ELECTRONIC THROTTLE BODY TUNING USING NON-LINEAR PID CONTROLLER

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in fulfilment of the requirements for the degree of
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DECLARATION

I declare that this project report entitled “Electronic Throttle Body Tuning Using Non-Linear PID Controller” is the result of my own work except as cited in the References

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Date : July 2017

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Automotive).

Signature : ....
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Date : July 2017

DEDICATION

Special dedicate to my wife, father and mother who never stop pray for me and give morale support. This dedication also for my supervisor who never give up to advise, teach and guide me to complete this Final Year Project. Not to forget my friends who always lend a hand during this project and during period of completing the report as well as lecturers and most of all Almighty Allah who gives me good health as well as strength to go through this period. All the effort during this program will be nothing without help from all of you.

ABSTRACT

Electronic throttle body (ETB) is one of the most important components in the gasoline engine system of the vehicle. It serves to regulate the amount of air flow into the engine during the induction stroke with the proper ratio. Even though the ETB have been used in the automobile industry for a long time, there still exist some difficulties in this technology in controlling the electronic throttle valve that causes the air and fuel ratio is not quite right as needed. The difficulties that affecting the ETB performance is attributed from the discontinuous nonlinear of the spring that force the valve plate to return to its original position and also the non-linearity that lies inside the system such as stick-flip friction and gear backlash. In this project, the ETB will be tuned using the Nonlinear Proportional Integral Derivative (PID) controller. ETB model will be built up using Matlab software and then the tuning simulation process of ETB is carried out using conventional PID controller for angle of 30º, 45º, 60º, 75º and 90º. After that, the Nonlinear PID controller will built up and then the tuning process will conduct using the k_P, k_I , and k_D gain from a selected angle as a reference. Finally, the results of tuning simulation using a Nonlinear PID controller will be compared with the conventional PID controller to evaluate its performance.

ABSTRAK

Badan Pendikit Elektronik (ETB) adalah salah satu komponen yang sangat penting di dalam sistem enjin kenderaan petrol masa kini. Ianya berfungsi untuk mengawal jumlah kemasukan udara ke dalam enjin semasa lejang masukan mengikut nisbah udara dan bahanapi yang betul. Walaupun ETB telah digunakan dalam industri automobil untuk masa yang lama, masih terdapat beberapa kesukaran dalam teknologi ini bagi mengawal injap pendikit elektronik yang menyebabkan udara dan nisbah bahan api tidak berapa tepat seperti yang diperlukan. Kesukaran yang menjejaskan prestasi ETB ini berpunca apabila berlakunya ketidaklinearan yang berlaku dari sifat spring yang menyebabkan injap plat ingin kembali kepada kedudukan asalnya, dan juga ketidaklinearan yang terjadi di dalam sistem ETB itu sendiri seperti geseran ‘stick-flip’ dan tindakbalas gear. Dalam projek ini, ETB akan ditala menggunakan Kawalan Proportional Integral Derivative (PID) Tidak Linear. Model ETB akan dibina menggunakan perisian Matlab dan kemudiannya proses simulasi penalaan ETB tersebut dibuat menggunakan kawalan PID konvensional bagi sudut 30º, 45º, 60º, 75º dan 90º. Setelah itu, Kawalan PID Tidak Linear pula dibina dan seterusnya proses penalaan bagi semua sudut tadi dilakukan menggunakan nilai gain k_P, k_I , dan k_D dari sudut yang dipilih sebagai rujukan. Akhir sekali, hasil dari keputusan simulasi penalaan menggunakan kawalan PID Tidak Linear ini akan dibandingkan dengan keputusan simulasi penalaan menggunakan kawalan PID konvensional untuk menilai prestasinya.

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LIST OF ABBEREVATIONS

ETB	Electronic Throttle Body
DC	Direct Current
NPID	Nonlinear Proportional Integral Derivative
PID	Proportional Integral Derivative

CHAPTER 1

INTRODUCTION

1.1 Background

The Electronic Throttle Body (ETB) is a very important component in engine system control the throttle valve opening angle for the purpose to regulate the amount of airflow into the engine meets the desired amount. The opening of the throttle valve is controlled by an electronic computing module (Ahmed AL-Samarraie & Khudhair Abbas, 2012; Bai & Tong, 2014). For modern automobiles, ETB system is one of the important drive by wire systems. The ETB consists of a direct current (DC) motor, a motor pinion gear, an intermediate gear, a selector gear, a valve plate and nonlinear spring (Figure 1 and Figure 2) (Pan, Özguner, & Dağci, 2008).

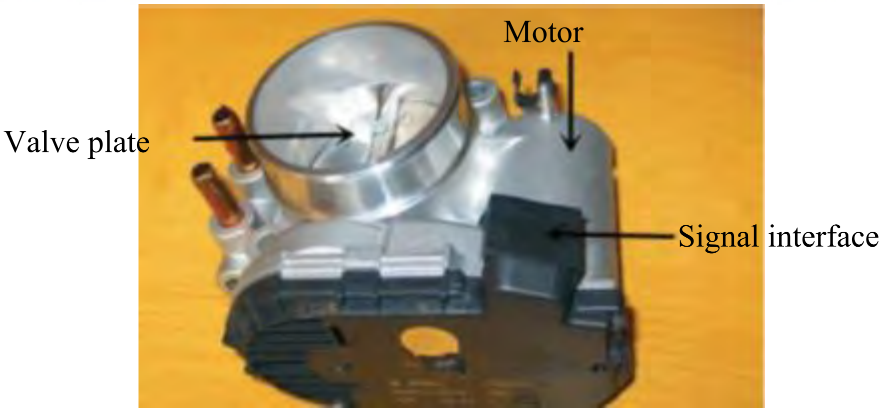


Figure 1.1: External view of ETB.

Figure 1.2: Internal view of ETB.

Traditionally, the throttle plate is connected directly by wire to the accelerator. So the mass air rate controlled according to the driver demand. In this method, many internal and external conditions such as fuel efficiency, road or weather condition to determine the throttle plate angle are ignored. As a result, all this factor will negatively affect to the overall efficiency of the engine (Mercorelli, 2009).

To determine accurately the throttle valve opening angle, an electronic control module (ECM) is used to overcome the above deficiency. Electrical wire or fiber optic cable is used to transmit the gas pedal and the measured signal to the central processing unit. It determines the optimum reference opening angle and send the signal to the ETB to let the valve plate follow the signal by using a proper controller (Bai & Tong, 2014) ("4. Delphi_Drive_by_wire_2000-01-0556," n.d.).

By using the ETB, there are some problem occur in this system which make the controller design difficult. There are non-smooth nonlinearities including stick-slip friction, gear backlash, and a nonlinear spring. Furthermore, the controller design becomes more difficult because most of control algorithms assume that the uncertainty is smooth and/or satisfies the matching condition, while as the parameters of these non-smooth nonlinearities cannot be known accurately, the non-smooth and also unmatched parameter uncertainties inherently exist (Pan et al., 2008) (Di Bernardo, Di Gaeta, Montanaro, & Santini, 2010).

By using a back-stepping approach, proportional integral derivative (PID) controller is designed for matching uncertain systems and may be implemented in an unmatched uncertain system (Pan et al. 2008). It is designed for the electronic throttle valve with the back-stepping approach together with the feedback linearization technique (Ahmed AL-Samarraie & Khudhair Abbas, 2012). The purpose of proportional integral derivative (PID) controller is to ensure the valve plate follows the reference signal using continuous-time sliding mode concept by deriving a controller with an observer. It is capable of coping with the uncertainties in the mathematical model non-smooth nonlinearities, which exist in the control region and some unmodeled mechanical phenomena, as a reason to select this method (Ahmed AL-Samarraie & Khudhair Abbas, 2012; Pan et al., 2008). The designed time-optimal controller achieves considerably faster transient, while preserving other important performance measures, like the absence of overshoot and static accuracy within the measurement resolution (Ahmed AL-Samarraie & Khudhair Abbas, 2012).

1.2 Problem Statement

Since the ETB consists of a direct current (DC) motor, a motor pinion gear, an intermediate gear, a selector gear, a valve plate and nonlinear spring, there exist multiple non-smooth nonlinearities including stick–slip friction, gear backlash, and a nonlinear spring, which make controller design difficult (Ahmed AL-Samarraie & Khudhair Abbas, 2012; Pan et al., 2008).

Due to the mechanical part moving in the ETB, certainly friction will occur. Friction is the motion resistance of the moving object relative to another. In ETB, it is a nonlinear phenomenon in which a force that produced by the resistance tends to oppose the motion of throttle plate such as coulomb, static, viscous, stribeck, etc. (Pan et al., 2008) (Conatser, Wagner, Ganta, & Walker, 2004). In this concept, static friction phenomena only have a static dependency on velocity and the coulomb friction is considered.

The typical feature of the electronic throttle valve includes a stiff spring, which is used as a fail-safe mechanism. When no power is applied, this spring act as a force to push the valve plate to return to the position slightly above the closed position, so that the small amount of air can be supplied into the engine in order to prevent a sudden lock of engine revolution while the vehicle is in motion when no control is available (Jiao & Shen, 2012). Moreover, the motion of the valve plate is limited between the maximum and minimum angles. These limited stops are realized by a highly stiff spring, ideally with infinite gain.

Due to the clearance formed between a pair of mounted gears, there exists backlash between gears where the gear backlash is another nonlinearity source in addition to friction and the non-linear spring.

All this factor affected to reach an ideal air fuel ratio (stoichiometric about 14.7:1) required by the engine especially when the drastically change to the velocity of the vehicle required by the driver. Therefore, the ETB which is controlled by the electronic control module need to do the tuning to achieve the desired throttle valve angle.

1.3 Objective

The objectives of this project are as follows:

1. To develop an ETB model in MATLAB software.
2. To design a Nonlinear PID controller to obtain the desire throttle angle.
3. To compare the result with conventional PID.

1.4 Scope of Project

The scopes of this project are:

1. Study about ETB especially the parameter and its function. Also, study the problem that occurs in this system to achieve the desire throttle angle.
2. This project only focuses on tuning simulation.
3. Perform the simulation by using MATLAB software.
4. Model the ETB provide by (Pan et al., 2008) using MATLAB Simulink application.
5. Apply the model of non-linear PID controller by using MATLAB Simulink
6. Compare the result of conventional PID with the non-linear PID controller.
7. Conduct the various simulations for the different throttle opening angle such as 30º, 45º, 60º, 75º and 90º.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes the previous well-known experimental and tuning method that has been performed in the field of electronic throttle body. However, some important explanation of this project will be explained first. A method for tuning electronic throttle body will describe in this chapter.

2.2 Electronic Throttle Body (ETB)

Now a day, throttle body system is no longer a foreign component in the automotive industry, but its use has become very popular and widespread. Electronic throttle body necessitates the use of an electric actuator motor because there is no mechanical linkage between the accelerator pedal and the throttle body. There are several reasons why electronic throttle actuation is preferable to a conventional throttle cable:

a. The electronic systems are able to control all of the engine's operation with the exception of the amount of incoming air.

b. Only the correct amount of throttle opening will receive by the engine for any given situation which ensured by using throttle actuation.

c. The harmful exhaust emissions are kept to an absolute minimum and drivability is maintained and ensured by the optimization of the air supply. Finer control can be achieved because coupling the electronic throttle actuation to the adaptive cruise control, traction control, idle speed control and vehicle stability control systems. ("Automotive Applications of Sliding Mode," n.d.)

The use of such a system has advantages over the conventional cable version by:

a. Make the system become simpler by reducing the number of moving parts by eliminating the mechanical element of a throttle cable and using with fast responding electronics. It requires minimum adjustment and maintenance.

b. Provides better response and economy because of the greater accuracy of data improves the drive ability of the vehicle (Goodwin, Graebe, & Salgado, n.d.).

However, by using the electronic throttle body, there are some problem occur in this system which make the controller design difficult. There are non-smooth nonlinearities including stick-slip friction, gear backlash, and a nonlinear spring. Furthermore, the controller design becomes more difficult because most of control algorithms assume that the uncertainty is smooth and/or satisfies the matching condition, while as the parameters of these non-smooth nonlinearities cannot be known accurately, the non-smooth and also unmatched parameter uncertainties inherently exist. (Conatser et al., 2004). A typical configuration of an ETB is shown in Figure 2.1.

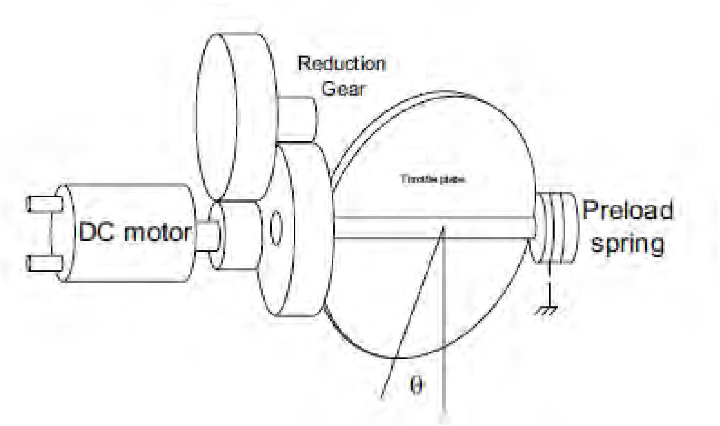


Figure 2.1: Electronic Throttle Body Schematic.

2.3 Nonlinearities

The nonlinearities, such as friction, nonlinear spring and gear backlash involved in the electronic throttle body system make the controlling of opening throttle valve angle and to realize a highly robust controller against uncertainties become difficult (Araki, n.d.), (Pan et al., 2008).

2.3.1 Friction

Friction is the motion resistance of the moving object relative to another. It is a nonlinear phenomenon in which a force that produced is tends to oppose the motion of throttle plate such as coulomb, static, viscous, stribeck, etc. Only the coulomb friction is considered in this work. Static friction phenomena only have a static dependency on velocity (Al-samarraie, 2012). The Coulomb friction model is demonstrated in the Figure 2.2 below.

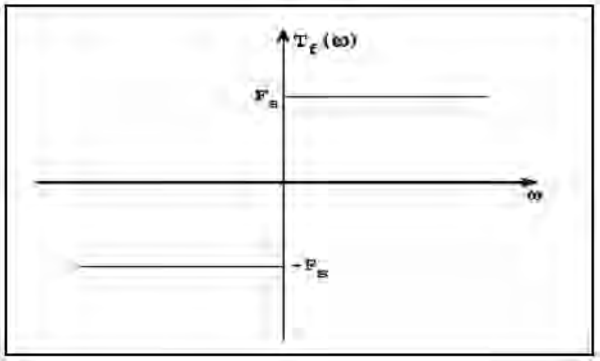


Figure 2.2: Coulomb friction.

Consequently, the Coulomb friction model mathematically is given by

$$T_f(\omega) = \begin{cases} F_{s,} & \omega > 0 \\ 0, & \omega = 0 \\ -F_{s,} & \omega < 0 \end{cases}$$

$$= F_{s,}\,\mathrm{sgn}(\omega) \qquad - \qquad (1)$$

where $F_{s,}$: is a positive constant (Ahmed AL-Samarraie & Khudhair Abbas, 2012).

2.3.2 Nonlinear Spring

Electronic throttle body component typically includes a stiff spring, which is used as a fail-safe mechanism. The purpose of this spring is to force the valve plate to return to the position slightly above the closed position when no power is applied. So that, when no control is available while the vehicle is in motion, the small amount of air can be supplied into the engine to prevent a sudden lock of engine revolution. Moreover, the motion of the valve plate is limited between the maximum and minimum angles. These limited stops are realized by a highly stiff spring, ideally with infinite gain. (Ma, Shao, & Yurkovich, 2005). The characteristic of the modelled spring is shown in Figure 3.3.

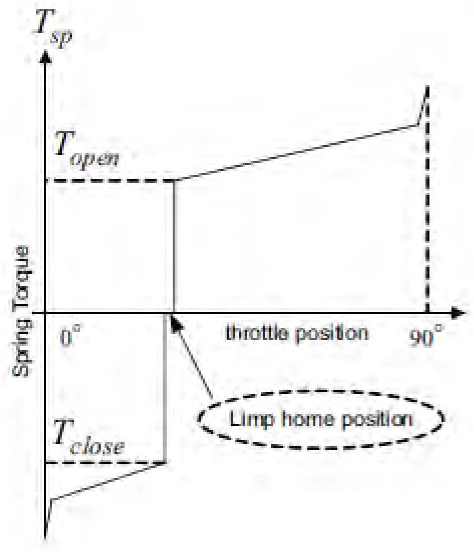


Figure 2.3: Nonlinear spring.

2.3.3 Gear Backlash

In addition to friction and the nonlinear spring, the gear backlash is another nonlinearity source due to the clearance formed between a pair of mounted gears. The error in profile, pitch, tooth thickness, helix angle, and canter distance, and run-out is the factors that affecting the amount backlash needs in the gear transmission system. The greater the accuracy the smaller the backlash needed. The way to reduce the gear backlash is by increasing the centre distances between the gears (Circle, n.d.). The gear backlash between two gear shown in figure 2.4. When writing the throttle valve mathematical model the nonlinearity coming from backlash phenomenon is ignored in this work. (Buckbee & Buckbee, 2009).

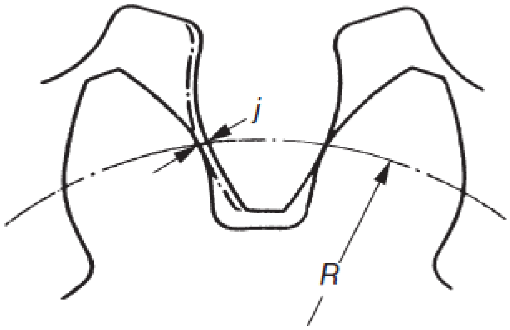


Figure 2.4: Gear backlash (j) between two gear.

The gear backlash is expressed as $y = f\mathrm{bl}\ (x, \delta)$; where x and y are the input and output torques, respectively, and δ is the dead bandwidth (Jiao & Shen, 2012).

2.4 Proportional Integral Derivative (PID) Controller

Proportional-Integral-Derivative (PID) control is the most common and popular control algorithm used in industry and has been universally accepted in industrial control. It is a very popular because allows engineers to operate them in a simple, straightforward manner and can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity (Goodwin et al., n.d.).

For the system that uses the PID controller as the main tool, PID control is the method of feedback control (Araki, n.d.). The block diagram of conventional feedback control system is shown as in figure 2.5. To get a very close particular value as an ideal value, PID is a very suitable to use because PID loop is a mathematical formula used to drive a process variable toward a particular value (the set point) by controlling an output. Most PIDs require tuning to maximize effectiveness, even though PID calculations are complex. To stabilize the system and increase efficiency, real-time changes to gain have to do, integral, and derivative values as necessary (Graebe, 2002).

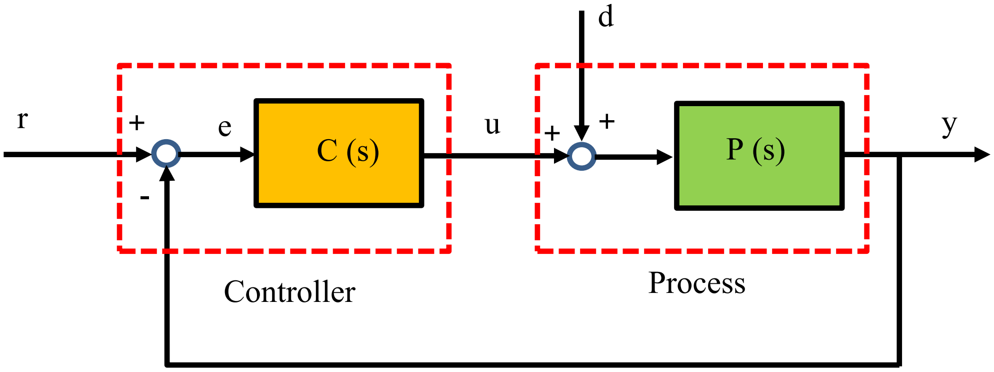


Figure 2.5: Conventional feedback control system.

In summary, it summing those three components to compute the output where PID controller is to read a sensor, then compute the desired actuator output by calculating proportional, integral, and derivative responses (Barić, Petrović, & Perić, 2005).

2.4.1 Proportional Response

The difference between the set point and the process variable will produce the proportional component which is directly depends on it. This difference is referred to as the Error term. The ratio of output response to the error signal is determined by the proportional gain (Kc). The speed of the control system response can be increased by increasing the proportional gain. However, the process variable will begin to oscillate if the proportional gain is too large. The oscillations will become larger and the system will become unstable and then even oscillate out of control if Kc is increased too much further (Araki, n.d.), (Buckbee & Buckbee, 2009).

2.4.2 Integral Response

The integral component sums the error term over time. The integral component will increase slowly even that result is a small error term. The effect of integral response is to drive the Steady-State error to zero when it continued increase over time unless the error is zero. The final difference between the process variable and set point is known as Steady-State error.

If the controller not driving the error signal toward zero when the integral action saturates a controller, integral windup results will occur (Gain, n.d.).

2.4.3 Derivative Response

If the process variable is increasing rapidly, the derivative component causes the output to decrease. The rate of change of the process variable is proportional to the derivative response. The speed of the overall control system response will increase when the control system reacts more strongly to changes in the error term by increasing the derivative time (T_d) parameter. Because the Derivative Response is highly sensitive to noise in the process variable signal, very small derivative time (T_d) is used to make the control systems more practical. The derivative response can make the control system unstable if the sensor feedback signal is noisy or if the control loop rate is too slow (Goodwin et al., n.d.).

2.4.4 Closed Loop System

The process variable is the process where system parameter that needs to be controlled, such as temperature (ºC), pressure (kPa), or flow rate (ltr/min) and etc. In this process, the desire or command value is the set point, and to get feedback to the control system are by using a sensor to measure the process variable. To determine the desired actuator output to drive the system, the control system algorithm uses the difference between the process variable and the set point. Closed loop control system is a process of reading sensors to provide constant feedback and calculating the desired actuator output is repeated continuously and at a fixed loop rate. Block diagram of a typical closed loop system is shown in figure 3.1 (Mhaskar, El-farra, & Christofides, 2004).

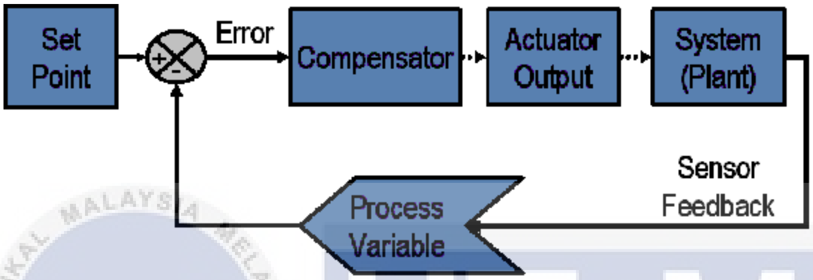


Figure 2.6: Block diagram of a typical closed loop system.

2.5 Non-Linear PID Controller

In this section, nonlinear structure was proposed by (Abdullah et al., 2015); (Su, Sun, & Duan, 2005) as known PID controller. A nonlinear PID controller will be used later in the throttle valve system where replacing the integral of the error function by an integral for the arc tan function to the error in the PID controller yields a nonlinear PID controller. The control action will force the state to follow the desired reference when the linear PID controller is adequate during the disturbance is constantly acting on the system dynamics. But, the linear PID will be able only to attenuate the disturbance effect with a linear integral control term when the disturbance term is not constant.

2.5.1 Electronic Throttle Body (ETB) Model

The model of electronic throttle control valve (Al-samarraie, 2012), (Pan et al., 2008) without backlash is developed where the rotor angular velocity is defined as ϖ and the valve plate position is defined as θ. The total inertia and total damping coefficient are respectively determined by (Pan et al., 2008),(Ahmed AL-Samarraie & Khudhair Abbas, 2012)

$$J_{tot} = J_m + K^2{}_{g1}J_{int} + (K_{g1}K_{g2})^2(J_{ps} + J_{sect})$$

$$B_{tot} = B_m + K^2{}_{g1}B_{int} + (K_{g1}K_{g2})^2 B_{ps} \qquad - \qquad (2)$$

Considering the friction and nonlinear spring torque, the dynamic equation is obtained as (Al-samarraie, 2012)

$$J_{tot}\dot{\varpi} = -B_{tot}\,\varpi - T_f\,(\varpi) - T_{sp}(\theta) + K_t\,z \qquad - \qquad (3)$$

Where z is the current through the dc motor windings. The relationship between the valve plate position and the rotor angular velocity is described by the following:

$$\dot{\theta} = (K_{g1}K_{g2})\varpi \qquad - \qquad (4)$$

As a result, including motor electrical part, the model of the electronic throttle body is given by

$$\dot{\theta} = (K_{g1}K_{g2})\varpi$$

$$\dot{\varpi} = -\frac{B_{tot}}{J_{tot}}\varpi - \frac{1}{J_{tot}}\, T_f\,(\varpi) - \frac{1}{J_{tot}}\, T_{sp}\,(\theta) + \frac{K_t}{J_{tot}}\mathrm{z}$$

$$\dot{z} = -\frac{K_v}{L}\varpi - \frac{R}{L}z + \frac{1}{L}\mathrm{u} \qquad - \qquad (5)$$

Where u is the input voltage to the dc motor.

The nonlinear function $T_f\,(\varpi)$ and $T_f\,(\theta)$ can be described with the signum function as

$$T_f\,(\varpi) = F_s sgn(\varpi) \qquad - \qquad (6)$$

$$T_{sp}\,(\theta) = \begin{cases} D + m_i\,(\theta - m_0), & \text{if } \theta_0 < \theta < \theta_{max} \\ -D - m_i\,(m_0 - \theta), & \text{if } \theta_{min} < \theta < \theta_0 \end{cases}$$

$$= m_i\,(\theta - \theta_0) + D\mathrm{sgn}\,(\theta - \theta_0) \qquad - \qquad (7)$$

Then, letting $x_1 = \theta$ and $x_2 = (K_{g1}K_{g2})\varpi$, the aforementioned dynamic equations can be simplified as

$$\dot{x}_1 = x_2 \qquad - \qquad (8)$$

$$\dot{x}_2 = a_{21}\,(x_1 - x_{10}) + a_{22}\,x_2 + a_{23}\,z - \mu\mathrm{sgn}(x_2) - \mathrm{ksgn}(x_1 - x_{10}) \qquad - \qquad (9)$$

$$\dot{z} = a_{32}\,x_2 + a_{33}\,z + b_3\,u \qquad - \qquad (10)$$

Where,

$a_{21} = K_{g1}K_{g2}m_1/J_{tot}$ $\quad\quad a_{22} = B_{tot}/J_{tot}$

$a_{23} = K_{g1}K_{g2}K_t/J_{tot}$ $\quad\quad a_{32} = -K_v/(LK_{g1}/K_{g2})$

$a_{33} = -R/L$ $\quad\quad b_3 = 1/L$

$\mu = K_{g1}K_{g2}F_s/J_{tot}$ $\quad\quad k = K_{g1}K_{g2}D/J_{tot}$

The Table 3.1 shows the normal values of parameters in equation (7). The control task is to let the valve plate track a smooth reference signal θ_r(t).

Table 2.1: Parameter value for simplified model

Parameter Names	Parameter Values
a_{12}	1/18
a_{21}	-1.6e3
a_{22}	-32.9
a_{23}	4.2e3
a_{32}	-11.6
a_{33}	-5.2e2
b_3	4.7e2
k	4.6
μ	2.1

2.5.2 Non-Linear PID Controller Model

The proposed nonlinear PID controller is taken from (Abdullah et al., 2015); (Su et al., 2005) that deals with the nonlinear difficulties. The parameters of the linear PID controller are obtained based on previous work and used for nonlinear systems. The automatic gain adjustment, k(e) is act as a nonlinear function of error, e(t) that is bounded in the sector $0 \leqslant k(e) \leqslant K_{max}$ as indicated in equation (11). This is identified as the range of options available for the nonlinear gain, k(e). The output produced from this nonlinear function is known as a scaled error and can be expressed as equation (12). Subsequently, the whole equation of the Nonlinear PID controller can be written as in equation (13).

$$k(e) = \frac{\exp(\alpha e) + \exp(-\alpha e)}{2} \qquad - \qquad (11)$$

$$e = \begin{cases} e & |e| \le e_{\max} \\ e_{\max}\operatorname{sign}(e) & |e| > e_{\max} \end{cases}$$

$$f(e) = k(e) \cdot e(t) \qquad - \qquad (12)$$

$$f(e) \cdot u_{PID} = k_p[k(e) \cdot e(t)] + \frac{k_p}{T}\int_0^t [k(e) \cdot e(t)]dt + K_p T_d \frac{d}{dt}[k(e) \cdot e(t)] \qquad - \qquad (13)$$

As in equation (13), e_{max} is a range of variation, while α, is represent the rate of variation of nonlinear gain. Figure 2.7 illustrate the variation of *k(e)* with respect to the error changes due to these selected values. It can be concluded that be seen that when the error, *e*= 0, the value of nonlinear gain, *k*(e) is equal to 1. In this situation, the controller seems to function as a conventional PID controller. That means, when there is the presence of errors, the automatic nonlinear gain will act immediately.

When designing the controller, one of the essential criterion that need to consider is stability. The variety of the gain *k(e)* as given in equation (11) should be chosen in the acceptable range in order to retain the stability of the system. The selection of the appropriate value of α and e_{max} should be taken into account especially when the load is added to the system in order to ensure that it can be achieved (Su et al., 2005).

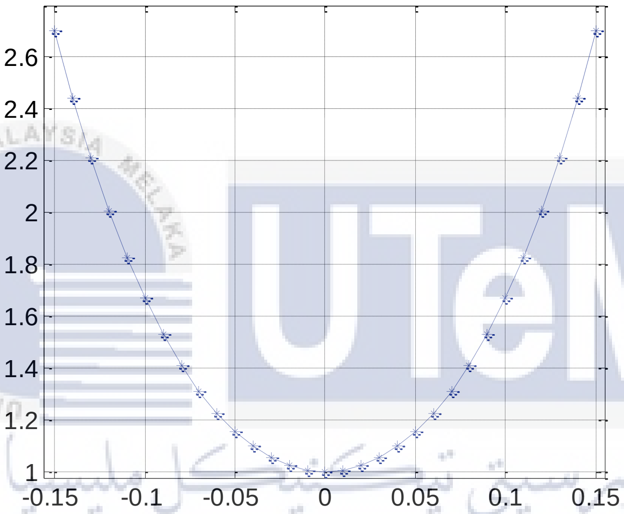


Figure 2.7: Relationship between various nonlinear gain and error

2.6 Sensitivity Analysis

A sensitivity analysis is method the used to find how vary value of an independent variable impact a particular dependent variable under a set of assumption. This method is used within a certain rule that depend on one or more input variable. So, in field of control engineering, the sensitivity analysis can be used in tuning a PID controller.

Sensitivity analysis is one of the offline ways to tune the PID. The sensitivity analysis starts by taking an initial condition. For an example, the PID value is set as 1, 0 and 0 respectively. Then, takes the Proportional Gain, K_P as the variable and fixed the value of K_i and K_d. After that, run the simulation to find out the error between the desire and the actual value. The least value of error will be the K_P for the next step.

So, for the next step is the value of K_i will be the variable and K_P and K_d will be the fixed. Run the simulation to find the least value of error and then the value of K_i can be determining. The steps for determine the K_d also same with the previous steps. After the three value P, I and D have been found, it will be the ideal condition for the PID controller.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the method used to make tuning on the ETB by using Nonlinear PID Controller. Nonlinear PID Controller methods are selected because it has a simple functionality and highly robust controller performance against uncertainties in the ETB's mathematic model with limited cost (Abdullah et al., 2015); (Ankur & Savani, 2014), (Su et al., 2005). It is proposed to the trajectory tracking of a throttle valve opening system. To produce a fast response, nonlinear gain is employed to this technique in order to avoid overshoot especially when relatively large gain is used. This tuning method is workable because it can vary automatically either increase or decrease depends on the error generated at each instant (Su et al., 2005). The performance of the proposed controller is evaluated by performing some experiments on the throttle valve setup. In most cases, the controller work rather well and meets the performance specification needs.

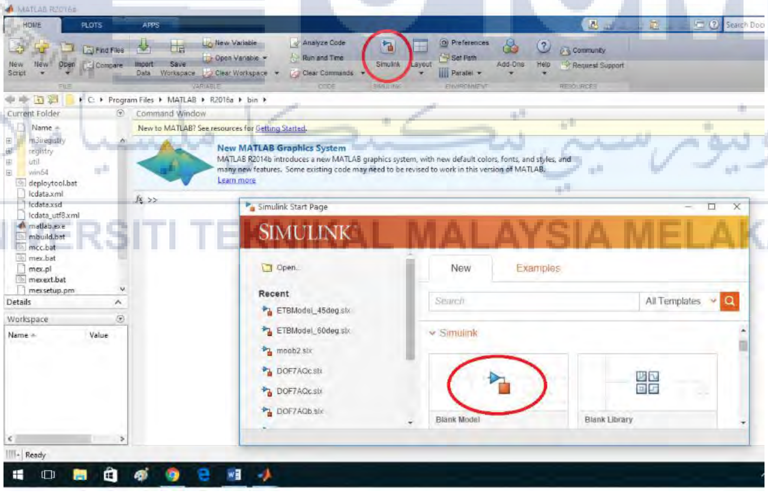
In this Chapter, present an analysis of PID parameter in mathematical simulator software for second order closed loop system and discusses them. The simulation result is demonstrated the performance analysis and its significance in the closed loop system.

3.2 ETB Model

Before doing the experiment, ETB must be established. In this experiment, the mathematic model is not derived from zero, but the mathematic model used is taken from the mathematic model which is used by (Al-samarraie, 2012); (Pan et al., 2008) in their experiment.

From the mathematic, ETB will be constructed by using MATLAB software. The MATLAB software has been used is R2016a version. The procedure to build up the ETB model is as follows:

1) MATLAB software has been run and Simulink Library has been clicked to open Simulink as shown in Figure 3.2.



New to MATLAB? See resources for Getting Started.

New MATLAB Graphics System

MATLAB R2014b introduces a new MATLAB graphics system, with new default colors, fonts, and styles, and many new features. Some existing code may need to be revised to work in this version of MATLAB.

Learn more

`>>`

Figure 3.1: Open Simulink window

2) New Model icon has been click to create a new Simulink model as shown in Figure 3.2.

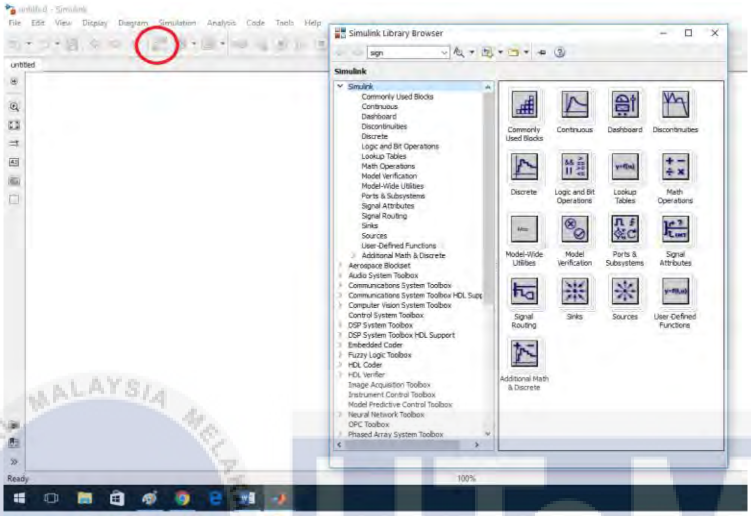


Figure 3.2: Open Simulink Library Browser window

3) Inside Simulink Library Browser window, select the desired Simulink block by referred the mathematic model in equation (9), hold and drag the window into the new model.

4) Draw line, connect all Simulink blocks that have been selected and then label the line and Simulink block with the correct label.

5) Resize the Simulink block to display the Simulink block parameter.

6) Insert the appropriate Simulink block parameter as in Table 1 by double clicking the Simulink block. ETB model which has been completed is shown in Figure 3.3.

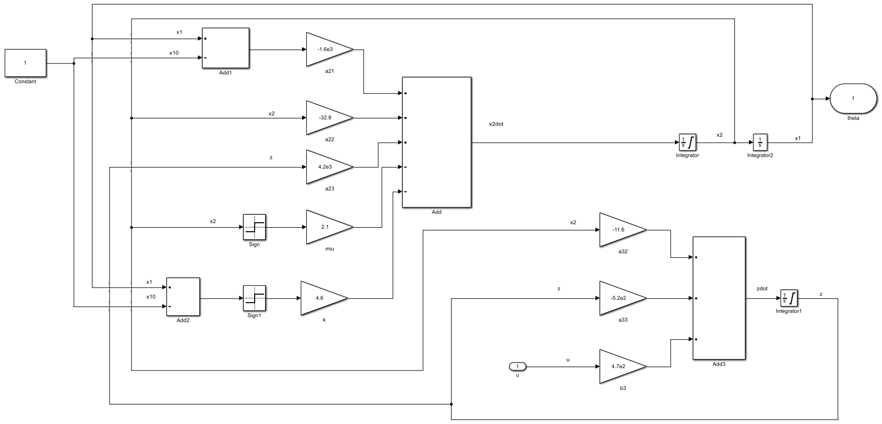


Figure 3.3: ETB model

7) Select all the ETB model block and create the subsystem by clicking the Diagram – Subsystem & Model Reference – Create Subsystem from selection. The ETB model subsystem is shown in Figure 3.4.

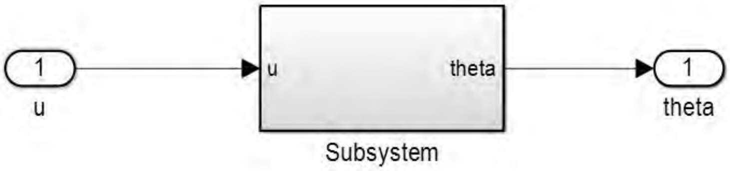


Figure 3.4: ETB subsystem model

8) Enter the appropriate Simulink blocks (Step block, Display block, RMS block, Workspace block and PID block) and connect it to the ETB subsystem as shown in Figure 3.5 below.

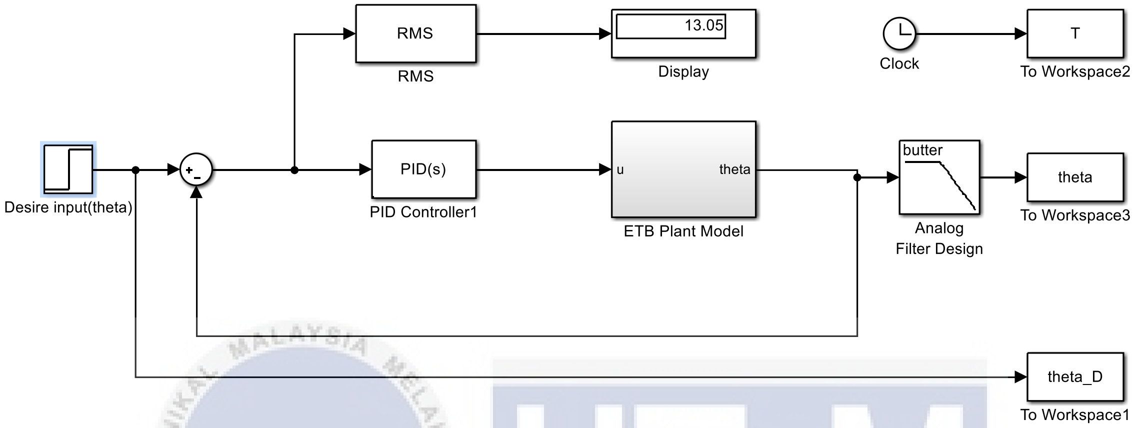
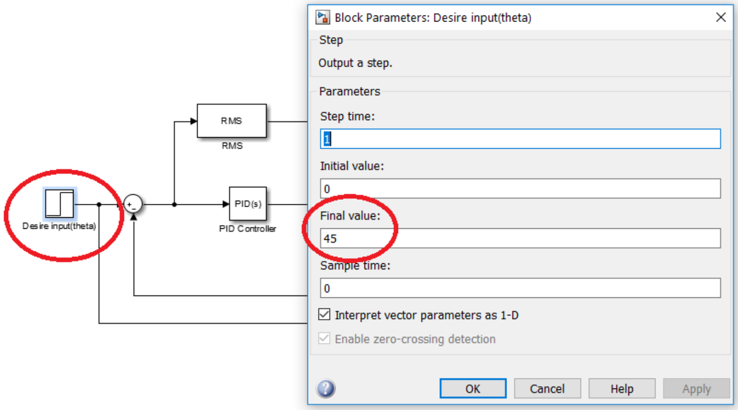


Figure 3.5: Tuning ETB model using PID controller.

3.3 Tuning the ETB Using PID Controller

After ETB using PID controller tuning model is set up, the next tuning process simulation can be conducted. However, the value of desire throttle opening angle must be set in this ETB model. In this simulation, desire angle set is 45º. The tuning process are as follows:

a. Double click the Desire Input block, the insert 45 in Final Value inside block parameter as shown in Figure 3.6.



Block Parameters: Desire input(theta)

Step

Output a step.

Parameters

Step time: 1

Initial value: 0

Final value: 45

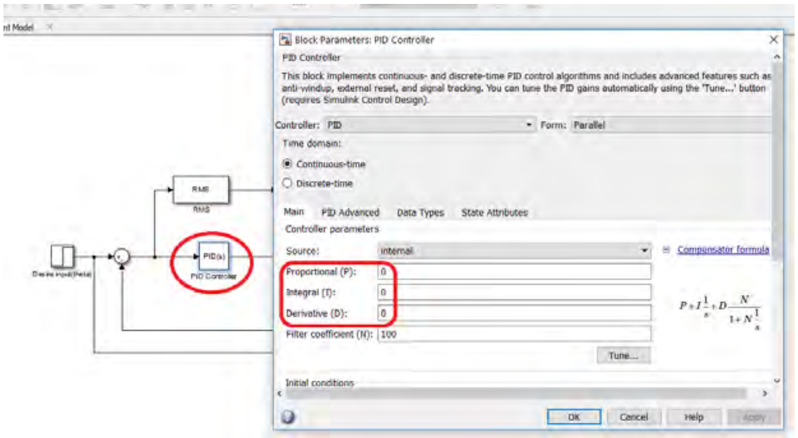
Sample time: 0

☑ Interpret vector parameters as 1-D

☑ Enable zero-crossing detection

Figure 3.6: Insert the final value inside block parameter

b. Double click the PID block and let $k_P = 1$, $k_I = 0$ and $k_D = 0$ (as shown in Figure 3.7), then run the simulation and plot the graph (Figure 3.8). The blue line indicates the desired ETB valve opening angle while the red line is the actual ETB valve opening angle that needs tuning to get the same angle as desired. In this controller tuning, the stability and fast response is needed (Gain, n.d.).



Block Parameters: PID Controller

PID Controller

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' button (requires Simulink Control Design).

Controller: PID

Form: Parallel

Time domain:

● Continuous-time

○ Discrete-time

Main | PID Advanced | Data Types | State Attributes

Controller parameters

Source: internal

Proportional (P): 0

Integral (I): 0

Derivative (D): 0

Filter coefficient (N): 100

$P+I\frac{1}{s}+D\frac{N}{1+N\frac{1}{s}}$

Initial conditions

Figure 3.7: Insert the k_P, k_I and k_D value.

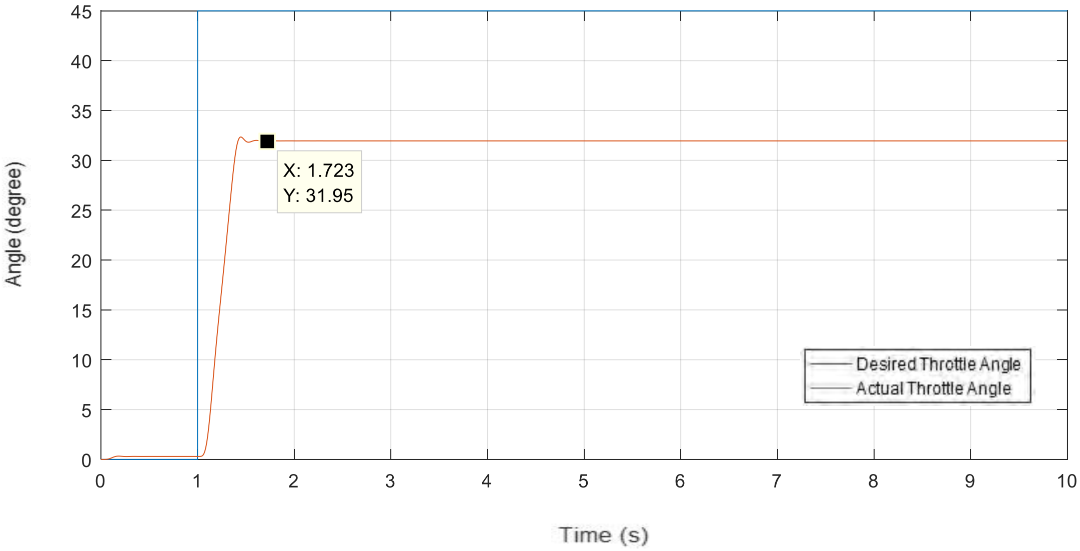


Figure 3.8: Graph of tuning ETB valve opening angle when k_P = 1, k_I = 0 and k_D = 0.

c. Due to differences between the desired angle and actual angle is too large, insert k_P value in multiple of 10 ranging from 10 up 50. If there still have a big difference angle, insert with a great value in multiple of 50 until almost reach the desired angle. Let k_I and k_D = 0.

d. The graph is when k_P = 250, k_I = 0 and k_D = 0 (Figure 3.9a and Figure 3.9b) and k_P = 300, k_I = 0 and k_D = 0 (Figure 3.10a and Figure 3.10b).

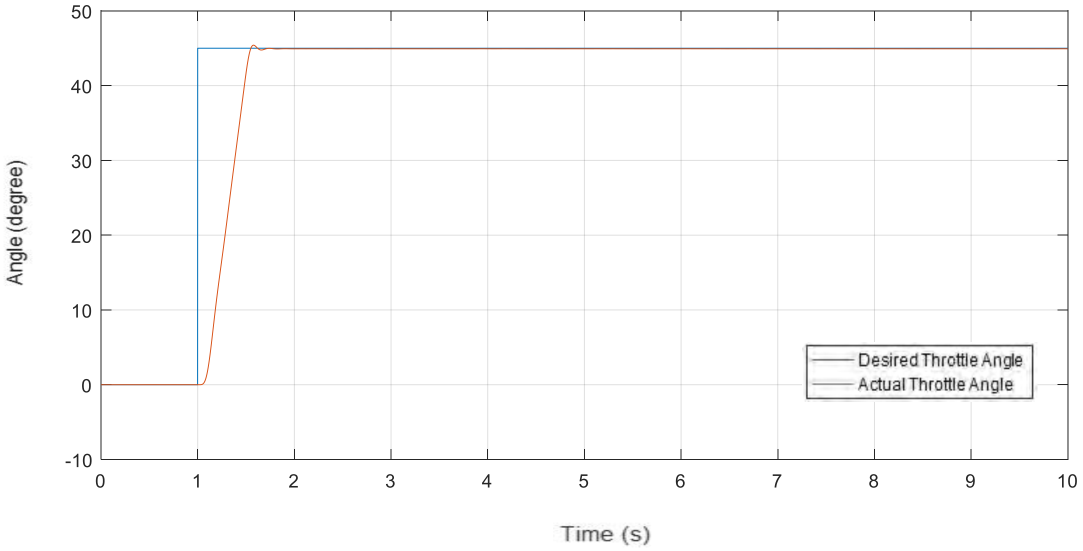


Figure 3.9a: Graph of tuning ETB valve opening angle when k_P = 250, k_I = 0 and k_D = 0.

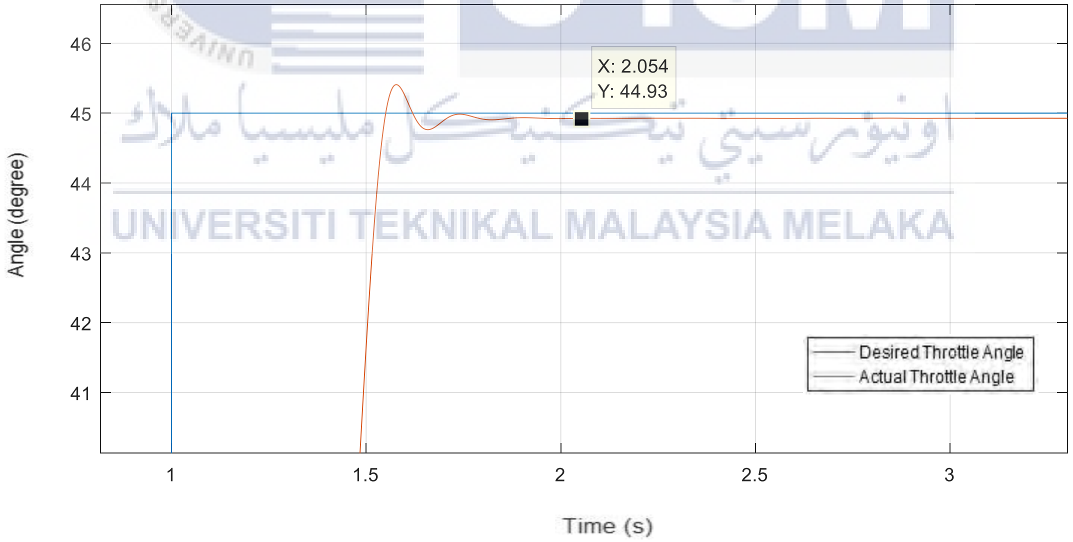


Figure 3.9b: Actual ETB valve opening angle almost reach the desired opening angle.

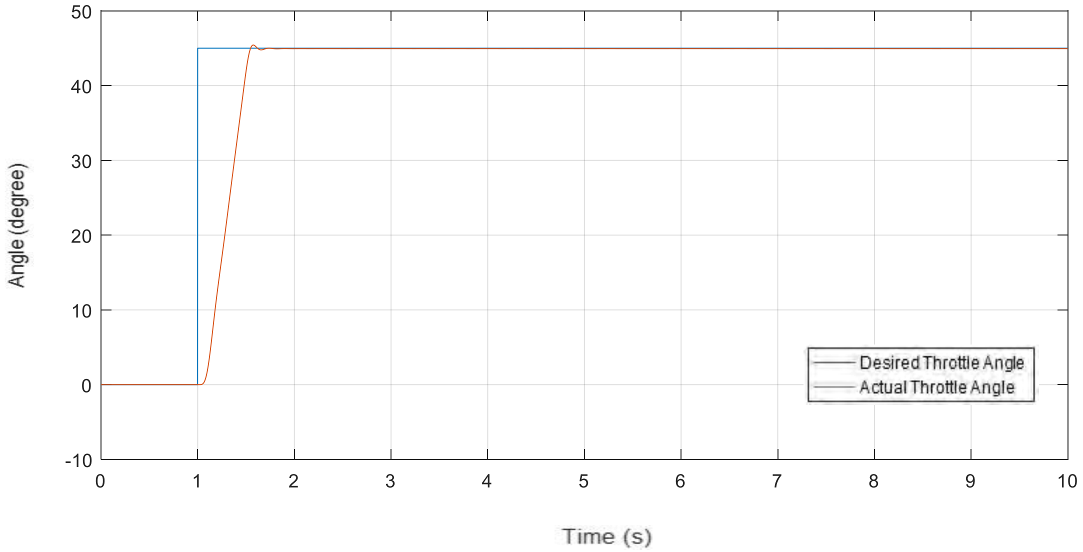


Figure 3.10a: Graph of tuning ETB valve opening angle when k_P = 300, k_I = 0 and k_D = 0.

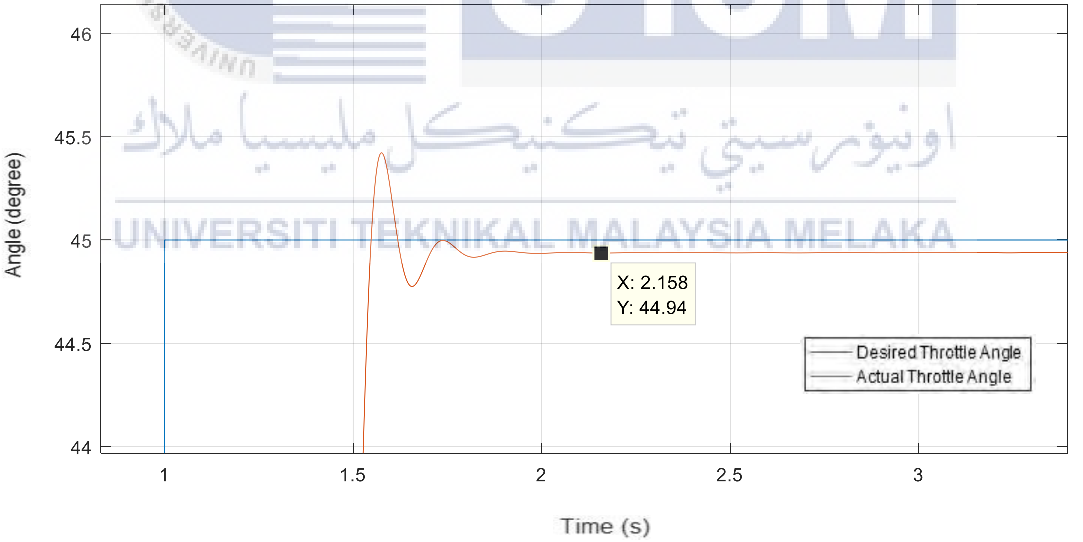


Figure 3.10b: Actual ETB valve opening angle bigger than the desired opening angle.

e. Fixed the value of $k_P = 250$ and let the value of $k_I = 0$, insert k_d value in multiple of 5 until get the actual ETB opening angle line is stable (Figure 3.11a and Figure 3.11b.).

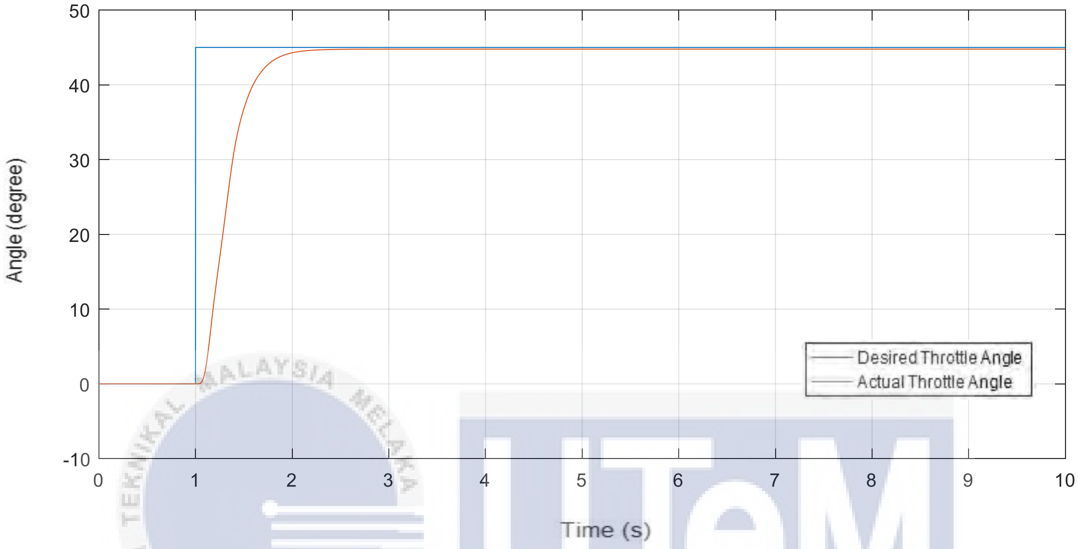


Figure 3.11a: Graph of tuning ETB valve opening angle when $k_P = 250$, $k_I = 0$ and $k_D = 40$.

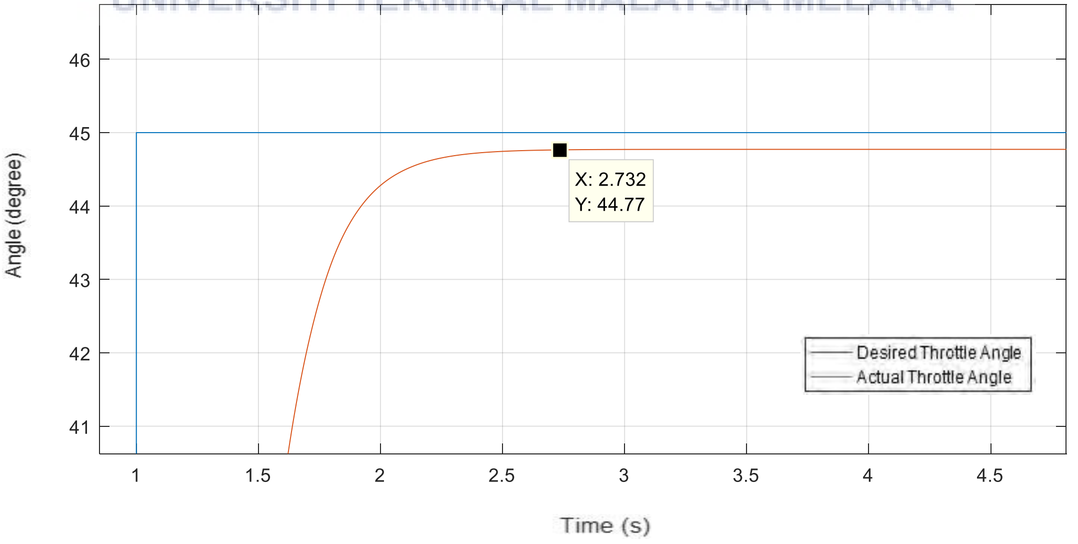


Figure 3.11b: Line of actual ETB valve opening angle has been stable.

f. After getting the stable graph, fixed the value of $k_P = 250$ and $k_D = 40$, try insert the value of k_I from 1 to 10 and determine what value that can make the actual ETB valve opening angle reach as desired opening angle as in Figure 3.12a and Figure 3.12b. After that, insert that value of k_I with plus one decimal place as in Figure 3.13.

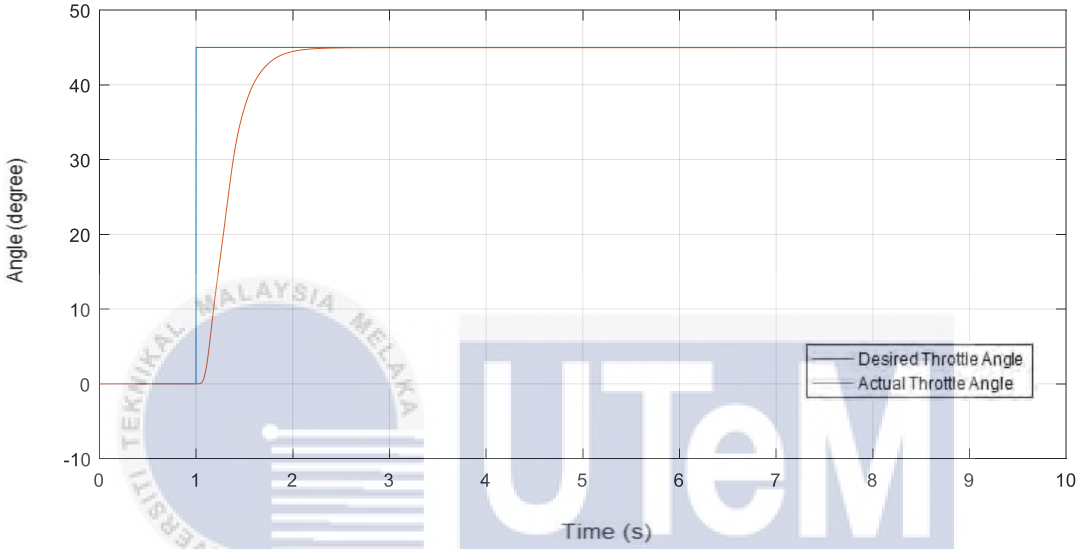


Figure 3.12a: Graph of tuning ETB valve opening angle when $k_P = 250$, $k_I = 4$ and $k_D = 40$.

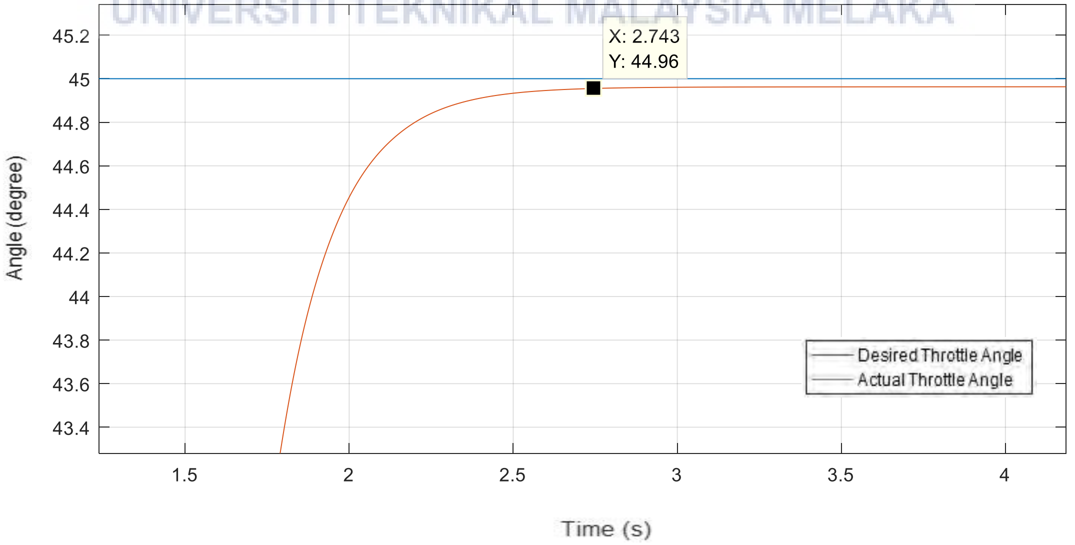


Figure 3.12b: ETB valve opening angle near the desired opening angle.

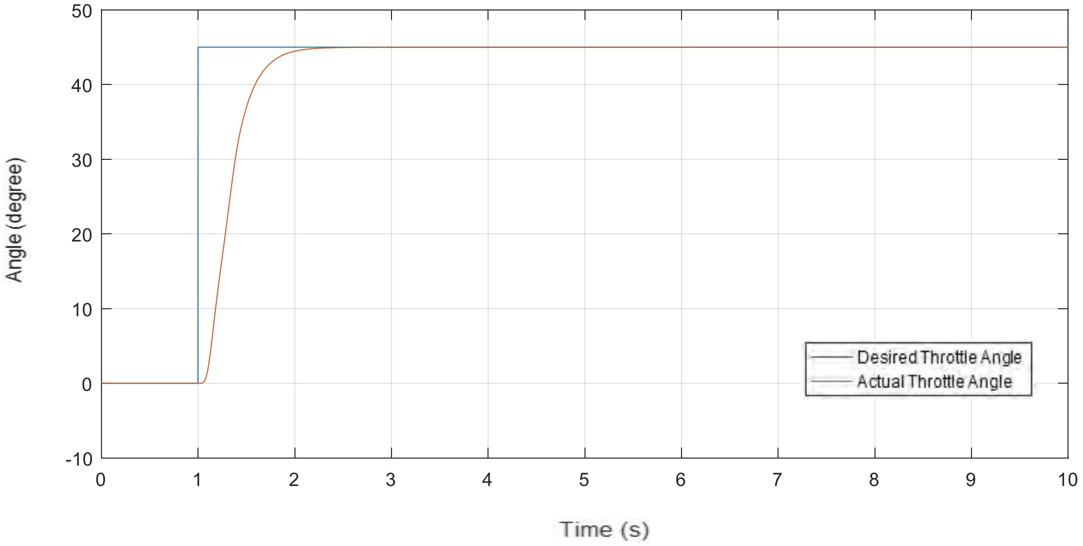


Figure 3.13a: Actual ETB valve opening angle graph when k_P = 250, k_I = 4.8 and k_D = 40.

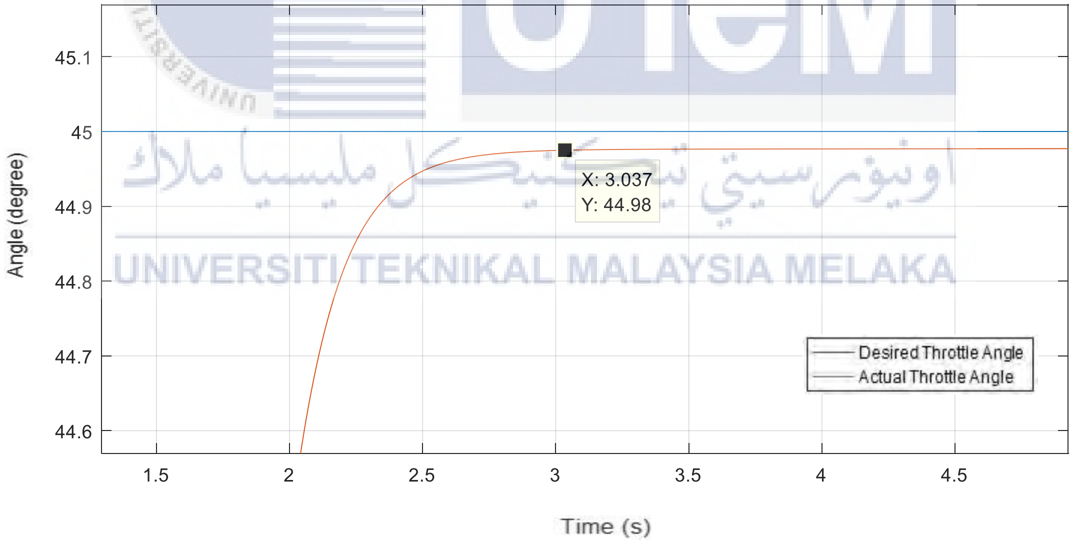


Figure 3.13b: Actual ETB valve opening angle almost same as the desired opening angle.

g. Repeat the same process for tuning another desired angle for 30º, 60º, 75º and 90º with the suitable value of k_P, k_I and k_D.

3.4 Nonlinear PID Controller

The proposed nonlinear PID controller is taken from (Abdullah et al., 2015), (Su et al., 2005) where the model is designed by follow the equation (11) to (13). The parameters of the linear PID controller are obtained based on previous work, where take the value of k_P, k_I and k_D for tuning the conventional PID controller for 45º. The automatic gain adjustment, *k(e)* is act as a nonlinear function of error, *e(t)* that is bounded in the sector $0 \leq k(e) \leq K_{max}$ as shown in Figure 3.14 and Figure 3.15. The Nonlinear PID controller where consists of a sector bounded nonlinear gain *k(e)* which is combined with PID controller, as shown in Figure 3.16.

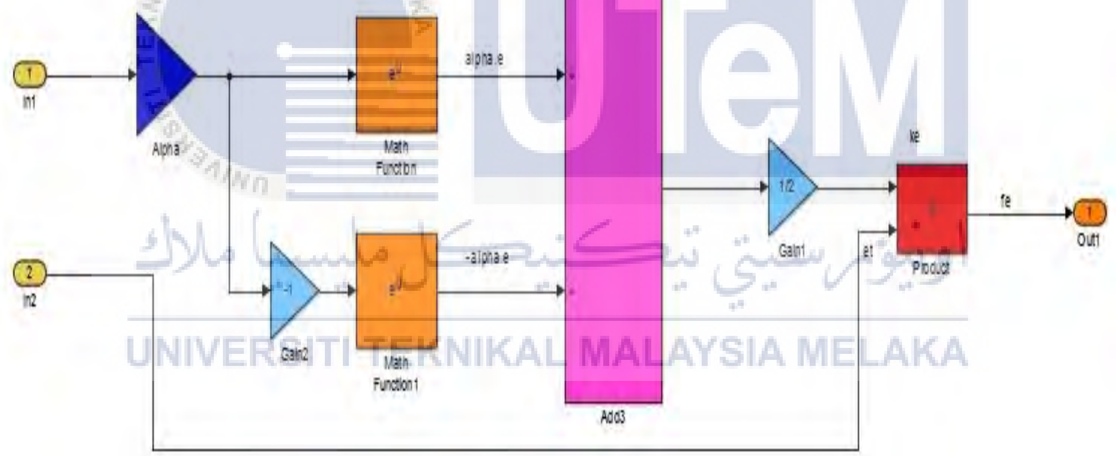


Figure 3.14: Nonlinear function of error block.

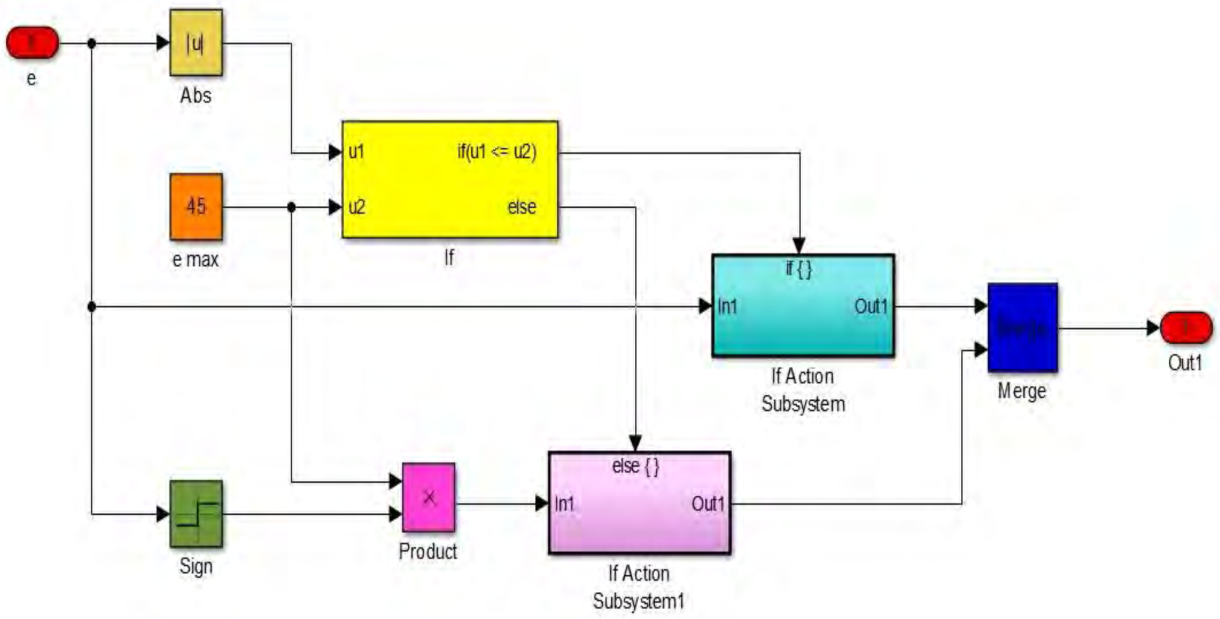


Figure 3.15: Nonlinear function of error, *e(t)* bounded in the sector $0 \leq k(e) \leq K_{max}$.

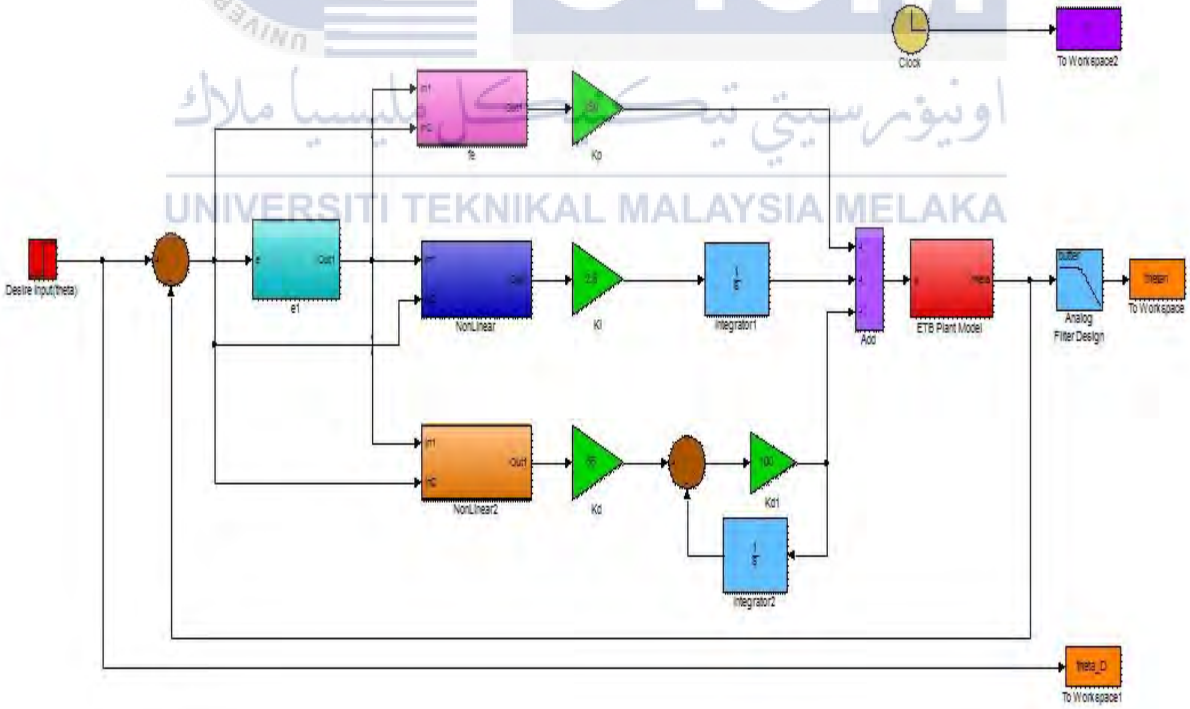


Figure 3.16: Nonlinear gain combined with PID controller.

3.5 Tuning the ETB Using Nonlinear PID Controller

When the Nonlinear PID controller has been completely set up, the tuning simulation can be carried out for the selected angle as a reference angle. In this paper, the throttle valve opening angle 45º is selected as a reference with the value of $k_P = 250$. $k_I = 4.8$ and $k_D = 40$. After that, these simulation result will be compared with the tuning simulation results of conventional PID as shown in Figure 3.17a and Figure 3.17b.

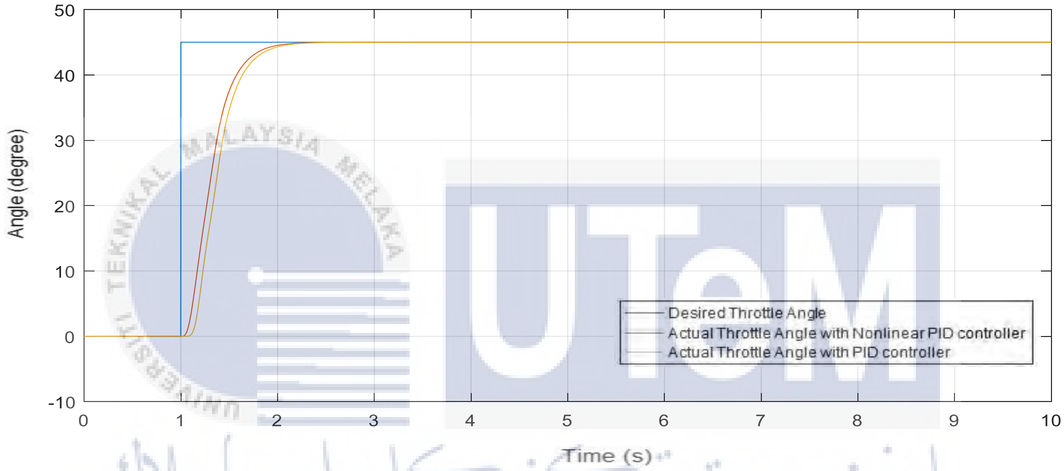


Figure 3.17a: Graph for comparison the ETB valve opening angle at 45º using Nonlinear PID controller and conventional PID controller.

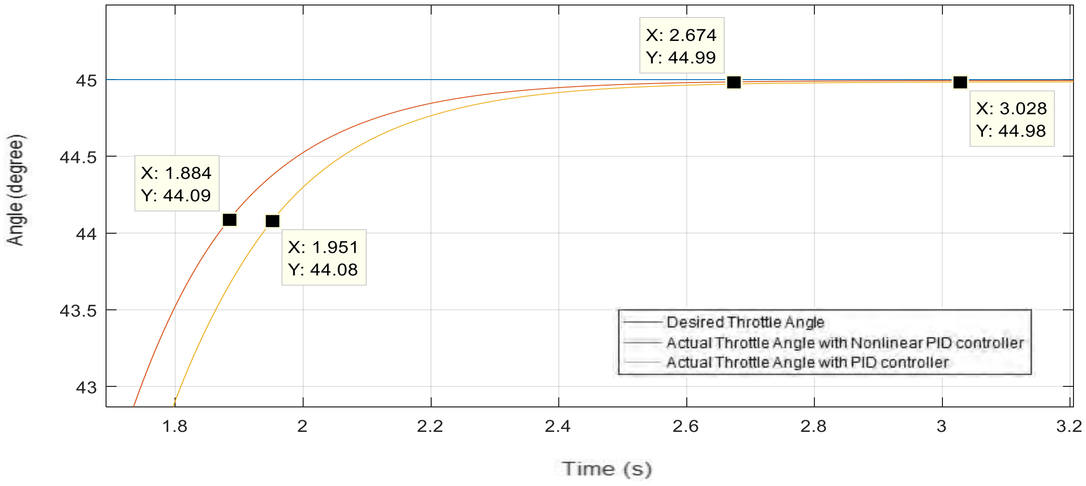


Figure 3.17b: Close up the graph to show the steady state and settling time in Figure 3.17a.

Since there is a differences between the both actual throttle angles in this graph, the value of alpha should be adjust to get almost the same angle for both (Figure 3.18a and Figure 3.18b). In this paper, the alpha value which is set is 0.004, 0.03 and 0.001.

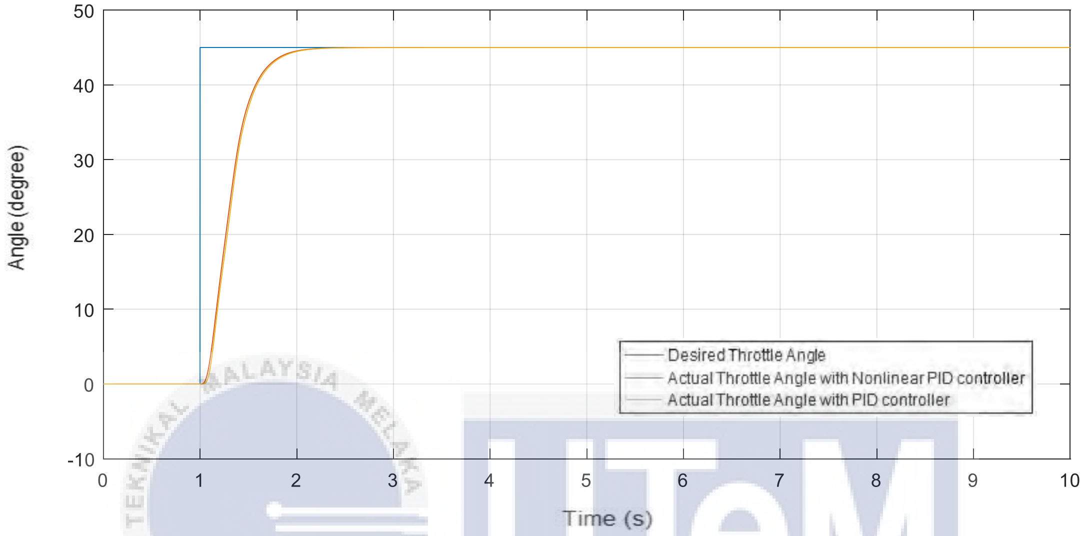


Figure 3.18a: Graph for comparison the ETB valve opening angle at 45°
after insert the alpha value.

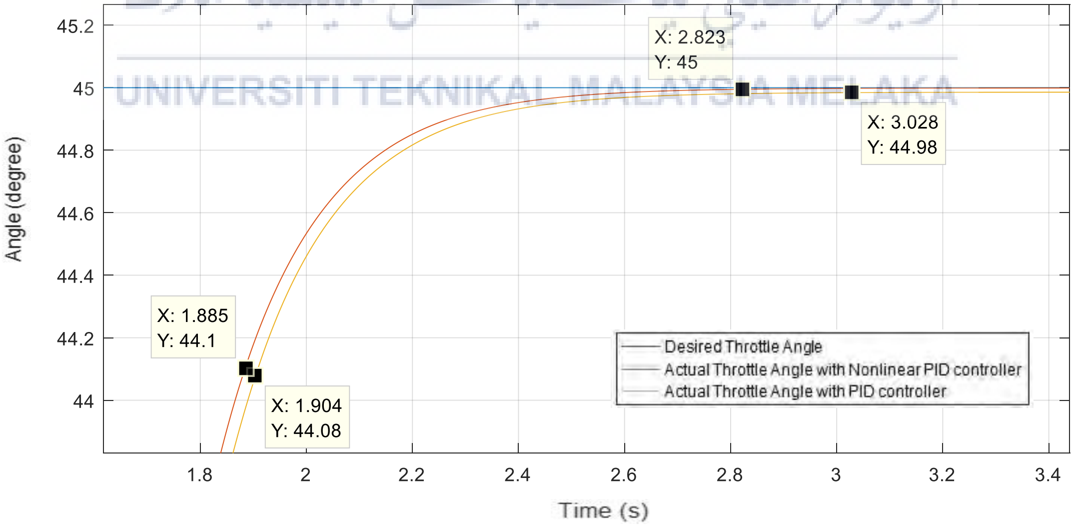


Figure 3.18b: Close up the graph to show the steady state and settling time in Figure 3.18a.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter will discuss about the result that have been obtained after conducted the tuning simulation. The performance of the ETB can be determined when the Nonlinear PID Controller is applied and compared with the conventional PID controller. Therefore, the result of tuning ETB with the conventional PID controller is compared to the ETB with Nonlinear PID Controller.

4.2 Tuning ETB Valve Opening Angle Using Conventional PID Controller

The value of PID to obtain the best result for tune the ETB valve opening angle using PID Controller and tune using Nonlinear PID controller is as in Table 4.1 and Table 4.2.

Table 4.1: The value of k_P, k_I and k_D for tune the ETB using PID Controller.

Angle	k_P	k_I	k_D
30°	300	7	40
45°	250	4.8	40
60°	300	3.3	55
75°	250	2.2	40
90°	250	1.5	55

The graph for tuning ETB valve opening angle using PID controller and using Nonlinear PID controller is as Figure 4.1 to Figure 4.6b

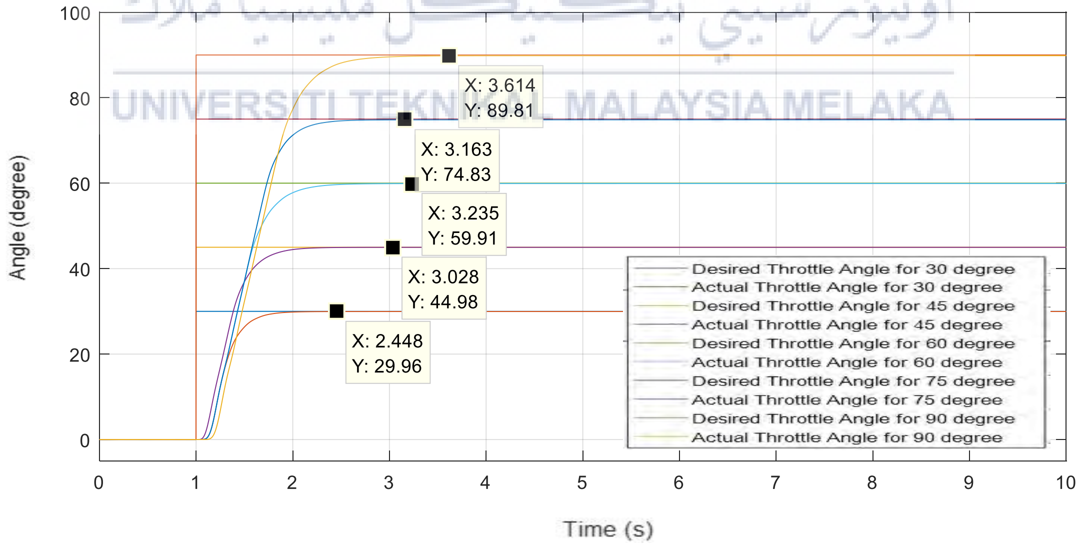


Figure 4.1: Graph for tuning ETB valve opening angle using conventional PID controller.

4.3 Comparison Tuning ETB Valve Opening Angle Using Conventional PID Controller and Nonlinear PID Controller.

In order to compare the simulation result of these two method, the value of k_P, k_I and k_D for tune the ETB using Nonlinear PID controller is the same value as PID controller for 45º, which is selected as a reference. Subsequently, it is also used for tune the ETB using Nonlinear PID controller for 30º, 60º, 75º and 90º.

4.3.1 ETB Valve Opening Angle of 30º

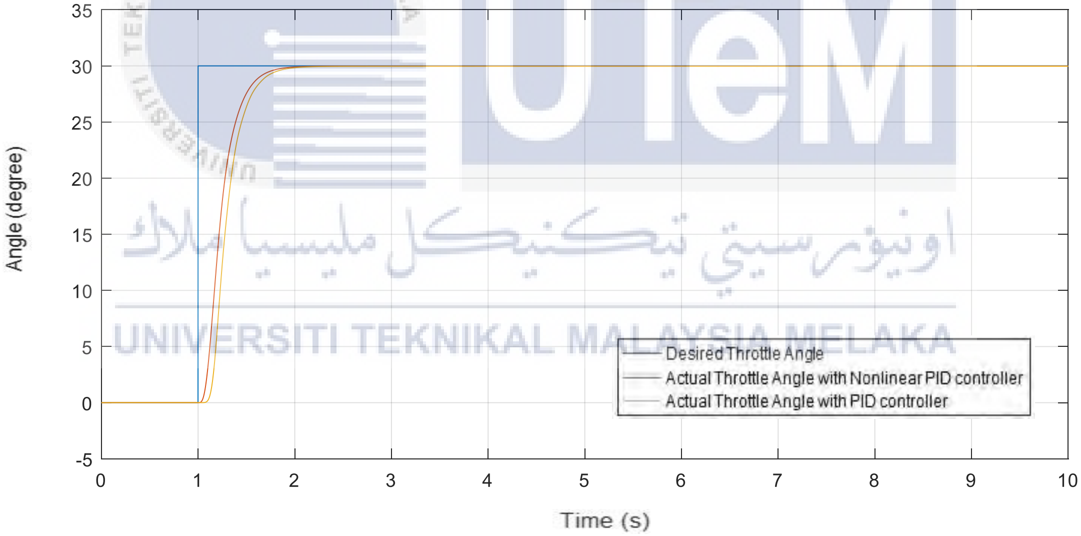


Figure 4.2a: Graph for comparison the throttle valve opening angle at 30º.

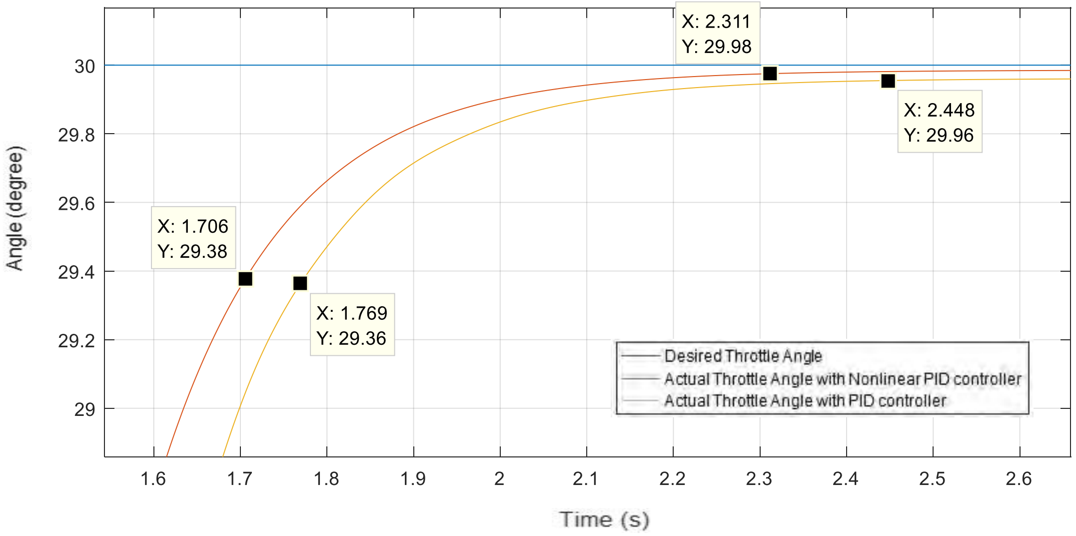


Figure 4.2b: Close up the graph to show the steady state and settling time in Figure 4.2a

From the Figure 4.2a and Figure 4.2b above is shown the different performance of tuning the ETB valve opening angle using the PID and Nonlinear PID controller for 30º. That performance can be evaluated by analyse both steady state and settling time, T_s. The steady state for ETB with PID controller is 29.96º, with steady state error, e_{ss} is 0.0013. While the steady state for ETB with Nonlinear PID controller is 29.98 with steady state error, e_{ss} is only 0.0007. It is shown that by using the Nonlinear PID controller is almost the same with the desired angle.

Settling, T_s time is the time for the graph to reach 98 percent of the final value. The settling time, T_s for using the ETB with Nonlinear PID controller is only takes 1.706 second to settle. For PID controller, is quite slowly to settle where it took 1.769 second. The different of the both settling time is 0.063 second where the settling time for ETB with Nonlinear PID controller is faster.

From the result of steady state and settling time, T_s shown that the performance of ETB using Nonlinear PID controller is much better compared to conventional PID controller.

4.3.2 ETB Valve Opening Angle of 45º

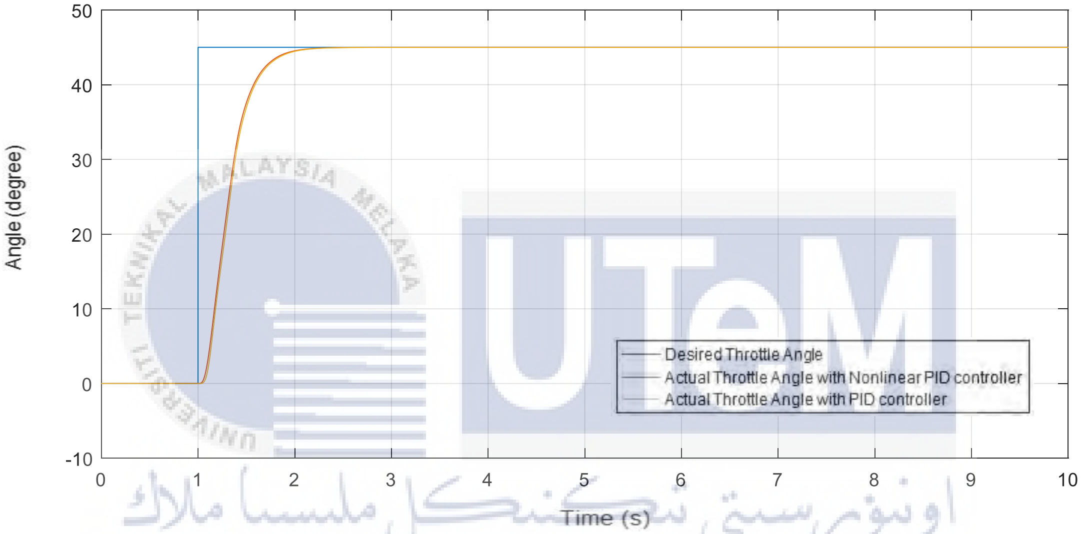


Figure 4.3a: Graph for comparison the throttle valve opening angle at 45º.

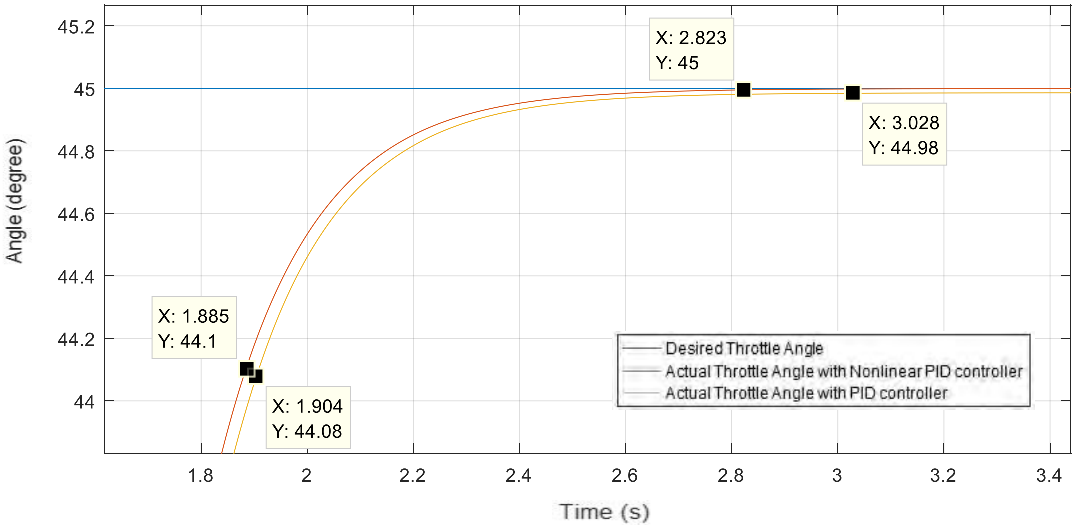


Figure 4.3b: Close up the graph to show the steady state and settling time in Figure 4.3a.

Figure 4.3a and Figure 4.3b above shown the comparison of the response performance of tuning the ETB valve opening angle using the PID and Nonlinear PID controller for 45º. For ETB with PID controller, steady state is 44.98º with steady state error, e_{ss} is 0.0004. While the steady state for ETB with Nonlinear PID controller is 45º, with zero steady state error, e_{ss}. It is shown that by using the Nonlinear PID controller, it reached the desired angle.

For ETB with PID controller, the settling time,T_s is 1.904 second but the settling time,T_s with Nonlinear PID controller is only 1.885 second. That means ETB with Nonlinear PID controller is faster to settle, lead 0.019 second from the PID controller.

Due to the steady state error and settling time,T_s the performance of Nonlinear PID controller is greater compared to the conventional PID controller.

4.3.3 ETB Valve Opening Angle of 60º

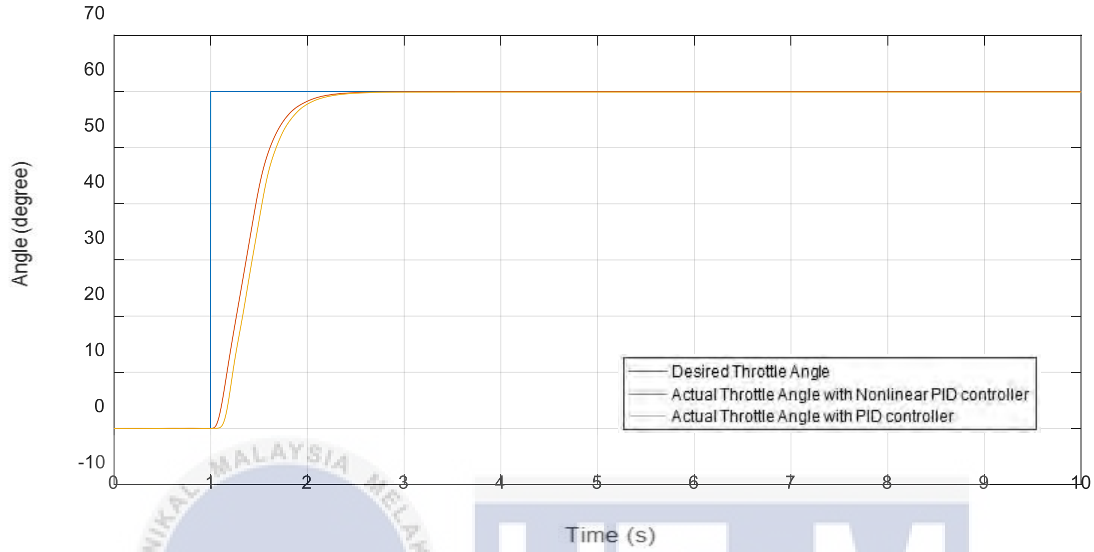


Figure 4.4a: Graph for comparison the throttle valve opening angle at 60º.

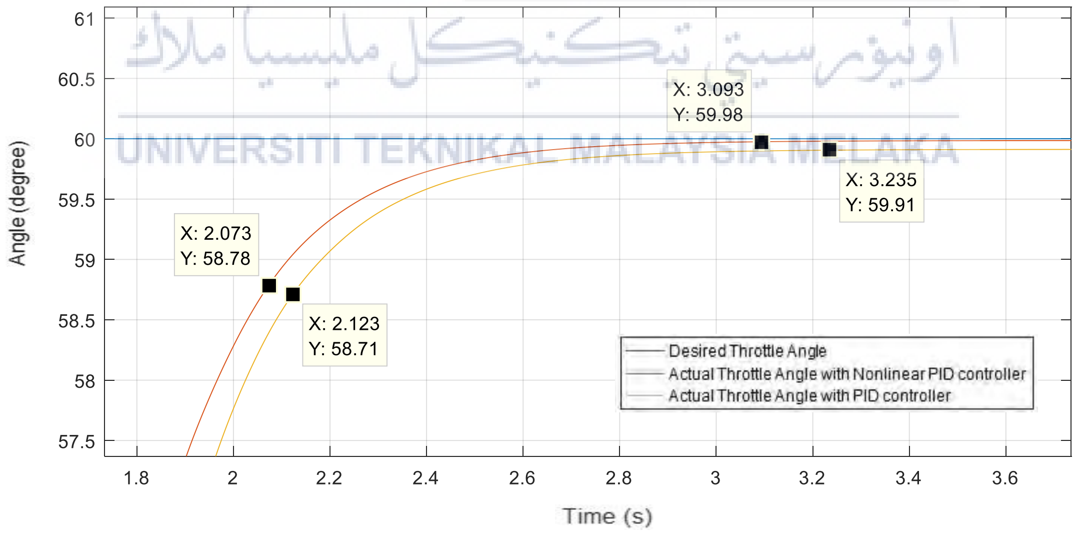


Figure 4.4b: Close up the graph to show the steady state and settling time in Figure 4.4a

Figure 4.2a and Figure 4.2b shown that the steady state for tuning the ETB valve opening angle using the PID controller of 60º is 59.91º with steady state error, e_{ss} is 0.0015 and the steady state for using Nonlinear PID controller is 59.98º with steady state error, e_{ss} is only 0.0003. It shown that, by using the Nonlinear PID controller is more accurate compared with PID controller.

The settling time, T_s is 2.123 second for using PID controller and for Nonlinear PID controller, the settling time, T_s is 2.073 second. The different settling time, T_s is 0.05 second shown that tuning using PID controller is quite slow compared with the Nonlinear PID controller.

The value of state error and settling time, T_s shown that the performance of Nonlinear PID controller is much better compared to the conventional PID controller.

4.3.4 ETB Valve Opening Angle of 75º

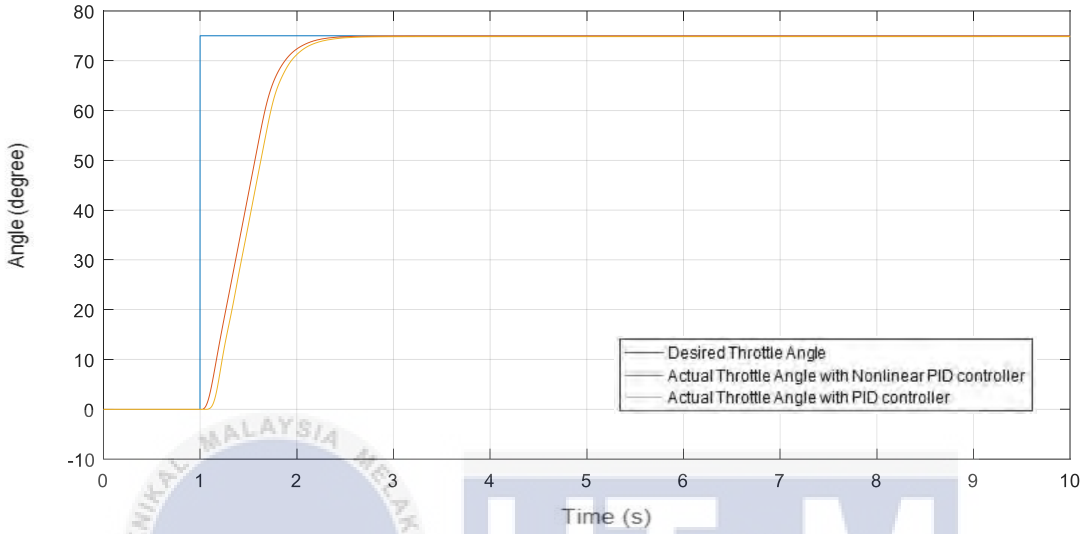


Figure 4.5a: Graph for comparison the throttle valve opening angle at 75º.

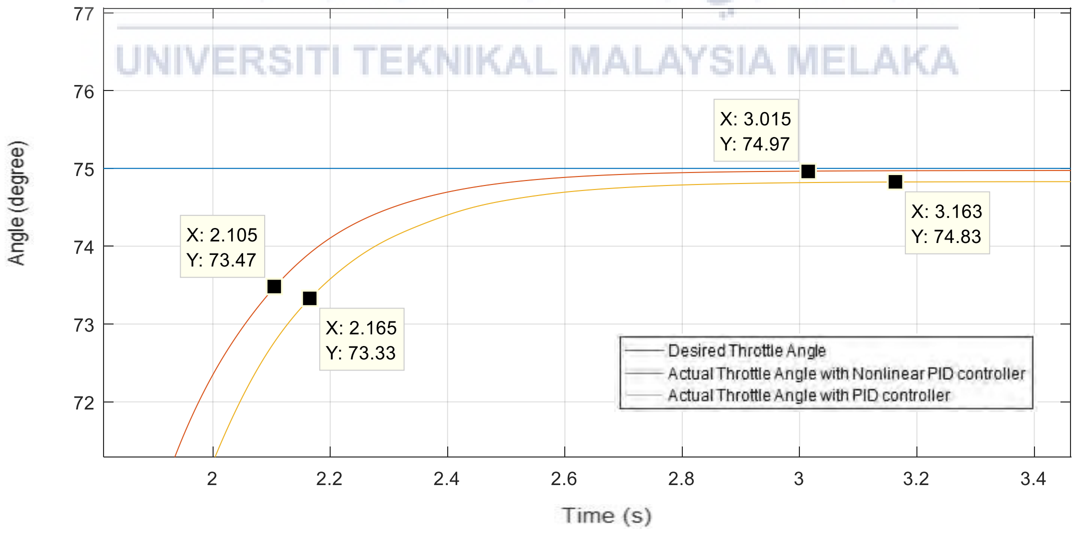


Figure 4.5b: Close up the graph to show the steady state and settling time in Figure 4.5a

From both of the graph above, it can describe the performance of the ETB by reviewing the steady state error and the settling time, T_s. For the steady state, the tuning ETB with Nonlinear PID controller have the steady state of 74.97º with steady state error, e_{ss} is only 0.0004. While 74.83º is the steady state values for the ETB using PID controller with steady state error, e_{ss} is 0.0023. The steady state error for the Nonlinear PID controller is smaller compared to the PID controller.

In terms of settling time, T_s, the ETB with Nonlinear PID controller takes 2.105 second to settle. However, the time taken for the ETB using the PID controller to settle is 2.164 second. In contrast, the conventional PID is quite slower compared to the Nonlinear PID controller. As the conclusion, the Nonlinear PID controller gives a great performance than the conventional PID for the 75º valve opening angle.

The value of state error and settling time, T_s described above prove that the performance of Nonlinear PID controller is much higher compared to the conventional PID controller.

4.3.5 ETB Valve Opening Angle of 90º

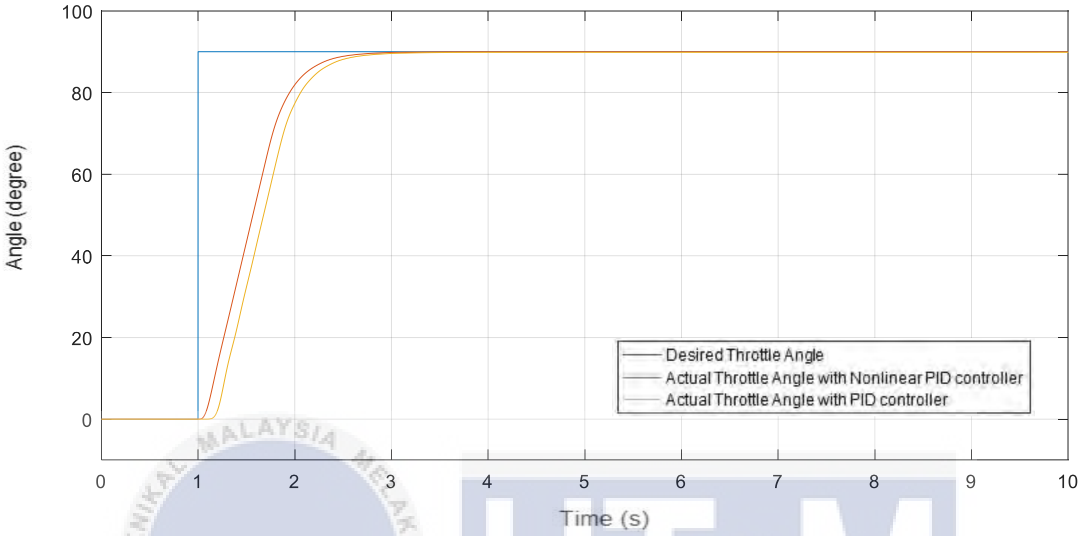


Figure 4.6a: Graph for comparison the throttle valve opening angle at 90º.

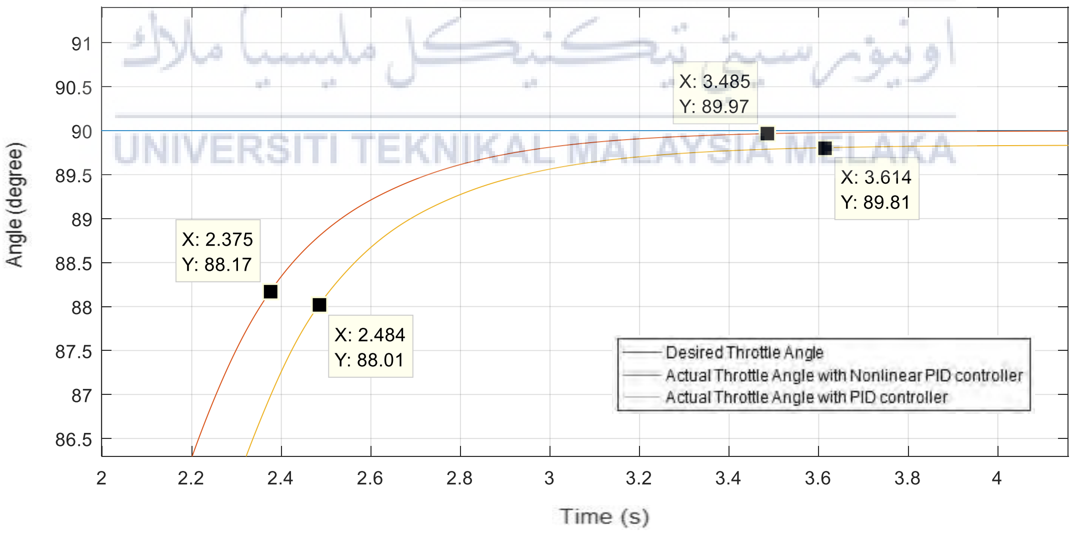


Figure 4.6b: Close up the graph to show the steady state and settling time in Figure 4.6a

Figure 4.3a and Figure 4.3b above shown the comparison of the response performance of tuning the ETB valve opening angle using the PID and Nonlinear PID controller for 90º. For tuning ETB with PID controller, the steady state is 89.91º with steady state error, e_{ss} is 0.0021. While the steady state for ETB with Nonlinear PID controller is 89.97º with steady state error, e_{ss} is only 0.0003. It is shown that by using the Nonlinear PID controller is almost reach to the desired angle.

For ETB with PID controller, settling time, T_s is 2.484 second but the settling time, T_s for Nonlinear PID controller is only 2.375 second. This means ETB with Nonlinear PID controller is faster to settle, lead 0.109 second from the PID controller.

As the conclusion, the Nonlinear PID controller gives a better performance than the conventional PID for the 90º valve opening angle.

CHAPTER 5

CONCLUSION AND SUGGESTION

5.1 Conclusion

The project was implemented for two semesters, where with the provision of time given it has been completed properly. In this project, tuning method for conventional PID controller and a Nonlinear PID controller has been studied. The design for Nonlinear PID controller has been made and applied to the Electronic Throttle Body (ETB) by using Matlab Software. After that the simulation was conducted to gain and verify the performance result and compared with the conventional PID controller.

ETB is the major component that controls the amount of air and fuel ratio enter into the engine combustion chamber during the induction stroke. The air and fuel ratio is controlled by controlling the throttle valve opening angle inside the ETB. However, to controlling the ETB throttle valve opening angle is so difficult because of the unknown disturbance mainly related with the discontinuous nonlinearities due to the friction occurs, the return spring and gear mechanism. Therefore, the automatic tuning technique which includes Nonlinear PID controller has been designed for achieving fast and accurate transient response.

Refer to the project objectives, the first objective is to develop an Electronic Throttle Body (ETB) model in MATLAB software. This objective is completed to achieve during the first session of this project, where the ETB model has been developed follow the model develop by (Pan et al., 2008). While, the second objective is completed during the second session where nonlinear PID controller has been designed by using the equation provided by (Abdullah et al., 2015), (Su et al., 2005). The last objective was accomplished when the ETB model, PID and Nonlinear PID controller has been complete design and the simulation was successfully conducted, and follow by comparison among each other.

In conclusion, this project has been made successfully due to the all objectives is achieved. From the comparison made using the simulation result, shown that the performance for tuning ETB with Nonlinear PID controller is much better and effective than the conventional PID controller. The value of k_P, k_I and k_D used for Nonlinear PID controller is 250, 4.8 and 40.

5.2 Suggestion

From the simulation results, describe the better performance of Nonlinear PID controller to adjust the throttle valve angle to follow the various sets of desired opening angle with more accurate and fast compared to conventional PID controller. Therefore, this effective control method is proposed to carry out on the actual ETB test platform and subsequently use as a major component in the engine system to tuning ETB valve opening angle with accurately.

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