Preliminary Development Of Prototype Of Savonius Wind Turbine For Application In Low Wind Speed In Kuala Terengganu, Malaysia

A. Albani, M.Z. Ibrahim

Abstract: The wind turbine is a technology which converting wind kinetic energy to electric power. Wind energy is easily accessible anywhere in the world and is one of renewable energy. However, some location such as in Kuala Terengganu, the lower average wind speed become one of the factors wind turbines has not been used widely as an alternative method for generating the electric power. Thereby, small scale wind turbine which can generate electric power in low wind speed must be designed. In this study, a Savonius type of vertical axis wind turbine (VAWT) has been designed, fabricated and its performances were tested. A simulate calculation also has been made to expect the power output generated by designed prototype. From the study, found that although low wind speed, small scale wind turbine still can perform its function and generate electric power. It proves that wind turbines can be as an alternative technology for generating the electric power in Malaysia especially in Kuala Terengganu.

Index Terms: Wind Turbine, VAWT, Savonius, Low Wind Speed, Kuala Terengganu

1 INTRODUCTION

Malaysia is one of many other countries that lie in the equatorial zone, which its climate is influenced by the monsoons. The weather in Malaysia is characterized by two monsoon regimes, namely, the Southwest Monsoon from late May to September, and the Northeast Monsoon from November to March. The Northeast Monsoon brings heavy rainfall, particularly in the east coast states of Peninsular Malaysia and western Sarawak, whereas the Southwest Monsoon normally signifies relatively drier weather. The transition period in between the monsoons is known as the inter-monsoon period. Kuala Terengganu is the largest city as well as the state and the royal capital of Terengganu state, Malaysia. Kuala Terengganu is located in front of South China Sea. As concerns for environmental issues such as global warming, the development and application of renewable and clean new energy are strongly expected. Among others, wind energy technologies such as wind turbine have developed rapidly and are about to play a big role in a new energy field [1]. The wind turbine can generally be categorized into two main categories, those whose rotor shafts rotate around a horizontal axis and those whose rotor rotates around a vertical axis. Horizontal axis wind turbines, or HAWTs, has blades mounted radially from the rotor. Modern types usually are generally used for large scale grid connected electrical power wind generation. Vertical axis wind turbines, or VAWTs, are not as common and only recently have they been used for large scale electricity generation and usually used for small scale turbine design [2].

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The wind speeds in Malaysia were in the range of low average wind speed value which is around 1 - 4 m/s [3]. It was also approved by Muzathik et.al. in year 2009 which said that monthly mean wind speeds between the years 2004 and 2007 in Kuala Terengganu were in low speed value [4]. This paper briefly discusses about designing of small scale wind turbine, which is compatible with low wind speed for generating electric power in Kuala Terengganu.

2 METHODOLOGY

2.1 Wind speed analysis for Kuala Terengganu

The wind data were collected from the Malaysian Meteorological Department (MMD) station [5]. Since the MMD station anemometer height varies by station, the wind speeds quoted here were all corrected to a standard height of 10 m by using the formula below [6];

$$X_h = X_{10}\left(\frac{0.02337}{0.656\log_{10}(h+4.5)}\right) \quad (1)$$

The Weibull probability density distribution function used for wind speed is [7, 8,9,10,11,12];

$$p(V)_w = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)^k\right] \quad (2)$$

Where *k* is a dimensionless shape factor and *c* is the scale factor. The linear approximation of the data is obtained by using the least square method.

2.2 Estimation of wind power

The basic equation wind power is as follows [2];

$$P = \frac{1}{2}\rho AV^3E \quad (3)$$

Where, *P*=power, *ρ*=the air density, *A*= swept area, *V*= speed, *E*=total efficiency. The equation for estimating power in any particular moving body is; As mentioned by [2], there are a number of considerations when calculating the overall efficiency of the wind turbine (E). These are efficiency of the rotor (E_r), generator efficiency (E_g), and transmission efficiency (E_t).

$$E = E_r \times E_g \times E_t \qquad (4)$$

2.3 Design of wind turbine

There are a number of approaches that can be taken towards wind turbine design, and there are many issues that must be careful. There are the design steps include the determine the application, review previous experience, select topology, preliminary loads estimate, develop tentative designs, predict performance, evaluate, design, estimate costs and cost of energy, refine the design, build prototypes, testing the prototype and doing simulation [13].

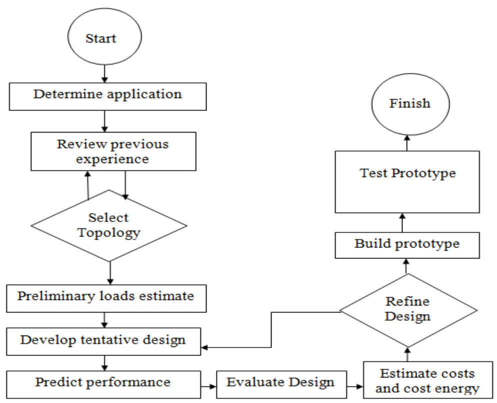


Fig. 1. *The methods for designing of small scale wind turbine.*

3 RESULT AND DISCUSSION

3.1 Wind Analysis for Kuala Terengganu

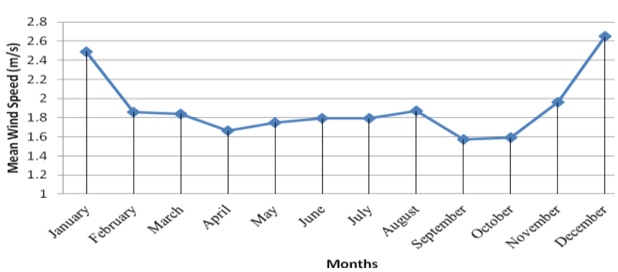


Fig. 2. *Monthly mean wind speeds in Kuala Terengganu*

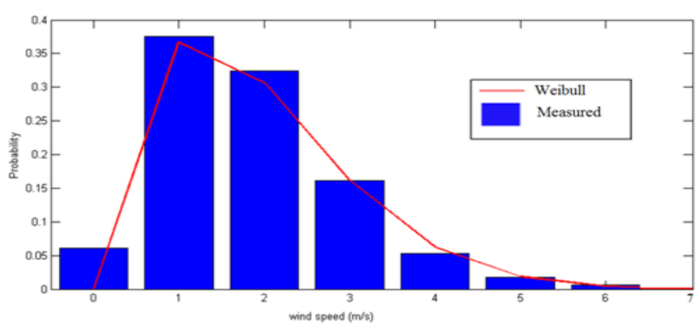


Fig. 3. *Frequency distribution in Kuala Terengganu*

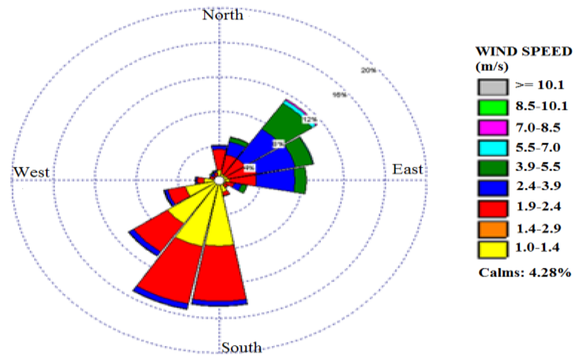


Fig. 4. *Wind Rose in Kuala Terengganu*

The data were collected from the Malaysian Meteorological Department (MMD) station Kuala Terengganu. The coordinates of MMD station are 05° 56'N, 116° 03'E. The wind speed collected from the Malaysian Meteorological Department (MMD) station. The monthly mean speeds in Kuala Terengganu for the year 2010 was shown in Fig. 2. The highest value was in December, 2.65 m/s and the lowest in September, 1.57 m/s. Kuala Terengganu faces the Northeast Monsoon from November to March for every year. The wind speed was higher in this season. Fig.3. showed the frequency distribution in Kuala Terengganu. The frequency is highly peaked in the range 1-4 m/s, this indicates that most of the wind speed at Kuala Terengganu lies in this range. This distribution of wind speed is important in determining the percentage of time during a year, the power that could be generated from small scale wind turbines. The prevailing wind direction was South southwest (SSW) on the site as shown in Fig. 4. This showed that the Kuala Terengganu has low wind speed and the specialized small scale wind turbine need to be designing and develop for generating electricity by using wind resources.

3.2 Choosing of suitable wind turbine

This paper focused on Vertical Axis Wind Turbine (VAWT), which is highlighted by many authors, as the best for the low wind speed application. The VAWT has rotors which move in the direction of the wind. The savonius rotor, proposed by the Finnish inventor S.J. Savonius in 1925, is a vertical axis rotor driven by a drag force [15]. The rotor blade design is principally modification of 'S' rotor consist of of two semi-circular rotor blades, but with the exception that the rotor blade have been horizontally displaced, as presented in [2]. Paper [2] also explain the mechanism of Savonius VAWT, where the rotor surfaces move with the wind for half a revolution and against it for the other half. The differences in drag between the concave and the convex surfaces create a pressure differential and induces rotation. One of the important things to note is the path of the streams through the rotor. The horizontal displacement of the rotor blades upturns the pressure difference by diverting wind upstream to excellently push the top blade into the wind. This helps increase torque of the rotor blade and its rotation. The efficiency of the S type of VAWT is able to achieve up to 20% [16]. The benefit of this type of rotor

a. Simple fabrication

b. Harvest of wind speeds from any direction without orientation (Yawing system as HAWT)
c. Low-cost to construct on a small scale

3.3 Mechanical design

This design consideration is based on the method applied in [2]. For a wind turbine the main design characteristics stem from the selection of blade type (rotor). The Savonius has been selected, as the rotor for the wind turbine, the mechanical elements of the rotor were inspected. There were a number of elements which to be considered for to finish up this VAWT design. These include the aspect ratio, overlap ratio, separation gap, cross-section profile and the number of blades or rotor.

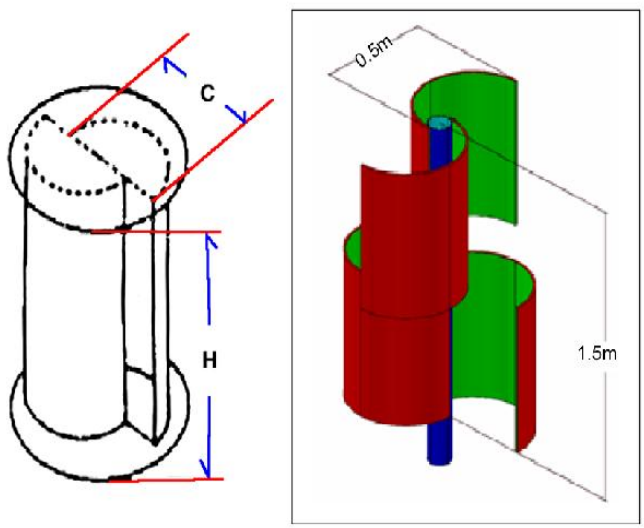


Fig. 5. *Aspect ratio of the design*

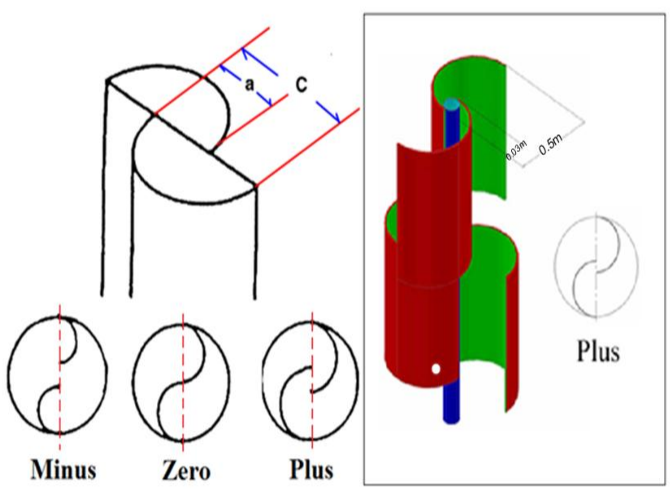


Fig. 6. *Overlap ratio of the design*

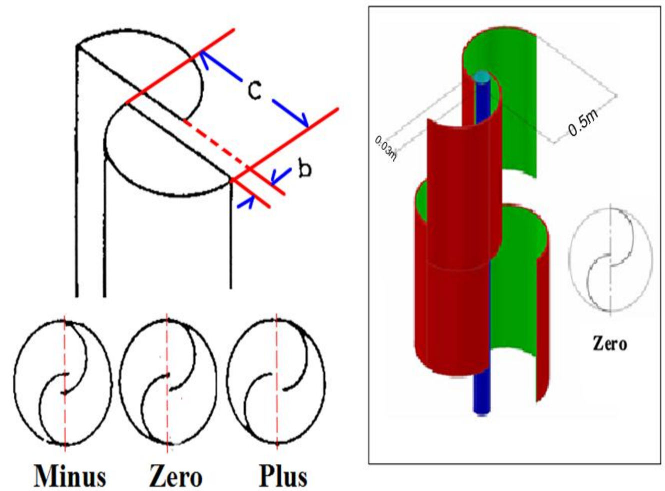


Fig. 7. *Separation gap of the design*

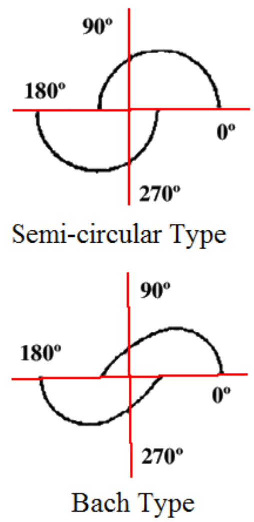


Fig. 8. *Cross-section profile*

Aspect ratio as shown in Fig. 5 is the ratio of the rotor height to the width. A large aspect ratio of around 3 to 5 provides the rotor with good torque and power characteristics [2]. The value of aspect ratio for this design was 3.

$$\text{Aspect ratio} = \frac{H}{c}$$

Where, *H* is the height of the rotor and c is the width of the rotor. Overlap ratio as shown in Fig. 6. is the ratio of the diameter of the rotor blade to the distance which the blades overlap. The overlap ratio for this designed wind turbine was 30%, comply with the best range of overlap ratio for WTG blade, (20 to 30%). Separation gap as shown in Fig. 7. is determined by the distance of the rotor blades from the vertical axis. The torque and power coefficient will decrease with an increment of separation gap ratio. The cross-section profile of a rotor blade is taken from a vantage point directly above the blade (See Fig. 8.). The other design criteria chosen in the design are Semi-circular type (cross section profile), two blades in 's' form and double stack of blades.

3.4 Generator selected for the design

The common capacity of the WTG generator for small scale applications WTG is up to at least 10kW [12]. The type of generator chosen are permanent magnet generator as suggested by [2]. The operating principles of permanent magnet generators are similar to that of synchronous machines, except that these machines are run asynchronously. That is, they are not generally connected directly to the AC networks. The power produced by the generator is initially variable voltage and frequency AC. This AC is often rectified immediately to DC. The DC power is then either directed to DC loads or battery storage, or else it is inverted to AC with a fixed frequency and voltage.

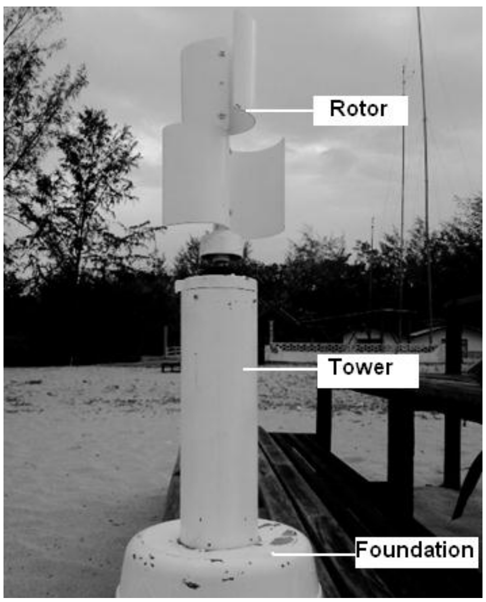


Fig. 9. *Model of Savonius Vertical Axis Wind Turbine*

3.5 Rotor balancing

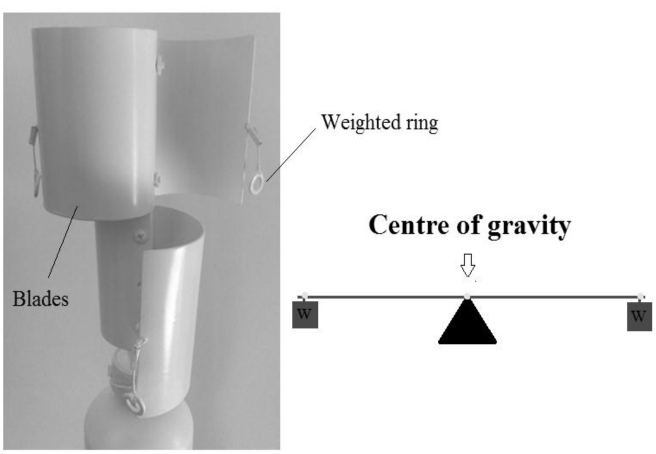
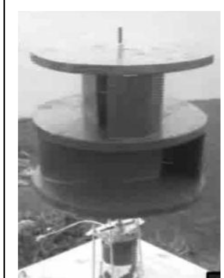


Fig. 10. *Method of rotor balancing*

The rotor or blades must be perfectly balanced or else vibration at high speeds can destroy the rotor. Balancing the wind turbine blades takes some patience. This study explains a basic theory for understanding of how the balancing works. Without a better understanding, it is difficult to correctly balance the blades. The method suggested in this study is by using weight ring which installed on each blade as showed in Fig. 10. This method involves suspending the object on a horizontal pivot and letting the object settle. Then the weights (ring) added, so the object does not settle to any dependent position because the center of gravity will be in the dead center. Conventionally, there are two other common methods for balancing the rotors, using structured and flat disc. The disadvantage of both methods for application in small scale wind turbine was mentioned in Table 1. However, the security and safety using the weighted ring for rotor balancing need detail study in future.

Table 1. *Comparison three types of balancing method*

Using weight ring	Using structure	Using flat disc
		
• Not disturb the low wind speed flowing from any side.	• Disturbing the low wind speed flowing from right and left side	• Rotor become heavier. • Disturb the low wind speed flowing from the top and bottom

3.6 Finished prototype

The simple prototype of VAWT was fabricated based on the discussed criteria. As can be seen from the Fig. 9, there are two stacks of impellers. This was to provide for starting from any wind direction and produce a more uniform torque. To estimate the power output of the system using equation (3), firstly, the total efficiency (*E*) need to be estimated. Taking a typical estimation for the rotor efficiency of 25% (assume similar to a single level of the blades), generator efficiency around 90%, and transmission efficiency around 90%, we achieved a total efficiency of 20.25% using equation (11). With the efficiency of the complete system calculated an estimation of the power output could be made using Eq. (3).

$$P = \frac{1}{2}\rho A V^3 E$$

Where, ρ=the air density (taken as 1.24 kg/m^3), A = Swept area (1.5 m^2), *V*=wind speed (taken from MMD Kuala Terengganu, mean wind to be 2.5 m/s), *E*= Total efficiency (0.203 as estimated above). Substituting these values into equation (3) gives power output of 2.4 W. This equates to around 0.1 kWh/day.

3.7 Practical applications

This design is in small scale, and to more practical application, the scales should be increased. Increasing the width and the height of the rotors swept area would increase the power output. As the wind speed is not available for all time, this small scale WTG is not suitable for on-grid application, thus a storage bank was needed. To determine the payback period, assume the cost of wind turbine is around $250 to fabricate, and assume the wind turbine power output was 0.10 kWh, the payback period can be computed. So it would take around 8 years to recover the mechanical costs of the wind turbine.

$$\text{Simple Payback Period} = \frac{\alpha}{\beta \times \gamma}$$

Where, α = Capital Cost of Turbine ($), β = Electricity cost, γ = Turbine Power Output

Therefore;

$$\text{Simple Payback Period} = \frac{\alpha}{\beta \times \gamma}$$

$$= \frac{250}{0.80 \times 0.10}$$

= 3,125 days $\approx$ 8 years.

4 RECOMMENDATIONS

Renewable energy has become the most valuable energy nowadays, especially after the increasing of fuel price around the world. Renewable energy is not only cost-effective energy and value for money in the long run, but also flexible where the generation of electrical power can be done without problem at remote area. The DC-Motor was the perfect wind generator comparing to the AC-Motor. The DC-Motor chosen also must compatible with the size and type of rotor. The size of the swept area of the rotor can be added in future design for enabling catching and trapping more wind. The more the wind trapped on the rotor, the more the rotation rate and more power will be generated. To achieve better results, the efficiency of multilevel-track of blades should be deeply studied. For future designs of small scale wind turbine, the wind turbine can be designed for application of street lighting in Kuala Terengganu especially in Pulau Warisan Kuala Terengganu and other attractive location.

5 CONCLUSION

In this design, a small, robust design which was relatively simple and cheap to construct was in essence the main criteria for wind turbine selection. A savonius type rotor was selected as it best fitted the design criteria. The overall size of the prototype of wind turbine rotor was 1.0m in diameter and 1.5m in height. With the basic design built measurements were taken, such as the area of the rotor blades swept by the wind, to determine the estimated power output which would be obtainable from the finished model. The results provided as a power output enabled suitable applications to be suggested. The Savonius rotor vertical axis wind turbine definitely has a place in electricity generation. It has many advantages despite its relatively low efficiency. On the other hand; small scale it is cheap, simple to design and construct and is also very robust.

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