UNIVERSITI PUTRA MALAYSIA

DESIGN OF AN AUTOMATIC TRANSMISSION SYSTEM TO IMPROVE ENERGY CAPTURE OF VERTICAL AXIS WIND TURBINE

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By

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DESIGN OF AN AUTOMATIC TRANSMISSION SYSTEM TO IMPROVE ENERGY CAPTURED OF VERTICAL AXIS WIND TURBINE

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Nowadays, renewable energies are highly demanded as they are sustainable and environmentally friendly. One of the renewable energy is wind, and it can be harvested by using a wind turbine. There are two types of wind turbines: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Large scale wind turbines mostly use Continuously Variable Transmission (CVT) as the transmission system, which is needless to say its efficiency; it is highly efficient. However, it comes with high complexity and cost too. Meanwhile, most small-scale wind turbines in the current market offer a one-speed gearing system only, which means no gear ratios are varied, resulting in low energy efficiency and leading to gears failure. They have recognized a need for the continuous monitoring of major wind turbine components, gearbox parts. These components are seen to require substantial maintenance and repair efforts. For a fixed-speed wind turbine, the generator is directly connected to the electrical grid and they have several drawbacks in which the reactive power or the grid voltage level cannot be controlled. This research concerns the design of an automatic transmission system in VAWT to increase its efficiency in harvesting energy. The gear and clutch system was designed and fabricated for VAWT and the system was analyzed. The gear and clutch system was calculated using the gear and clutch formula. Then, the system was designed using Solidworks and fabricated using a 3D printer for VAWT. The gear ratios have been varied and the number of gears has been increased to two. A Centrifugal clutch is applied to the gear to perform its automatic gear shifting. During the test, incoming wind speed is firstly increased until the vertical axis wind turbine started to spin, then the wind speed is decreased. The incoming wind speed is restricted from 0 m/s to 20 m/s. The energy harvesting efficiency is measured by comparing a vertical axis wind turbine's output voltage and output power with automatic and without automatic transmission systems. The result shows that applying automatic transmission systems with a centrifugal clutch for VAWT is reliable and improves its efficiency. Generally, with the application of an automatic transmission system, the start-up wind speed for VAWT to spin was reduced from 20 m/s to 13 m/s. The VAWT

with an automatic transmission system started to spin at 13 m/s of wind speed and it could maintain its spinning even the incoming wind speed was reduced. The voltage and power produced also show that the VAWT can optimize energy harvesting efficiency with less energy loss.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

REKA BENTUK SISTEM PENGHANTARAN AUTOMATIK UNTUK MENINGKATKAN TENAGA YANG DITERIMA OLEH TURBIN ANGIN PAKSI MENEGAK

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Pada masa ini, tenaga yang boleh diperbaharui sangat diperlukan kerana ia berkelanjutan dan mesra alam. Salah satu tenaga yang boleh diperbaharui adalah angin, dan ia dapat dituai dengan menggunakan turbin angin. Terdapat dua jenis turbin angin: Horizontal Axis Wind Turbine (HAWT) dan Vertical Axis Wind Turbine (VAWT). Turbin angin berskala besar kebanyakannya menggunakan Transmission Variable Continuously (CVT) sebagai sistem penghantaran, yang tidak perlu dikatakan kecekapannya; sangat cekap. Walau bagaimanapun, ia dilengkapi dengan kerumitan dan kos yang tinggi. Sementara itu, kebanyakan turbin angin berskala kecil di pasar saat ini hanya menawarkan sistem roda satu kecepatan, yang bermaksud tidak ada rasio roda gigi yang bervariasi, menghasilkan kecekapan tenaga yang rendah dan menyebabkan kegagalan roda gigi. Mereka telah menyedari bahawa terdapat keperluan untuk pemantauan berterusan komponen turbin angin utama, bahagian kotak gear. Komponen ini dilihat memerlukan usaha penyelenggaraan dan pembaikan yang besar. Untuk turbin angin berkelajuan tetap, penjana dihubungkan terus ke grid elektrik dan mereka mempunyai beberapa kelemahan di mana daya reaktif atau tahap voltan grid tidak dapat dikendalikan. Penyelidikan ini menyangkut reka bentuk sistem penghantaran automatik di VAWT untuk meningkatkan kecekapannya dalam pengambilan tenaga. Sistem gear dan klac dirancang dan dibuat untuk VAWT dan sistem dianalisis. Sistem gear dan kopling dikira menggunakan formula gear dan kopling. Kemudian, sistem ini dirancang menggunakan Solidworks dan dibuat menggunakan pencetak 3D untuk VAWT. Nisbah gear telah berubah-ubah dan jumlah roda gigi meningkat menjadi dua. Klac sentrifugal digunakan pada roda gigi untuk melakukan pertukaran gear automatiknya. Semasa ujian, kelajuan angin masuk pertama kali ditingkatkan sehingga turbin angin paksi menegak mulai berputar, kemudian kelajuan angin menurun. Kelajuan angin masuk dibatasi dari 0 m / s hingga 20 m / s. Kecekapan penuaian tenaga diukur dengan membandingkan voltan output dan kuasa output turbin angin paksi menegak dengan transmisi automatik dan tanpa sistem

penghantaran automatik. Hasilnya menunjukkan bahawa penggunaan sistem transmisi automatik dengan klac sentrifugal untuk VAWT boleh dipercayai dan praktikalnya meningkatkan kecekapannya. Secara amnya, dengan penerapan sistem transmisi automatik, kecepatan angin permulaan untuk berputar VAWT dikurangkan dari 20 m / s menjadi 13 m / s. VAWT dengan sistem transmisi automatik mulai berputar pada kecepatan angin 13 m / s dan dapat mempertahankan putarannya bahkan kecepatan angin yang masuk berkurang. Voltan dan kuasa yang dihasilkan juga menunjukkan bahawa VAWT dapat mengoptimumkan kecekapan pengambilan tenaga dengan kehilangan tenaga yang lebih sedikit.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CAD	Computer-Aided Drawing
DC	Direct Current
DWT	Ducted Wind Turbine
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbine
HSS	High-Speed Shaft
ISS	Intermediate-Speed Shaft
MFC	Macro Fiber Composite
PV	Photovoltaic
RPM	Revolutions Per Minute
TWh	Terawatt-hours
VAWT	Vertical Axis Wind Turbine

CHAPTER 1

INTRODUCTION

1.1 Research Background

In recent years, Wind Power is considered the world's fastest-growing source of renewable energy. Currently, wind energy is the second-largest source of renewable energy, and by the year 2035, wind energy will take up to 25% of total renewable energy, according to the Global Wind Energy Council (GWEC)'s 2013 wind report. Traditionally, wind turbines are located onshore, but lately, they are increasingly installed offshore due to community demands. A turbine can produce electricity up to 70-85 percent of the time, reliant on local wind speed. Wind energy is highly demanded as it is sustainable and environmentally friendly (Update, 2013).

For wind energy, wind turbine applications need to be appropriately selected. This innovation has broadened to a few world areas and created a great foundation with comparative costs (Chiang et al., 2008). There are three types of wind turbines classified based on the shaft orientation and axis of rotation: horizontal axis wind turbines, vertical axis wind turbines, and ducted wind turbines. The first type of wind turbine, the Horizontal axis wind turbine (HAWT), is a turbine with a shaft-mounted horizontally parallel to the ground. This type of wind turbine is more commonly used. The second type of wind turbine is the vertical axis wind turbine (VAWT), which its shaft is normal to the ground. This type of wind turbine is less frequently used which Savonius and Darrieus are the most common in the group. The third wind turbine can be either horizontal or vertical axis, but the turbine blades are encased in a shroud or hollow-shaped duct and known as a Ducted Wind Turbine (DWT). These wind turbines are mainly used for electricity generation (Paul, 2016).

The VAWT is not as regular and has just as of late been utilized for a huge-scale power era. A few studies have shown that the purpose of the VAWT offers more favorable circumstances than the HAWT. The VAWT does not require to be orientated to the course of the wind. Other than that, it does not need to be bothered with a tower, thus decreasing capital costs. The generator is mounted at ground level to ease access (Kanellos and Hatziargyriou, 2008, Yeh and Wang, 2008, Ibrahim, 2009). In this research, Vertical Axis Wind Turbine is designed with an automatic transmission system to improve electric generation efficiency.

1.2 Problem Statement

The reliability of wind turbines is a prerequisite to ensure the healthy growth of wind energy. Even if certification bodies validate new designs and prototypes performed by manufacturers and could offer safer and more reliable wind turbines, their development and related improvement are still based on the experience with smaller turbines than those currently being erected. Therefore, the technology is still coming up against its limits. To this end, it has been recognized that there is a need to continuously monitor major wind turbine components such as gearbox, generator, and rotor blades. These components are seen to require substantial maintenance and repair efforts or even retrofits (Nivedh, 2014). Figure 1.1 shows a quick review of the cause of failures that occurred on a wind turbine. Sheng, in his report, claimed that the gearbox is the most significant contributor to turbine failure and costliest to repair. In his observation, both bearing and gear failures are concentrated in the parallel section. Furthermore, the top failure mode is happening at a high-speed shaft (HSS) or intermediate-speed shaft (IMS) bearing axial cracks (Sheng, 2013).

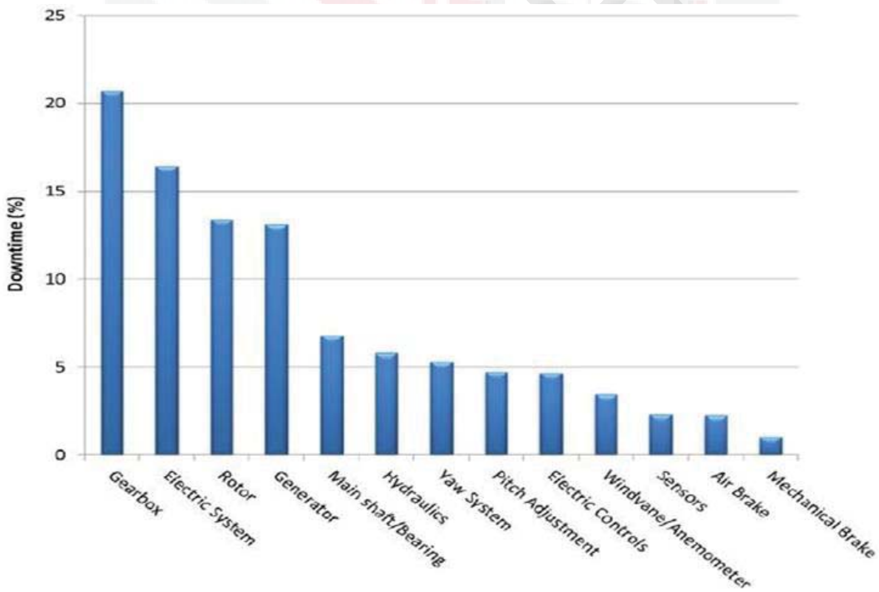

Figure 1.1: Aggregated failures per turbine subsystem. (Sheng, 2013)

Verma and Pachori stated that wind turbines could either operate at fixed speed or variable speed. For a fixed-speed wind turbine, the generator is directly connected to the electrical grid. The most common type of wind turbine is the fixed-speed wind turbine with the induction generator directly connected to the grid. This system has several drawbacks, however. The reactive power and, therefore, the grid voltage level cannot be controlled. Most of the drawbacks of a fixed wind turbine are avoided when variable-speed wind turbines are used. These turbines improve the dynamic behavior of the turbine and reduce the noise at low wind speeds. For a variable speed wind turbine, the generator is controlled by power electronic equipment. There are several reasons for using the variable-speed operation of wind turbines; among those are possibilities to reduce stresses of the mechanical structure, acoustic noise reduction and the possibility to control active and reactive power. However, in variable speed wind turbines, there are losses in power electronics and some components. It can even cause an increase in the cost of equipment because of the power electronics (Verma et al., 2015).

In this research, the experimental VAWT is a fixed-speed wind turbine. The grid voltage level cannot be controlled since the generator is directly connected to the grid by referring to N. Verma and A. Pachori. These problems lead to some issues as follows:

i. The current wind turbine only has a one-speed gearing system which when the wind speed is inconsistent, the gearbox is not capable of varying the gear ratio, which contributes to the gears cracking and gearbox failures (Cho et al. 2017)

ii. The gearbox cannot vary the gear ratio due to the one-speed gearing system, leading to less efficiency in harvesting the power from wind energy. Hence, energy loss occurred.

1.3 Research Objectives

The main purpose of this thesis is to improve the energy harvesting of vertical axis wind turbines regarding the wind speed in Malaysia. Therefore, the specific objectives of this thesis are as following:

i. To design the automatic transmission systems for vertical axis wind turbines.
ii. To perform testing on gearing and clutch system for vertical axis wind turbine.
iii. To analyze the automatic transmission system for improving energy harvest in vertical axis wind turbine.

1.4 Scope and Limitation of Work

The development of automatic transmission systems for vertical axis wind turbines might cover a large area of study. However, in this thesis, the scope and limitations are as following:

i. The studies only cover the application of automatic transmission systems by using a centrifugal clutch, not Continuously Variable Transmission (CVT) or planetary gear. Thus, any computational control system is not involved.

ii. The mechanical property of the material in the fabrication of gears and parts is not considered since the gears and parts were fabricated using 3D- printer. Due to the mechanical rotation of the vertical axis wind turbine, it might have broken some parts of the gears and the mounting structure.
iii. At testing, incoming wind speed is firstly increased until the vertical axis wind turbine started to spin, then the wind speed is decreased. The incoming wind speed is restricted from 5 m/s to 20 m/s.
iv. The energy harvesting efficiency of vertical axis wind turbines with and without an automatic transmission system is measured by comparing the output voltage and power.

1.5 Thesis Organization

The thesis layout visualized the flow and the content of this thesis on developing an automatic transmission system for a vertical axis wind turbine. This thesis is divided into 5 chapters which will be explained as follows:

i. Chapter 1: Introduction. This chapter reviewed general wind turbines and automatic transmission systems. The problem statement encountered in the wind turbines and the objectives of this project were discussed in this chapter.
ii. Chapter 2: Literature Review. In this chapter, the information and knowledge of wind turbines, automatic transmission systems, and anything related to this project were reviewed and revised from the previous studies.
iii. Chapter 3: Methodology. This chapter discussed the process and its method of developing automatic transmission systems for vertical axis wind turbines. The calculations and parameters involved were revised in this chapter.
iv. Chapter 4: Results and Discussions. The results from the testing of vertical axis wind turbine with automatic transmission system were compared to the vertical axis wind turbine without automatic transmission system. The results were in the form of voltage and power produced. Then, the results were discussed.
v. Chapter 5: Conclusions and Recommendations. This chapter concluded this research from the results and discussions obtained. The recommendations for future studies were also suggested.

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