A STUDY ON DESIGN FACTORS OF A HYBRID WIND-PV MICRO TURBINE GENERATOR

[1]Pusparini Dewi Abd Aziz, [2]Nor Shafiqin Shariffudin, [3]Nabiha Azman, [4]Ahmad Khairul Ramzi Ahmad, [5]Nulida Ab Aziz, [6]Yanuar Z. Arief

[1]Universiti Kuala Lumpur British Malaysian Institute, Bt. 8, Jalan Sungai Pusu, 53100 Gombak, Selangor, Malaysia

[6]Universiti Teknologi Malaysia, 81310 Skudai,Malaysia.

ABSTRACT: *Effectiveness of a design is the most important part in building a micro wind turbine generator. Many factors need to be considered to assure that the generator functions properly and perform with highest efficiency. This study consists of two main parts; the blade design and the generator performance. In blade design, simulation was performed using Qblade software. A few parameters have been set such as number of blades, angles of attack, drag and lift coefficients to comprehend the impact in maximizing the output power generation. This simulation was made according to the actual wind condition and speed within 2 up to 8 m/s. This wind speed was measured using anemometer and measurement was made at various locations with time. In the second part of this study, the generator was built according to the suitable design from the simulation. The wind turbine has three blades and employs VAWT that able to detect slow wind speed. The solar radiation captured by solar panel, then converted into electrical energy. The wind turbine and solar panel are connected in series. Lead acid battery is used to store excess energy and also as back up during shortage supply. The output system is varying based on the solar radiation and wind speed. The output of this project is depending on the availability of the source. Higher in wind speed and solar radiation gives better output.*

1. INTRODUCTION

The non-renewable energy sources such as coal, gas, and oil started to depleted and soon will no longer accommodate the demand of these sources [1]. Due to high in demand of these sources, there will be an increment in price and gives great effect to well develop countries. Although high in demand, non-renewable energy has some global climate change issue. This is due to its carbon dioxide and sulphur dioxide emission from its production [2]. Due to these problems, the renewable energy generation is the solution to be implemented to replace non-renewable energy as primary sources of power generation [2]. The advantage of using renewable energy is cost effective, low to non-carbon emission, climate friendly and unlimited. Some forms of renewable energy are solar, tidal, biomass and biofuel, geothermal, and wind. Wind turbines are widely used all over the world and it is regarded as an alternative source for electrical power generation [3]. Malaysia falls on the region in Southeast Asia which has a very low wind speed which is below 5m/s [4]. However, the countries at equatorial region like Malaysia receive abundant of sunlight in a year. With the combination of both sources, the generation of electricity can be continuous and enough for domestic usage to supply DC or AC loads. Many factors needed to consider in designing the suitable wind turbine and solar to assure better performance and high efficiency.

Wind turbine can be classified into two types; horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). The VAWT type is the new discovery and has the ability to capture wind from any directions. The Savonius is the VAWT type and incorporated the drag force. Small wind turbines are generally those rated at 10kW or less. One of the major problems of inefficiency with wind turbine is the design itself. Some wind turbines are designed large and heavy. As a result, the wind turbine is difficult to harness the energy [5, 6]. Nowadays, many researchers have started to harness the power from wind by designing a small wind turbine which can operate at low wind speed with low Reynolds number [7, 8]. With proper design by considering several factors such as number of blades, blade shapes and length, angle of attack, drag and lift coefficients can maximize the aerodynamic efficiency in terms of output power from the wind.

Malaysia receives about six hours of sunshine per day and the temperature during day time is between 24˚C to 32˚C and during the night time is from 21˚C to 24˚C. The average solar radiation is between 400 to 600 MJ/m^2 per month. Due to this, Malaysia is suitable for large scale solar power installation.

The hybrid wind-PV system consists of a few components; wind turbine, PV module, rechargeable battery, power inverter and solar controller as shown in Fig. 1. The wind turbines and PV modules are in parallel arrangement to ensure reliable and continuous power. Since both energy sources depending on seasonal shifts, therefore with this hybrid system, the system capable of generating and supply the load although only one source available.

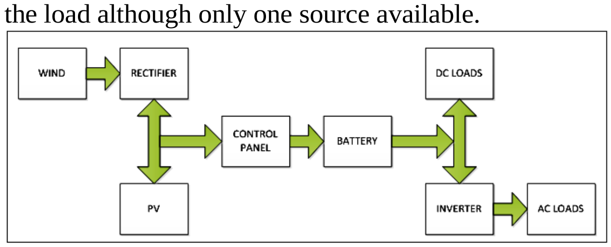

Fig.1 Hybrid Wind-PV System Model.

2. MATERIAL AND METHODS

2.1 Consideration Factors on Airfoils for Wind Turbine Design

The airfoils configuration for blades is the key factor for high efficiency of the turbine to convert from kinetic to mechanical energy. The conversion was made using rotor and generator that converts the mechanical energy to electrical energy. The event of cut in the wind speed is when rotor starts to generate power. The cut out of the wind speed is when the rotor starts to reduce its speeds and power is generated [8, 9]. The relation effect between cut in and cut out rotor with the wind speed and resulting the power generated is illustrated in Fig. 2.

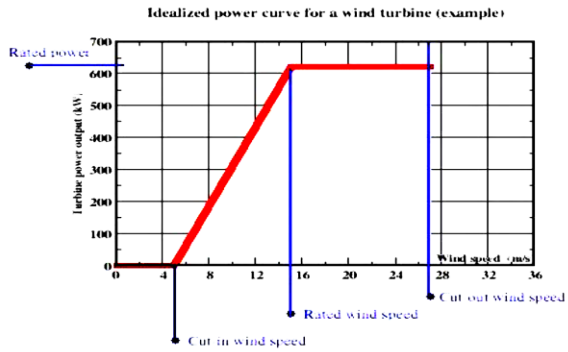

Fig.2 Relationship of wind turbine against wind speed.

The Lift Coefficient (Cl) is the lifting force and Drag Coefficient (Cd) is the drag or resistance force that generated by the airfoils are important role in designing wind turbine. These two forces are related to each other in giving precise information on the lift and drag ratio (Cl/Cd) in the airfoils configuration. Thus increasing the drag force, less power is produced and practically less efficient. These forces associated with Angle of Attack (AoA). The AoA is used to determine the forces to be high or low at a particular AoA applied. The maximum Cl for a certain AoA applied for an airfoil is known as stall angle. The common stall angle is between 10 to 15 degrees [10]. Tip Speed Ratio (TSR) related to the number of blades used in the wind turbine. The number of blades influenced the turbine performance due to its rotor solidity as in equation below:

$$\sigma = \frac{Nbc}{r} \qquad (1)$$

Where σ is solidity, *Nb* is number of blades, *C* is length of blades chord and *r* is radius of the blade to rotor. In this research the number of blades varies from 3, 5 and 8 blades and the performance in terms of the power produced is studied. More blades applied to the wind turbine, the TSR value is reduced and this finding is supported by the respective equation [7]:

$$TSR_{max} = \frac{4\pi}{Nb} \qquad (2)$$

2.2 Simulation on Airfoils Configuration

Simulation using Qblade software was done to test the performance of the airfoil designs. The airfoils employ the National Advisory Committee on Airfoils (NACA) with four digit series: NACA0012 and NACA0015. The selection of airfoil design is based on the performance of the Cl/Cd ratio although both have low starting torque. The airfoils specification and configuration is shown in Table 1 and Fig. 3 respectively.

Table: 1 Thickness of the airfoils.

Airfoils Configuration	Thickness	Camber
NACA0012	12.00	0
NACA0015	15.00	0

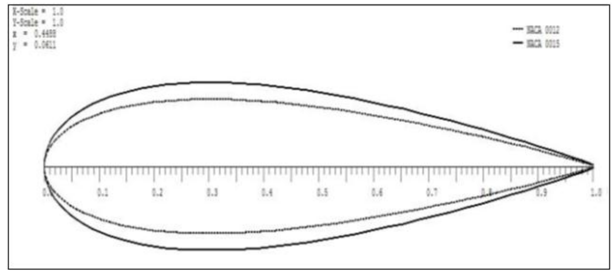

Fig.3 Comparison of shape for NACA0012 and NACA0015.

The analysis of the coefficient ratio (Cl/Cd) of the airfoils against AoA in Reynolds number (Re) ranging from 50000 up to 100000. The rotor-blade was designed and simulated using the data obtained from the airfoils to test the coefficient (Cp) against TSR. The simulation was done using three blades with different airfoils. The specification for the rotor-blade is based on data provided in Table 2 and the designed as illustrated in Fig. 4.

Table: 2 Rotor-Blades specification.

Height of the turbine	0.66m
Chord of the turbine	0.167m
Radius of the blade from the rotor	1.00m

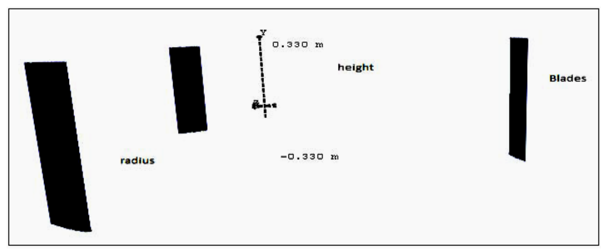

Fig.4 Side view of rotor blade design.

2.3 Hybrid Wind-PV Model Setup

The overall hybrid wind-PV system as illustrated in Fig. 1. The system employs the designed wind turbine and PV module (solar panel) as the main source. The solar panel specification as in Table 3. This model is selected based on the condition of the solar irradiance of certain location. A rectifier circuit is employed to convert AC into DC so that it is easy to be process in the control panel. A rechargeable battery is a lead acid type, 12V with a capacity of 1.2AH and initial current ±2.36A. This battery is suitable for this system due to its advantage especially in terms of easy handling. This battery functions as energy storage when there is excessive energy produced by the sources. To provide AC output, an inverter is included in this system.

Table: 3 Solar panel specification

Parameter	Rating
Pmax	5W
Tolerance	±5%
Vmp	18V
Imp	0.27A
Voc	21.4V
Isc	0.29A
Maximum system voltage	750V
Size	185mmx285mmx18mm
Test condition	1000W/m^2,AM1.5,25°C

3. RESULTS AND DISCUSSION

3.1 Airfoils Configuration Simulation

Simulation was done for both airfoil configurations; NACA0012 and NACA0015 to compare the performance in terms of the coefficient ratio (Cl/Cd) that affects the angle of attack (AoA). Based on the resulting plot shown in Fig. 5, NACA0015 gives better performance with low wind speed. The coefficient ratio (Cl/Cd) is important for the airfoil to stay elevated and dragged by the force. In wind turbine application, this ratio will keep the blades spin.

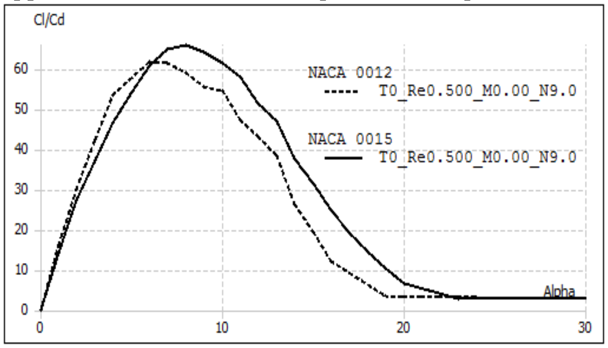

Fig.5 Comparison of Cl/Cd versus AoA for NACA0012 and NACA0015 in 50000 Re.

In terms of the number of blades in this research, the maximum tip ratio speed (TSR) is tested on different blades numbers; 3, 5 and 8 blades. From the simulation, three blades give the best TSR_{max} compared to 5 and 8 blades. The TSR_{max} values produced by 3, 5 and 8 blades are clearly shown in Table 4. From the TSR_{max} finding (3 blades), the airfoils were tested on the thickness of the blades as well as the output power generated. In Fig. 6, NACA0015 capable in generating more power output compared to NACA0012. The difference between NACA0015 and NACA0012 is the thickness of the each blade; 15 and 12 respectively.

Table: 4 Calculation value for TSR_{max} for various number of blades

Number of blades	TSRmax
3	4.2
5	2.5
8	1.6

Torque is an important factor to ensure the turbine self-rotating and work as stand-alone application. Based on the simulation on torque effects with number of blades, it was found that the higher the number of blades results in better torque in low wind speed application. However, more blades will reduce the power generated.

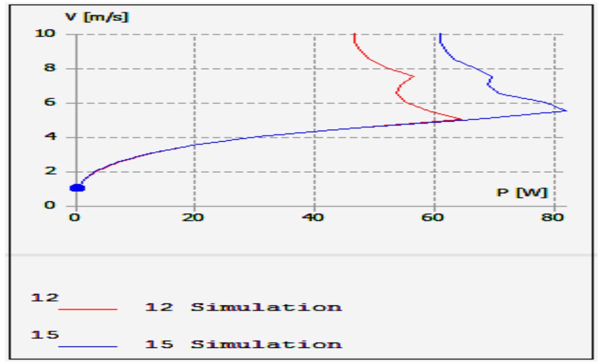

Fig.6 Comparison of power generated versus speed for NACA0012 and NACA0015

3.2 Hybrid Wind-PV Model Setup

The model was tested for its performance and the outputs obtained were recorded and analyzed. The power generated is wholly depending on the wind and solar radiance availability. The wind speed was measured using anemometer. A few of data were taken in different time, day and location and the average value were taken for analysis as in Table 5.

Table: 5 Average output voltage generated based on the average wind speed.

Average wind speed (m/s)	Average Output Voltage (V)
1	0.12
2	0.36
3	0.84
4	1.07
5	1.23
6	1.58

The average wind speed values that produce the average output voltages were plotted as in Fig. 7.

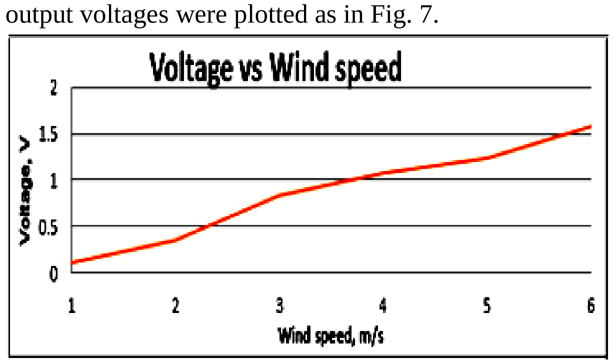

Fig.7 Relationship between voltages generated and wind speed.

Based on the plot, it shows that the higher the wind speed, the more output voltage can be generated. Based on the actual application, the least output voltage generated at minimal speed i.e. 1m/s is 0.12V. The highest output voltage is 1.6V generated at 6m/s wind speed. When the wind speed increases, the number of rotation increases, more power will be generated. Testing was also conducted for the case for unavailability of the wind, where the generator is wholly depending on the solar source. Several data collection was taken in different days and the resulting average output were tabulated in Table 6 and plotted in Fig. 8. Based on the result obtained, it can be seen that the highest average output voltage (Voc) is at time 1300 hours (1300GMT) at average temperature of 34˚C (the highest irradiance of the sunlight). When combining both sources, the battery charger is full charged at short time especially at highest temperature.

Table: 6 Solar panel output generated based on time and temperature.

Times (Hours)	Average Temperature (ºC)	Average Voc (V)
0700	27	12.01
0800	27	12.96
0900	28	13.5
1000	30	18.75
1100	31	20.01
1200	31	20.73
1300	**34**	**21.29**
1400	31	20.45
1500	31	19.67
1600	31	18.56
1700	31	17.93
1800	31	17.74

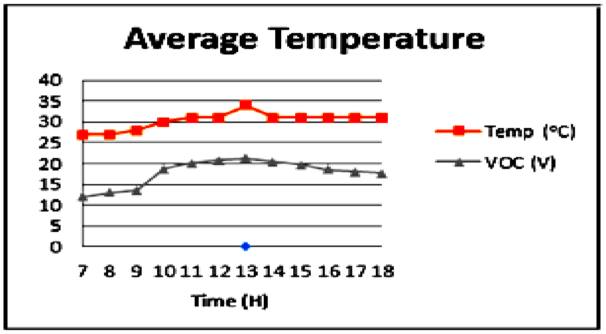

Fig.8 Average temperature versus time.

4. CONCLUSION

From the findings, it can be concluded that the suitable configuration airfoils for low wind speed application is NACA0015. It gives good performance with a stall angle between 10 to 15 degrees compared to NACA0012. The output power is generated higher using NACA0015. In term of the wind turbine design, 3 blades is the optimal for this application and has stable power. For the hybrid wind-PV system, it able to generate electricity even in area with slow wind speed and cloudy sky. The turbine uses VAWT design due to its capability to capture wind at any directions. On the other hand, it also suitable to be applied at urban area since it can create turbulence wind to maximize the rotation speed.

5. ACKNOWLEDGEMENTS

The authors would like to express sincere gratitude to the staffs and students of Universiti Kuala Lumpur – British Malaysian Institute for their effort to make this research happened. Special gratitude to the Short Term Research Grant for sponsoring this research.

6. REFERENCES

[1] John Ziagos, K.W., Energy Crisis: Will Technology Save Us. March 24, (2007).

[2] Rougé, A.G.a.L., Polluting Non-Renewable Resources, Innovation andGrowth: Welfare and Environmental Policy. August, (2003).

[3] Cleveland, I.K.a.C.J., Energy return on investment (EROI) for wind energy. June 7, (2007).

[4] Mahmuddin, F., Studi Densitas Energi Dengan Distribusi Weibull. Jurnal Riset Teknologi Kelautan, (2013).

[5] Wood, David. Small wind turbines. Springer Berlin Heidelberg, (2011).

[6] Wright, A. K., and D. H. Wood. "The starting and low wind speed behaviour of a small horizontal axis wind turbine." Journal of Wind Engineering and Industrial Aerodynamics 92.14, 1265-1279, (2004).

[7] Sridech, Wikanda, and Tawit Chitsomboon. "Optimal speed for stall-regulated wind turbines in Thailand."Invisu ,"Topic 3-Turbine Formula", WindAtlas, August 24 2009.Web 11 May, (2014).

[8] S. Mekhilef, A. Safari, W.E.S , R. Saidur, R. Omar, M.A.A. Younis, "Solar energy in Malaysia: Current state and prospects". Renewable and sustainable energy review, Vol.**16** (1), pp. 386-96, (2012).

[9] Sunyoto, A.; Wenehenubun, F.; Sutanto, H., "The effect of number of blades on the performance of H-Darrieus type wind turbine," QiR (Quality in Research), 2013 International Conference on , vol., no., pp.192,196, 25-28 June, (2013).

[10] Wikipedia contributors. "Lift coefficient." Wikipedia, The Free Encyclopedia. Wikipedia, The Free Encyclopedia, 17 Apr. 2014. Web. 11 May, (2014).