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Assessment of C-Type Darrieus Wind Turbine Under Low Wind Speed Condition

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Assessment of C-Type Darrieus Wind Turbine Under Low Wind Speed Condition

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Abstract. Harvesting wind energy in in a low wind speed region is deem un-economical if not daunting task. Study shows that a minimum cut in speed of 3.5 m/s is required to extract a meaningful wind energy for electricity while a mean speed of 6 m/s is preferred. However, in Malaysia the mean speed is at 2 m/s with certain potential areas having 3 m/s mean speed. Thus, this work aims to develop a wind turbine that able to operate at lower cut-in speed and produce meaningful power for electricity generation. A C-type Darrieus blade is selected as it shows good potential to operate in arbitrary wind speed condition. The wind turbine is designed and fabricated in UMS labs while the performance of the wind turbine is evaluated in a simulated wind condition. Test result shows that the wind turbine started to rotate at 1 m/s compared to a NACA 0012 Darrieus turbine that started to rotate at 3 m/s. The performance of the turbine shows that it have good potential to be used in an intermittent arbitrary wind speed condition as well as low mean wind speed condition.

Keywords: Wind turbine, C-type Darrieus, Tip speed ratio.

1. Introduction

Wind turbine is analogues to renewable energy and have been widely accepted as one of the common way to produce electricity, cost effectively. This technology has supplied electricity amounting to 3% of total global electric consumption [1]. Essentially, wind turbine converts kinetic energy from rotary motion of the blade/shaft assembly to electrical energy and store them in a battery or other energy storage means [2].

Generally, there are two types of wind turbine; horizontal axis wind turbine and vertical axis wind turbine [3]. Horizontal axis wind turbine is more common as it can produce electricity at higher output than vertical axis wind turbine in the lower mean speed range. But this type of wind turbine is heavy and can't operate efficiently in turbulent wind condition. Vertical axis wind turbine can operate at arbitrary condition and it can harvest wind power from any direction due to the versatility of the blade construction [4].

Malaysia mean wind speed is 2 m/s with high wind speed recorded up to 6 m/s at certain locations. However, because of monsoon season the mean speed for a location varies at different month of the year. This is further emphasized by geographical setting of Malaysia which is naturally shielded in west Malaysia by the Indonesian island cluster. On the eastern seaboard, Malaysia is exposed to the South China Sea which caused the area to register higher wind speed at peak monsoon season. In sabah, one district that shows potential for wind turbine utilization as an alternative electricity source

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is the Kudat region. However, the mean wind speed registered are relatively low at 3 m/s and barely enough for an economically viable wind turbine electricity generation.

The vertical axis wind turbine is available in two design type; lift and drag type [3]. In a slow wind speed condition, vertical axis drag type wind turbine is better suit compared to both horizontal and vertical axis-lift type turbine. However, vertical axis lift-type turbine performs better at higher wind speed condition. The Darrieus wind turbine is an example of lift type vertical axis wind turbine that perform efficiently at high wind speed condition. Furthermore, the design requires smaller number of components; easily accessible for maintenance work; low noise emissions and ability to operate at near ground level [5]. However, it is well known that Darrieus wind turbine have a distinct disadvantage compared to both a horizontal wind turbine and drag type wind turbine; its inability to self-start in low wind speed condition. Thus, several solutions have been proposed to overcome this drawback; variable pitch mechanism [6], hybrid Savonius-Darrieus configuration [7] or custom blade profile that improves the self-start capabilities of Darrieus turbine [8].

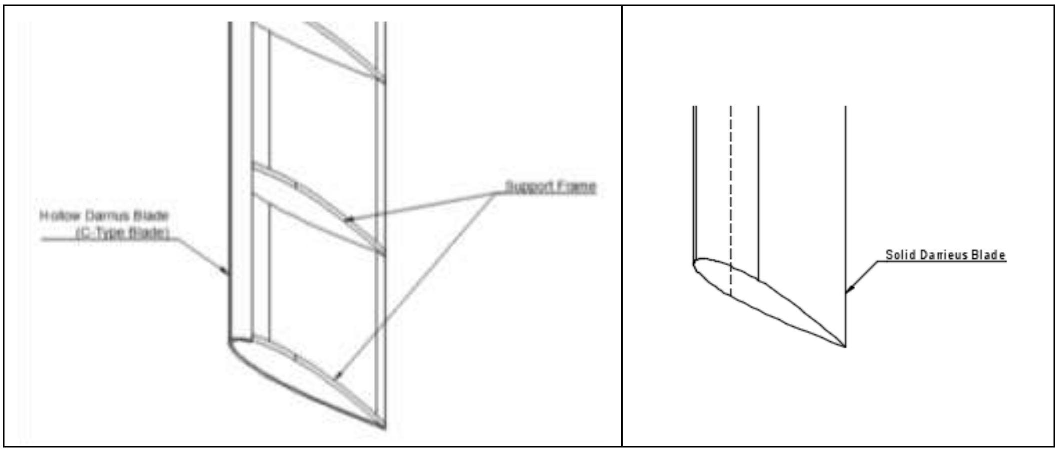
The blades play an important role in determining the overall efficiency of the wind turbine, thus wind turbine manufacturer concentrated their effort to design and developing new blade design to increase the performance of their wind turbine [9]. The development of a blade with self-start capability is a challenging engineering task as effort is concentrated on improving the blade profile rather than the use of extra components. This is to keep the Darrieus blade design simple as possible as additional complex mechanism affect reliability and cost [5].

Designing of wind turbine blades is a true multi objective engineering task. The aerodynamic effectiveness of the turbine need to be balanced with the system loads caused by the rotor [10]. Recent study shows blade improvement such as turbine blade with feasible laminated layout and thin construction of blade improved the efficiency and durability of the turbine [11]. Light weight is one of the factor affecting wind turbine efficiency [12], thus material selection and blade/turbine design are an important phase to ensure that the turbine have lower cut-in speed and faster response time.

Most the wind turbine design available in the market today are design to have wind cut-in speed at 3.5 m/s. As a result, these turbines will not constantly run due to the low wind speed with intermittent high speed wind condition recorded in Malaysia. Thus, a Darrius wind turbine that able to self-start at low wind speed while operate efficiently at high wind speed is highly desirable. Hence, this paper objective is to develop a Darrius wind turbine blade capable to start at low wind speed while running efficiently at high wind speed. A C-type wind turbine is proposed in this paper as a solution to the current demand. The C-type blade is a hybrid design; a combination of Darrieus section with NACA 0012 profile which provide lift type characteristic while a hollow section provides drag type characteristic.

2. Methodology

The C-type Darrieus blade profiles are generated with the NACA 0012 profile as the reference. The design of this unique blade structure is that it is hollow and exposed at one side, while having the NACA 0012 profile as the cross section as shown in figure 1. The generation of the NACA 0012 profile were done using online tools (airfoiltools, 2014) and the major dimension are shown in figure 2.



(a) (b)

Figure 1. Blade design for (a) C-Type (b) Solid Type.

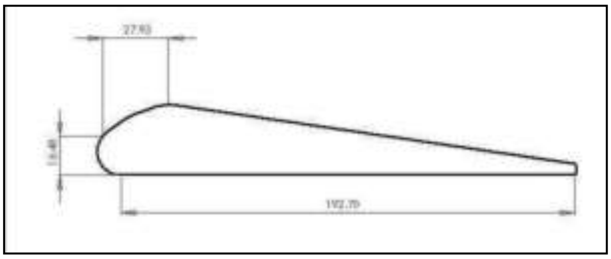


Figure 2. Dimension in mm for C-type with NACA 0012 profile.

To demonstrate the effect of the C-type design, the rotation of the turbine is divided into two phase as shown in figure 3. In front facing phase, the profile gave less drag to the overall assembly. However, it is noted that at the beginning of front facing phase the drag force is higher due to the C-profile exposed to wind stream. Thus, a three blade system is used to counter this issue. While in the rear facing phase, the C-type profile significantly increases the driving force of the blade thus giving higher torque.

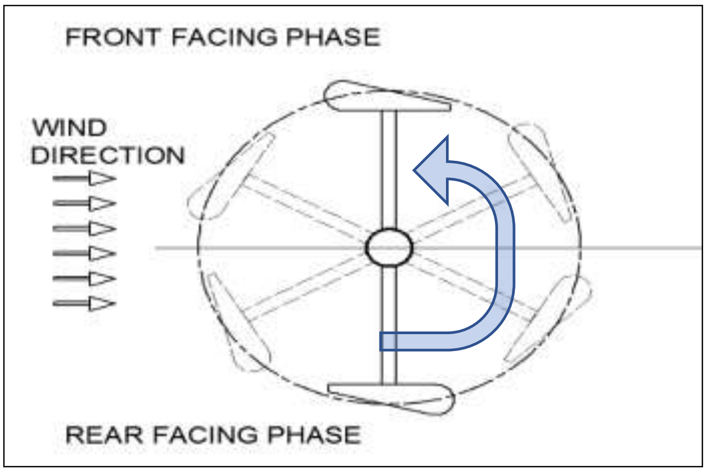


Figure 3. Rotation phase for C-type Darrieus turbine.

The turbine blade was designed using CAD software and fabricated in the faculty in-house manufacturing facility. It was designed in such a way that different angle of attack can be used, thus enable us to study the effect of angle of attack on the wind turbine performance. The material used for the blades prototype was mainly aluminum sheet as it has adequate yield strength to withstand the low wind force and easy to be shaped. Balsa wood were used as the supporting frame for the blade while the centre rotor hub was made from aluminum shaft. The final design of the wind turbine is as shown in figure 4.

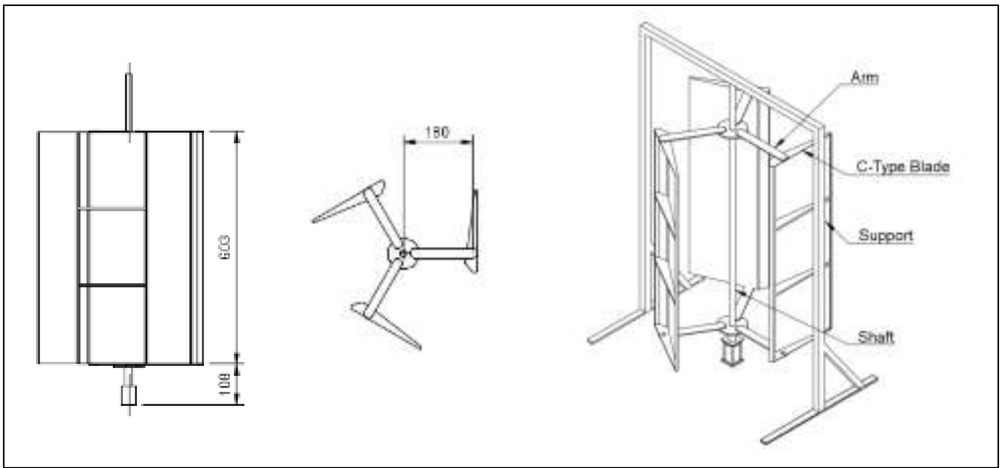


Figure 4. Schematic figure of C-type Darrieus wind turbine.

3. Experimental Work

To assess the performance of the C-type Darrieus turbine, the wind turbine undergoes simulated wind condition with rotation speed recorded at 1 m/s wind speed increment up to 5 m/s. Six different rotor pitches at -3^o, -6^o, 0, 3^o and 6^o representing different angle of attacks were tested. NACA 0012 Solid Darrieus blade was also tested at similar wind condition and angle of attack for comparison purpose. The rotor speed was measured using a digital tachometer and the wind speed is determined using a digital anemometer. The purpose of this study is to investigate the performance of the C-type Darrius blade turbine and compare it with the solid blade NACA 0012 turbine at different wind speed. Thus, the performance of the machine can be expressed in term of tip speed ratio at different wind speed. Tip speed ratio is defined as the ratio of blade tangential speed to actual wind speed and is written in equation (1);

$$TSR = \frac{\omega R}{v} \tag{1}$$

4. Discussion

A total of 6 experiments were conducted for each turbine; C-type Darrieus blade and NACA 0012 blade. For each experiment sets, the minimum wind speed is 1 m/s and increased up to 5 m/s. Figure 5 shows the tip speed ratio for C-type Darrieus turbine at various wind speed and angle of attack. Due to the C-type design, the turbine started to rotate as low as 1 m/s an incrementally increased its rotation speed as the wind speed increases. Notably, C-type Darrieus turbine with angle of attack 3^o performs extremely well compared to other angle of attacks with maximum TSR at 1.8. As for NACA 0012 Darrieus blade turbine, the Tip Speed Ratio (TSR) data are shown in Figure 6. As expected, the turbine only started to rotate at wind speed 3 m/s which is typical of this kind of blade. The TSR incrementally increased as the wind speed increases, however different angle of gave clear TSR deviation from each other. Such behavior were not observed in the C-type Darrieus turbine where the value of TSR does not differ much at all wind speed at the exception of angle of attack 3^{o} and 0^{o}. The best performance recorded for NACA 0012 Darrieus turbine is the 0^{o} angle of attack configuration with maximum TSR value recorded at 1.15.

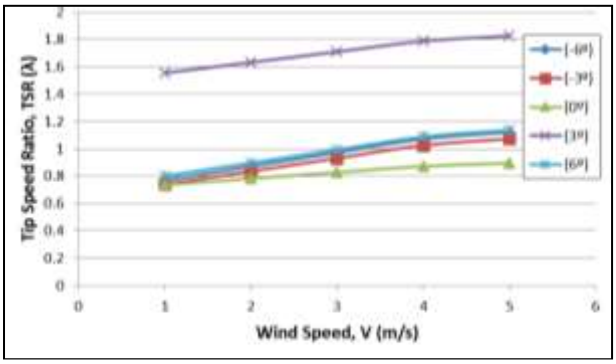


Figure 5. Tip speed ratio (TSR) for C-type Darrieus wind turbine.

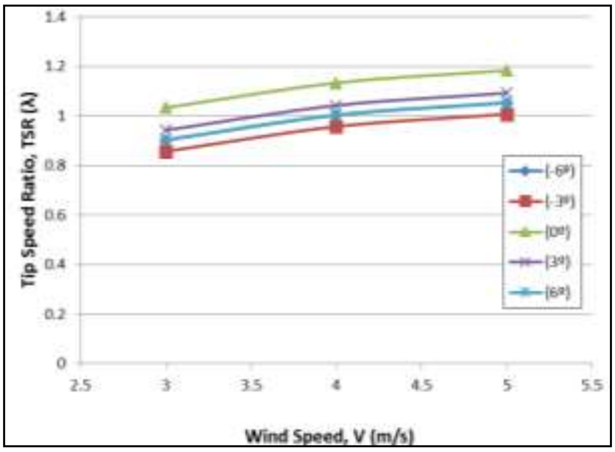


Figure 6. Tip speed ratio (TSR) for NACA 0012 Darrieus wind turbine.

The experimental result shows that the hybrid design of the C-type turbine have successfully aided the turbine to self-start at low wind speed. The hollow side of the C-type blade provide sufficient drag when is exposed to down-wind force during the rear-facing-phase while the NACA 0012 profile kept a low drag force in front-facing phase. Comparing this to a solid Darrieus blade design, the turbine only started to rotate at higher wind speed albeit at lower tip speed ratio.

5. Conclusion

In this work, a C-typed Darrieus wind turbine was designed, build and tested against a NACA 0012 Darrieus wind turbine at various wind speed and pitch angle. Test result shows that;

a) C-type Darrieus wind turbine started to rotate at lower wind speed of 1 m/s compared to NACA 0012 Darrieus turbine which only start to rotate at 3 m/s.

b) Generally, C-type Darrieus turbine TSR value have small difference in value with NACA 0012 Darrieus turbine at similar wind speed. However, for angle of attack 3^o the TSR is significantly higher.

As a conclusion, the C-typed Darrieus wind turbine shows good potential as an alternative design specifically for arbitrary wind speed condition as observed in Malaysia. However, the flimsy blade construction might pose a challenge to design a reliable wind turbine especially in larger size. Future study need to focus on studying the effect of different NACA C-type profile on the wind turbine performance as the current study only focus on a single NACA 0012 profile.

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