Design of Microcontroller Based Dual Braking Mechanism for Micro-Wind Turbine

by

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LIST OF SYMBOL

k_p	Proportional gain
k_i	Integral gain
k_d	Derivatives gain
k_c	Controller gain
T_s	Settling time
ω_n	Damping frequency
ξ	Damping ratio
λ	Tip speed ratio
C_T	Coefficient of torque
C_p	Coefficient of power
J	Moment of inertia
B	coefficient of Viscosity
A	Swept area of wind turbine
r	Radius of blade
ρ	Density of air

I	Current
V	Voltage
E	Induce voltage
$k_{\emptyset}$	Voltage constant
R	Total resistance

LIST OF ABBREVIATIONS

PID	Proportional, integrals and derivatives
USB	Universal Serial Bus
Rpm	Rotational per minute
ITAE	Integral time absolute error
MOSFET	Metal oxide semiconductor field effect transistor

Mereka Pengawal Mikro Berdasarkan Mekasima Dual untuk Kincir Angin Mikro

ABSTRAK

Kajian ini membentangkan mekanisma pembrekan dual yang mengandungi brek dinamik dan juga pengawalan rewang. Kedua-dua mekanisme ini dapat memberikan perlindungan kepada kincir angin mikro daripada beroperasi melebihi had laju maksimum dan turut berfungsi sebagai pengawal kelajuan. Pembrekan konvensional bagi kincir angin mikro menggunakan sistem pembrekan yang pasif. Isu yang berkaitan dengan sistem pembrekan yang pasif mempunyai lingkungan kelajuan angin yang terhad. Oleh itu, matlamat kajian ini ialah melanjutkan lingkungan operasi kincir angin mikro dan juga menghalangnya daripada melebihi had kelajuan maksimum. Kajian ini menggunakan "The Proportional Integral Derivatives (PID)" untuk mengawal mekanisme pembrekkan yang berteraskan kriteria "Integral Time Absolute Error (ITAE)" bagi menentukan nilai PID. Mekanisme yang dicadangkan menunjukan keupayaannya dalam mengekalkan kelajuan putaran dibawah had maksimum apabila kelajuan angin dinaikan dari 4.8 hingga 5.2 m/s tanpa memerlukan operasi penutupan

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ABSTRACT

The work proposes dual braking mechanism. It consisted of dynamic braking and yaw control. Both mechanism is used to provide safety to the micro-wind turbine. It protects from over speed and also functioning as speed regulator. A conventional braking system for micro wind turbine uses passive braking system. The limited wind speed range is an issue when to deal with the passive braking system. Therefore, the goal of this study is to extend the range of operation of micro wind turbine and preventing it from over speed condition. The Proportional Integral Derivatives (PID) algorithm is used to control the braking mechanism based on Integral Time Absolute Error (ITAE) criteria to determine its coefficient. The proposed mechanism able to maintain rotational speed under the maximum limit when wind speed increase from 4.8-5.2 m/s without the needs to shutdown operation.

CHAPTER 1

INTRODUCTION

1.1 Background

This paper introduces the braking system in multi-rotor micro-wind turbine where the power generation is below 1 kW. The multi-rotor configuration is introduced to overcome the difficulties of producing a larger blade with a specific characteristic namely low mass with high strength capabilities. This is due to lack of technology advancement (Habib, Ibrahim, & Rafukka, 2016). These requirements involve with upscaling theory when power generation is scaled with the size of the blade (Troldborg & Sørensen, 2012). The upscaling theory has a limitation because the mass of wind turbine increased in cubic. Meanwhile, power generated only posed increase in the square .The idea of installing small multi-rotor micro-wind turbine to boost power generation that equivalent to the single unit large wind turbine (Velázquez et al., 2014). Therefore, due to smaller blade size and generator, the mass was significantly reduced. In addition, it also allows to use single support structure compare with an individual wind turbine that configured in a wind farm. For a micro wind turbine, its output power is less comparing with small scale wind turbine (Ledo, Kosasih, & Cooper, 2011). Due to low power generation, application focused in standalone power system such as charging battery (Li, Reynolds, & Fergal, 2011).

The main problem in a multi-rotor wind turbine is over speed condition which each rotor can have different rotational speed. Due to high-speed condition bearing of the rotor will wear faster and produce abnormal temperature. This will increase the risk of fire especially for a wind turbine that used flammable fiberglass resin and oil deposited in wind turbine nacelle (Uadiale et al., 2014). A direct-drive wind turbine requires less rotating component that contribute to the risk of fire which will reduce the risk and improve reliability (Polinder et al., 2013) . Normally, for small and micro-scale wind turbines, a fixed pitch is used to reduce the complexity of the system and cost.

1.2 Problem statement

Micro wind turbine expected to harvest a wind power from the low range of wind speed. In term of power generation perspective, high wind speed is good because wind turbine can produce more electrical power. However, when micro wind turbine operate at high wind speed region, it has a major drawback such as shorten it bearing life span and increase possibility for support structure failure due to vibration. For multi-rotor configuration, the swept area of wind turbine also increased. During gust wind, the wind speed can rise up to 7.71 m/s or more in a short period of time. This may cause one of the wind turbines experiences different wind flow from one another. As result, these causes one of the wind turbine to accelerate thus may lead to over speed condition. This condition requires control mechanism to regulate each of rotor speed at safe level when wind speed suddenly exceed rated speed

1.3 Objective

1) To develop over speed protection system for micro wind turbine. This is to ensure micro-wind turbine keep protected against high wind speed.
2) To develop control system that able to regulate micro-wind turbines speed within safe limit.

1.4 Scope of project

The scope of this project is limits to a braking system which involve with yaw control and dynamic braking mechanism for multi-rotor configuration. The controller is designed based on Proportional Integral Derivatives (PID) for both mechanisms. The micro wind turbine used consisted of DC generator that rated at 24V. The range of wind speed that controller that can cover to prevent wind turbine from overspeeding in range 0-6.2 m/s.

1.5 Thesis outline

Chapter 1 introduces the background of the micro wind turbine and multi-rotor configuration. Chapter 2 is about review yaw mechanism, dynamic braking and PID controller by using Integral Time Absolute Error (ITAE) tuning. Chapter 3 involve with linearization of the wind turbine by using Taylor series and PID controller design based on ITAE tuning. Chapter 4 is about braking mechanism and controller testing. Chapter 5 is a discussion about the significant result and finding on braking system of micro wind turbine and controller system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The micro-wind turbine is defined as a micro power generation wind turbine usually under 1 kW (Drumheller et al., 2015). Normal operation of a micro wind turbine is within 2 to 4.5 m/s range will produce voltage up to 4 V. One of the distinguishing feature of micro-wind turbine is smaller in size as compare with small-scale wind turbine. This micro-wind turbine is configured in the array with the same structure which need a braking mechanism to control the operation speed and also for full stop operation. The braking system can be implemented by studying some techniques that were used in medium and large wind turbine to protect them against over speed that is caused by high wind speed. The analysis of wind speed is needed to set the range of cut-off speed due to mechanical constraints of the micro-wind turbine.

2.2 Wind classification and wind profile

The mechanical constraint that imposed on the wind turbine due to wind characteristic is non-uniform flow in nature. The wind speed depends on several factors namely the height, atmospheric pressure, and surrounding terrains. Beaufort scale was developed in 1805 by Sir Francis Beaufort to provide the classification of wind according to the speed. Wind speed can be computed by using equation 2.1 according to Beaufort number.

$$v = 0.836\ B^{\frac{3}{2}} \qquad (2.1)$$

v is the velocity of wind and B is the Beaufort number.

Table 2.1 shows that estimation of wind speed according to Beaufort number. According to a study conducted by Razali et al. (2010), when wind speed that exceeds 21 m/s, it can have a disaster impact on the wind turbine. One of the criteria for support structure of wind turbine, it must able to withstand high exerting forces and cyclic loading with certain limit without any sign of mechanical failure (Muskulus & Schafhirt, 2014). These criteria make micro-wind turbine range of operation is limited if low mechanical strength material is used. However, wind speed in the range from gale to storm is a rare case that occurs in Malaysia unless during tropical storm or typhoon.

Table 2.1 Classification of wind

Type of wind		Description
Beaufort number (B)	Wind speed interval(m/s)	
0	0.00-0.39	Calm
1	0.40-1.79	Light air
2	1.80-3.49	Light breeze
3	3.50-5.79	Gentle breeze
4	5.80-8.49	Moderate breeze
5	8.50-10.99	Fresh breeze
6	11.00-13.99	Strong breeze
7	14.00-.16.99	Near gale
8	17-20.99	Gale
9	21.00-24.99	Strong gale
10	25.0 above	Storm

According to Albani, Ibrahim, & Hamzah (2013), the highest average wind speed across Malaysia from the year 2007 to 2011 at 10 meter height is 3.4 m/s during the northeast monsoon. This condition will not affect the normal operation of the wind turbine except during storm or gust wind blow. Furthermore, wind speed will increase when height levitated above the ground especially when micro-wind turbine is installed in a tall building or in the height terrain. Often the data on high-altitude is not available for analysis thus predicted model is used.

There are several methods that can be used to estimate the wind speed at a certain height such as logarithmic wind profile method that was describes by Noram I. Ramli (Ramli, Ali, Saag, & Majid, 2009). Equation 2.2 is the logarithmic profile that shows the nonlinear relationship between estimated wind speed and height.

$$V_2 = V_1 \frac{\ln\left(\frac{Z_2}{Z_0}\right)}{\ln\left(\frac{Z_1}{Z_0}\right)} \quad (2.2)$$

where V_2 is estimated wind speed, V_1 is wind velocity at reference height, Z_2 is height above ground, Z_1 is reference height and Z_0 is surface roughness length

Table 2.2 shows that estimated wind speed variation depend on the type of terrain, for example, a dense urban area such as in large city have a large impact on estimated wind speed compared to an open area. However, the measured average wind speed can be different from the calculated one due to simplistic approach in estimation in equation 2.2.

Table 2.2 Roughness length derived from terrain classification

Class	Surface	Landscape description	Z_0 (m)
1	Sea	Open sea, fetch at least 5 km	0.0002
2	Smooth	Mud flats, snow, little vegetation, no obstacle	0.005
3	Open	Flat terrain; grass few isolated obstacle	0.03
4	Roughly open	Low crops; occasional large obstacle	0.1
5	Rough	High crops; scatter obstacle	0.25
6	Very rough	Orchard, bushes; numerous obstacle	0.5
7	Closed	Regular large obstacle coverage (suburban area, forest)	1.0
8	Chaotic	City center with high and low rise building	>2

2.3 Operation of wind turbine

The wind turbine speed operation is according to region 1, 2, and 3 in Figure 2.1. In region 1, wind turbine starts to operate when the wind speeds higher than cut in wind speed. At this region, variable power scheme is used to extract wind power. In region 2, where wind turbine reaches optimal wind speed generation, power, and rotational speed will be regulated (Aho, Buckspan, & Laks, 2012). Lastly, in region 3 where the wind speed exceeding safe operation of a wind turbine, the power generation is reduced by applying a brake to reduce the rotation speed. When the wind turbine reach maximum speed; the braking system will make it stop.

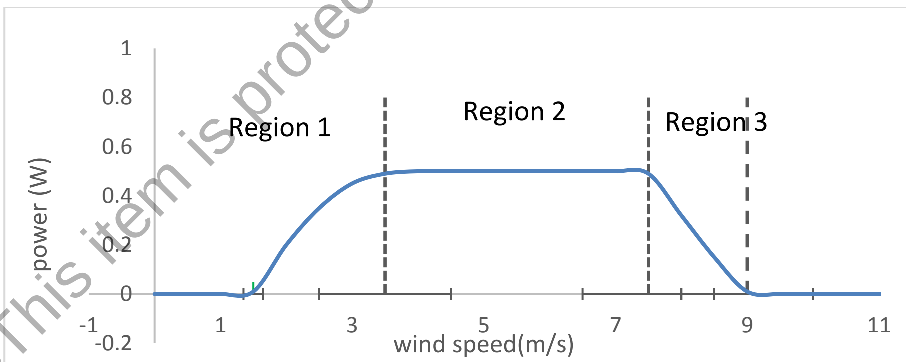

Figure 2.1 Region scheme operation for wind turbine

2.4 Yaw control

Yaw system is a mechanism that rotates nacelle along the horizontal axis for a horizontal wind turbine. Existing yaw systems can be categorized as passive yaw and active yaw system. Passive yaw system is a system that depends on the alignment of wind direction. This system eliminates the need of alignment motor of the wind turbine to the wind direction. However, this system only useful for small lightweight wind turbine. The disadvantage of this system is it will follow direction of high wind speed during gusty wind blow which can damage the wind turbine. An active yaw system has an advantage over passive yaw system where it has anemometer attached to provide feedback to the controller. It ensures that the system applies the brake when the wind speeds over a specific threshold value.

In the proposed active yaw system (Wu & Wang, 2012), the worm gear mechanism is used to provide rotation along the vertical axis to provide speed reduction and high torque capabilities for yaw motor. Figure 2.2 shows yawing operation of wind turbine to align with wind direction.

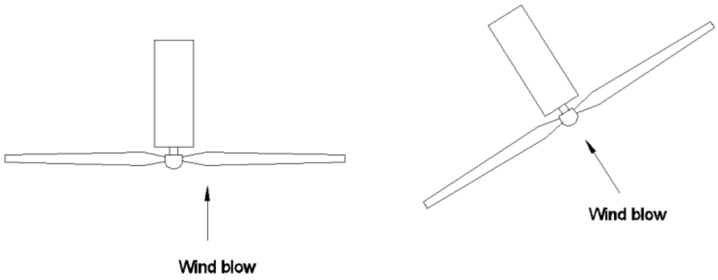

Figure 2.2 Yawed wind turbine

2.5 Furling mechanism

The furling mechanism is similar to the passive yaw mechanism, but it's main purposes is for over speed protection. It is designed to have offset angle between tail fin to keep it balance during normal operation. The principle of furling mechanism involves with thrust force acting on the blade of the wind turbine. During high wind speed, the total thrust force acting blade of wind turbine allows it to turn around horizontally or vertically (Muljadi, Forsyth, Butterfield. 1998). Figure 2.3 depicts the photo of vertical and horizontal furling wind turbine.

Figure 2.3 Furling wind turbine (Woofenden l Piggott H, 2007)(Rick & Jordan, 2007.)

2.6 Dynamic braking

Dynamic braking is a method of small wind turbine control that involves short-circuiting the generator stator windings. A short-circuit results in large back-torque whose magnitude depends on rotation speed and configuration of the generator; radial or axial flux designs. The acceleration of the wind turbine rotor depends on the net torque: a net positive torque will cause the rotor to accelerate; while a net negative torque will result in deceleration.

The problem for high wind speed, the magnitude of the rotor torque often exceeding back-torque. In certain circumstance, it is impossible for dynamic braking to make wind turbine decelerate (McMahon, Burton, & Sharman, 2015). On positive side, dynamic braking is possible without involving mechanical brake. This is an advantage for micro-wind turbine since installing mechanical brake is not a feasible solution.

The dynamic series resistor configuration has been proposed for over current protection (Saini, 2013). However, to limit the rotational speed of rotor the dynamic resistor with DC generator must be in parallel connection.