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Optimization of the Helical Wind Turbine Blade

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Abstract: The application of wind energy is not a foreign thing, especially in this era of unlimited globalization where humans need green energy to run their daily lives. Therefore, the idea of evaluating the aerodynamic performance of the helical wind turbine blade designs is the major factor for the start-up of this project. Besides, the scope of the study for this project is to develop helical wind turbine CAD models by using SolidWorks software and also perform CFD simulation for the helical wind turbine design by using ANSYS software. This project involves combining the process of Computer-Aided Design (CAD) and Computational Fluid Dynamics (CFD). Computer-Aided Design (CAD) is used to design the wind turbine blade and Computational Fluid Dynamics (CFD) is used to simulate the wind turbine blade. This project is carried upon few blade characteristics tested such as blade length and blade angle and from the simulation, the final degree of torque could be obtained thus enable the power generated to be calculated by using a mathematical equation of power. The results for the best blade angle show that 45 Degree blades produce the highest power. Next, the results for the best blade length show that a 100 cm blade produces more power compare to the other. The 45 Vertical Blade produced less power compare to the commercial design which is 177.96 Watts in the transverse direction but proved more efficient in the longitudinal direction as it generates the power of about 475.76 Watts.

Keywords: Computational Fluid Dynamic (CFD), Computer-Aided Design (CAD), Wind turbine, Wind energy

1. Introduction

By the year 2025, the Malaysian government with the collaboration of Malaysian renewable energy experts already targeted achieving 20% of renewable energy penetration. By the year 2019, Malaysia only achieving about 2% of renewable energy penetration which can be considered as low because our country still depending on non-renewable energy such as natural gas and coal [4]. Wind is known as renewable energy which means the energy that will never disappear from our world same as water and the sun. Wind can be converted into energy by using windmills or wind turbines. In a windy country such as Netherland, they have a lot of windmills so that they will have enough energy to power up their homes, factory, and shopping complex. The wind has been utilized as energy for 3000 years ago. People use wind energy back then mainly at cruise ships and farms. The ships that use wind energy can travel thousands of nautical miles more than the traditional ships where a lot more man energy is needed to sail. The farm that used wind energy can spread the grain much more efficient compare to the traditional ways as it has a lot of limitations. The design of the wind turbines changed a lot about 3000 years later with a more efficient design applied. In the early 90s, American engineer Charles Brush design a direct flow windmill generator that can produce 12 kW of power [1,2].

Be that as it may, there still less exposure to people in the 20th century about the utilization of wind energy. The technology limitations may be one of the reasons why the utilization of wind energy is not so much needed by them. One striking advancement is during 1941, Smith-Putnam built a large wind turbine that can produce power of about 1250 kW. The specifications of that wind turbine are to have a steel rotor with 53 m in a distance across, equipped with full-range pitch control, and fluttering sharp edges to reduce the load force. That wind turbine remains the largest wind turbine in the world for about 40 years [3-5]. The new enthusiasm for wind vitality in recent years has prompted the effective improvement of business wind turbines of expanding unit size.

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The current age ranges from 500 kW-l MW. These wind turbines are a specialized accomplishment in that they have a long working life, permitting long haul support agreements and business protection to be given at good terms [6]. They are a monetary achievement in that new wind turbines at blustery areas, for example, the north-western waterfront locales of Europe are serious with the shopper cost of modem coal-power age, which in a few European nations incorporates generous vitality and ecological charges.

The chance for utilization of the wind turbine in Malaysia is quite low because of our weather. If one day, the Malaysian government wanted to utilize wind energy then they must come out with a brilliant idea on how to produce high energy with just a slow wind speed. As the maximum wind speed that occurs in Malaysia in normal weather is about 15.4 m/s or equal to 55 km/h [7]. The normal wind speed in Malaysia is very low and not suitable for the European wind turbine designs as the average wind speed is only about 1.8 m/s or equal to 4 km/h [8]. The wind turbine only can be widely used if the turbines can produce more with just 3-5 m/s of wind speed [9]. The northwest shore of Sabah and Sarawak locale additionally potential to the use wind vitality because of solid wind that reaches 20 bunch or more. Because of greatest win can be acquired during the rainstorm season which is between October to March, the half and half arrangement of wind vitality are practical to supplement power gracefully during rainstorm season.

The principal wind ranch in Malaysia was set up on Terumbu Layang-Layang Island, Sabah. The usage percentage of wind energy in Malaysia is still low compare to the European country. This is because the weather in our country is different compare to theirs. As our country is perfectly on the equator line this is the main reason why we have sunny and rainy weather across the year [10]. As our country still dependent on coal, natural gas, and fossil fuel to generate electricity for our homes.

Following are the objective of this project. The objectives are stated to determine the project's success and to overcome the problem statement. The objectives are:

i. To evaluate the aerodynamic performance of the helical wind turbine blade designs.
ii. To investigate the effect of blade parameters on aerodynamic performances of the helical wind turbine blade.
iii. To compare and the performance of optimum helical blade design with that of commercial wind turbine blade design.

The project scope acts as a guide towards achieving the objective. Following is the scope of this project. The scope of the study as follows:

i. Develop helical wind turbine CAD models by using SolidWorks software.
ii. Perform CFD simulation for the helical wind turbine design by using ANSYS software.
iii. Perform CAD model optimization based on CFD results obtained.

The significant study in this research are as follows:

i. Wind turbine operator and manufacturer: The data obtained from the simulation also can be used for future usages such as improvement need to be done to meet the certain requirement by the manufacturer or the operator for them to get the most benefit out of it.
ii. Learning institutions: As this research will be published by the institutions it can benefit other students and lecturers for their future research work or lesson and teaching source.
iii. Individuals: This research can help individuals understand more about details about the wind turbine such as its characteristics, complex design, and energy outcome.
iv. Communities: This research can help communities by helping them to learn and discover about green energy more than ever before. The use of green energy has a lot of benefits to the community, especially in Malaysia.

1.1 History of Wind Turbine

As a renewable energy source directly available in most parts of the world, wind energy has played an important role throughout human history. For example, wind energy provided the ventilation needed to sustain the combustion of firewood and bring in new oxygen to maintain an acceptable level of air quality when cooking became an indoor activity. Persian chimneys invented several hundred years ago, made use of wind flow to air-condition rooms by condition rooms by pulling air over a body of water, which caused evaporative cooling [11]. In most parts of the world today, the supply of fresh air in buildings is controlled by wind rather than mechanical systems. The wind is also important for dispersing and diluting pollutants, e.g. emissions released from stacks.

1.2 Wind Turbine Utilization in Malaysia

Before the utilization of the wind turbine being applied in Malaysia, first, it is a must for us to understand the weather in our country. This is because without suitable weather all the ideas for an applied wind turbine in Malaysia go to nothing. Malaysia can be considered a low wind area because of the rain and sunny weather across the year. However, there still potential to further with wind energy. Malaysia additionally has the potential for seaward wind power which has not been tapped. Wind blowing from the South China Sea will typically happen during the storm season in November to February [12]. Detailed history data verifiable information of wind must be examined in a particular site to guarantee the suitability of the undertaking.

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Considering discoveries from past research, Mersing in Johor and Kudat in Sabah are thought of as potential destinations with midpoints of 3 (m/s) at 60-meter statures. For the most part, the southern piece of peninsular Malaysia has more wind potential and more wind in the long stretch of January due to the storm season [13]. Backing and motivators from the Government are required at the underlying phase of the organization of wind power in Malaysia, as this is capital-concentrated speculation.

1.3 Importance of the Renewable Energy

We should appreciate the never-ending sustainable power source that we have today. Sustainable power is known as it is clean and very eco-friendly to the eco-systems. It produced lesser pollution the mother nature. Energy such as fossil fuel will be causing very bad air pollution because of the carbon that is contained in it. Most sustainable power source speculations are spent on materials and staff to fabricate and keep up the offices, instead of on exorbitant vitality imports. With the use of transportation that using this traditional fuel is increasing very fast making the usage of fossil fuel is rising year by year. Every people usually will just neglect the bad effect that fossil fuels will cause. There still more job to do to convince and promoting the use of sustainable energy in daily life as it has great potential to leave a great impact on our life. Sustainable energy experts around the world are working very hard day and night exploring this space. They are finding better approaches to utilize these wellsprings of vitality viably [7]. Lately, because the weather changed drastically that being brought from the consumption of non-renewable energy such as coal, oil, and natural gas. It is very sad to see this change to the world that we all fall in love with.

1.4 Working Principle of The Wind Turbine

Most of the wind turbines comprise of three edges mounted to a pinnacle produced using rounded steel. There are less normal assortments with two cutting edges or with cement or steel cross-section towers. At 100 feet or progressively over the ground, the pinnacle permits the turbine to exploit quicker wind speeds found at higher heights. Turbines get the wind's energy with their propeller-like sharp edges or also being called an aerofoil shape, which acts a lot like a plane wing. At the point when the wind blows, a pocket of low-pressure air shapes on one side of the cutting edge. The low-pressure air pocket at that point pulls the cutting edge toward it, making the rotor turn. This is called lift. The power of the lift is a lot more grounded than the wind's power against the front side of the sharp edge, which is called drag. The mix of lift and drag makes the rotor turn like a propeller.

2. Methodology

2.1 Commercial Package Software

SolidWorks is a Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) that runs on Microsoft Windows. This software is a design and published by Dassault Systems a French software corporation that put a focus on 3D product design, simulation, manufacturing, and many more. The SolidWorks that the author uses is the version of 2016. The SolidWorks 2016 version offers various tools such as Evaluate, Dimensions, Spline tools, and many more. The author has been learning this software in the Engineering Drawing class and being exposed to the basic features in that class. It is very good exposure as the author still using the software to finish this study.

ANSYS or Analysis System is a Computer Fluid Dynamics (CFD) software created by ANSYS Inc. a company based in Pennsylvania, United States. It is founded by John Swanson in 1970 [14]. The software is mainly focused on engineering simulation for multi-purpose in the engineering field. ANSYS has a lot of tools to use such as Fluent, Harmonic Acoustics, Rigid Dynamics, Static Structural, Magnetostatic, Electric, and many more. The ANSYS tool that the author is the ANSYS Fluent. ANSYS Fluent is one of the most used software in the industry now as it has various tools. It can also use to predict fluid-flow, heat, mass transfer chemical reactions, and many more [15].

2.2 Designing Process

2.2.1 Determine of the best blade angle

As the aim of this project is to optimize and evaluate the aerodynamic performance of the Helical Wind Axis Turbine (HWAT) blade. Therefore, there are 2 major steps which is the first one to find the best angle and the second step is to find the best length for the blade. To find the best angle, the angle that being tried by the author at first is only 40º, 45º, 50º and 65º. All this blade has the same length and blade diameter which is 100 centimeter or equal to 1 meter and 10 mm of blade diameter.

Table 1 – Spec. for each wind turbine blade design

Turbine	Diameter (mm)	Length (mm)	Type	Blade angle
Design 40	10	1000	HVAWT	40º
Design 45	10	1000	HVAWT	45º
Design 50	10	1000	HVAWT	50º
Design 65	10	1000	HVAWT	65º

2.2.2 Determine of the best blade length

After getting the result for the best angle blade, the next step is to determine which blade length can produce power the most by applying a 45º blade angle. The length that is calculated is 50 cm, 75 cm, and 100 cm. With different lengths, the number of blades also different as 100 cm has 8 blades, 75 cm has 7 blades and 50 cm has 6 blades.

Table 2 – Spec. for each wind turbine blade design

Turbine	Diameter (mm)	Length (mm)	No. of blade	Blade angle
Design 50	10	500	6	45º
Design 75	10	750	7	45º
Design 100	10	1000	8	45º

2.2.3 Single blade simulation

After getting the results for the best angle and length for the blade, then the specifications being applied for the next design which is named 'Single Blade'. This design already in use at the Universiti Tun Hussein Onn Malaysia (UTHM) campus located at the Parit Raja campus. For this simulation, the wind is set to come in the transverse directions.

Table 3 – Detail single specification

Turbine	Diameter (mm)	Length (mm)	No. of blade	Blade angle
Solar Mill® SM1-1P	10	1000	1	45º

3. Results and Discussion

3.1 Validation Results for Solar Mill®: SM1-1P

This blade is a project collaboration between UTHM and Wind Stream Energy Technologies a green energy company based in Hyderabad, India. The actual name for this blade is Solar Mill®: SM1-1P. This blade is designed by the author by using the specs results obtained in this study with the combination of the Wind Stream Energy Technologies existing design. This is because it is not enough to only run through the design in Computational Fluid Dynamics (CFD) software simulation. The design itself must be tested through experimental in the real-life condition too. Even though the real specs of the blade are not 100% the same as the Design Single blade but because of the differences is not much so that we can assume that the specifications are the same.

Table 4 – Blade specifications details [9]

Wind components	
Turbine Related Power Output	143 W @ 11 m/s
Maximum Power Output	500 W @ 17 m/s
Maximum Voltage & Current	57 DC & 30Amps
Rotor Diameter	0.33 m
Cut-In Wind Speed	2 m/s
Cut-Out Wind Speed	18.5 m/s
Swept Area	0.980 m^2
Turbine Material	Galvanized G-90 Steel

From the simulation, the power produced by the blade is about 362.63 (Watts). Based on the Table 5, it shows that the power that the wind turbine blade can produce is 500 (Watts) which is depending on the wind speed itself. This showed that the results gained by the author is accurate and can be validated.

Table 5 – Results for the 45 Vertical Blade simulated

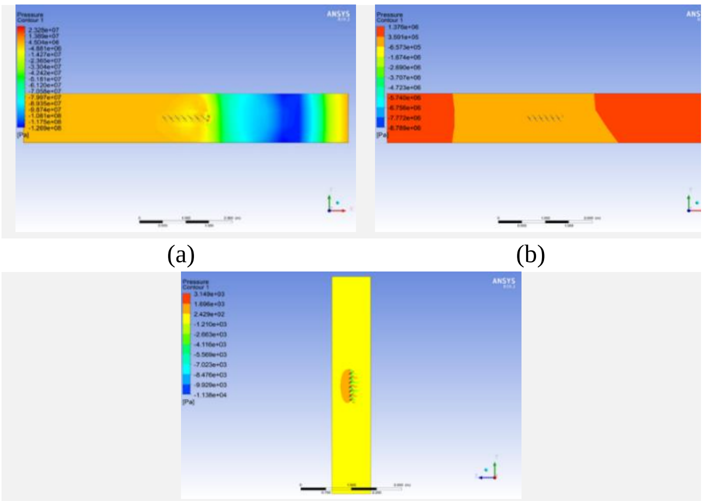
Blade	SM1-1P
Forces	405.65
Lift coefficient, C_l	73.14
Drag coefficient, C_d	298.99
Torque (Nm)	0.97
Power (W)	362.63

3.2 Aerodynamics Performances

The aerodynamic performance that illustrates as a contour such as pressure contour, velocity streamline, velocity vector. In addition, the velocity contour of the wind in all designs is almost the same as the values are 6.231e+03 (m/s). As for velocity streamline, the value for the velocity is the same for all designs as the patterns of the streamline for all blade designs are almost the same. Besides, for the velocity vector, the 45 Degree blade has the highest value compared to the others design with the value 5.546e+03 (m/s). In addition, for the velocity vector of the wind the 100cm blade design has the highest value which is 6.231e+03 (m/s).

3.2.1 Pressure contour

For the blade angle determination simulation, design 60 degrees has the highest value is 4.504e+06 (Pa). For the blade length determination simulation, design 50cm has the highest value of pressure is 1.223e+06 (Pa). For the 45 Vertical blade simulation, the highest-pressure value that occurs to the blade is 3.149e+03 (Pa) which is located at the inlet side of the blade. The pressure contour shows in the following Fig. 1.



(a) (b) (c)

Fig. 1 – Pressure contour (a) Design 65º; (b) 500 mm blade; (c) 45ºvertical blade

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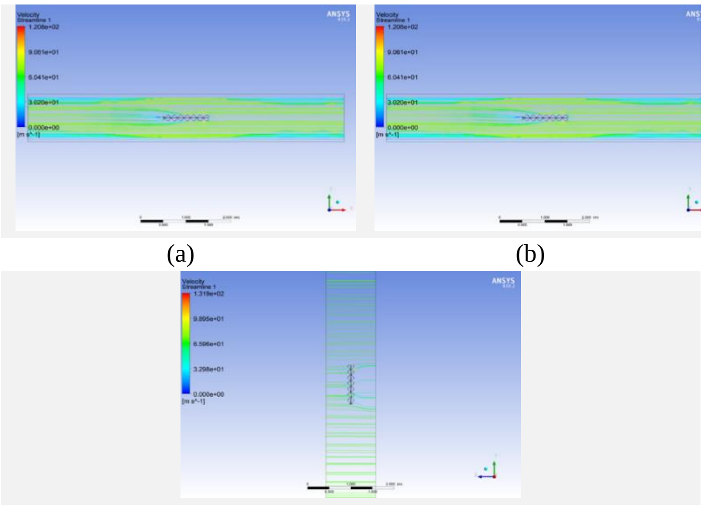
3.2.2 Streamline

For the blade angle determination simulation, the highest velocity occurs is to the 45° is 9.06e+01 (m/s). For the blade length determination simulation, the highest velocity occur is to the 100cm blade is 9.06e+01 (m/s). For the 45° vertical blade simulation which in the transverse direction, for the velocity streamline, the highest value that occurs to the blade is 6.596e+01 (m/s).

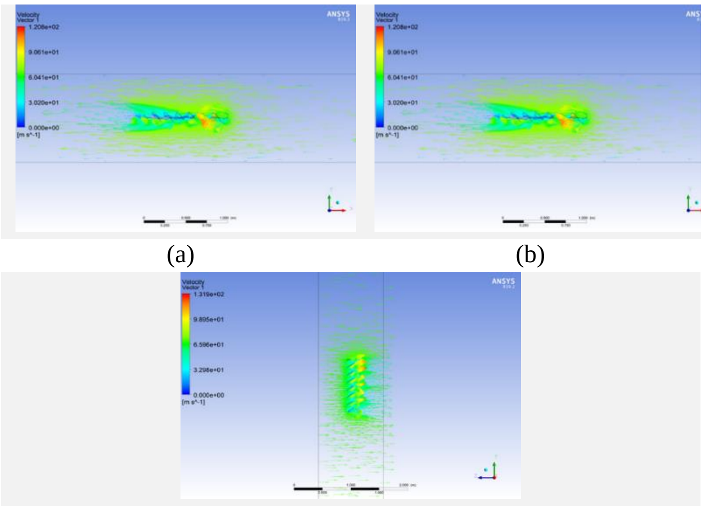


(a) (b) (c)

Fig. 2 – Streamline (a) 45° blade (b) 1000 mm blade; (c) 45°vertical blade

3.2.3 Velocity vector

For the blade angle simulation, the maximum speed of the wind occurs to the 45° blade is 9.06e+1 (m/s). For the blade length simulation, the maximum speed of the wind is 9.06e+1 (m/s). For the 45 Vertical blade simulation which in the transverse direction, for the velocity vector, the highest value that occurs to the blade is 6.596e+01 (m/s).



(a) (b) (c)

Fig. 3 – Velocity vector (a) 45° blade (b) 1000 mm blade; (c) 45°vertical blade

3.3 Power Estimation

3.3.1 Blade angle and blade length simulation

The simulation run until 3000 iterations and the torque produced by the by each design can be calculated. The torque used to determine the power produced by each design. Table 5 shows the summary for the power produced for different blade angles while Table 6 summarize the power produced for the different length of the blade simulated.

Table 5 – Power produced by different blade angle

Blade angle	40°	45°	50°
Forces	26.20	156.63	35.84
Lift coefficient, C_l	0.98	1.72	0.48
Drag coefficient, C_d	0.97	2.37	1.35
Torque (Nm)	1.14	1.50	1.46
Power (W)	427.14	561.18	544.15

Table 6 – Power produced by different blade length

Blade length (mm)	500	750	1000
Forces	136.89	156.07	186.63
Lift coefficient, C_l	1.32	3.66	1.72
Drag coefficient, C_d	2.26	5.66	2.37
Torque (Nm)	1.05	1.30	1.50
Power (W)	392.95	487.07	561.18

3.3.2 Solar Mill®: SM1-1P Comparison

After getting the results and the validation for the Solar Mill®: SM1-1P blade, the power needs to be compared as we want to know which blade can produce more power when being tested in transverse directions or Z-directions. The design that is compared is the design with the best specs that just being tested by the author with 45 Vertical which has the specs of 45° angle and 100cm length which being named as 45 Vertical. Both blades are tested with the same parameters. By 3000 iterations, the torque produced by the 100cm long blade is equal to 1.50253 Nm. Then, this torque value can be inserted into the above formula to find Power.

$$C_p = \frac{0.476634 \times 373.37}{\frac{1}{2}\rho A v^2} = 0.108 \quad (1)$$

$$P_{turbine} = \frac{\rho A v^2}{2} \times 0.108 = 177.96 \text{ Watt} \quad (2)$$

Based on the above calculation, Solar Mill®: SM1-1P blade can produce a higher torque value compare to the 45 Vertical which is 0.97123 (Nm) and 0.47663 (Nm) for the 45 Vertical blades. The comparison shows in the Table 7 below.

Table 6 – Power produced by different blade length

Blade	Torque (Nm)	Power (Watt)
Solar Mill®: SM1-1P	0.97123	362.63
45 Vertical	0.47663	177.96

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4. Conclusion

After all the calculations are done and the optimized results are gained, then it is important too to conclude it. This study has already compared three main different designs which are to evaluate their aerodynamic performance. One of the conclusions is the best specification to be applied at this wind turbine design is with 45 degrees of blade angle and 100cm of length. The blade with 45 degrees and a length of 100cm produced the most power which is 561.18 (Watts). As in the previous study which is studying applying the wind turbine at the high-speed train the blade that didn't apply these specs can only produce power of about 475.76 (Watts). There still recommendation needs to be done as if there anyone wanted to continue this study in the future. Firstly, every design that is tested through computer simulation also needs to be tested in a real-life experiment. This is because there still limitations in the computer simulation which some factors can't be added to computer simulation. Then, improve the blade designs such as by adding other components so that the wind turbine can produce more power than the existing designs so that this design can be used widely.

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