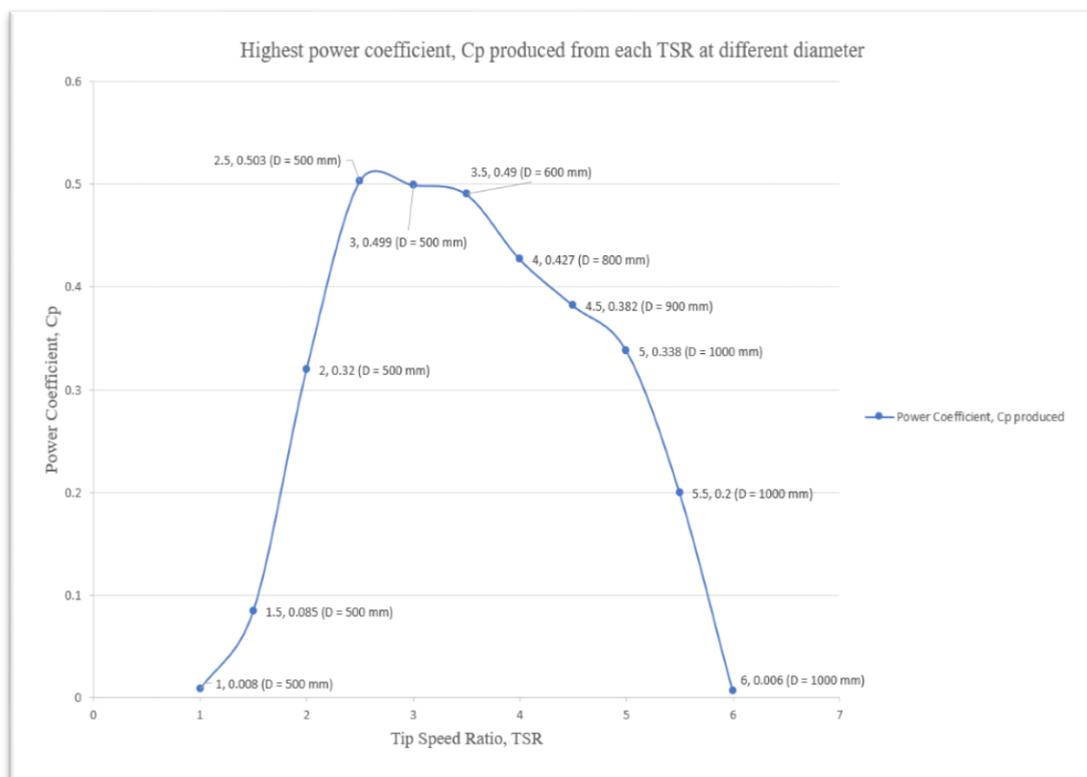


Figure 10: The highest C_p produced from each TSR at different rotor diameter

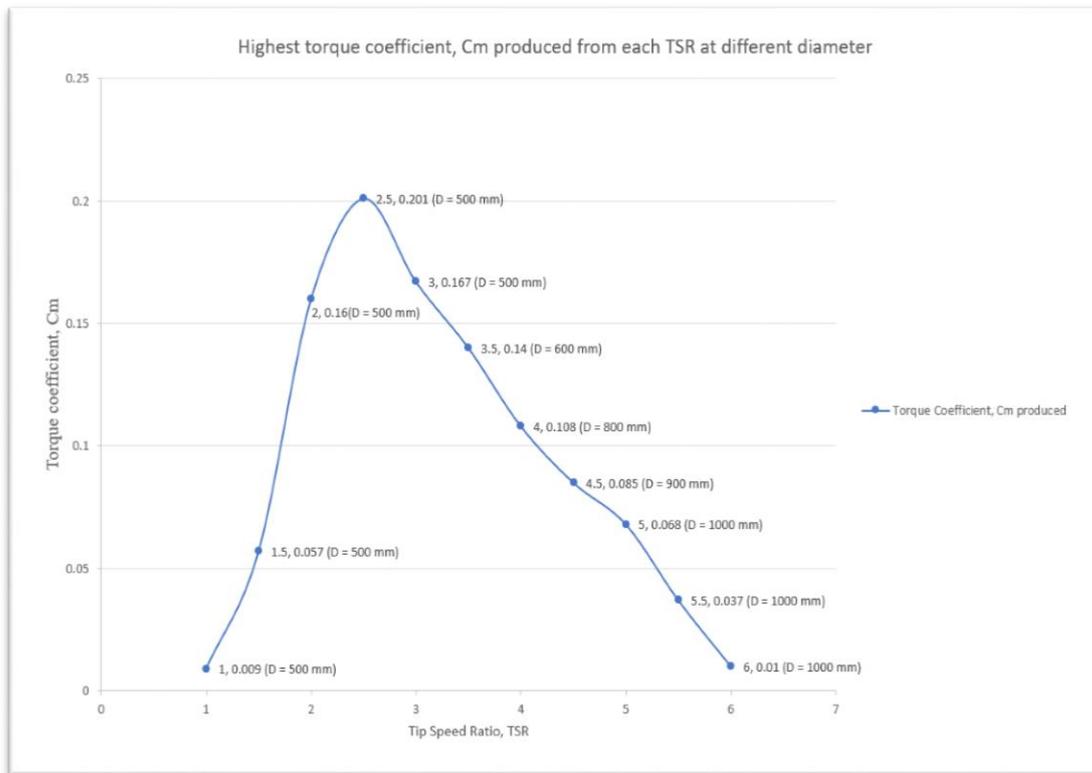


Figure 11: The highest C_m produced from each TSR at different rotor diameter

4. Conclusion

The best performance and most efficient wind turbine are the one that produced the highest value of C_p and C_m in every interval rotor diameter from the simulation study in rotor DMS module of QBlade software. Based on the results obtained, every rotor diameter except the 700 mm rotor diameter plays a huge part to make an efficient wind turbine. Every TSR have a suitable rotor diameter where it will have the highest C_p and C_m when been set at the right length of rotor diameter in this study. Based on the simulation result, the proposed adjustable wind turbine is expected to produce the highest C_p and C_m as its diameter adjusted at each TSR. Therefore, theoretically every time this wind turbine is operating, it will operate at its best performance and efficiency.

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