VARIABLE SPEED CONTROL FOR A TWO-MASS WIND TURBINE SYSTEM

MOHD SYAMIM ASRAF BIN NORIZAN

BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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MOHD SYAMIM ASRAF BIN NORIZAN

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2019

DECLARATION

I declare that this thesis entitled “VARIABLE SPEED CONTROL FOR A TWO-MASS WIND TURBINE SYSTEM” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have checked this report entitled “Variable Speed Control for a Two-Mass Wind Turbine System” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature :

Supervisor Name :

Date :

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to all those who provided me with the possibility to complete this final year project in 14 weeks period. A special gratitude I give to my supervisor, Lecturer of Universiti Teknikal Malaysia Melaka, Dr. Muhammad Nizam bin Kamarudin who give me the opportunity to be supervised under him and contribute me in giving the knowledge and give suggestion about the final year project title "***Variable Speed Control for a Two-Mass Wind Turbine System***".

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ABSTRACT

Wind power is a potential free energy resource that had a rapid growth in the world since the 1990s due to the limited amount of fossil fuel resources. A wind turbine system (WTS) transforming electrical energy from the kinetic energy and consists primarily of an aeroturbine that converts wind energy into mechanical energy, a gearbox that reduces the torque and increases speed, and a generator used to convert electrical energy from the mechanical energy. The objective of this project is to design a variable speed control to maximize the output power from wind turbine. Beforehand, a model of two-mass wind turbine system is developed. For a variable wind turbine, the control approach is required on controlling the speed rotor to get the optimum value of tip-speed-ratio a precise dynamic model. By control the wind speed of the rotor, the aerodynamic power is extracted from the wind by the blades. In low or moderate winds, the generator torque is required and the resulting rotor speed to controlled so that allow the wind turbine to operate and maximize efficiency. The established wind turbine dynamics neglect the stiffness as an integrator to the system. The proportional-integral (PI) controller is therefore designed to extract the maximum power point of a wind turbine system (MPPT) of variable speed. The MPPT is available for the wind power conversion system and is used for small and large systems. The design assumption is made to ensure that the PI controller only operates in the partial load area. The results of the numerical simulation are presented and analysed. The result indicates that the speed rotor and maximum output power are smoothly regulated.

ABSTRAK

Kuasa angin adalah merupakan potensi sumber tenaga bebas yang mengalami pertumbuhan yang pesat di dunia sejak tahun 1990-an disebabkan oleh sumber bahan api fosil yang terhad. Sistem turbin angin (STA) mengubah tenaga kinetik menjadi tenaga elektrik dan sebahagian besarnya terdiri daripada aeroturbine yang mengubah tenaga angin menjadi tenaga mekanikal, kotak gear yang meningkatkan kelajuan dan mengurangkan tork, dan penjana yang digunakan untuk menukar tenaga mekanikal menjadi tenaga elektrik. Objektif projek ini adalah untuk merancang kawalan kelajuan ubah untuk memaksimumkan kuasa keluaran dari turbin angin. Sebelum ini, satu model sistem turbin angin dua pemberat telah dimodelkan. Untuk turbin angin ubah, pendekatan kawalan diperlukan untuk mengawal kelajuan rotor untuk mendapatkan nilai optimum nisbah laju hujung model dinamik yang tepat. Dengan mengawal kelajuan pemutar angin, kuasa aerodinamik diperoleh dari angin dengan bilah. Dalam keadaan angin rendah atau sederhana, tork penjana diperlukan dan kelajuan pemutar yang dihasilkan dikawal untuk membolehkan turbin angin mengendalikan dan memaksimumkan kecekapan. Dalam laporan ini, kekukuhan, B sebagai penyepadu sistem diabaikan. Oleh itu, pengawal berkadar-integral (KI) direka untuk mengeluarkan titik kuasa maksimum sistem turbin angin (MPPT) dari kelajuan berubah-ubah. Pengesan kuasa titik maksimum (PKTM) untuk sistem penukaran tenaga angin ditawarkan dan mengunakannya untuk sistem skala besar dan kecil. Reka bentuk andaian dibuat supaya pengawal KI kerja-kerja di rantau beban separa sahaja. Keputusan simulasi berangka dibentangkan dan dianalisis. Projek ini hanya memerlukan penyelidikan dan perisian untuk simulasi dengan menggunakan peralatan Simulink dalam MATLAB. Keputusan menunjukkan bahawa kelajuan rotor dan keluaran kuasa maksimum adalah berkait.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	**Definition**
J_r	Rotor inertia (Kg.m^2)
J_g	Generator inertia ($Kg.m^2$)
K_r	Rotor external damping ($N.m.rad^{-1}.s^{-1}$)
K_g	Generator external damping ($N.m.rad^{-1}.s^{-1}$)
γ	Gearing ratio
P_m	Aerodynamic power (Watt)
T_m	Aerodynamic torque ($N.m$)
T_{ls}	Low-speed shaft torque ($N.m$)
T_{hs}	High-speed shaft torque ($N.m$)
ω_r	Rotor speed ($rad.s^{-1}$)
ω_g	Generator speed ($rad.s^{-1}$)
B_r	Rotor stiffness ($N.m.rad^{-1}$)
B_g	Generator stiffness ($N.m.rad^{-1}$)
Cp	Power Coefficient
ρ	Air density (kg/m^3)
V	Wind speed (m/s)
R	Blade radius
λ	Tip speed ratio
ω_r	Rotor speed
β	Pitch angle
PI	Proportional Integral Controller
IAE	Integral of absolute error
ISE	Integral of squared error

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The wind is a potential energy give a force to the turbine so that it rotates the blade producing a kinetic energy and it will be converted to the electrical energy. Wind power is one type of renewable energy and most of the generation system of wind power uses a variable speed wind turbine to achieve reliable and efficient the conversion wind power to electrical [1]. The enhancements of wind energy conversion system were more focused on the low cost, highly efficient and reliable power generation which led to the development of large-scale wind turbines. Since the variable speed wind turbine is commonly used to obtain the energy supply, all problems associated with the wind turbine system including disturbance should be overcome in order to obtain maximum power output.

1.2 Problem Statement

The rotor speed must be controlled with the proposed controller to achieve the optimum speed ratio. The main objective of wind turbine at variable speed is to achieve maximum output. In order to achieve this objective, the turbine tip-speed ratio should be maintained at the optimum value. At a commercial rate, the wind turbine speed should be between 4 m/s and 25 m/s so that the system operates and achieves the maximum output. The aerodynamic efficiency $Cp(\lambda,\beta)$ depends on the tip-speed ratio, λ and the pitch angle, β. Given β, the efficiency coefficient Cp has a maximum for a certain λ. It is thus obvious that to maximize the efficiency of the turbine should be able to vary its rotational speed to follow the wind speed. The fluctuating nature of the wind makes the variable speed turbine a non-trivial object to control.

In any case, there is generally no control over how much vitality can be expected. The truth is that the captured control should be restricted in the above-rated wind speed. Although both mechanical and electrical requirements exist, the more serious is the generator and converter regularly. Therefore, the optimum speed must be achieved by controlling the rotor speed in order to achieve maximum power output. In fact, the steadiness of the wind turbine is too low to be measured. The reason for relaxing the stiffness is to ease the design of the controller. The presence of stiffness in the wind turbine system will increase the difficulty in designing and stabilizing the controller. This is because the external stiffness occurs with a dynamic wind turbine integrator and is difficult to handle. So, the stiffness is neglect. In addition, the stabilization of the steady wind turbine requires a high mathematical complexity.

1.3 Objectives

This project embarks into the following objectives:

- To develop a mathematical model of the two-mass wind turbine system.
- To design a variable speed controller in order to achieve optimum tip-speed ratio and hence, to obtain maximum power output.
- To analyze the effectiveness of the proposed technique in term of output power.

1.4 Scope

This project focuses on formulating the two-mass wind turbine systems mathematical model. Using a PI controller, a variable speed controller is designed to achieve maximum power output when maintaining the tip-speed ratio of the turbine. The results are obtained using MATLAB with SIMULINK toolbox through simulation works.

1.5 Organization of the Report

This thesis is essentially divided into five chapters, and this section gives a short overview of the chapters.

Chapter 1: Introduction

This chapter includes general information on variable speed control for wind turbine and the study of this thesis. This chapter containing five sub-themes that form the background, problem statement, goals, scope and report organization. The background explaining clear information on this study and provides the reader with the important information. The problems that arise in this chapter will also explain why this study should be carried out and the goals that must ultimately be achieved. The study fields and limitations are also shown in this chapter.

Chapter 2: Literature review

This chapter discussing on theories, ideology and the purpose of the project. This chapter requires a wide range of journals, books, articles, research papers and so on to obtain a wealth of knowledge and study material to ensure that the studies carried out are relevant. In this chapter it is contain the introduction, body, and conclusions. The introductions will give a quick overview of the subject of the literature review, the body parts will contain the discussion of the sources of the study and the conclusion will be discussed on what was achieved by this literary review.

Chapter 3: Methodology

In this chapter, the independent, dependent and controlled experimental design variables are composed. It gives detailed information on how the experiment is carried out and the checklist before the experiment is carried out.

Chapter 4: Results and discussion

This chapter presents the results of the experiment. It also comments on obtained results and interprets the obtained data. The discussion section of the report discusses the results and the problems. The objective is to distinguish the key project results from the results obtained.

Chapter 5: Conclusion and Recommendations

This chapter presents the results of the experiment. It also comments on obtained results and interprets the obtained data. The discussion section of the report discusses the results and the problems. The objective is to distinguish the key project results from the results obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the literature review based on journal, reference book, web page information and previous researchers relevant to this project. This chapter includes several sub-themes, such as the theory of wind turbines, wind turbine control configuration, controller design and a summary of the work involved.

2.2 Wind Turbine

Wind turbine have generally two types which are the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) [3]. Wind turbines transform kinetic power into mechanical power in the wind. This mechanical power can be used for a specific task such as a generator, which can turn the mechanical power into household electricity. When the wind passes the rotor blades of the turbine, the blades turn the wind energy into kinetic energy. This energy spins the rotor in a generator that converts the kinetic energy into electricity. The wind turbine was divided into two functions, the first of which generates high-speed wind electricity and this wind turbine was built specifically for areas with low wind speeds. Based on previous researchers, most of them use a two-mass wind turbine model because it can be used.

2.2.1 Horizontal Axis Wind Turbine (HAWT)

One the type of a wind turbine is a horizontal axis (HAWT). This wind turbine was named HAWT because a nacelle was installed perpendicular to the turbine tower and horizontally in the ground. The HAWT components are the rotor shaft, the generator, the gearbox, and the turbine blades. All of the components give their own functionality. By using HAWTS, there are many advantage could be achieved. Firstly, the variable pitch of blades used for the horizontal wind turbine enables the maximum amount of wind energy to be collected. Secondly, a horizontal wind turbine offers higher efficiency because the perpendicular of the blades to the direction of the wind and therefore receives more power for rotation. Thirdly, traditional designs also facilitate easy installation and maintenance and horizontal wind turbines are popular options as energy sources from home use to application in hybrid systems. The other advantage is this HAWT has high-speed propeller which is commonly used because of its excellent aerodynamic efficiency [5]. Figure 2.1 shows the Horizontal Axis Wind Turbine.

Figure 2.1: Horizontal Axis Wind Turbine

2.2.2 Vertical Axis Wind Turbine (VAWT)

The vertical axis wind turbine (VAWT) is another type of the wind turbine and it has two type which are a Savonius rotor and a Derrieus rotor. Savonius operates under drag forces, meaning that the wind actually give a force by pushing the turbine to make it rotate, while the Darrieus is operational due to lift forces created by pressure differentials created by the wind. Figure 2.2 and 2.3 show the Savonius and Darrieus type of vertical axis wind turbine [6]. The advantages of VAWT is given because the design of the turbine is near to the ground, so they are easy to be controlled and implemented on the falling structure and they can produce electricity in any wind direction.

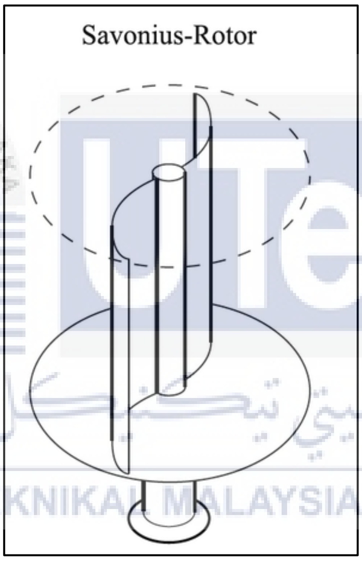


Figure 2.2: Savonius type of vertical axis wind turbine

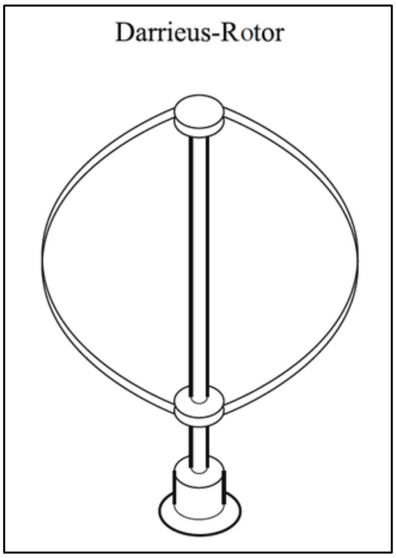


Figure 2.3: Darrieus type of vertical axis wind turbine

2.3 Control Configuration

2.3.1 Variable Speed Wind Turbine (VSWT)

There are wind turbine control configurations that are constant speed and variable speed wind turbine. Based on other research, the variable speed wind turbine was mainly used as a model configuration [7] [8] [9]. Previous studies have shown that wind turbines with variable speed are obviously or more common due to their behavior affecting the control system. The control system used is aerodynamic control for controlled torque, speed, and power [7]. High-order sliding mode control studies of variable-speed wind turbines show the main objective of variable-speed wind turbines; maximization of power efficiency.

In addition, a survey such as that constant wind turbine. The advantages of a variable wind turbine is that it increases the captured energy and reduces loads of the drive train [10]. The variable speed wind turbine usually uses aerodynamic control systems that usually vary in length. It's expensive, complex and turns out to be a lot more as the turbine gets bigger. This is an inspiration for considering alternative approaches to control. The variable speed wind turbine implements and results in lower capital costs, better reliability and reduced maintenance costs in this report. The turbine is controlled in the system to be exanimated to reduce its rotational speed at its high wind speed. This is expert by dynamically constraining the rotor.

2.3.2 Variable Pitch Control (VPC)

The angle of the pitch may be defined as the angle of the wind with the blade. Changing the angle of the pitch means changing the angle of the attack of the wind. For example, if the angle of the pitch is 0^0 and the wind speed is 12 m/s, the maximum power will be achieved. However, when the pitch angle is changed to 5^0 and 10^0 for the same wind speed, the output power decreases and this indicates the effect of the pitch angle on the output. The pitch angle value must be evaluated for optimum wind speed in order to obtain the best output power, as it automatically changes when the speed is high or low and the optimum pitch angle value for the wind turbine is set by proper position control.

This position control system changes the angle of the pitch according to the wind speed. For a high wind speed the pitch angle is decrease and for low wind speed the pitch angle increases as to obtain constant speed and then the best output power and the safety of the blade structure. This method contains a mechanism that turns the blades around their longitudinal axes physically. At low wind speed, this feature is used by a control system to maximize wind energy. The power or torque can be easily limited to its rated value by adjusting the pitch angle, β during higher wind speed. Furthermore, axial aerodynamic strength is reduced. This method is almost used with variable speed of turbines to enable a high wind speed and safety operation [11].

2.4 Wind Turbine Operation Regions

The power curve is an indicator of the wind turbine performance and the overall health of the wind turbine. The power that had been captured by the rotor is higher than electric output power from the generator due to losses in gear train and the generator.

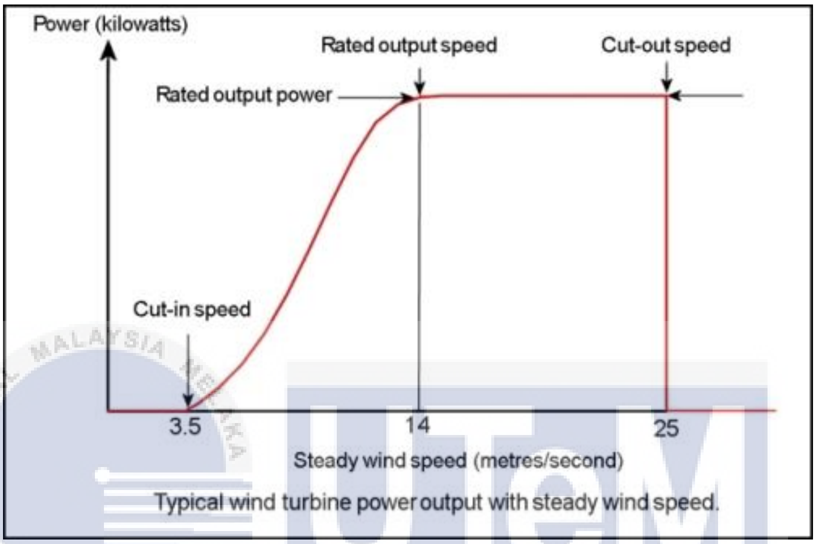


Figure 2.4: The power curve, where cut-in speed and cut-out speed is presented

The cut-in-speed is that the turbine at its lower wind speed, it will start to generate power. This usually occurs in HAWTs between the speed 3.5 m/s and 4 m/s and varies from the wind turbine. As shown in Figure 2.4, electrical output increases rapidly when the wind rises above the cut-in-speed. The output power reaches the limit that the generator can reach between 12 m/s and 17 m/s. This limit is called the rated power output, the rated output and the wind speed at which this limit is reached. But the turbine power output is maximum at that point. The turbine design was being controlled to reduce power to this maximum level and to stop the increase in output power. It varies depending on the design how this goal is achieved, but for larger turbines the angle of the blades is adjusted. The cut-off speed is the wind speed at which the wind turbine stops the power output increasing, even if the speed of the wind is increases, and is usually around 25 m/s per second. This is based on the limit of what the alternator can achieve and there is a high risk of damaging the turbine and structure from high loads [12] [13] [14].

2.5 Wind Turbine Modelling

2.5.1 Model Wind Turbine

The expression of the nonlinear for aerodynamic power been captured by the wind turbine is referred by [8] [16]:

$$P_{aero} = \frac{1}{2}\rho\pi R^2 v^3 C_p(\lambda,\beta) \tag{2-1}$$

where,

P_{aero} = the power extracted from the wind
ρ = air density (kg/m^3)
R = radius of blade
V = wind speed (m/s)
$C_p(\lambda,\beta)$ = power coefficient

For each turbine, the power coefficient $C_p(\lambda,\beta)$ can be obtained from the look-up table. The control scheme highlights the optimum speed ratio as the maximum power coefficient can be obtained for variable speed wind turbine. There are no accurate ways to determine the power coefficient [7]. This paper shows the alternative approach in the strict back wind turbine model to obtain the empirical value of the power coefficient. The empirical power coefficient model is shown in [16] as:

$$C_p = c_1 - c_2.(\beta - c_3).\sin(\lambda_i) - (\lambda - c_5).(\beta - c_3)$$
$$\lambda_i = \frac{\pi.(\lambda + 0.1)}{14.8 - 0.3(\beta - 2)} \tag{2.2}$$

The parameter c_i (i=1,5) is given in the appendix.

And the tip speed ratio is given by [18]:

$$\lambda = \frac{R\omega_r}{v} \tag{2.3}$$

where is,

ω_r is the speed rotor of the turbine

R is blade radius and

λ is the tip speed ratio

Figure 2.5 shows the power coefficient characteristic for various β. For a regulated pitch angle at $\beta = 2$, it gives the maximum value of Cp [16].

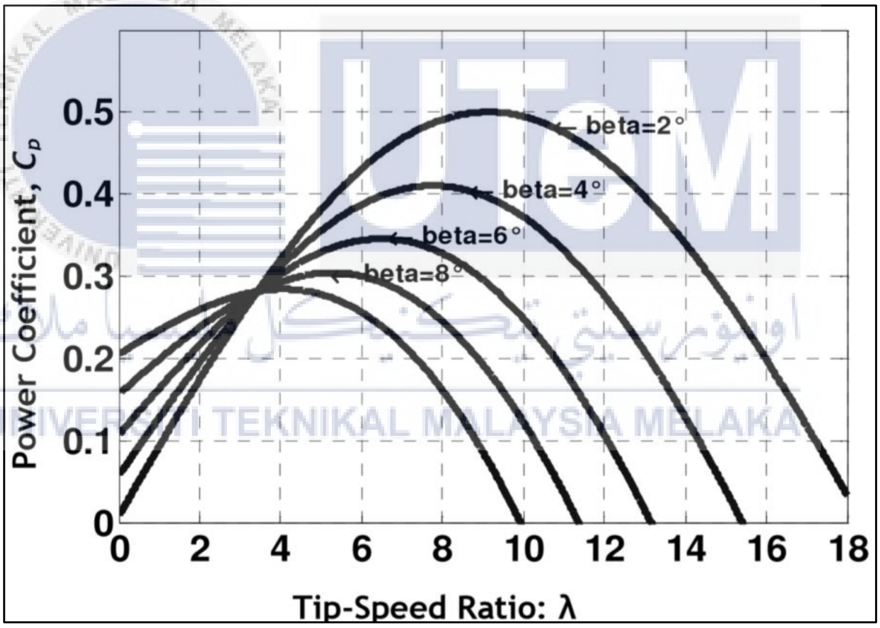


Figure 2.5: Power coefficient versus tip-speed ratio for a different values of the pitch angle β.

From the curve, the value of Cp is 0.5 and the value λ is defined as the optimum value of tip-speed ratio, $\lambda_{opt} = 9.15$ representing the optimum speed ratio. So that the maximum power point tracker can be applied.

The maximum turbine speed given by the wind,

$$\omega_r = \frac{v.\lambda}{R} \tag{2.4}$$

The power of aerodynamic can be expressed as below:

$$T_{aero} = \frac{P_{aero}}{\omega_{opt}}$$

where,

$$T_{aero} = \frac{\rho R^2 v^3 C_p}{2\lambda_{opt}} \tag{2.5}$$

2.5.2 Model of the gearbox

The turbine is coupled with the generator shaft through a gearbox whose gear ratio, G is chosen to set the speed of the generator shaft within the a desired speed range [9] [16].

$$T_g = \frac{T_{turb}}{G} \tag{2.6}$$

2.6 Maximum Power Tracker (MPPT) Control Method

The maximum power point tracker is the maximum power extraction algorithm soft research that can be classified into three main control methods: tip speed ratio, power signal feedback, and mountain climb search [19]. The optimal tip speed ratio can be achieved by controlling the rotor speed using a PI controller in this project. Recent studies suggest that wind turbines of variable speed are commonly used in the area of energy supply [7] [8] [9] [17]. But the difference is the control approach used for the wind turbine at variable speed to obtain maximum output. First, the multivariable control strategy for the wind turbine at variable speed [18].

In this study, the control approach was called multivariable by combining a non - linear dynamic state feedback torque control strategy for the angle of the blade pitch. The multivariable controller used the PID and Linear quadratic regulators (LQR), both of it which is lead to an acceptable result for the rotor velocity control, but shows limited power control performance. The objective of the paper [18] is to achieve certain performance, a non-linear torque control system is proposed. The controller allows a good regulation but the rotor speed unfortunately present large variations. So they combine both PID and LQR controllers.

The second study shows the variable wind speed with the sliding mode controller in high order. In this paper, to obtain maximum output power as the above objective, the tip speed ratio was considered to obtain maximum output. This paper showed that the controller was selected because it can guarantee the stability of operation of the wind turbine [7]. In fact, the high-order sliding mode approach is used to prevent the generated torque from chatting.

However, the sliding mode has disadvantages such as a problem of chatting, sensitive and dynamic formulation equivalent. In addition, previous studies indicated that the control device used was backstepping [16] [17]. This paper showed that the backstepping controller proposed maximizing variable-speed wind turbine power extraction. One of the research [16] used backstepping to demonstrate excellent response during large operating conditions and to ensure the stability of the system.

However, there is a research that provides information on the advantages of backstepping, which is difficult to find a function Lyapunov [20].

2.7 Controller

2.7.1 Proportional Controller (P)

Proportional controller is mainly used with a single energy storage process in the first order to stabilize the unstable process. The main use of the P controller is to reduce the system steady state error. As the proportional gain factor K is increases, the steady state error of the system will be decreases. However, despite of the reduction, P control can never manage to eliminate the steady state error of the system. As increase the proportional gain, it offers smaller amplitude and phase margin, faster dynamics that satisfy larger frequency bands and greater noise sensitivity.

Furthermore, it can easily be concluded that the P controller reduces the increased time and after a certain reduction in the steady-state error, the increase in K only causes the system response to overflow. P control also causes the oscillation if it is aggressive enough in the presence of delays and dead periods. Furthermore, it directly amplifies the noise process [2].

2.7.2 Proportional Integral Controller (PI)

The PI controller used to eliminate a steady state error resulting from a P controller. However, the speed of response and overall system stability have a negative impact. The controller is used in areas that are not a problem with the speed system. PI controller cannot eliminate the oscillations and decreasing the rise time as it does not have the ability to predict the future errors of the system [2].

2.8 Conclusion

As a conclusion for the literature review part, the research mainly used a wind turbine with variable speed instead of a constant wind turbine. The two-mass modelling is used because it can be used efficiently and accurately. Based on past research, HAWT with propeller blades is the common one used because it has 60% of its efficiency which higher than VAWT [3]. The controls used are sliding mode, backstepping, multivariable controller; PID and LQR. They all have certain disadvantages that can disturb the wind turbine system. The controller proposes therefore the Proportional-Integral (PI) in this paper. The conventional PI controller is easy to design for the linear system, because of the criteria for designing the optimal controller which is the stability investigation.

CHAPTER 3

METHODOLOGY

3.1 Project Overview

The project methodology describes the method of conducting this project according to the objective to be achieved. The project flow, such as the literature review, extracts data from the literature step by step. Proper planning of the project is important to ensure that the project is carried out on time.

3.2 Flowchart

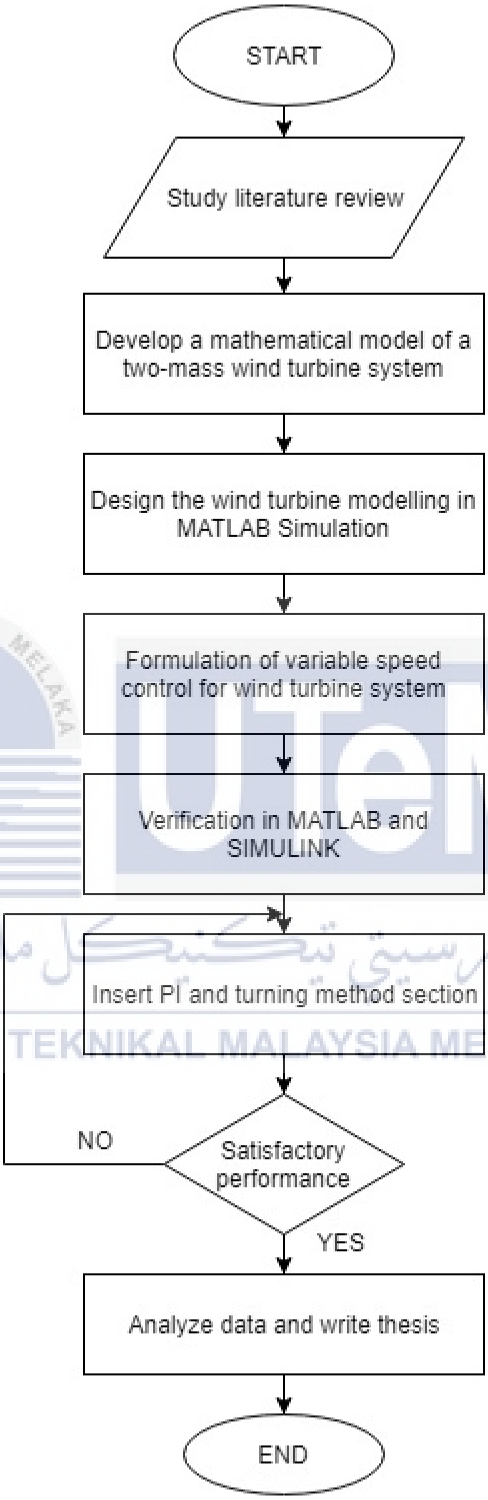


Figure 3.1: Flowchart

Based on Figure 3.1, to understand of this project firstly need to study the literature review on the theory regarding by the project. The literature review was studied thoroughly as to ensure the project could be done perfectly. Second after study the literature review, a mathematical model of a two-mass wind turbine system model been developed before designing the wind turbine by modelling it MATLAB Simulation. The process to developed the mathematical model and designing the turbine are take time as it needs to be done carefully so that there is no mistake as it would affect the project process. Formulation of variable speed control for wind turbine system is the process that the derivation of the equation by studying from the article that it needs to be insert in a subsystem in MATLAB Simulation to perform a complete a wind turbine system. Just after the turbine been perform, the verification in MATLAB and Simulink of the wind turbine system. PI is a controller that should tune Kp and Ki to get a proper result. If the result is wrong, then it would turn back the process to the tuning the PI controller until the right and proper result are achieved. Lastly after getting the result, the data have been analyzed thoroughly so that it could be explained on how getting that kind of result and then writing it in thesis.

3.3 Develop a mathematical model of a two-mass wind turbine system

The proposed control method is applied to a two-mass turbine system. Figure 3.2 shows the two-mass wind turbine system and Table 3.1 tabulates the wind turbine parameter. The dynamic model of the two-mass horizontal axis wind turbine (HAWT) is refering to its mechanical power side only that consists of turbine rotor model and aero turbine model. The turbine rotor consists of blades, hubs, and pitch while the aero-turbine consists of brake, gearbox, rotor dynamics (low speed shaft and high speed shaft), and mechanical dynamics of the generator [4].

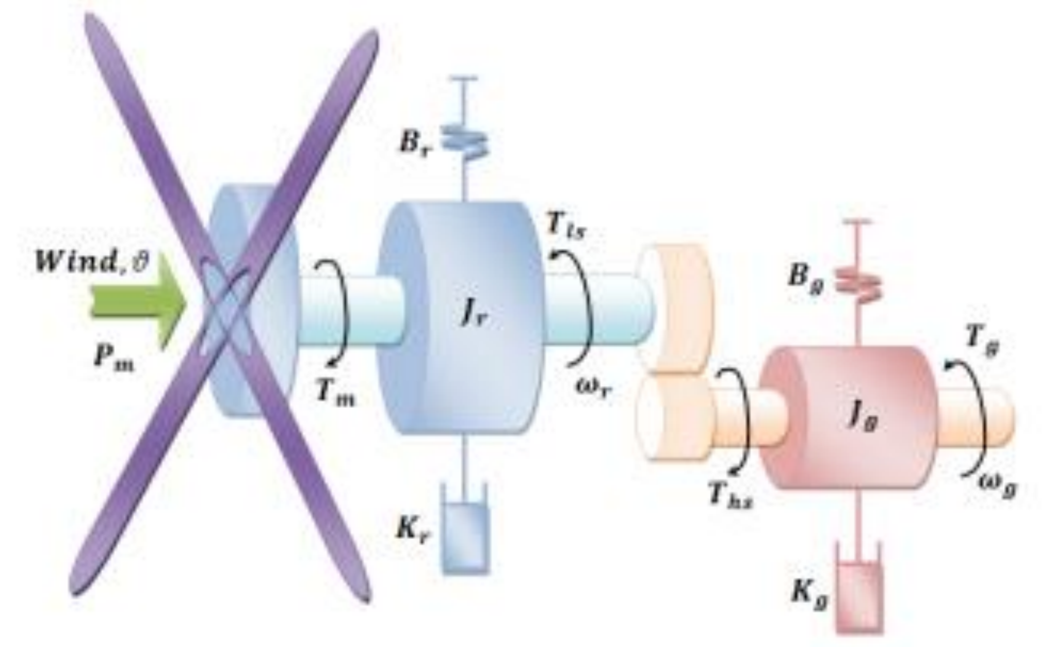


Figure 3.2: The two-mass wind turbine system

Table 3.1: Wind turbine parameters

Symbols	Definition
J_r	Rotor inertia (Kg.m^2)
J_g	Generator inertia ($Kg.m^2$)
K_r	Rotor external damping ($N.m.rad^{-1}.s^{-1}$)
K_g	Generator external damping ($N.m.rad^{-1}.s^{-1}$)
Υ	Gearing ratio
P_m	Aerodynamic power (Watt)
T_m	Aerodynamic torque ($N.m$)
T_{ls}	Low-speed shaft torque ($N.m$)
T_{hs}	High-speed shaft torque ($N.m$)
ω_r	Rotor speed ($rad.s^{-1}$)
ω_g	Generator speed ($rad.s^{-1}$)
B_r	Rotor stiffness ($N.m.rad^{-1}$)
B_g	Generator stiffness ($N.m.rad^{-1}$)

3.3.1 Turbine Rotor Model

The wind turbine capturing the kinetic energy from the wind and converted it into rotational energy in turbine. However, the conversion of energy depends on the wind speed and the turbine's swept area. The swept area shown in Figure 3.3 is the region where the kinetic energy been captured, where R denotes the blade radius.

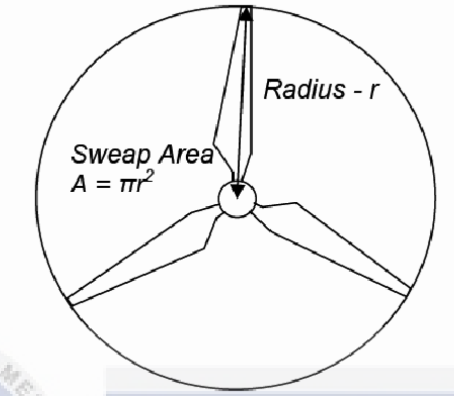


Figure 3.3: Turbine swept the area

In wind turbine system, the turbine produced the aero-dynamic, P_m depends on instantaneous wind power, P_{wind} and the power coefficient of the unique wind turbine $C_p(\lambda, \beta)$, as shown in equation (3.1).

$$P_m = P_{wind} C_p(\lambda, \beta) \tag{3.1}$$

Where P_m in equation (3.1) is the power from the wind, ρ is air density (kg/m^3), R is blade radius (m), v is wind speed (m/s) and $C_p(\lambda, \beta)$ is power coefficient which is a function of both tip speed ratio (TSR) λ and blade pitch angle, $\beta(deg)$ which is described as [15].

$$P_{wind} = \frac{1}{2}\rho\pi R^2 v^3 \tag{3.2}$$

The power coefficient C_p is obtained via look-up-table which is provided by each turbine manufacture in equation (3.3) is a nonlinear function depending on the tip-speed ratio, λ, and β blade pitch angle. It is given by

$$C_p(\lambda,\beta) = 0.5(116\frac{1}{\phi} - 0.4\phi\beta - 5)e^{-21\frac{1}{\phi}} \tag{3.3}$$

where the function ϕ

$$\frac{1}{\phi} = \frac{1}{\frac{1}{\lambda - 0.08\beta}} - \frac{0.035}{\beta^3 + 1} \tag{3.4}$$

In the research [4], the pitch angle β is regulated at 0° in order tp facilititate fixed-pitch system. Hence the power coefficient can be expressed as

$$C_p(\lambda, 0°) = 0.5(\frac{116}{\lambda - 0.0001} - 9.06)e^{-\frac{21}{\lambda - 0.0001} + 0.735} \tag{3.5}$$

The TSR which is the ratio of the blade tip speed and wind turbine and wind speed can be represented as

$$\lambda = \frac{R\omega_r}{v} \tag{3.6}$$

where ω_r is the speed rotor of the turbine.

From Figure 3.4 shows power coefficient characteristic for various β. For a regulated pitch angle at $\beta = 0$, it gives the maximum value of Cp.

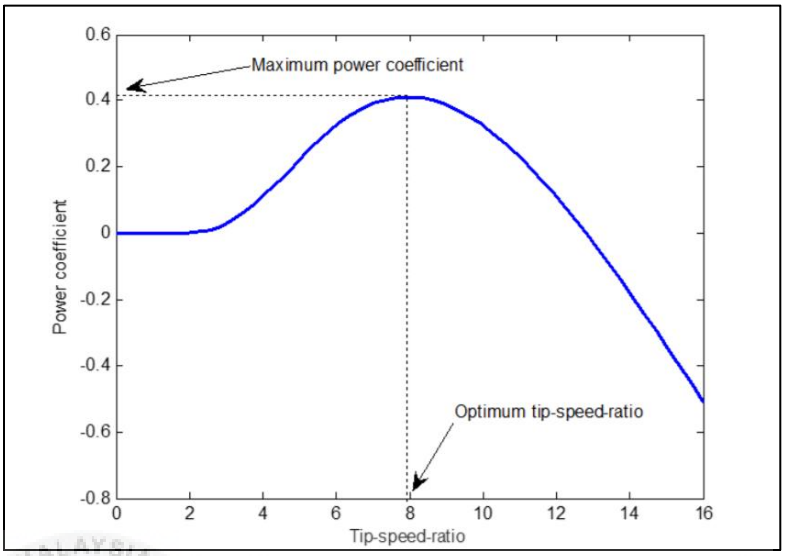


Figure 3.4: Power coefficient versus the tip-speed ratio for values of the pitch angle $\beta = 0°$

From the curve, the value of Cp_{max} is 0.4109631031 and the value of λ is defined as the optimum value of tip-speed-ratio, $\lambda_{opt} = 7.953925991$ which represent the optimum speed ratio. So that the power point tracker at maximum can be applied.

3.3.2 Aero Turbine Model

This section will provide the step to identify the mathematical modeling of the two-wind mass turbine modeling and the transfer function obtained. The wind turbine mathematical modeling in which the stiffness is neglected [4]. Model aero-turbine has two turbine and generator inertia. This model is mainly used by aerodynamic torque, T_m deriving from an aerodynamic power ratio and a rotor speed, ω_r a similar to the equation (3.7).

$$T_m = \frac{P_m}{\omega_r} \tag{3.7}$$

By considering the second law of Newton for rotational motion, the equilibrium differential equation on the rotor side. The low speed shaft that producing the torque can be expressed

$$\begin{aligned} T_m &= T_{ls} + J_r \frac{d\omega r}{dt} + K_r \omega_r \\ &= T_{ls} + J_r \dot{\omega}_r + K_r \omega_r \\ T_m - T_{ls} &= J_r \dot{\omega}_r + K_r \omega_r \end{aligned} \tag{3.8}$$

The generator is driven by the T_{hs} high-speed torque and exposed by the electromagnetic torque generator T_g. The transmission output torque at the high-speed shaft can therefore be written as

$$\begin{aligned} T_{hs} &= T_g + J_g \frac{d\omega_g}{dt} + K_g \omega_g \\ T_{hs} - T_g &= J_g \dot{\omega}_g + K_g \omega_g \end{aligned} \tag{3.9}$$

Through the gearbox, the rotor speed, ω_r is increased by the gearing system with gear ratio,γ. Thus, the generator speed, ω_g is obtained by the increment of ω_r by a factor of γ. Then this is the standard gearing ratio,

$$\gamma = \frac{\omega g}{\omega r} = \frac{T_{ls}}{T_{hs}} \tag{3.10}$$

From equation (3.10),

$$T_{hs} = T_{ls} (\frac{\omega r}{\omega g}) \tag{3.11}$$

Getting the turbine system dynamic requires several steps. Insert equation (3.11) into equation (3.9),

$$T_{ls} \left(\frac{\omega r}{\omega g}\right) - T_g = J_r \dot{\omega}_g + K_g \omega_g \tag{3.12}$$

From equation (3.10), know that $\omega_g = \gamma\omega_r$, insert into equation (3.12)

$$\frac{T_{ls}}{\gamma} - T_g = J_r\gamma\dot{\omega}_r + K_g\,\gamma\,\omega_r$$

$$\frac{T_{ls}}{\gamma} = T_g + J_r\gamma\dot{\omega}_r + K_g\,\gamma\,\omega_r$$

$$T_{ls} = \Upsilon T_g + J_g\gamma^2\dot{\omega}_r + K_g\gamma^2\omega_r \qquad (3.13)$$

Substitute (3.13) into (3.8),

$$T_m - \gamma T_g + J_g\gamma^2\dot{\omega}_r + K_g\gamma^2\omega_r = J_r\dot{\omega}_r + K_r\omega_r$$

$$T_m - \gamma T_g = [J_r + J_g\gamma^2]\dot{\omega}_r + [K_r + K_g\gamma^2]\omega_r$$

$$J\dot{\omega}_r + K\omega_r = T_m - \gamma T_g \qquad (3.14)$$

Equation (3.14) is in the time domain, so changed it into frequency domain,

$$J_s\omega_r(s) + K\omega_r(s) = T_m(s) - \gamma T_g(s)$$

$$[J_s + K]\omega_r(s) = T_m(s) - \gamma T_g(s)$$

$$\frac{\omega_r(s)}{T_m(s) - \gamma T_g(s)} = \frac{1}{J_s + K} \qquad (3.15)$$

The modeling of the wind turbine can be obtained from the above transfer function (3.15) where the stiffness is neglected. Where J is the total inertia of the turbine and K is the total coefficient of viscous friction.

3.4 Wind Turbine Modelling in MATLAB Simulink

As the software is chosen, the beginner draft of the wind turbine modelling without any controllers can be designed in the MATLAB Simulink toolbox. In this phase, the modeling of the wind turbine and the various components of the wind energy conversion system will be described. Figure 3.5 shows the modeling of the wind turbine that can be drawn in the MATLAB simulation toolbox.

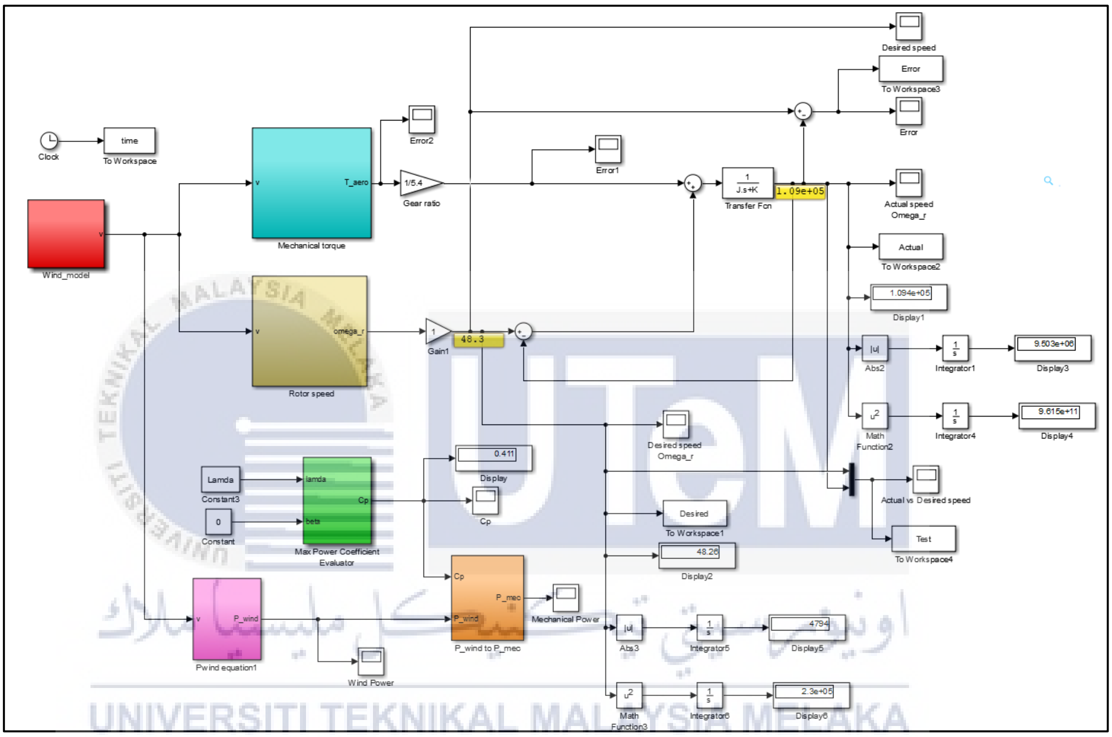


Figure 3.5: Modeling of wind turbines using MATLAB Simulink

Figure 3.5 shows the overall speed control block diagram without a controller. From previous research, the source that is the wind was taken. The sine wave is placed as the source at the beginning, but the wind cannot be smooth as the sin waveform at the end. As we know, the characteristic of the wind is not constant and fluctuating. So the sine wave as Figure 3.6 is changed to the real wind. The function of scopes is to show the waveform of actual speed, desired speed and the error between actual and desired speed.

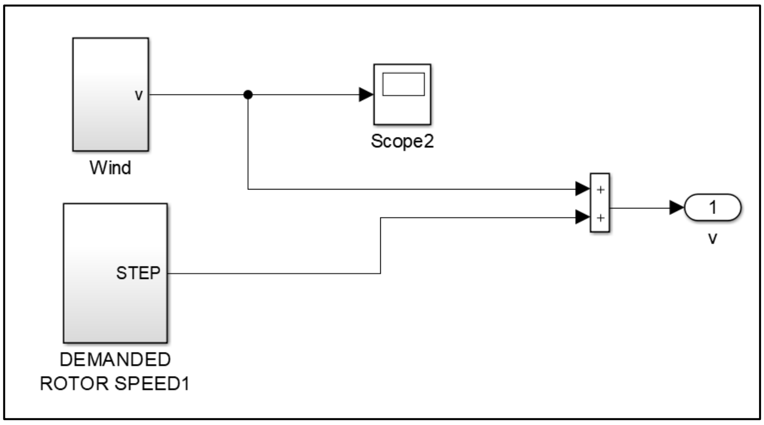


Figure 3.6: Subsystem Wind model

Figure 3.7 shows rotor speed wind turbine was created in MATLAB Simulink based on equation (3.6).

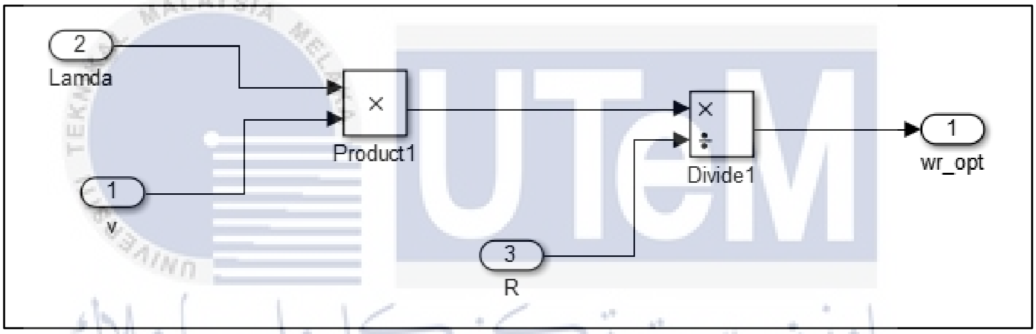


Figure 3.7: Subsystem rotor speed

Figure 3.8 shows mechanical tourqe was created in MATLAB Simulink.

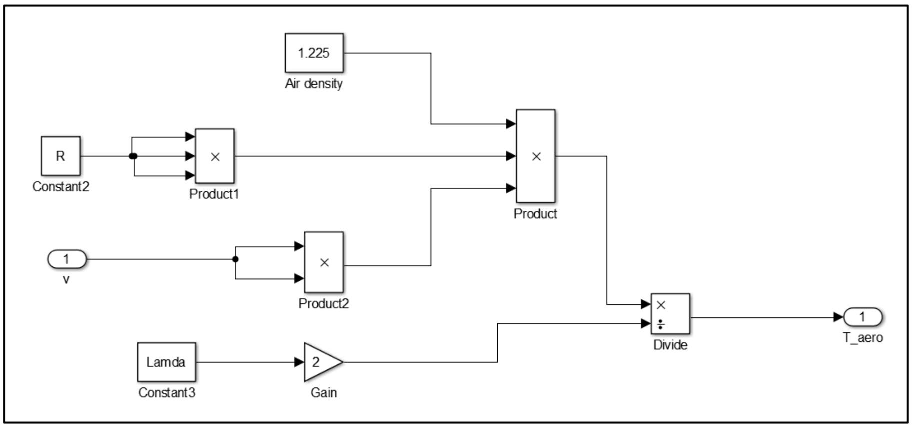


Figure 3.8: Subsystem mechanical torque

Figure 3.9 shows wind power is created based on equation (3.1).

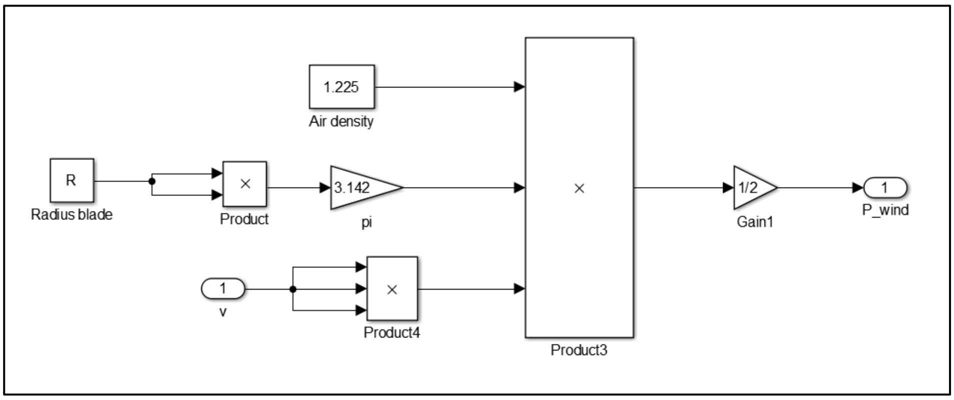


Figure 3.9: Subsystem wind power equation

Figure 3.10 shows the power coefficient C_p in equation (3-3) is a nonlinear function depending on the tip-speed ratio,λ, and β blade pitch angle based on equation (3.4) and (3.5).

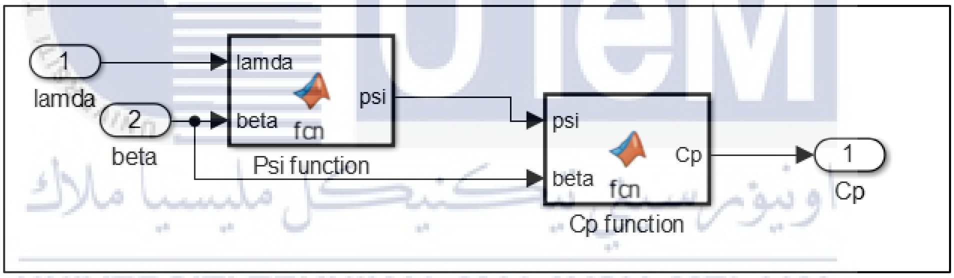


Figure 3.10: Subsystem Max power Coefficient

Figure 3.11 showing the coefficient of power multiple wind power to produce mechanical power.

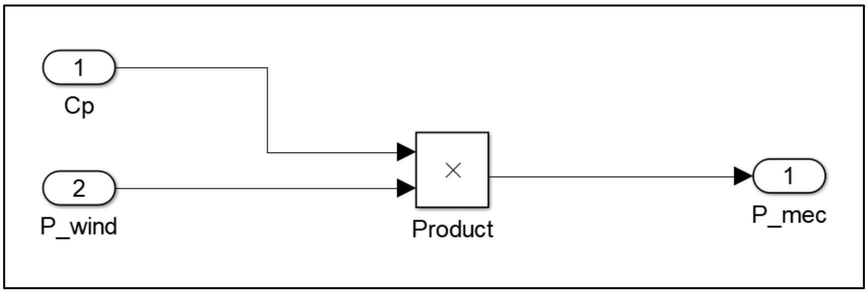


Figure 3.11: Subsystem wind power and mechanical power

3.5 Controller Design

This paper use Proportional-Integral (PI) as the maximum power point tracker (MPPT) controller for maximum power output. Due to the criteria for designing the optimal controller which is characteristic of stability, the conventional PI is quiet easy on designing the linear systems. The PI regulator been designed as it is to stabilize the loop of speed control and improving the dynamics of the controlled systems. The design should be made by Kp and Ki parameters to improve the dynamics of the controlled system during transient state with steady state error at zero. The Figure 3.12 shows the simplified speed control block diagram with the controller.

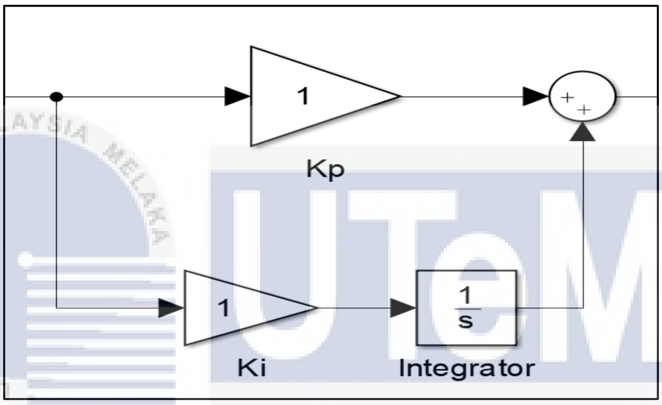


Figure 3.12: The PI controller applied in the wind turbine system

3.5.1 Turning Method (Systematic try and error method)

Systematic try and error method is called as the value of Ki is hold until the satisfied value of Kp is found by tuned that. Then, the Kp value is hold, the Ki is tuned.

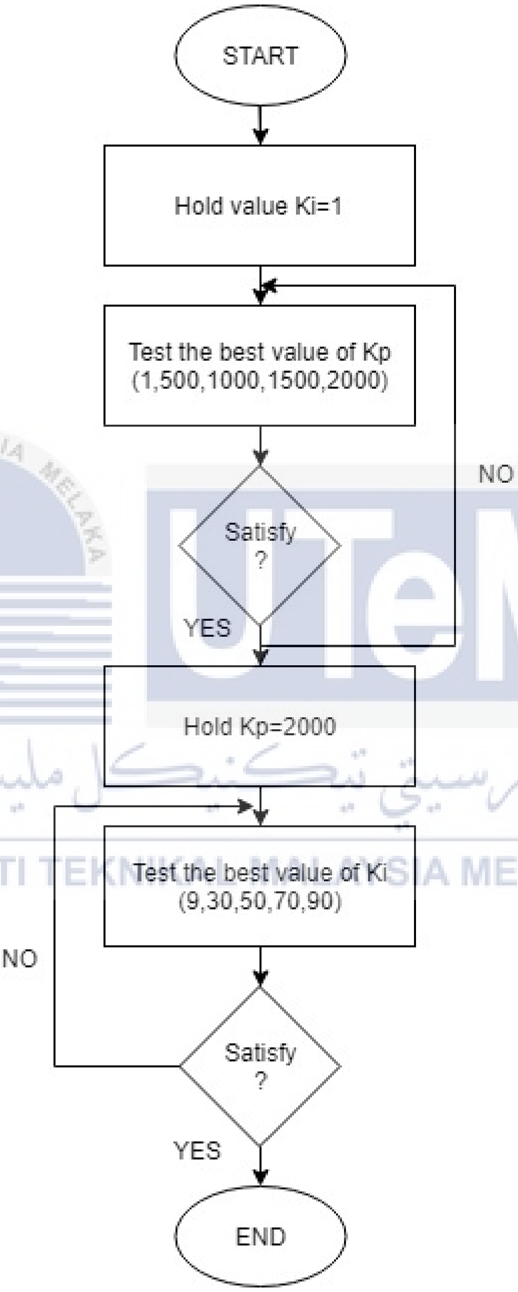


Figure 3.13: Flow chart for controller design tune Kp and Ki

Based on Figure 3.13, after the controller is applied it gives the value of Kp and Ki to be varies. For systematic try and error tune or apply Kp and Ki best value. The techniques of optimization are a method of systematic try and error. First, hold the Ki=1 and then tune the Kp to try and error method. Kp value is 1, 500, 1000, 1500 and 2000. The best value of Kp is 2000. Then tuning the Ki value by holding Kp=2000. The Ki value is 9,30,50,70 and 90. Ki best value is 90. The reference value for the Kp and Ki is 2000 and 90 respectively that will be used in the system.

3.6 Summary

In this project, the MATLAB software has been chosen to implement transient performance such as transient response and the steady state error. In the wind turbine modeling, the Simulink toolbox is functioning to design a variable speed controller. The MATLAB is chosen for its capacity to design a non-linear system that is not possible to use a transfer function and for initial requirements. Based on the modeling of the wind turbine, the transfer function was obtained where the stiffness is neglected. Where J is the total inertia of the turbine and K is the total coefficient of viscous friction. When systematic try and error method was applied as the value of Ki is hold until the satisfied value of Kp is found by tuned that. Then the Kp value is hold, the Ki is tuned. Thus, the reference value for the Kp and Ki is 2000 and 90 respectively that will be used in the system.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will provide the result of the research. In this chapter the result will include the control loop speed without controller and when the controller is applied. Then the technique to tune the value of Kp and Ki is approached by use try and error method.

4.2 Rotor Speed Control Loop

4.2.1 Control loop without controller

Based on Figure 4.1 shows the demand and actual speed of wind turbine without controller. The blue colour shows the desired speed that have been set up manually while the magenta colour shows the actual speed of wind turbine which is flow into the wind turbine. The desired speed starts at 0 and raises its speed at 48 rad/s and maintains at 5 seconds. The actual speed starts at 0 and dramatically increase its speed at 175 rad/s and maintains at 5 seconds.

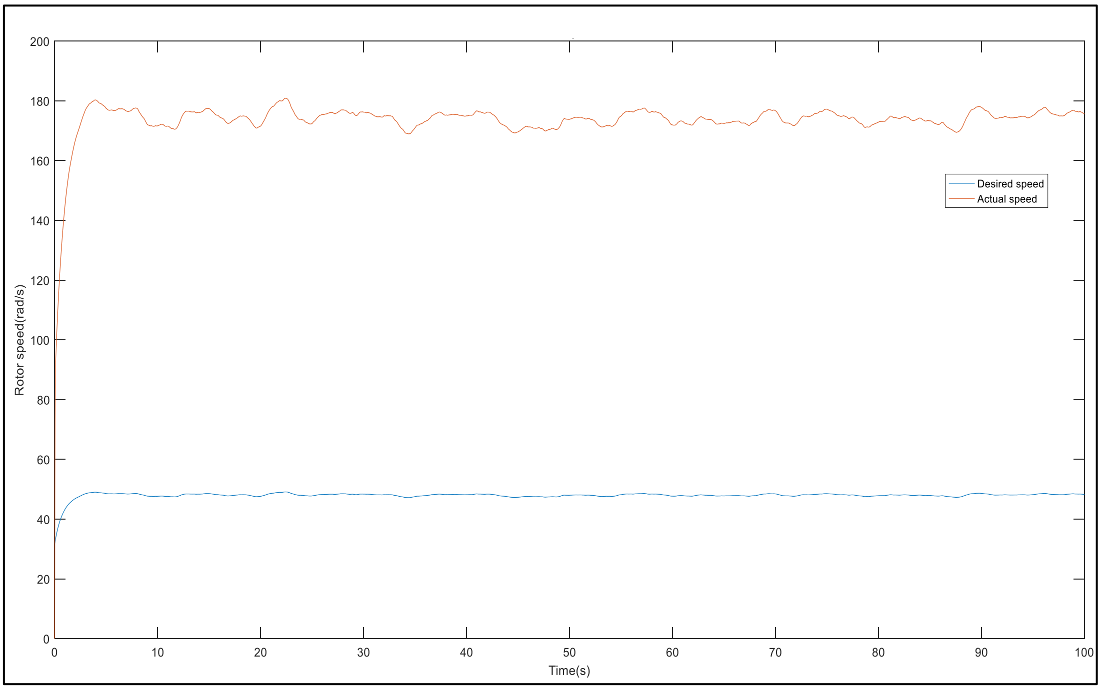


Figure 4.1: The actual and desired speed without controller

Figure 4. 2 shows the error between the actual and desired speed which is start at zero then it start drop at 127 rad/s and it maintains at 9 seconds.

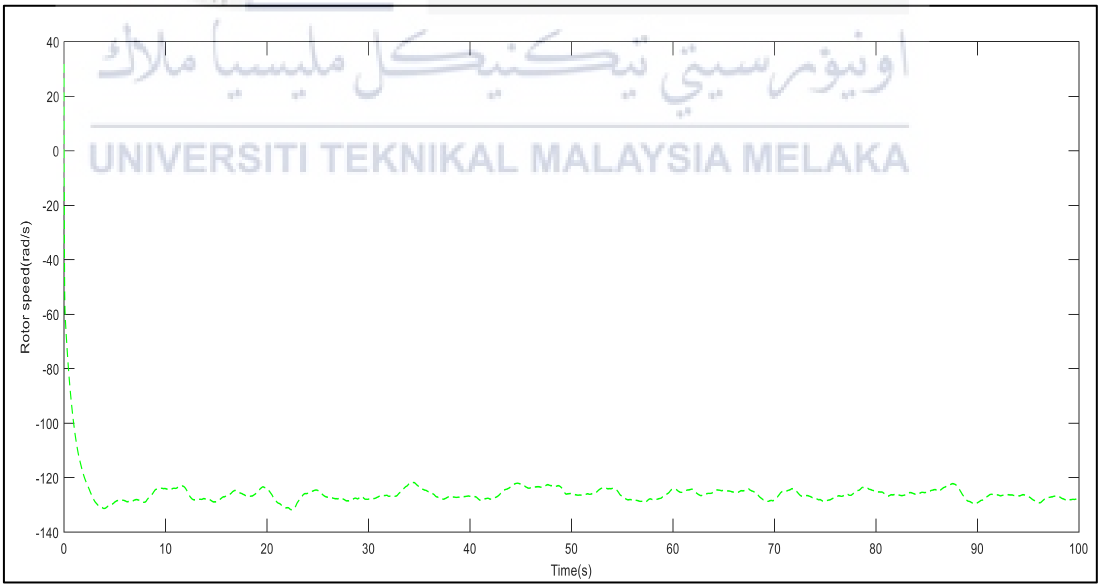
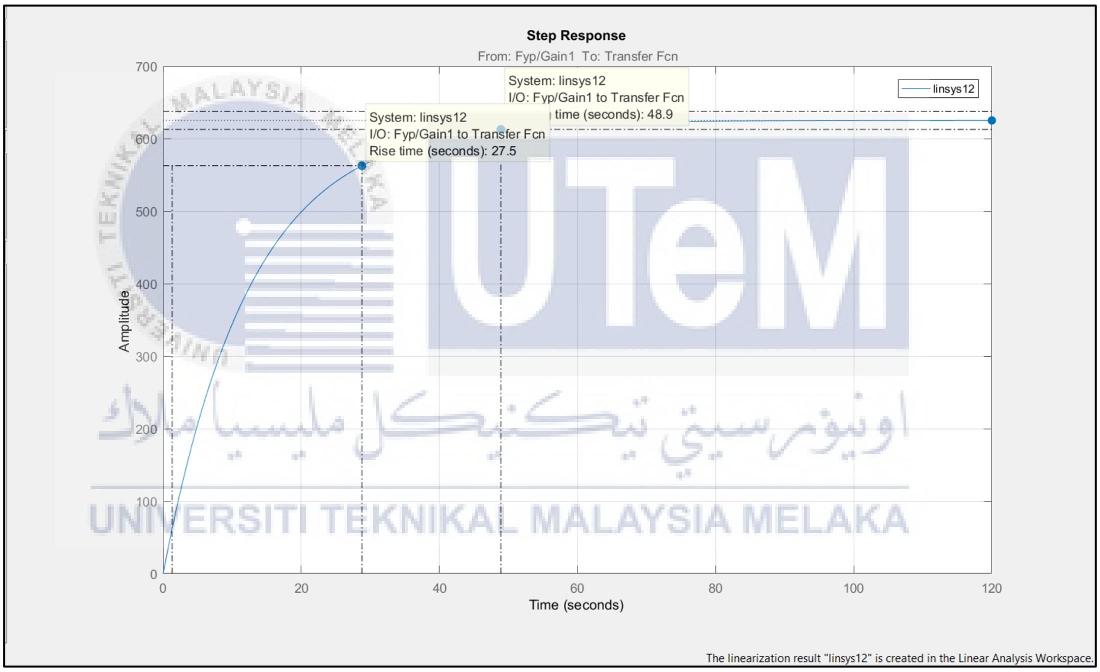


Figure 4.2: Error between actual and desired speed without controller

Figure 4.3 shows the performance rotor speed without controller and Table 4.1 shows the transient response performance without controller. The error between the desired speed of wind turbine are obviously not really smooth and they become fluctuated because no controller was applied. The requirement is overshoot must less than 2%. Settling time must be less than 2 seconds and Rise time less than 1 seconds. The rise time, Tr(s) which is the time required for a pulse to rise from 10% and to 90% of its steady value, given the time at 27.5 seconds. The settling time, Ts(s) which is time taken for a measuring or control instrument to get within a certain distance of a new equilibrium value without subsequently devisting from it by that amount give the time at 48.9 seconds. The overshoot(%) of the error without controller is 0%.



The linearization result "linsys12" is created in the Linear Analysis Workspace.

Figure 4.3: The performance rotor speed without controller

Table 4.1: The transient response performance without controller

Transient response performance	Value
Settling time, Ts (s)	48.9
Rise time, Tr (s)	27.5
Overshoot (%)	0

4.2.2 Control loop with PI controller

Figure 4.4 shows the actual and desired speed when the controller is being applied. The blue color shows the desired value with a maximum peak of around 48.8 rad/s. Next, the magenta color shows the actual speed control when applying the PI controller (Kp=1 and Ki=1) to follow the desired rotor speed and go through 48 rad/s. From that, the actual wind speed is the range of the wind specification compared to the graph of the speed without controller.

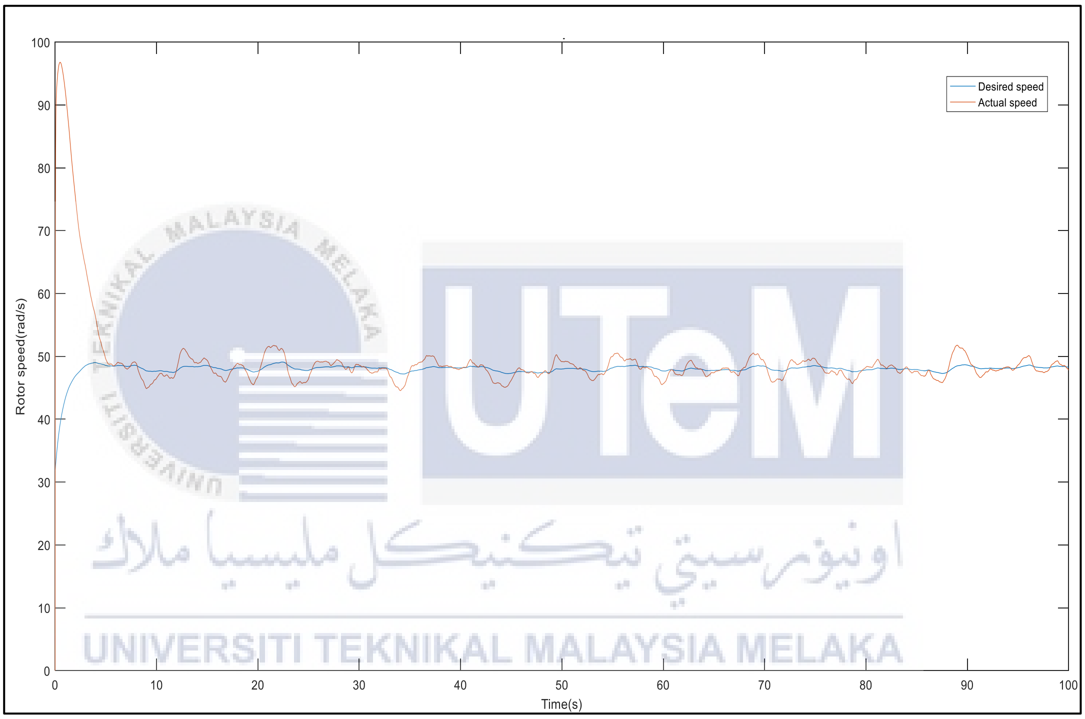


Figure 4.4: Actual and desired speed of wind turbine with controller

From Figure 4.5, the error between the actual and desired speed shows that the maximum peak is 31 rad/s and decreases at 58 rad/s and increases again until maintains at 50 to 100 seconds.

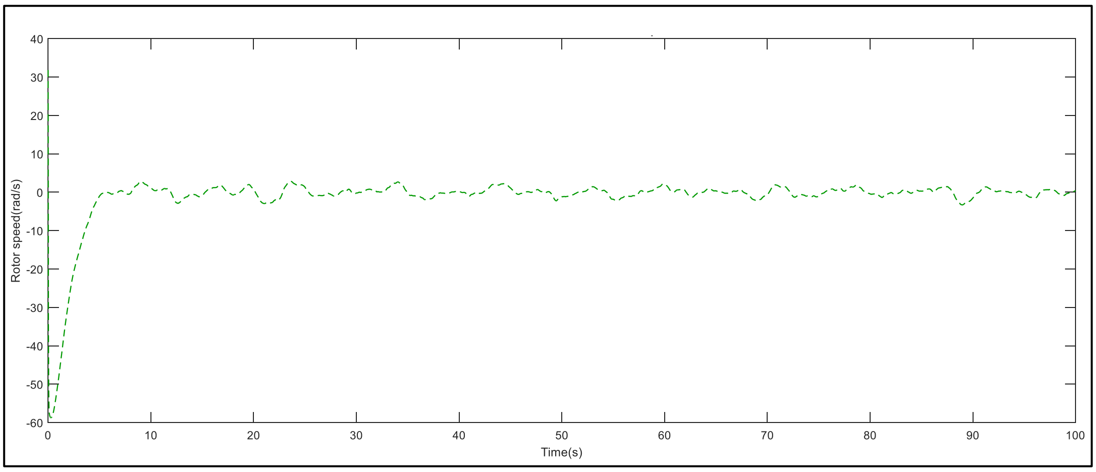


Figure 4.5: Error between actual and desired speed with controller

Figure 4.6 shows the uncontrolled performance speed of the rotor and Table 4. 2 shows the transient response performance without controller. Obviously, the error between the desired wind turbine speed is not really smooth and they become fluctuated because the controller just applied but not tuned. The requirement is overshoot must less than 2%. Settling time must be less than 2 seconds and raise time less than 1 seconds. The rise time, Tr(s), which is the time required for a pulse to rise from 10 percent to 90 percent of its steady value, given the time at 0.0417seconds. The settling time, Ts(s) that is taken for a measuring or control instrument to get within a certain distance of a new equilibrium value without subsequently deviating from it by that amount give the time at 0.0669seconds. The overshoot(%) of the error without controller is 0%.

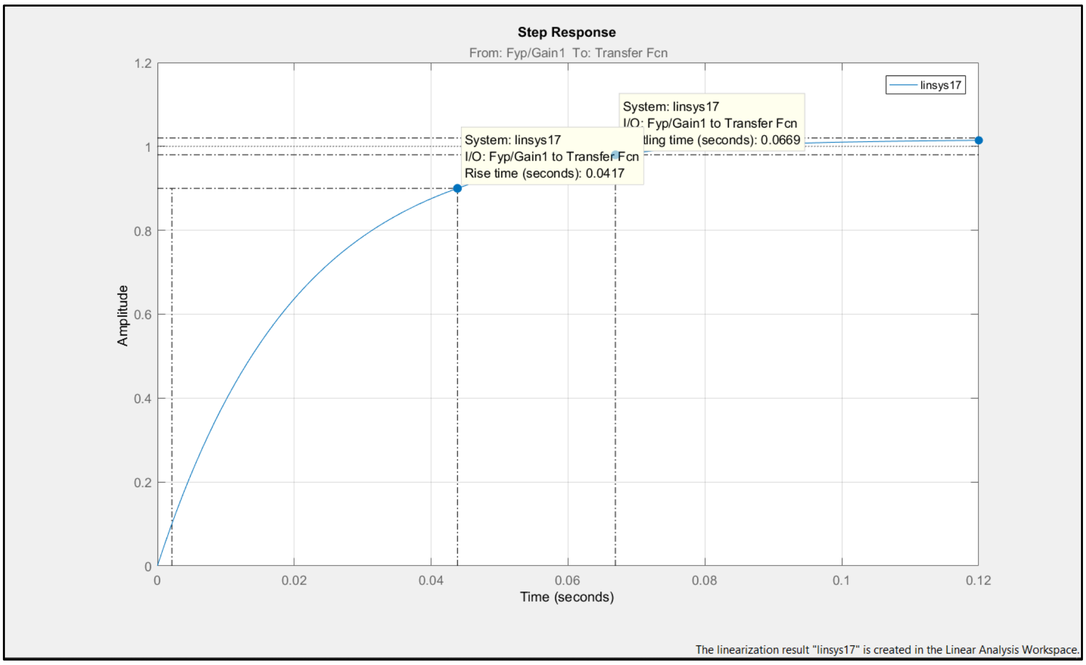


Figure 4.6: The performance rotor speed with controller (Kp=1 and K=1)

Table 4.2: The transient response performance with controller (Kp=1 and Ki=1)

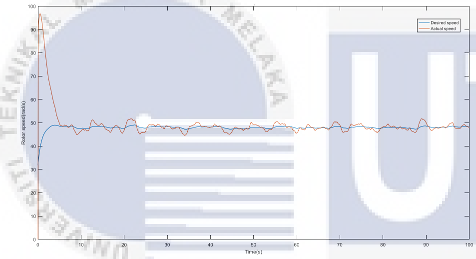
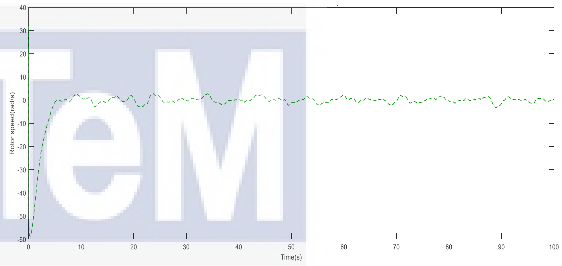
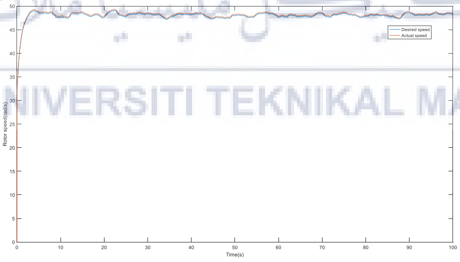
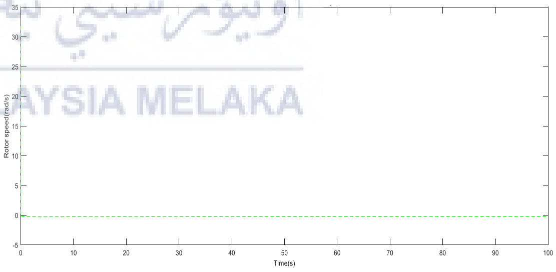
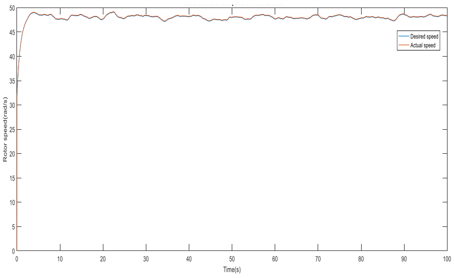
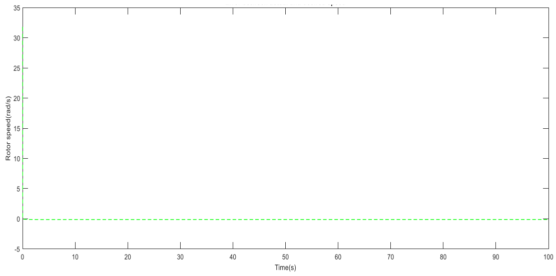
Transient response performance	Value
Settling time, Ts (s)	0.0669
Rise time, Tr (s)	0.0417
Overshoot (%)	0

4.3 Optimize Technique (Systematic Try and Error)

4.3.1 Hold Ki = 1

Table 4.3 shows the result of the method of systematic try and error. First of all, the value of Ki=1 while the value of Kp is tuned in this method. Table 4.4 shows the transient response performance with controller. The requirement must be exceeded by less than 2%. Settling time must be less than 2 seconds and raise time less than 1 seconds. When tune Kp=1, the value rise time is 0.00439 and settling time is 0.00782. The Kp is tune and stop tuning when get exactly value. The best value of Kp is 2000.

Table 4.3: The differences of the error when tune the Kp and Ki=1

Kp	Actual and Desired speed	Error Signal
1		
500		
1000		

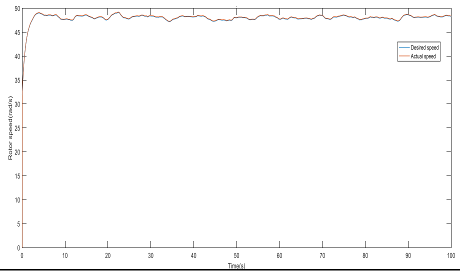
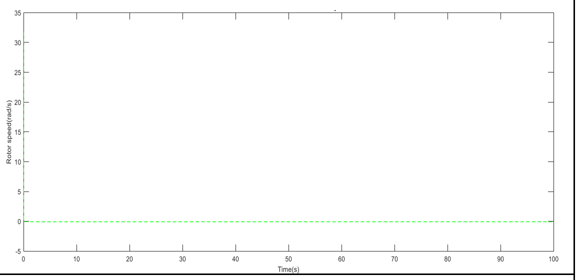
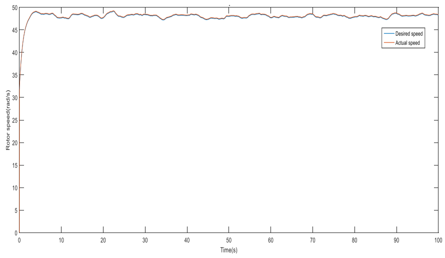
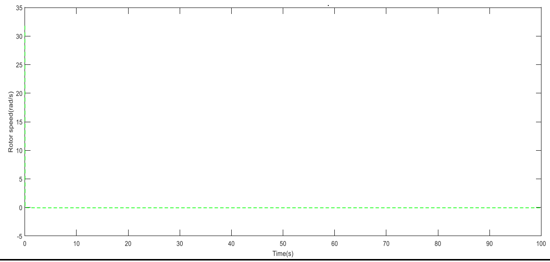
1500		
2000		

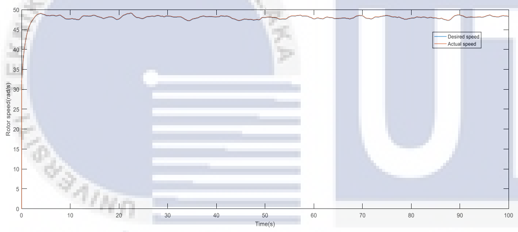
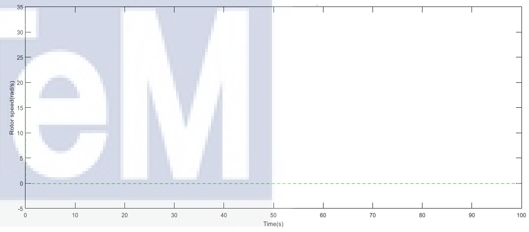
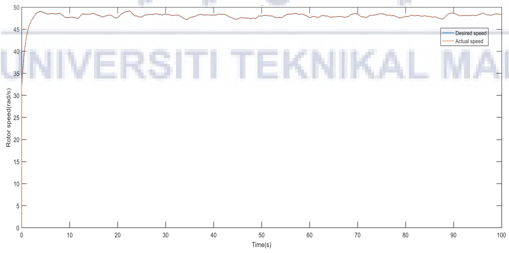
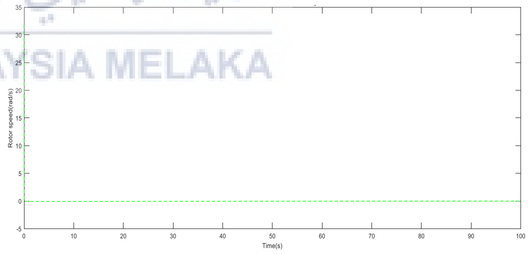
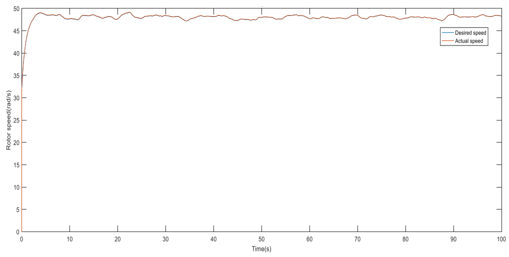
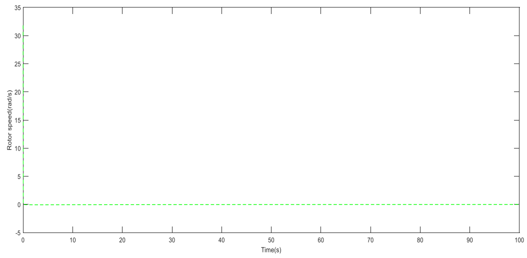
Table 4.4: The transient response performance with controller (Hold Ki=1 and tune Kp value)

Value Kp	Rise time, Tr (s)	Settling time, Ts (s)	Overshoot (%)
1	0.00439	0.00782	0
500	0.0000879	0.00156	0
1000	0.0000439	0.00782	0
1500	0.0000293	0.00522	0
2000	0.0000022	0.00391	0

4.3.2 Hold Kp=2000

Table 4.5 shows the result of the method of systematic try and error. In this method, the value of Kp=2000 is held first while the value of Ki is tuned method. In this method, firstly the value of Kp=2000 is hold while value of Ki is tuned. Table 4.6 shows the transient response performance with controller. The requirement must be exceeded by less than 2%. Settling time must be less than 2 seconds and raise time less than 1 seconds. The value increase time is 0.000022 when tuning Ki=9 and the settling time is 0.0000391. The Ki is tune and stop tuning when it gets the best value. The best value of Ki is 90.

Table 4.5: The differences of the error when tune the Ki and Kp=2000

Ki	Actual and Desired speed	Error Signal
9		
30		
50		

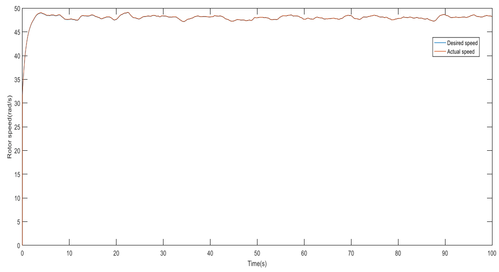
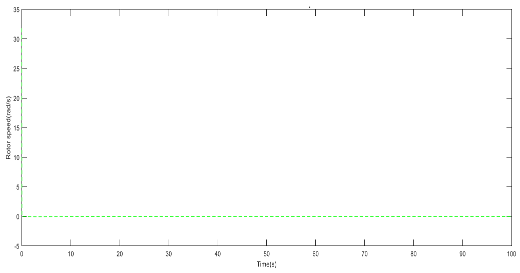
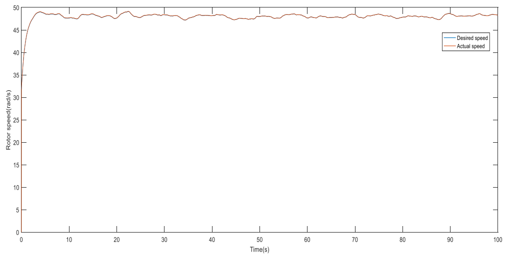
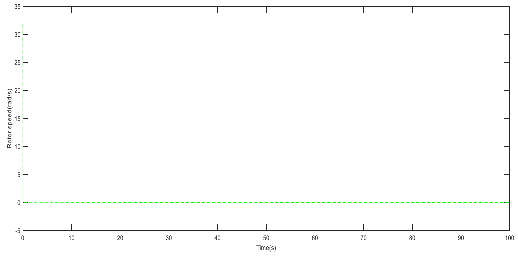
70		
90		

Table 4.6: The transient response performance with controller (Hold Kp=2000 and tune Ki value)

Value Ki	Rise time, Tr (s)	Settling time, Ts (s)	Overshoot (%)
9	0.000022	0.0000391	0
30	0.000022	0.0000391	0
50	0.000022	0.0000391	0
70	0.000022	0.0000391	0
90	0.000022	0.0000391	0

4.3.3 Path Tracking Performance and Evaluation

Table 4.7 shows the path tracking performance are evaluated based on integral of absolute error (IAE), and integral of squared error (ISE) when tune Ki and Kp.

Table 4.7: Performance indices and their descriptions

Performance Indices	Formula / Programming	Details and Purpose
Integral of Absolute Error (IAE)	● Continuous form: $\mathrm{IAE}=\int_0^{\mathrm{T}} \lvert e(t)\rvert \, dt$ ● Discrete form: $\mathrm{IAE}=\sum_0^{\mathrm{T}} \lvert \mathrm{e(k)} \rvert$	- Area under the curve of error versus time. - Detailed and deeper perspective on indexing the overall tracking performances.
Integral of Square Error (ISE)	● Continuous form: $\mathrm{ISE}=\int_0^{\mathrm{T}} (e(t))^2 \, dt$ ● Discrete form: $\mathrm{IAE}=\sum_0^{\mathrm{T}} (e(k))^2$	- Squared of the area under the curve of error versus time. - Penalize large error (peak).

Table 4.8 shows the performance index between desired speed (IAE and ISE) and actual speed (IAE and ISE) when tune Kp. Figure 4.7 shows the performance index between desired speed (IAE) and actual speed (IAE) when tune Kp. The purpose of integral of absolute error (IAE) is to deeper perspective on indexing the overall performance area under the curve of error versus time. The value of (IAE) is 4794 for desired speed and remained constant when Kp=1,500,1000,1500,2000. The actual speed (IAE) steadily increase when Kp was tuning based on Figure 4.7. Integral of Error (ISE) is squared of area under the curve of error versus time and penalize large error(peak). Based on Figure 4.8, the value desired speed (ISE) is remained constant. The value ISE is 230000. The value actual speed (ISE) is slightly increase. There is percentage of error between desired speed (IAE) and actual speed (IAE) when tune Kp=1 is 2.67%, Kp=500 is 0.48%, Kp=1000 is 0.25%, Kp=1500 is 0.19% and

Kp=2000 is 0.14%. Beside that, there is percentage of error between desired speed (ISE) and actual speed (ISE) when tune Kp=1 is 6.50%, Kp=500 is 0.86%, Kp=1000 is 0.48%, Kp=1500 is 0.35% and Kp=2000 is 0.26%. As conclusion, when value of Kp is bigger, the percentage of error become decrease.

Table 4.8: Performance Index between Desired speed (IAE and ISE) and Actual speed (IAE and ISE) when tune Kp value and hold Ki=1

	Desired speed		Actual speed	
	Integral of Absolute Error (IAE)	Integral of Square Error (ISE)	Integral of Absolute Error (IAE)	Integral of Square Error (ISE)
Kp=1	4794	230000	4922	246000
Kp=500	4794	230000	4817	232000
Kp=1000	4794	230000	4806	231100
Kp=1500	4794	230000	4803	230800
Kp=2000	4794	230000	4801	230600

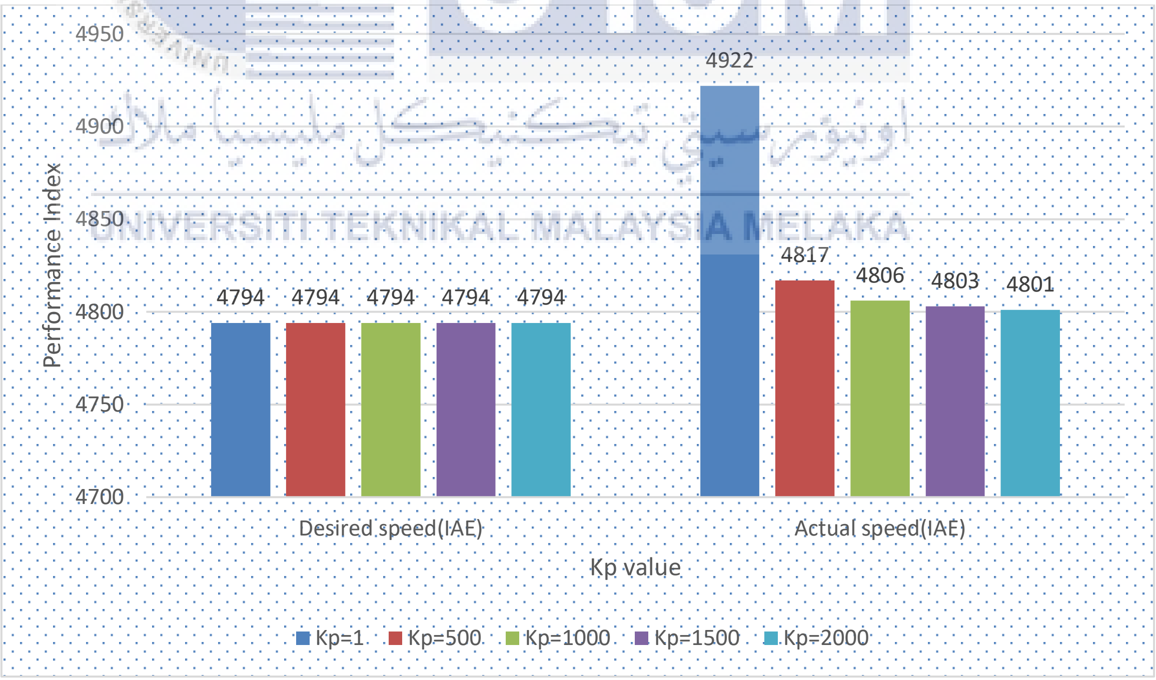


Figure 4.7: Performance Index between Desired speed (IAE) and Actual speed (IAE) when tune Kp value

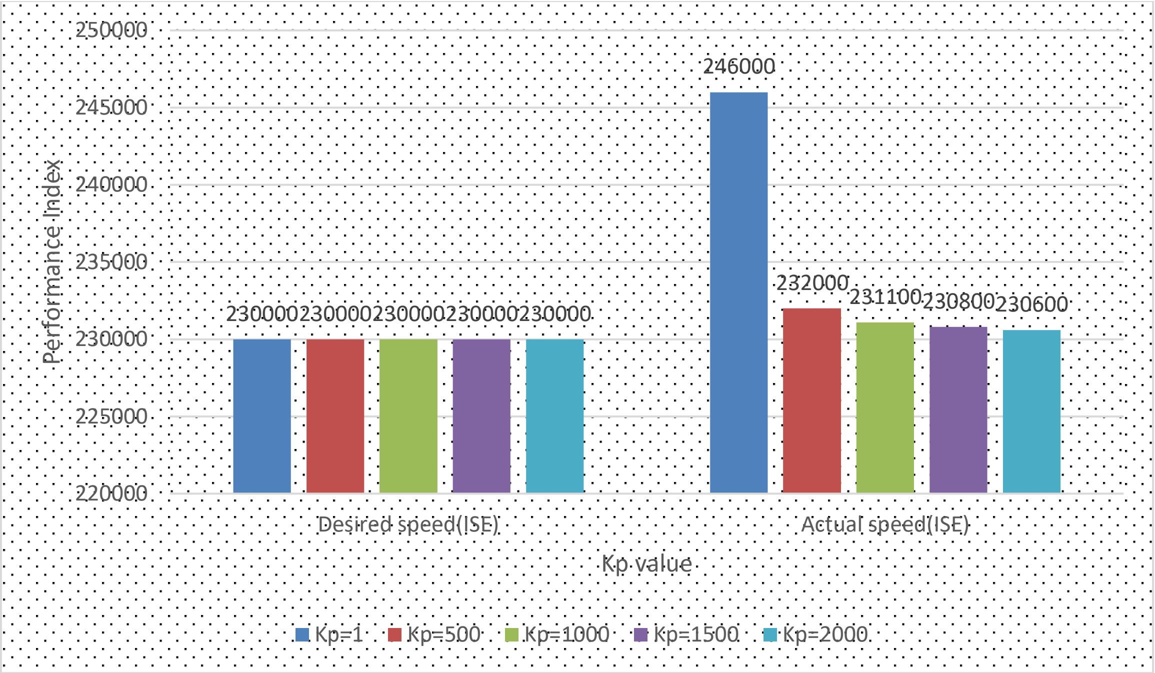


Figure 4.8: Performance Index between Desired speed (ISE) and Actual speed (ISE) when tune Kp value

Table 4.9 shows the performance index between desired speed (IAE and ISE) and actual speed (IAE and ISE) when tune Ki. Figure 4.9 shows the performance index between desired speed (IAE) and actual speed (IAE) when tune Ki. The purpose of integral of absolute error (IAE) is to deeper perspective on indexing the overall performance area under the curve of error versus time. The value of (IAE) is 4794 for desired speed and remained constant when Ki=9,30,50,70,90. The actual speed (IAE) steadily increase when Ki was tuning based on Figure 4.9. Integral of Error (ISE) is squared of area under the curve of error versus time and penalize large error(peak). Based on Figure 4.10, the value desired speed (ISE) is remained constant. The value ISE is 230000. The value actual speed (ISE) is slightly increase. There is percentage of error between desired speed (IAE) and actual speed (IAE) when tune Ki=9 is 0.13%, Ki=30 is 0.08%, Ki=50 is 0.06%, Ki=70 is 0.04% and Ki=90 is 0.04%. Beside that, there is percentage of error between desired speed (ISE) and actual speed (ISE) when tune Ki=9 is 0.22%, Ki=30 is 0.22%, Ki=50 is 0.09%, Ki=70 is 0.09% and Ki=90 is 0.04%. As conclusion, when value of Ki is bigger, the percentage of error become decrease.

Table 4.9: Performance Index between Desired speed (IAE and ISE) and Actual speed (IAE and ISE) when tune Ki and Kp=2000

	Desired speed		Actual speed	
	Integral of Absolute Error (IAE)	Integral of Square Error (ISE)	Integral of Absolute Error (IAE)	Integral of Square Error (ISE)
Ki=9	4794	230000	4800	230500
Ki=30	4794	230000	4798	230500
Ki=50	4794	230000	4797	230200
Ki=70	4794	230000	4796	230200
Ki=90	4794	230000	4796	230100

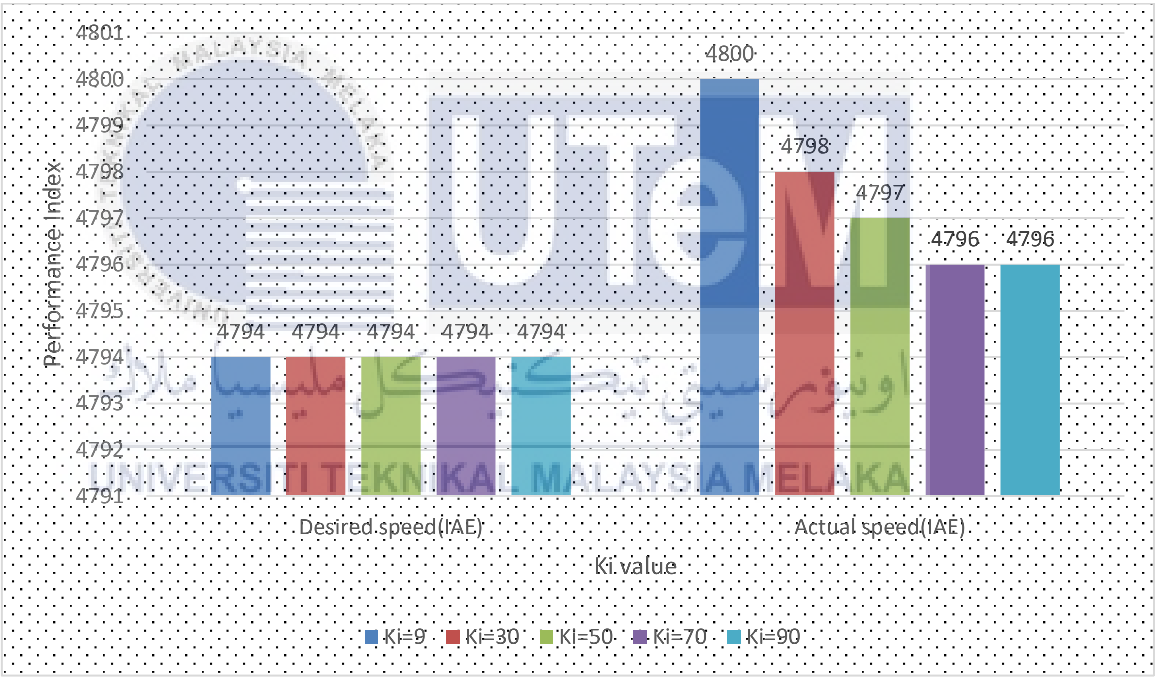


Figure 4.9: Performance Index between Desired speed (IAE) and Actual speed (IAE) when tune Ki value

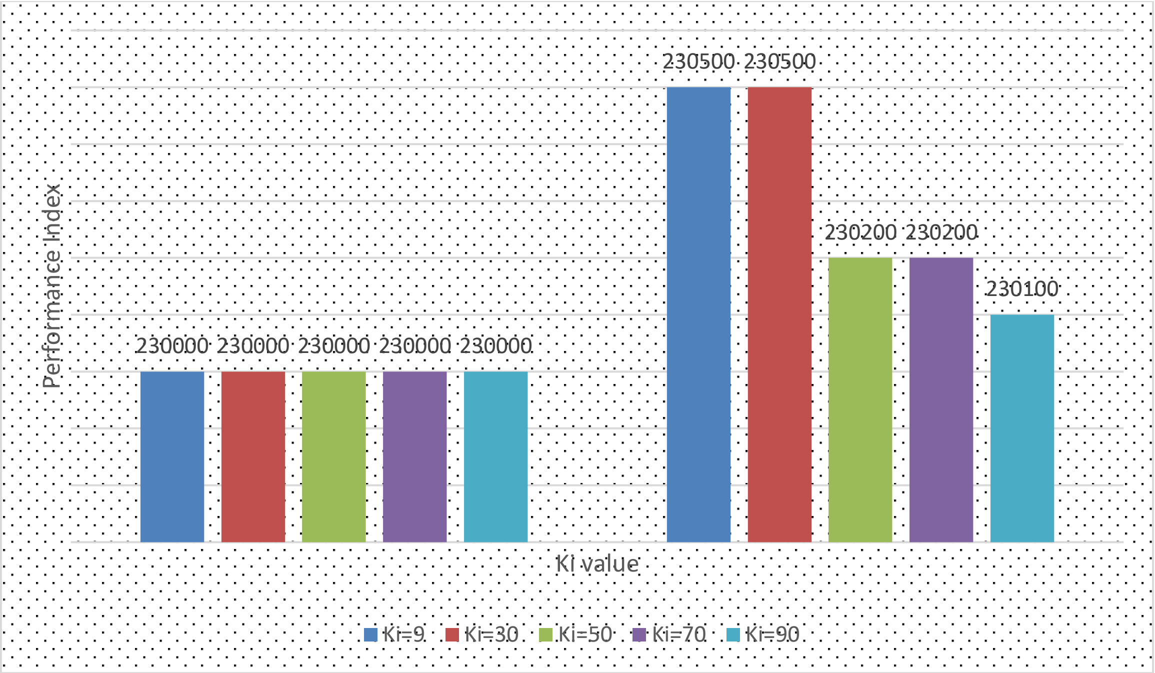


Figure 4.10: Performance Index between Desired speed (IAE) and Actual speed (IAE) when tune Ki value

4.3.4 The reference value of Kp and Ki after tuned

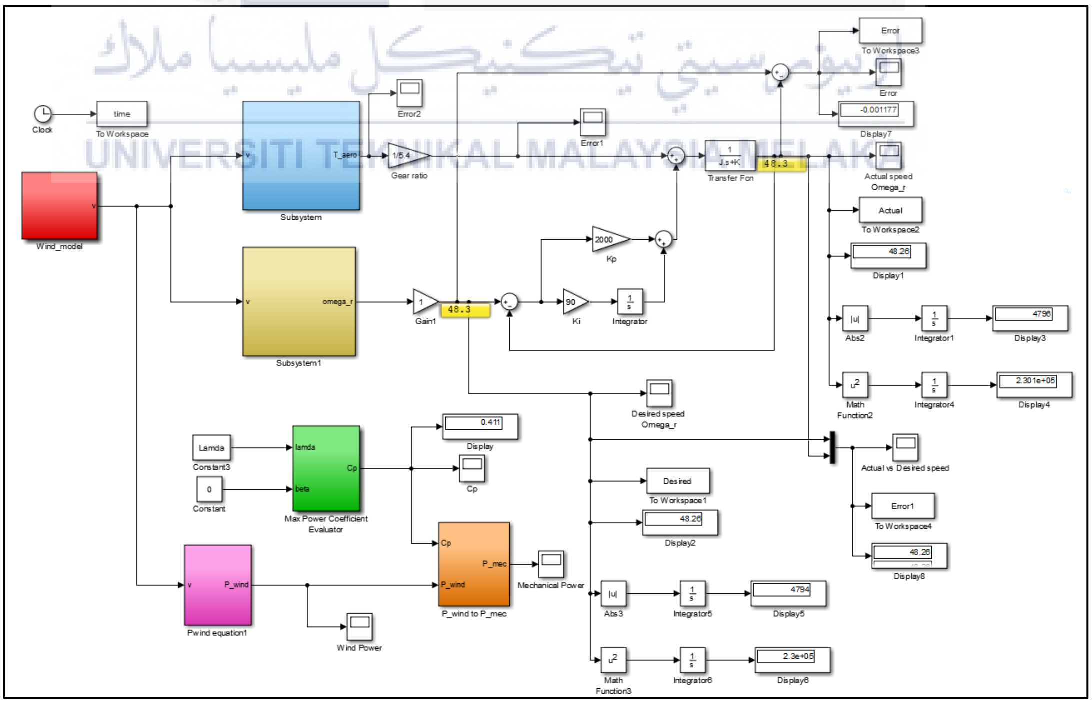


Figure 4.11: The control loop speed with the PI controller (Kp=2000 and Ki=90)

Based on Figure 4.12, the transient response performance characteristics are analyzed. The error between the desired and actual speed of wind turbine are very smooth as after the tune Kp=2000 and Ki=90.

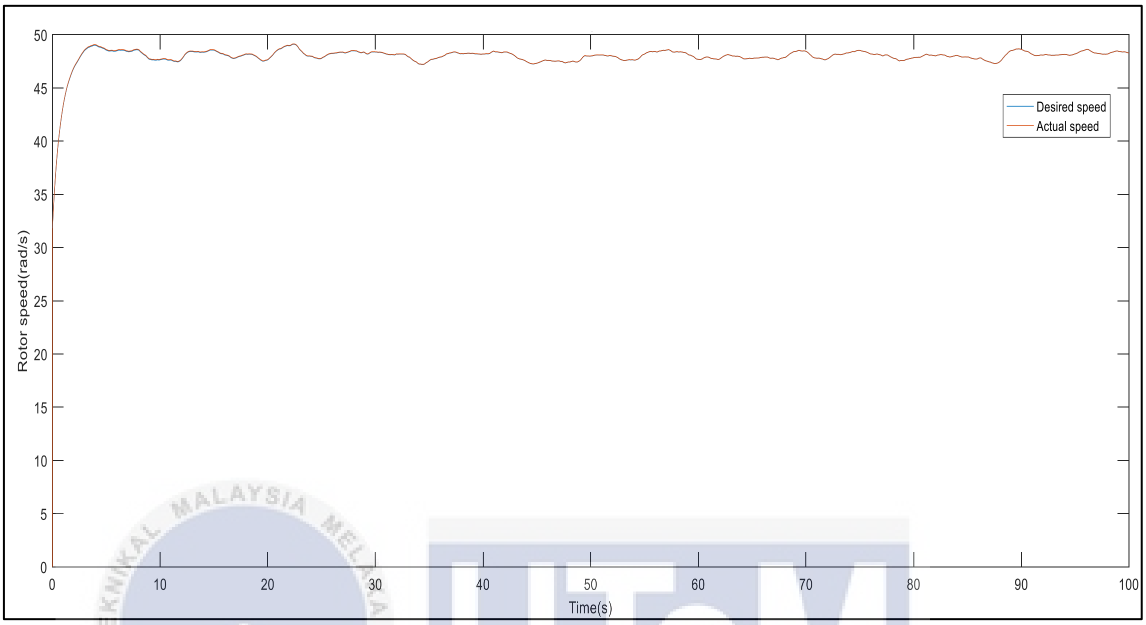


Figure 4.12: The actual and desired speed when Kp=2000 and Ki=9000

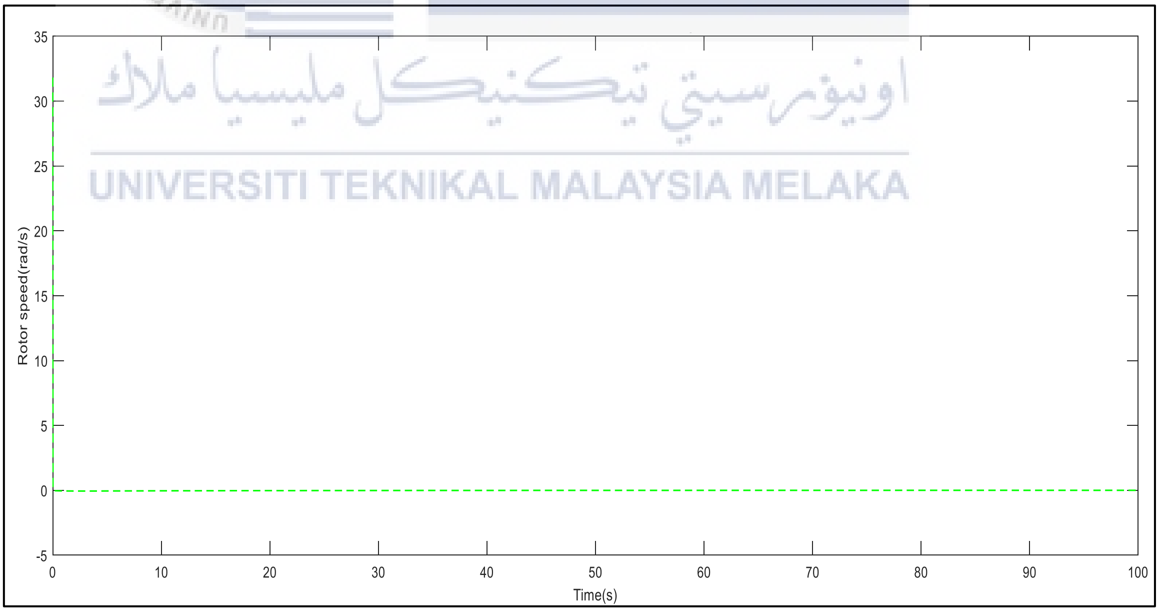


Figure 4.13: Error between actual and desired speed

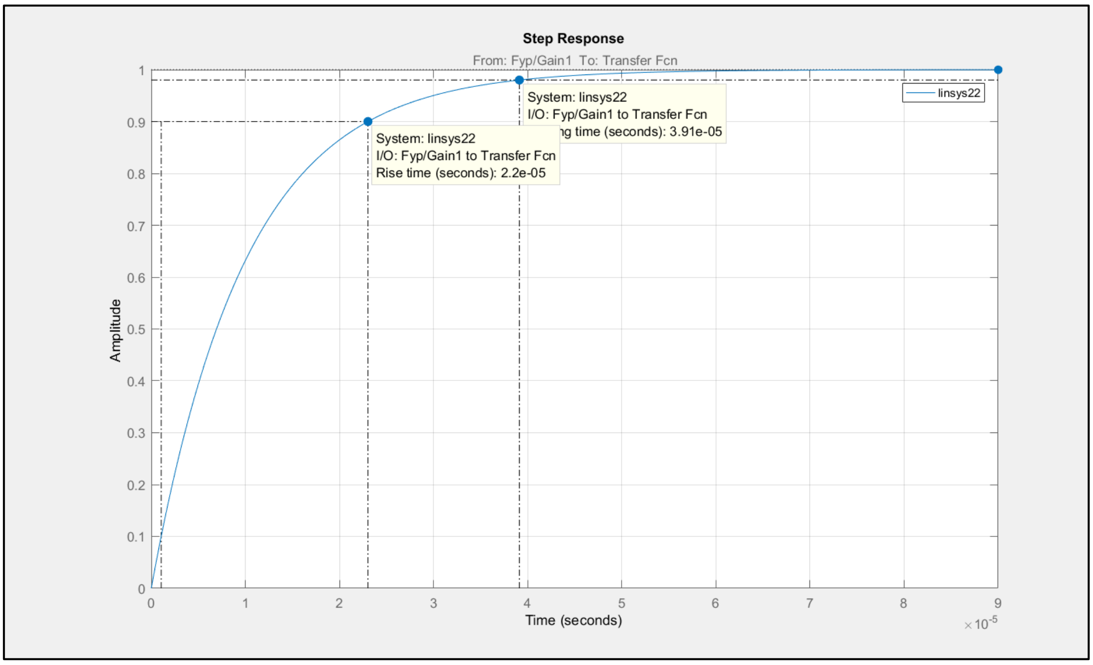


Figure 4.14: The performance rotor speed with controller (Kp=2000 and Ki=90)

Table 4.10: The transient response performance with controller (Kp=2000 and Ki=90)

Transient response performance	Value
Settling time, Ts (s)	0.000022
Rise time, Tr (s)	0.0000391
Overshoot (%)	0

4.4 Analysed Aerodynamic Power

Figure 4.15 shows the speed of wind profile used in Simulink simulation, corresponding to sub-synchronous mode.

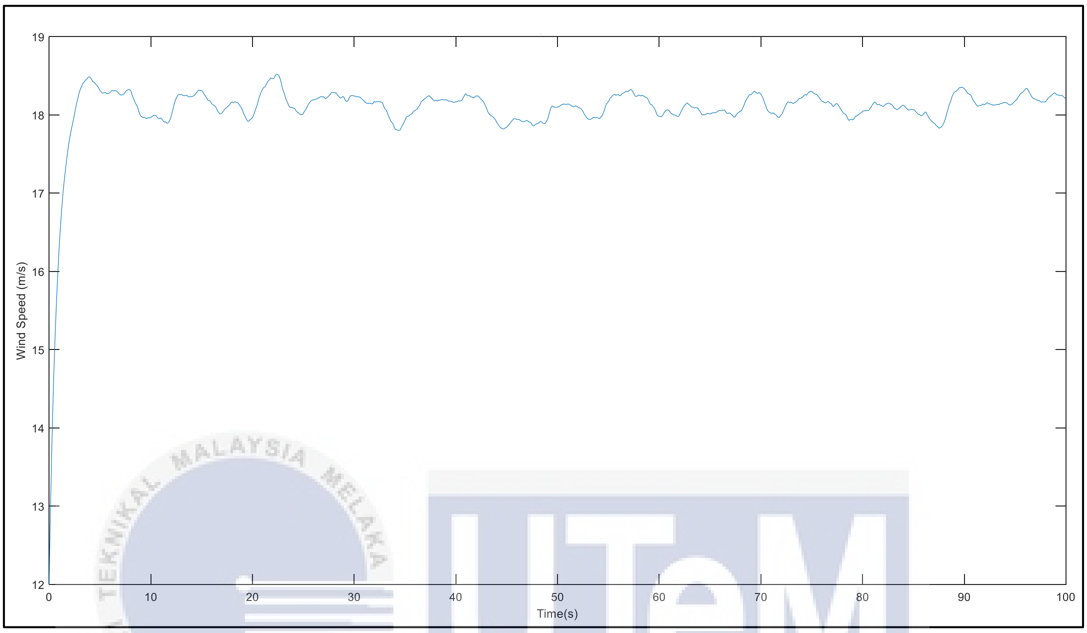


Figure 4.15: Variable wind speed profile

Figure 4.16 presents the evolution of coefficient power reaches the optimal value is ($C_{p\_max} = 0.411$).

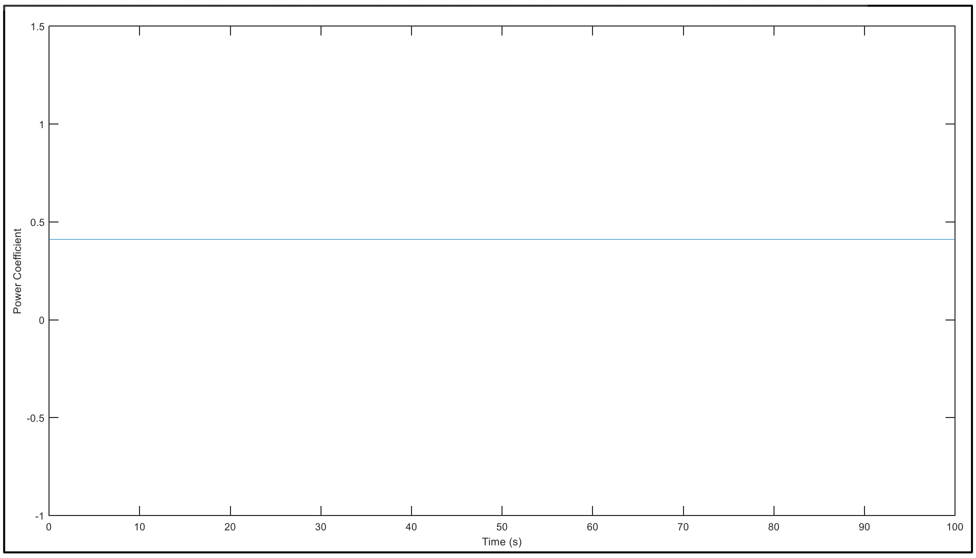


Figure 4.16: Power Coefficient

Figure 4.17 shows the wind power that produced from simulation. It reaches the optimal value $P_{wind} = 0.1044MWatt$.

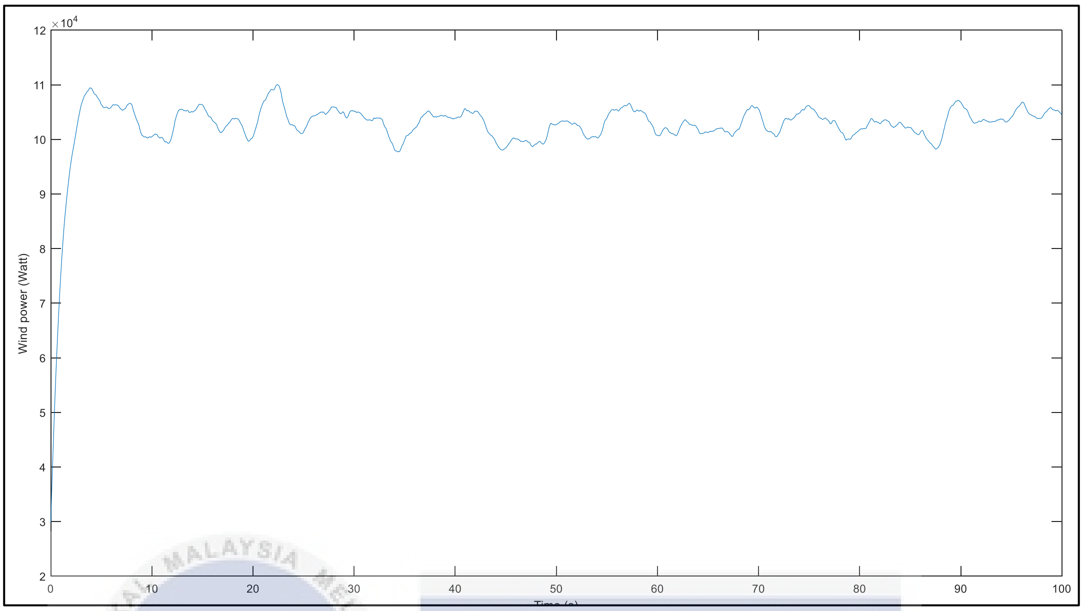


Figure 4.17: The wind power profile

Figure 4.18 shows the aerodynamic that produced from simulation. It reaches the captured power, $Pm = 0.04292MWatt$.

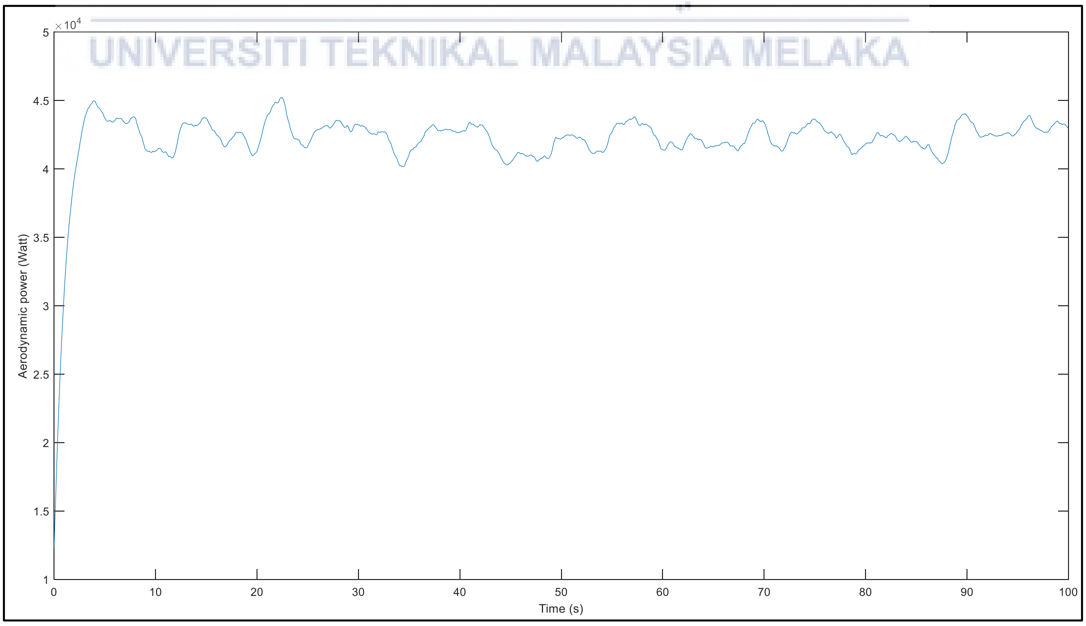


Figure 4.18: The aerodynamic power

And output power distribution. The wind power is recorded as

$$Pwind = 0.1044MWatt$$

and the captured power,

$$Pm = 0.04292MWatt$$

Therefore, the simulated Betz limit

$$\text{Betz Limit} = 100\% - (\frac{Pwind-Pm}{Pwind}) \text{ x } 100$$
$$= 41.11\%$$

The result is tabulated in Table 4.11. The power flow is shown in Figure 4.19.

Table 4.11: Betz limit

	Calculation	Simulation
Betz limit	41.11111111%	41.1%

With a guaranteed rotor speed tracking, the optimum tip-speed ratio is obtained to produce turbine maximum power output. With a variable speed algorithm based on limited back-stepping, 0.04292 MWatt is captured from 0.1044 MWatt wind power. As such, the calculated Betz limit of around 41.1% is confirmed by the algorithm. Betz limit is named after a German physicist Albert Betz who concluded that no wind turbine can converting exceed than 59% of the wind kinetic energy into the mechanical energy that turns the turbine rotor.

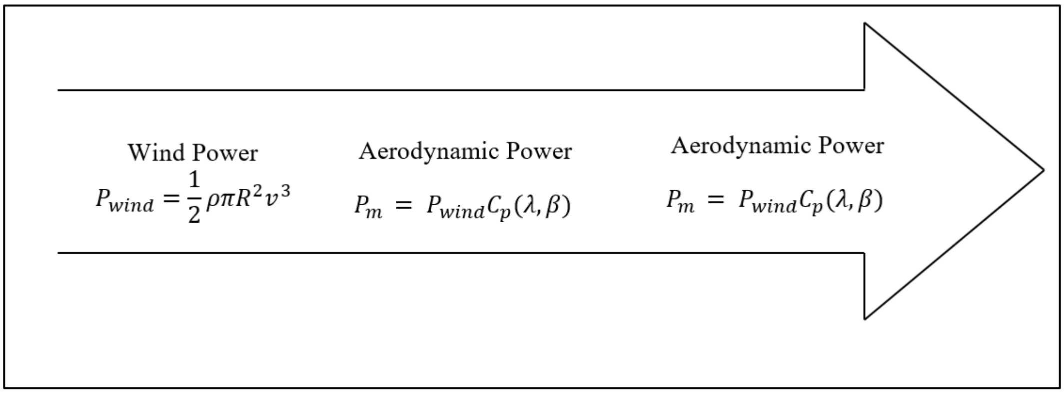


Figure 4.19: Shows the power flow diagram for wind turbine system

4.5 Conclusion

The chapter is highlighted to tune or apply Kp and Ki best value. The techniques of optimization are a method of systematic try and error. First, hold the Ki=1 and then tune the Kp to try and error method. Kp value is 1, 500, 1000, 1500, 2000. The best value of Kp is 2000. Then tuning the Ki value by holding Kp=2000. The Ki value is 9,30,50,70 and 90. Ki best value is 90. The reference value for the Kp and Ki is 2000 and 90 respectively that will be used in the system.

CHAPTER 5

CONCLUSION

5.1 Conclusion

To conclude, research on Variable Speed Control for a Two-Mass Wind Turbine System was done by finding the journal as a reference for doing the project. In this paper, the mathematical model of the two-mass wind turbine system is determined by deriving from the turbine mathematical dynamics (low-speed shaft) and the generator mechanical dynamics (high-speed shaft). From the transfer function derivation, the output is the power meanwhile the input control is the wind turbine with rotor speed. The speed of the rotor is controlled because I proposed a variable speed wind turbine in this project. In this project, the MATLAB software was chosen to implement transient performance such as transient response and steady-state error. The Simulink toolbox is used to design a variable speed control in the variable speed wind turbine. A variable speed controller will be designed to achieve maximum power output by controlling the rotor speed. The controller proposed is a Proportional-Integral (PI). Due to the conventional PI controller it is quite easy to design the PI controller for linear system because of the criteria for designing the optimal controller which is the stability investigation. All the transient response was done to fulfill the system requirement. The method chosen to turn the value of Kp and Ki is using the method of systematic try and error. The best value for the Kp and Ki is 2000 and 90 respectively that used in the system. Last but not least, this project has achieved the second objective where the error between desired and actual speed is successfully reduced. The system achieved the maximum power output when the error is reduced.

5.2 Future Recommendation

There are some major topics that I would like to point out for further progress on the wind turbine controller development. First, I want to find the most suitable controller such as PID and Fuzzy controller. Additionally, it is possible designing a variable speed variable pitch controller for two-mass wind turbine with stiffness. It is recommended that the pitch controller be used in future work to extend the application of the variable speed controller over a wide range of operations. In a full-load region, the speed of the wind turbine rotor must be maintained at its rated value. This can be achieved with the use of a pitch angle controller. The pitch controller also helps to smooth output power. This recommendation, however, requires a greater complexity of the design process. Nevertheless, it is worth adding the recommended variable speed and variable pitch controller in future experiments to achieve maximum output power.

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APPENDICES

APPENDIX A

Table 1: Wind Turbine Parameter

Parameter	Value	Units
Rated power, Pn	10	kW
Density of air, ρ	1.225	Kg/m^3
Number of blades	3	-
Radius of rotor, R	3	M
Gear ratio, G	5.4	-
Turbine total inertia, J	0.02	Kg.m^2
Total viscous friction, B	0.0016	N.m/s

Table 2: Coefficient Value

C_1	C_2	C_3	C_4	C_5
0.5	0.0167	3	0.00184	3

APPENDIX B

Table 3: Gantt chart

Tasks	October			November				December				March				April				May				June			
	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Literature Review	■	■	■	■	■	■	■																				
Modelling of two-mass wind turbine system	■	■	■	■	■	■	■																				
Verification of wind turbine model in MATLAB Simulation				■	■	■	■																				
Formulation variable speed control for wind turbine				■	■	■	■																				
Collecting and Analyze Data					■	■	■																				
Writing Report			■	■	■	■	■	■	■	■	■																
Presentation PSM 1						■	■																				
Analysis the problem of project												■	■	■	■	■	■	■	■	■	■	■	■				
Optimization technique selection												■	■	■	■	■	■	■	■	■	■	■	■				
Choose method to tune Kp and Ki												■	■	■	■	■	■	■	■	■	■	■	■				
Do simulation and an analysis												■	■	■	■	■	■	■	■	■	■	■	■				
Writing Report			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Presentation PSM 2																						■	■				
Submit final report																									■	■	