Faculty of Engineering

The Efficient Wind Turbines Design for Low Wind Speed Air

Wong Lee Kwang

Masters of Engineering
2018

UNIVERSITI MALAYSIA SARAWAK

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The Efficient Wind Turbines Design for Low Wind Speed Air

Wong Lee Kwang

A thesis submitted

In fulfillment of the requirements for the degree of Master of Engineering

(Mechanical Engineering)

Faculty of Engineering
UNIVERSITI MALAYSIA SARAWAK
2018

DECLARATION

I, Wong Lee Kwang (15020313), Faculty of Engineering hereby declare that the work entitled The Efficient Wind Turbines Design for Low Wind Speed Air is my original work. I have not copied from any other students' work or from any other sources except where due reference or acknowledgement is made explicitly in the text, nor has any part been written for me by another person. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Name: Wong Lee Kwang (15020313)

Date: 11 January 2018

DEDICATION

Specially dedicated to

My beloved Family and Friends

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ABSTRACT

The fossil fuels produce carbon dioxide and carbon monoxide during the incomplete combustion, which lead to environment pollution. A few types of environmentally friendly wind turbine is proposed for operation under low wind speed. These types of wind turbines are suitable to the wind speed of this country, Malaysia. Numerical simulation is implemented, comparison between conventional and new design model related to flow condition. Prototypes have been manufactured, experimental tested, and compared. The first study of this thesis refers to a novel lantern wind turbine designed and compared to a darrieus vertical-axis wind turbines (VAWTs). Both wind turbines is VAWTs design. The second study refers to waterwheel wind turbine compared to a modern horizontal-axis wind turbine (HAWT), both of the wind turbines is a HAWT designed. The lantern wind turbine has wide range of improvement since it is a new design in development process, the angle of attack of the lantern wind turbine can be increases to provide more pressure difference on the blade and some of the rotor availiable has very high torque, rotor of 1V and 3V should be tested. The results are shown in the form of power coefficient vs tip speed ratio for wind velocities between 3 m/sec to 6 m/sec. The experimental result of the lantern wind turbine shows no rotation when it is compared to Darrieus VAWTs. The modern HAWT model gives the maximum power coefficient of 0.27 at a wind speed of 5 m/s and tip speed ratio of 0.6 which is higher than the waterwheel wind turbine model. The modern HAWT model gives the maximum power coefficient of 0.32 at a wind speed of 3.5 m/s and tip speed ratio of 1.4. The modern HAWT has the optimum torque of 0.01N and 540 RPM. The water waterwheel wind turbine has the optimum torque of 0.01N and 900 RPM. The water wheel wind turbine shows a wide range of improvement at lower speed, which is suitable for rural area in Malaysia.

Keywords: flow condition, *Cp*, TSR, velocity, RPM, torque

Reka Bentuk Turbin Angin Cekap untuk Kelajuan Angin Rendah

ABSTRAK

Beberapa jenis turbin angin mesra alam dicadangkan untuk beroperasi di bawah kawasan pengedaran kelajuan angin yang rendah. Jenis turbin angin ini sesuai dengan kelajuan angin negara ini, Malaysia. Simulasi berangka dilaksanakan, perbandingan antara model reka bentuk konvensional dan baru yang berkaitan dengan keadaan aliran. Prototaip beberapa reka bentuk telah dihasilkan, uji cuba eksperimen, dan dibandingkan. Kajian pertama tesis ini merujuk kepada turbin angin tanglung baru yang direka dan dibandingkan dengan turbin angin paksi angin darat (VAWTs). Kedua-dua turbin angin adalah reka bentuk VAWTs. Kajian kedua merujuk kepada turbin angin kincir angin berbanding dengan turbin angin paksi (HAWT) yang moden, kedua-dua turbin angin adalah direka bentuk HAWT. Turbin angin tanglung mempunyai pelbagai penambahbaikan kerana ia merupakan reka bentuk bahan dalam proses pembangunan, sudut serangan turbin angin tanglung dapat meningkat untuk memberikan lebih banyak tekanan pada bilah dan beberapa rotor yang dapat digunakan memiliki tork yang sangat tinggi, pemutar 1V dan 3V perlu diuji. Hasilnya ditunjukkan dalam bentuk nisbah kelajuan pukulan berbanding dengan ujung kuasa untuk halaju angin antara 3 m/s hingga 6 m/s. Hasil eksperimen dari turbin angin tanglung tidak menunjukkan putaran bila dibandingkan dengan Darrieus VAWTs. Model HAWT moden memberi pekali kuasa maksimum 0.27 pada kelajuan angin 5 m/s dan nisbah kelajuan tip 0.6 yang lebih tinggi daripada model turbin roda angin. Model HAWT moden memberikan pekali kuasa maksimum 0.32 pada kelajuan angin 3.5 m/s dengan nisbah kelajuan tip 1.4. HAWT moden mempunyai tork optimum dari 0.01N dan 540 RPM. Turbin roda angin mempunyai tork optimum 0.01N dan 900 RPM.

Kata kunci: *syarat mengalir, Cp, TSR, halaju, RPM, tork*

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Symbol	Name
P	Power (W)
F	Force vector (N)
λ	Tip speed ratio
v	Wind speed (m/s)
ω	Blade revolution per minutes (rad/s)
L	Length of the wind turbine blade (m)
r	Distance from the center of radius
Cp	Power coefficient
HAWT	Horizontal axis wind turbine
VAWTs	Vertical axis wind turbines
RPM	Revolution per minutes
CFD	Computational fluid dynamics
TSR	Tip speed ratio
Re	Reynolds number

CHAPTER 1

INTRODUCTION/ LITERATURE REVIEW

1.1 Background of research

The wind turbine is a type of renewable energy device that generates electricity. As wind blows the forces that acted on the blades of the wind turbine causes the rotor to rotate produces electricity. Production of electricity reduces the use of natural gas (hydrocarbon fossil fuels) that produces typically carbon dioxide and carbon monoxide during the incomplete combustion in order to generate electricity (Demirbas, 2004). The wind turbine system is capable of producing 5-8GWh of energy annually, which is equal to 1 ton per day of burning coal to produce electricity. The UK's has the objective to increase the renewable source of energy by 14% by 2020. The country has a total renewable energy of 64.4 TWh in 2014 (Musgrove et al., 2010). Therefore, this study is conducted to increase the source if renewable energy. There are two types of wind turbine, the horizontal wind turbine refers to the shaft, which is horizontal to the ground, is known as horizontal axis wind turbine (HAWT), and vertical wind turbine refers to the shaft, which is parallel to the ground, which is known as Vertical-axis wind turbines (VAWTs) (Jamieson, 2011.).

This thesis has two studies; first study refers to a novel lantern wind turbine design compared to a Darrieus wind turbine the conventional design, both of the design is a vertical design. The second study refers to waterwheel wind turbine compared to modern HAWT both of the design is a horizontal design. The results from comparison the study showed that lantern wind turbine has wide range of improvement and waterwheel wind turbine has high performance at low wind speed distribution area.

1.1.1 VAWTs wind turbines

Cycloturbine is one of the VAWTs wind turbines, which uses an aerodynamic shape blade to produce mechanical orientation the pitch of the blades to achieve maximum efficiency. The Darrieus VAWTs design has the ability to start up and rotate in low wind velocity with high efficiency (Tjiu et al., 2015).

Figure 1: Darrieus VAWTs market designs (Castelli, 2011)

Muller et al. (2009) shown that the Sistan type windmill that produce the drag force energy converted it for building integration. It proven that thier design increases the theoretical efficiency to about 48% or 61%, the experimental research has proven that the wind turbine generates the efficiency which is higher than 40%. Our new design lantern wind turbine belong to one of the VAWTs designed, which is not available in the market, inspired by the shape of the Chinese lantern. The design uses multiple aerodynamic shape blades to produce rotation of the blade. This design allows the torque generated by the wind energy to remain constant over wide angle that allow this system to generatas maximum torque as possible in order to produce more power.

1.1.2 HAWT

Modern HAWT large wind turbine uses a servomotor with a gearbox that turns a low rotation into a higher rotation to power up the electrical generator. (Drewry & Georgiou, 2007).Modern HAWT is often found in wind farms; it generates high renewable energy source and currently used out by many countries (Moroni et al., 2016). However, the conventional wind turbines are huge and consume a lot of space. It requires space to maintain, when these wind turbines are installed. The diameter of a wind turbine can be larger than 124 m with a total height of 200 m (Dutton et al., 2010). The interested readers should refers to Digraskar (2010) regarding CFD simulations on horizontal axis wind turbine. Multiple cases of modern HAWT have exploded recently due to high rotating speed. On the January 29, 2016 Enviro-news showed that wind turbine exploded and caught a fire due to wind turbine excessive speed (Urry, 2016). Dailymail UK news on 6 Jan 2012 also reported that a wind turbine rotating at high speed exploded (Luke & Rob, 2011).

1.2 Problem Statement

The huge and big conventional wind turbine in the wind farm has taken up lots of spaces and a distance is required to place another wind turbine. The development of wind power plant which taken up a lot of space have a direct impact towards citizen such as noise pollution and road accessibility (Hand et al., 2009). A wind power plant project is usually time consuming therefore it requires the cleaning of lands for development in the particular area, which has the possibility of significant degradation and effects on quality of the ecosystem (Arnett, 2013). There are multiple cases of wind turbine explosions due to high speeds, such as an incident where a wind turbine caught a fire due to mechanical failure (Emerson, 2016). Wind turbine accident statistics in Figure 2 shows the yearly increase of the number of wind turbine related accidents. The expected growth in the installation of wind turbines, also bring the expectation of an increase in the number of accidents of wind turbines.

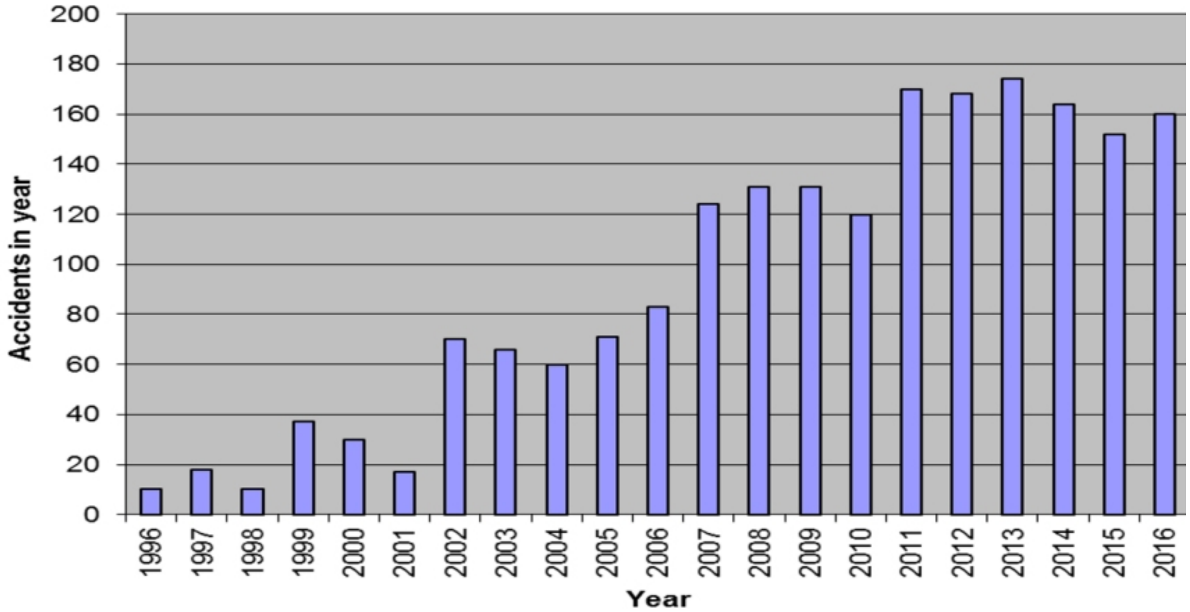

Figure 2: Wind Turbine Accident (Caithness Windfarm Information, 2016)

The high rotating geared of wind turbines that are continuously distressed by numerous gearboxes. The bearings failure within the gearbox is the most significant problem associated with the turbines which lead to explosion and fire. Once a fire is ignited in a wind turbine, the situation rapidly escalates because the high wind favoured by turbine locations enhances the supply of oxygen that lead to fire and explosion.

1.3 Objective

i. A novel design for lantern wind turbine studied through numerical simulations
ii. Study of novel design for lantern wind turbine regarding the wind turbine *Cp* vs TSR, velocity vs RPM , RPM vs torque at low wind speed to reduce mechanical failure and gear distress. Data for *Cp*, TSR, and torque is obtained.
iii. novel design waterwheel wind turbine is studied through numerical simulations

iv. Study of novel design waterwheel wind turbine regarding the wind turbine *Cp* vs TSR, velocity vs RPM, RPM vs torque at low wind speed to reduce mechanical failure and gear distress. Data for *Cp*, TSR, and torque is obtained.

v. reduce the large wind turbine to a smaller wind turbine to reduce land consumptions from their installations

1.4 Aerodynamic consideration

Most of the blade design in this thesis used the basic theory of aerodynamics. Aerodynamics is the interaction between the motion of air and the airfoil design with a curved surface on the top and a flat surface at the bottom. When a laminar flow of air passes through an airfoil, with an angle of attack, the speed above the airfoil is higher which produces lower pressure. The airfoil has a lower speed below it; these differences produce high pressure, which leads to lifting where the airfoil is lifted perpendicular to the direction of the wind flow. The first study in this thesis is about lantern wind turbine compared to a darrieus VAWTs, while the second study is regarding water wheel wind turbine compared to a modern HAWT. All of the studies are designed with aerodynamic consideration.

1.4.1 Tip Speed Ratio

The Tip Speed Ratio (TSR) λ refers to the angular velocity of the rotating turbine and the flow velocity with the formula as shown below:

$$\lambda = \frac{r\omega}{v} \tag{1.1}$$

Where, ω is the angular velocity of the turbine, r is the radius of the turbine and v is the flow velocity. The operating Tip Speed Ratio is chosen for the wind turbine to work at. The flow velocity depends on the mechanical generator that converts the mechanical energy of the spinning wind turbine into electrical energy (Bhutta et al., 2012; Abdulrahim et al., 2015). Therefore, the operating of Tip Speed Ratio vs *Cp is* plotted at where a constant Reynolds number is usually obtained (Ragheb & Ragheb, 2011). Furthermore, the optimum Tip Speed ratio which will give the highest efficiency can be identified.

1.4.2 Power coefficient

The power coefficient (*Cp)* is a dimensionless parameter that expresses the amount of power that the turbine is able to be extracted from the flow of the wind in our study. Thus, the *Cp* is the ratio of the actual power extracted from the flow to the power available from it (Howell et al., 2010; Zanforlin &Letizia, 2015). The power generated by the kinetic energy of a free flowing stream is given by the following equation.

$$P_a = \frac{Sv}{2} \tag{1.2}$$

Where, S is the cross-sectional area and v is the flow velocity. The power extracted from the turbine is defined as,

$$W = \frac{1}{2} I \omega^2 t \tag{1.3}$$

Where, I is the moment of inertia (kg.m^2), ω *is the* angular velocity (rad/s) and t refers to time. The equations 1.3 and 1.5 are combined in order to get an expression for the power coefficient,

$$Cp = \frac{W}{Pa} = \frac{\frac{1}{2} I \omega^2}{\frac{\rho S v^3}{2}} \tag{1.4}$$

The chart *Cp* vs TSR plot is obtained to identify the TSR of the wind turbine. If the rotor of the wind turbine is extracting more power from the free stream; the value of this *Cp* would be 1 in an ideal case (Gupta et al., 2006).