Analytical Study in Rotational Motion on Different Blade-shape Design of HAWT for Wasted Kinetic Energy Recovery System (WKERS)

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ABSTRACT – Wasted Kinetic Energy Recovery system (WKERS) is a wind renewable gadget to harvest the discharged wind from cooling tower. The WKERS is installed on the cooling tower outlet to capture the wind sources for electrical energy regeneration purpose. This study is to determine the best blade-shape design for a horizontal axis wind turbine (HAWT) as it is believed that the blade-shape design present a critical part in WKERS. Hence, elliptical blade, swept blade and NREL Phase IV blade are selected to go through Computational Fluid Dynamics (CFD) analysis in SolidWorks design software undergoing rotational flow simulation. During this benchmarking process, 10.0 m/s wind speed is set for the rotational simulation.

1. INTRODUCTION

Renewable energy industry is still less popular in Malaysia under Fifth Fuel Policy 2003 [1]. Solar power, hydropower and wind power are common and well known renewable energy [2], [3]. However, it is not geographical for wind power development in this country because of the low and unstable wind source which is analysed to be less than 2.0 m/s all along the year [4]–[6]. On the other hand, the requirement cut-in wind speed for a standard modern horizontal axis wind turbine (HAWT) has to be minimum 3.0-4.0 m/s (7-9 mph), defined in National Wind Watch. Therefore, a standard industrial cooling tower is selected as the optimum wind source in this study because it discharges a merely constant wind speed up to 11.0 m/s[7].

The number of blade of HAWT is the essential topic in the wind turbine development since the aerodynamical efficiency configuration and stress of chattered blades are proved to affect the experiment result in spinning motion [8]–[10], which is projected in Figure 1 . Therefore, three blades HAWT shows the best combination of high-spin-low-stress condition and proven as a criterion wind turbine based on the concept of aerodynamic.

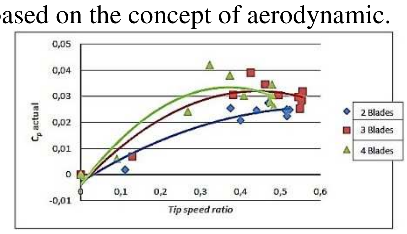


Figure 1 Power coefficient C_P variation vs tip speed ratio [9].

2. METHODOLOGY

The study of WKERS consists of rotational flow simulation on three different blade-shape designs, which are elliptical blade, swept blade and NREL Phase VI blade. Both elliptical and swept blade-shape are benchmarked from the aircraft wing of Supermarine Spitfire fighter aircraft and Boeing 747-8 commercial airplane. Hence, the NREL Phase VI blade is from standard modern HAWT. Besides, three different blades are designed according to aerofoil NACA 2209.4, BACxxx-il and S809 respectively [11]. As shown in Figure 2, all designs are done by SolidWorks CAD design software. After all, three set of HAWT with different blade-shape designs are proceed to CFD rotational flow simulation by the same CAD software as well.

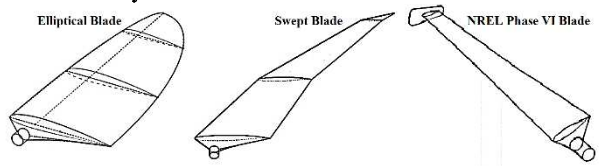


Figure 2 3D Wireframe Design of Three Different Blade.

During CFD analysis, rotational flow simulation was ran with every set of HAWT with 10 m/s of gas/air velocity, as this wind speed illustrated the wind source discharged from the cooling tower outlet. All the important parameter such as air density, air humidity, air temperature, air direction and etc. were input into the simulation project. In order to increase the value of this study, the blade angle, θ is adjusted from 0° with increasing of every 10° until 90° for each experiment to obtain the best angle of blade for rotating motion [7].

In order to accurately analyse and execute the study methods, some of the standard formulae were referred in this research. One of the most important formula is to calculate the power, P as in Equation (1) for each blade-shape design, which is related to the kinetic energy, KE and mass flow rate, $\dot{m}$,

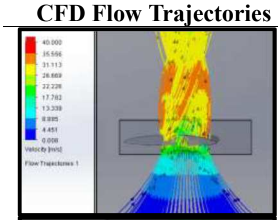
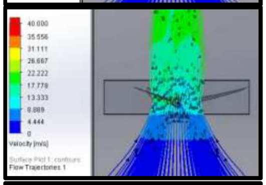
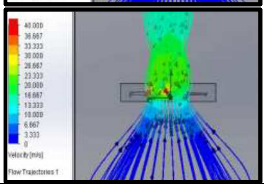
$$P = \frac{1}{2} \times \rho \times A \times v^3 \qquad (1)$$

where ρ is the density of fluid, A shows the rotor swept area and v illustrates the velocity. Lastly, the aspect ratio and the twisted idea of the blade design will be included among the criterion in analysis process as it will affect the blade performance.

3. RESULTS AND DISCUSSION

CFD rotational flow simulation illustrates better for the analysis by showing the animation of the fluid stream on the blade through the HAWT in the system. The parameters for the performance analysis are considered by the air velocity resulted from the system together with the flow trajectories of the fluid motion. The best performance of each set HAWT is shown in Table 1, as well as showing the best blade angle and maximum velocity produced by each design.

Table 1 CFD Result for Three Different Blade-shape HAWT

CFD Flow Trajectories	HAWT Blade-shape
	• Elliptical blade • Best Blade angle: 60° • Max velocity: 35.556 m/s
	• Swept blade • Best Blade angle: 70° • Max velocity: 26.667 m/s
	• NREL Phase VI blade • Blade angle: 20° • Max velocity: 23.333 m/s

Based on the CFD result of rotational flow simulation presented in Table 1, the elliptical blade-shape HAWT with 60° of its blade angle could produce the maximum velocity at 35.556 m/s. However, the NREL Phase VI blade-shape HAWT only produced the highest 23.333 m/s of the velocity with 20° blade angle.

Swept blade-shape HAWT showed a consistant air flow with 70° blade angle and managed to produce up to 26.667 m/s velocity. Nevertheless, the NREL Phase VI blade-shape HAWT clearly shows its unconsistency performance within the center of the fluid motion among the flow trajectories, and that is believed to cause a minor dragging force to the system according to the Bernoulli's principle.

4. CONCLUSIONS

The hightlight of this analytical study is to improve the performance in Wasted Kinetic Energy Recovery System (WKERS) by comparing the mechanical motions between different blade-shape designs of HAWT. According to the main formula in Equation (1), the power is directly propotional to the cube of velocity, while the rotor swept area, and the density of fluid is considered as fixed variable. Thus, the higher velocity will affect the HAWT to gain a higher power in WKERS. Therefore, the elliptical blade-shape HAWT with the blade angle of 60° is concluded as the best performance among the other blade-shape HAWT. Further study is needed to implement this WKERS in the real industry.

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REFERENCES

[1] C. Chong, W. Ni, L. Ma, P. Liu, and Z. Li, "The Use of Energy in Malaysia: Tracing Energy Flows from Primary Source to End Use," *energies*, vol. 8, no. 4, pp. 2828–2866, 2015.

[2] A. Y. Azman, A. A. Rahman, N. A. Bakar, F. Hanaffi, and A. Khamis, "Study of renewable energy potential in Malaysia," *2011 IEEE 1st Conf. Clean Energy Technol. CET 2011*, pp. 170–176, 2011.

[3] N. A. Rahim, R. Saidur, and A. Wadi Abbas Al-Fatlawi, "Researching Social Acceptability of Renewable-Energy Technology in Malaysia," *3rd IET Int. Conf. Clean Energy Technol. 2014*, p. 65 (5 .)-65 (5 .), 2014.

[4] G. Basil, "Possibility of electricity from wind energy in Malaysia : Some rough," *New Straits Times*, p. 7, 2013.

[5] K. Sopian, M. Y. H. Othman, and A. Wirsat, "The wind energy potential of Malaysia," *Renew. Energy*, vol. 6, no. 8, pp. 1005–1016, 1995.

[6] A. M. Najib, M. A. Mustafa, Z. Jamaludin, A. M. Zulfattah, and A. R. Hashim, "Regenerative Energy Air Flow System For Cooling Tower," vol. 699, pp. 498–503, 2015.

[7] J. B. Goh, Z. Jamaludin, F. A. Jafar, N. Ali Mokhtar, and M. Mat Ali, "The experimental study of waste kinetic energy recovery system (WKERS)," *ARPN J. Eng. Appl. Sci.*, vol. 12, no. 16, pp. 4831–4836, 2017.

[8] S. Muluk, "Wind Turbine Design for Optimum Energy Output," *Natl. High Sch. J. Sci.*, pp. 1–7, 2014.

[9] F. Wenehenubun, A. Saputra, and H. Sutanto, "An experimental study on the performance of Savonius wind turbines related with the number of blades," *Energy Procedia*, vol. 68, pp. 297–304, 2015.

[10] S. Megraw, "WHY DON â€™ T WIND TURBINES HAVE MORE THAN 3 BLADES?," 2012. [Online]. Available: https://explorecuriocity.org/Explore/ArticleId/193/why-dont-wind-turbines-have-more-than-3-blades-193.aspx. [Accessed: 27-Mar-2017].

[11] J. B. Goh, Z. Jamaludin, F. A. Jafar, M. M. Ali, M. N. Ali Mokhtar, and C. H. Tan, "Analytical study on different blade-shape design of HAWT for wasted kinetic energy recovery system (WKERS)," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 210, no. 1, 2017.