A CRITICAL ANALYSIS OF PID TUNING METHODS FOR AUTOMATIC VOLTAGE REGULATOR SYSTEM

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A report submitted in partial fulfillment of the requirement for the degree Of electrical engineering

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2018

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To my beloved mother (Roqaiah) and father (Ali)

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ABSTRACT

The automatic voltage regulator (AVR) is widely used in many applications and different fields to obtain the stabilized voltage for diverse apparatuses. For that advantage, the fluctuating in voltage level causes massive changes in the system dynamics. It leads to reduce the performance and life span of the connected apparatus. The delivered voltage to our home sometimes fluctuates that can cause real and huge damages to our appliances. Based on that, the PID controller is widely used to control AVR system in term of its simplicity of design and implementation where the PID controller aims to improve the performance of the AVR system. Related to the aforementioned problem, there are three objectives to solve the problem. The first objective is to investigate the model of AVR system and PID tuning methods. The second objective is to implement the several PID tuning methods to an AVR system model. The last objective is to analyze the performance of the AVR system with implementation of PID tuning methods. In this project, the model of AVR system is controlled by PID controller using different tuning methods such as Ziegler Nichols (Z-N), Cohen coon, C-H-R and manual tuning methods. The tuning methods used to obtain the PID yields that leads to control the AVR system with good performance. Controlling the AVR system using PID controller based on these tuning methods is validated using simulation based on Simulink-MATLAB. The performance of PID controller for AVR system is analyzed based on settling time (T_s), rise time (T_r), overshoot (OS %), and steady-state error (e_{ss}). The result shows that manual tuning method of PID controller achieved a good improving in terms of the T_s and T_r(0.6845s and 0.2176s respectively) compared to the result of the AVR system without controller and others tuning methods. As well, the manual tuning method performed with almost 0.0 e_{ss}. Hence, the manual tuning method can be used to obtain the PID yields for controlling the AVR system with a good performance.

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ABSTRAK

Pengatur voltan automatik (AVR) digunakan secara meluas dalam banyak aplikasi dan bidang yang berbeza untuk mendapatkan voltan yang stabil untuk pelbagai peralatan. Untuk kelebihan itu, turun naik dalam voltan menyebabkan perubahan besar dalam dinamik sistem. Ia membawa kepada mengurangkan prestasi dan jangka hayat alat yang bersambung. Voltan dihantar ke rumah kita kadang-kadang turun naik yang boleh menyebabkan kerosakan yang nyata dan besar ke peralatan kita. Berdasarkan itu, pengawal PID digunakan secara meluas untuk mengawal sistem AVR dari segi kesederhanaan reka bentuk dan pelaksanaan di mana pengawal PID bertujuan untuk meningkatkan prestasi sistem AVR. Berkaitan dengan masalah yang disebutkan di atas, terdapat tiga objektif untuk menyelesaikan masalah tersebut. Objektif pertama adalah untuk menyiasat model sistem AVR dan kaedah penalaan PID. Objektif kedua adalah untuk melaksanakan beberapa kaedah penalaan PID kepada model sistem AVR. Objektif terakhir adalah untuk menganalisis prestasi sistem AVR dengan pelaksanaan kaedah penalaan PID. Dalam projek ini, model sistem AVR dikawal oleh pengawal PID menggunakan kaedah penalaan yang berbeza seperti Ziegler Nichols (Z-N), Cohen coon, C-H-R dan kaedah penalaan manual. Kaedah penalaan digunakan untuk mendapatkan hasil PID yang mengarahkan untuk mengawal sistem AVR dengan prestasi yang baik. Mengawal sistem AVR menggunakan pengawal PID berdasarkan kaedah penalaan ini disahkan menggunakan simulasi berdasarkan Simulink-MATLAB. Prestasi pengawal PID untuk sistem AVR dianalisis berdasarkan masa penyelesaian (T_s), naikkan masa (T_r), overshoot (OS%), dan ralat keadaan mantap (e_ss). Hasilnya menunjukkan bahawa kaedah penalaan manual pengawal PID mencapai peningkatan baik dari segi T_s dan T_r (0.6845s dan 0.2176s masing-masing) berbanding keputusan sistem AVR tanpa pengawal dan kaedah penalaan lain. Selain itu, kaedah penalaan manual dilakukan dengan hampir 0.0 e_ss. Oleh itu, kaedah penalaan manual boleh digunakan untuk mendapatkan hasil PID untuk mengawal sistem AVR dengan prestasi yang baik

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CHAPTER 1

INTRODUCTION

1.1 Background

The automatic voltage regulator (AVR) is an electrical and electronic device that is used to regulate the level of the voltage for a power system. Moreover, The AVR is considered as the essential part of the power system network as well it keeps a fixed voltage from changes in the terminal load. Furthermore, the function of an AVR is to catch the magnitude of the terminal voltage for a synchronous generator at a specified level. A simple AVR System comprises four main components which are amplifier, exciter, generator, and sensor[1][2].On the other hand ,the AVR system performance is not sufficient for a power system since it has poor specifications that cause negatively effect in equipment[3] . Hence, The PID controller is used to improve transient response as well as to reduce or eliminate the steady-state error[2].

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Since the half of the last century, the PID controller is known as a popular feedback controller which is being used in diverse applications. The PID controller is mainly considered as a good controller that can provide a desired performance of process plant. The PID controller also consists of three yield parameters proportional, integral and derivative parameters respectively[4].

Nowadays, The PID controller is mainly utilized in the industrial process due to its reliable performance. The complexity that associated with the PID controller is to adjust the three yields parameters in order to satisfies the system performance based on the design requirements[5].

1.2 Motivation

The AVR system is a significant device that is utilized to stabilize the voltages in specific levels. Hence, the AVR system is widely used in many aspects of life such as process plant and control applications to avoid the consequent costs with equipment damage and downtime caused by poor voltage levels. the apparatuses in a power system network are in rated voltage thus any fluctuating in voltage levels causes massive changes in the system dynamics.it leads to reduces the life span and performance of the connected apparatus[6].

The AVR system uses to stabilize the voltage of some home devices than can damage the device or causes severe spoiled in appliance in case there is no AVR system. Furthermore, other application of AVR is to regulate the output voltage from alternator of the vehicles to provides the sufficient voltage for electrical system in the vehicles and prevent the raise of voltage that will be harmful the electrical system.

1.3 Problem Statement

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An (AVR) is an electronic device or circuit that maintains an output voltage to be consistent to its load current. For that reason, the voltage delivered to residential area may sometimes fluctuate which can cause real and huge damages to home appliances; if not totally destroying it. Thus, the PID controller is widely used to control AVR system in order to control the output voltage parameters to be in a stable manner. This is because, the AVR system has long settling time, high overshoot, and large steady-state error[7][2].

Several PID tuning methods have been implemented to design the PID controller by various researchers [8][9][10]. The PID tuning methods aim to obtain yields parameters that are suitable for the modeling system. Thus, most of the PID tuning methods have been implemented for PID controller design to control different system for different applications. However, many researchers have utilized different PID tuning methods to controlling the AVR system [11][5][12] to improve its performance such as accuracy, efficiency and quality, the comparative study on the various tuning methods of PID controller has not done yet to state the best method.

1.4 Objectives

The goal of this research project is to regulate the voltage levels of AVR system by using the PID tuning methods. Specifically, the objectives of the research project are

1. To investigate the model of AVR system and PID tuning methods.
2. To implement the several PID tuning methods to an AVR system model.
3. To analyze the AVR system performance with implementation of PID tuning methods.

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1.5 Scope

Relating to the objectives, there are some limitations that have to be taken in consideration in order to achieve the objectives as follow:

1. The modeling system that will be implemented in this project is AVR system.
2. The project will be done in simulation rather than hardware.
3. Overshoot, settling time, raise time and steady-state error will be improved based on various PID tuning methods.
4. MATLAB Simulink will be conducted to validate yield parameters of PID tuning methods.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the pervious study of AVR system. The AVR system will be described and explained in detail. Then, the state of the art will be stated with the most related researches of the project title. Based on that, the summary of the state of the art will figure out the gap of the knowledge that will be the problem statement of the project.

2.1 Background of Automatic Voltage Regulator

The automatic voltage regulator (AVR) system is an electrical device designed to maintain the output voltage automatically at specific constant level. The AVR is widely utilized in many applications and different field to obtain the stabilized voltage for diverse apparatuses[13]. In our daily life it is known that voltage could be either high or low for the purpose of the electricity supplies. For that reason, various electrical appliances will be destroyed. Furthermore, constant voltage at the generator terminal is essential to satisfy the main power supply, Since various disturbing factors can affect the terminal voltage such as (power factor, load, speed, and temperature rise)[14].Consequently, the voltage regulator is utilized for its important role to save the electrical equipment[15] and to keep the voltage stable, even when it is affected by the disturbance factors[4].

The voltage regulator has been invented in the middle of the last century due to its significant function, where it stabilize the output voltage used in automobile alternator , electrical equipment and power system network[14][5]. The main objective of the AVR system as follow:

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1. To get a better voltage regulation for the system.
2. To enhance stability.
3. To decrease over-voltage on loss of load[14].

2.2 Model of the Automatic Voltage Regulator

The (AVR) system consist mainly from four components namely amplifier, exciter, generator, and sensor. Figure 2.1 illustrates the AVR system components as a real model.

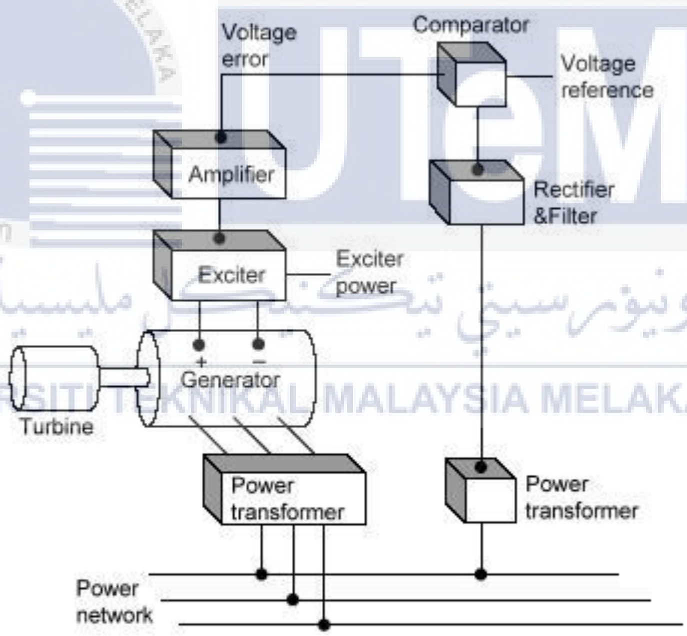

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Figure 2-1: The Real Model of The AVR System

In synchronous generator, the AVR system is utilized to keep the terminal voltage value at a constant specified level. The four AVR main components transfer functions in term of their corresponding gain and time constants typical ranges are shown in table 1.0[5][4][16].

Table 2-1: Transfer function of the component of AVR

AVR component	Transfer function	Range of the gain (K)	Range of the time constant T (s)
Amplifier	$Ga = \frac{K_a}{1+T_a s}$	10-40	0.02-0.1
Exciter	$Ge = \frac{K_e}{1+T_e s}$	1-10	0.4-1.0
Generator	$Gg = \frac{K_g}{1+T_g s}$	0.7-1	1.0-2.0
Sensor	$Gg = \frac{K_s}{1+T_s s}$	0.9-1.1	0.001-0.06

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The AVR system arrangement components is shown in Figure 2.2. The sensor function is to sense the generator terminal voltage ΔVt(s) continuously and compare the sensed terminal voltage with the desired reference voltage ΔVref(s). The amplifier is used to amplify the error voltage ΔVe(s) that produced from the difference between the reference and the sensed terminal voltages. The exciter function is to excite the generator by the amplified error voltage ΔVe(s).

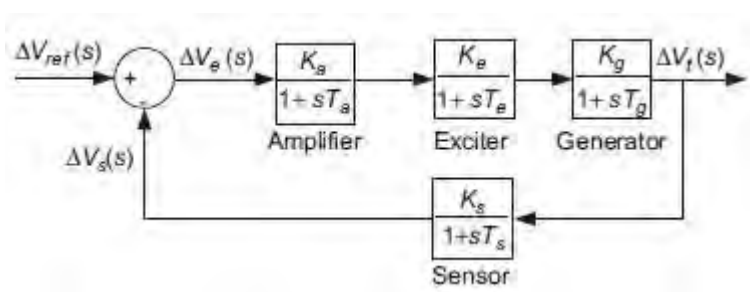

Figure 2-2: Model of the Automatic Voltage regulator (AVR)

The transfer function of all components explained in details , respectively, as follows[2][7][13][5][4][16]:

2.2.1 Model of the Amplifier

The transfer function of amplifier model is represented by a gain KA and a time constant TA, thus the transfer function is

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+T_R s} \tag{2.1}$$

Typical values of K_A are in the range of 10 to 40. The amplifier time constant is very small ranging from 0.02 to 0.1 s.

2.2.2 Model of the Exciter

The transfer function of a modern exciter may be represented by a gain KE and a single time constant TE

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1+T_E s} \tag{2.2}$$

Typical values of KE are in the range of 1 to 10. The time constant TE is in the range of 0.4 to 1.

2.2.3 Model of the Generator

In the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain KG and a time constant TG

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1+T_G s} \tag{2.3}$$

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These constants are loaded dependent; KG may vary between 0.7 to 1.0 and TG between 1.0 and 2.0 s from full load to no load.

2.2.4 Model of the Sensor.

The sensor is modeled by a simple first-order transfer function, given by

$$\frac{V_S(s)}{V_F(s)} = \frac{K_R}{1+T_R s} \tag{2.4}$$

The parameters of the AVR system can be selected from the table 2.1 to drive the transfer function of the AVR system. The selected parameters from pervious researches are shown in Table 2.2[7].

Table 2-2: Values of Gain and Corresponding Time

Gain	Value	Time Corresponding	Value
K_A	10	T_A	0.1
K_E	1	T_E	0.4
K_G	1	T_G	1
K_S	1	T_S	0.01

Thus, the transfer function of the AVR system without a controller is

$$GAVR = \frac{V_T(s)}{V_{ref}(s)} = \frac{0.1s+10}{0.0004s^4+0.045s^3+0.555s^2+1.51s+11} \tag{2.5}$$

The input signal of the above system is step signal. the system has one zero at Z= -100, two real poles at $S_1 = -98.82$ and s2= -12.63, and two complex poles at $S_{3,4}$= -0.53 ± 4.66 j ,the following Table 2.3 shows the resulted values of AVR system without controller [7][2][1].

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Table 2-3: AVR performance without PID controller

parameter	Gain K	steady-state value	settling time	rise time	peak amplitude
value	K= 250	0.909	6.98 sec	0.2607sec	65.72%

The performance of AVR system is acceptable, even though it has oscillatory response. Hence, it is desired to improve the system by applying any controller[9][12].

2.3 PID Controller

PID control stands for Proportional-Integral-Derivative that has been efficiently utilized in industrial control systems and wide range of applications. PID control become a popular due to its robustness, Simplicity and a wide range of applicability. Further, it reduces the parameters that will be tuned[6].

The PID controller is used to enhance the transient response and to decrease or remove the steady-state error. The transient response is improved by using the derivative controller where a finite zero is added to the transfer function of open-loop plant. The steady-state error is reduced by using the integral controller where a pole at the origin is

added to increase the system type by one. Figure 2.3 shows and describes the basic structure of the PID controller with a plant by the following transfer function[9]:

$$G_C(s) = K_P + K_d s + \frac{K_i}{s} \tag{2.6}$$

Where K_P, K_i and K_d are the coefficient that will be tuned to enhance the transient response and to decrease or remove the steady-state error. These coefficients consider as the main components of the PID namely the proportion coefficient, differential coefficient, and integral coefficient, respectively[8].

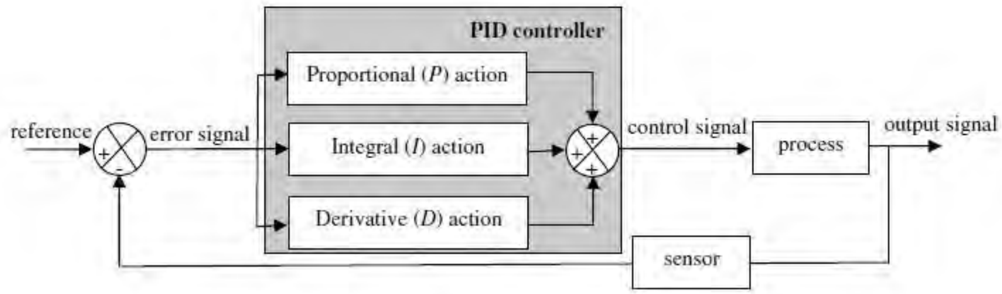

Figure 2-3: Closed Loop Block Diagram of PID Controller

2.3.1 P- Controller:

The P yield is short symbol for the proportional controller that gives an important role for output to be proportional to the current error. The main function is to compare the desired value with real value through feedback block. Based on the comparing of the desired and actual value, the output will be produced by the multiplying the resulting error with constant of the proportional (P). Hence, the value of the controller output will be zero when the value of the error is zero[10].

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2.3.1.1 P-Controller Response

The manual reset in this controller is required when it is lonely used. This is because the steady state condition is never reached .the steady state error is always maintained when the P provides the stable operation .the proportional constant increases when the speed of response is increased[17].

2.3.2 I-Controller

The PI controller stands for proportional integral which it is needed due to the existence of an offset between the set point and process variable. The steady state error is eliminated when the necessary action is provided by the PI controller. Further, the error value is reached to zero by integrates the error over specified time. Moreover, the negative error is taken a place when the output of integral control is decreased. Also, the speed of response is limited, and the stability of the system is affected by applying the PI controller. The decreasing of the proportional integral increases the speed of response[18].

2.3.2.1 PI Controller Response

The decreasing in proportional gain leads to decreasing in the steady state error .especially, when the high speed response is not required[19].

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2.3.3 D-controller

PD controller is a short form of the proportional derivative and its main function is to anticipate the future behavior of the error. This is because the PI controller is not capable to predict the future behavior of the error. The output of PD is depended on multiplication of the derivative constant and the change rate of error with respect to time. The PD allow the kick start for the output to increase the system response.

2.3.3.1 PD Controller Response

The PD response is getting more compared to PI and its output settling time is decreased. Also, the system stability is improved by compensating phase lag caused by the PI controller. Further, the speed of the system is increased when the proportional derivative is increased.

Finally, we noticed that combination of these three controllers give the desired response for the system. Hence, the design of PID controllers are totally different based on the divers manufacture algorithms[17].

2.4 Tuning PID Methods

PID Tuning methods are mainly used to obtain the corresponding values parameter of PID controller to improve the system performance and meet design requirement. As well as, the classification of PID tuning methods mainly consist of two categories which they are closed loop and open loop methods. The tuning techniques of closed loop is referred to methods which the controller is tuned during automatic state while the plant is operating under a closed loop. The tuning techniques of open loop is referred to the methods which the controller is tuned when it is in manual state and the plant operates under open loop. In addition, the main aim of PID tuning methods are to obtain Fast responses and desired stability. Moreover, many of the PID tuning methods was introduced to obtain the acceptable performance and some of them will be explained in detailed in this research[4][20].

2.4.1 Manual Tuning

The PID controller parameters can be tuned by the manual tuning methods in order to get a satisfied performance. In addition to, Manual tuning method consider as the simplest tuning method to get the value of the parameters due to the mathematical calculation is not required. Even though, there are several tuning methods available, the manual tuning method is still play an important role in PID controllers. Using this method, long time is needed, but the experienced person can shorten the time[8].It is can be done by varying the PID parameters K_p,$K_i$and k_d .

2.4.2 Ziegler Nicolaus

The Ziegler Nichols tuning method is widely utilized in control application and industries. It was developed by Ziegler and Nathaniel B Nichols in 1940s. Ziegler Nichols considers as a useful method since the PID controllers parameters can be determined by this method. The PID controllers parameters K_P,K_i and K_d are determined based on formulas in Table 2.3[20][13].

Table 2-4: Formulas of the Ziegler Nichols method

Controller	**Parameter**		
	K_P	K_i	K_d
P controller	0.5 K_{cr}	∞	0
PI controller	0.45 K_{cr}	$T/1.2$	0
PID controller	0.6 K_{cr}	$T/2$	$T/8$

Where: K_{cr} is a critical gain that makes the system consistently oscillates. As well, T is a time for one cycle measured in second.

2.4.3 Cohen Coon

C-C tuning method considers as a second popular method after Ziegler Nichols methods. This method was published in 1953 by Cohen and Coon .C-C is extra flexible compared to Z-N method in term of the huge variety of processes. Based on the Table 3.3 the PID controller parameters are computed by using the formulas stated there[20].

Table 2-5: Cohen Coon method in PID controller

Controller	**Parameter**		
	K_c	K_i	K_d
P controller	(P/NL)*(1+ $(R/3)$)	-	-
PI controller	(P/NL)*(0.9+ $(R/12)$)	L* $(30+3R)/(9+20R)$	-
PID controller	(P/NL)*(1.33+ $(R/4)$)	L* $(30+3R)/(9+20R)$	$4L/(11+2R)$

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Where: L $= T_{dead}$

R $= Tdead/T$

P/NL $= K_O$

P = percent change of input

N $= percent\ change\ of\ output/T$

2.4.4 Chien, Hrones and Reswich (C-H-R)

Chien, Hrones and Reswich (C-H-R) have proposed this method as a modification of Ziegler and Nichols method (open loop). They proposed design criterion to use "quickest response with 20% overshoot" or "quickest response without overshoot"[21]. Further, they importantly observed the tuning based on load disturbance and set point responses which they are different. Thus, the tuning of PID controller parameters regarding to C-H-R method are determined with same way of Z-N method of the first order in term of dead time by using formulas stated in Table 2.6.

Table 2-6: Formulas of C-H-R method

Overshoot	**0%**			**20%**		
Controller Type	K_c	K_i	K_d	K_c	K_i	K_d
P	$\frac{0.3}{K_m}\frac{T}{L}$	----	----	$\frac{0.7}{K_m}\frac{T}{L}$	----	-----
PI	$\frac{0.35}{K_m}\frac{T}{L}$	$2T$	----	$\frac{0.6}{K_m}\frac{T}{L}$	$1.2T$	----
PID	$\frac{0.6}{K_m}\frac{T}{L}$	T	.5L	$\frac{0.95}{K_m}\frac{T}{L}$	$1.4T$	0.47L

2.5 Pervious Research

In [1] the PID controller was utilized and tuned by the Ziegler Nichols and tuned controller to control the AVR system . The results of simulations show that the Ziegler Nichols has better performance over the tuned controller based on the settling time raise time and overshoot.

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In paper [2] , the Particle Swarm Optimization (PSO) and genetic algorithm (GA) methods were implemented to tuned the PID controller of AVR system . The performance of these methods compared in term of efficiency and robustness for improving the step response of an AVR system using simulated results. The (PSO) showed the better performance than (GA).

In paper [5] an integer order and fractional order proportional plus integral plus derivative (IOPID & FOPID) controller is used to control an (AVR) system. The (IOPID) parameters are tuned and optimized by Ziegler Nichols and grey wolf optimizer (GWO). The FOPID parameters are optimized using Nelder-Mead (NM) method. From the results of Simulation, the (FOPID) shows better performance in term of settling time and the efficacy of step response.

This paper [13]deals with the fractional-order PID (FOPID) controller tuned with Ziegler Nichols and PID controller tuned with Ziegler Nichols and Cohen Coon methods. Regarding to the simulated results, the (FOPID) performed better than the PID in term of the settling time and overshoot. On the other hand, (FOPID) has larger raise time than PID.

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In[22], PID controller was used and optimized by Chaotic Particle Swarm Optimization (CPSO) algorithm and standard Particle Swarm Optimization (PSO). From the simulated results, the CPSO performed better than PSO in terms of overshoot and settling time.

2.5.1 Summary of Review

Regarding to the previous research, many of PID tuning methods have been implemented to the AVR system due to improving the AVR system performance. Ziegler Nichols is one of the famous tuning methods that has been used to tune the PID controllers.

The PID parameters is tuned by tuning methods to obtain the good and satisfied performance. Table 2.4 shows the comparison among the PID tuning methods.

Table 2-7: Literature review of the PID tuning methods

NO	Type of method	Year published	Advantages and Disadvantages
1	Ziegler Nichols	2015	By comparing with tuned controller. Advantages: ▪ Less settling time ▪ Less raise times ▪ Less and overshoot
2	Particle Swarm Optimization (PSO)	2004	By comparing with genetic algorithm (GA) methods. Advantages: ▪ Good efficiency ▪ Better robustness in improving the step response
3	FOPID parameters are optimized using Nelder-Mead (NM) method	2015	By comparing with (IOPID) tuned and optimized by Ziegler Nichols and grey wolf optimizer (GWO). Advantages: ▪ Less settling time ▪ Good efficacy of step response

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4	fractional-order PID (FOPID) controller tuned with Ziegler Nichols	2015	By comparing with PID controller tuned with Ziegler Nichols and Cohen Coon methods. Advantages: ▪ Less settling time and overshoot Disadvantages: ▪ Larger raise time
5	Chaotic Particle Swarm Optimization (CPSO) algorithm	2015	By comparing with standard Particle Swarm Optimization (PSO) Advantages: ▪ Less settling time ▪ Less and overshoot.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will be explained precisely how the objectives of this project will be achieved. the flow chart of the project is used to demonstrate the flow of project. Then, the investigation of the AVR system and several PID tuning methods is done by finding the model of AVR system and the mathematical modeling of the most three common PID tuning methods. After that, various PID tuning methods will be implemented to AVR system by simulation in order to obtain better performances for the system. At the end, the results obtain from the simulation will be analyzed and compared to get the better performance method.

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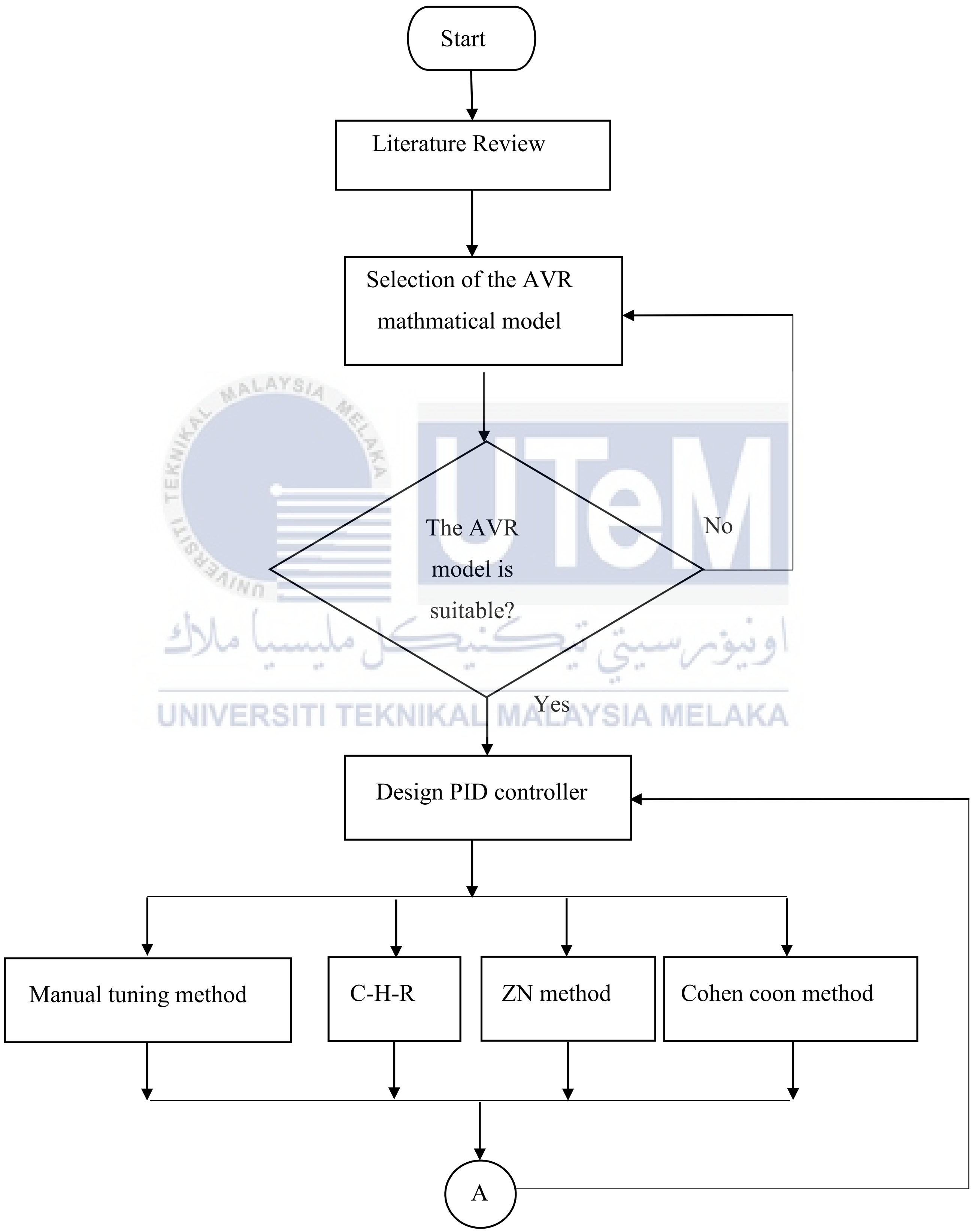
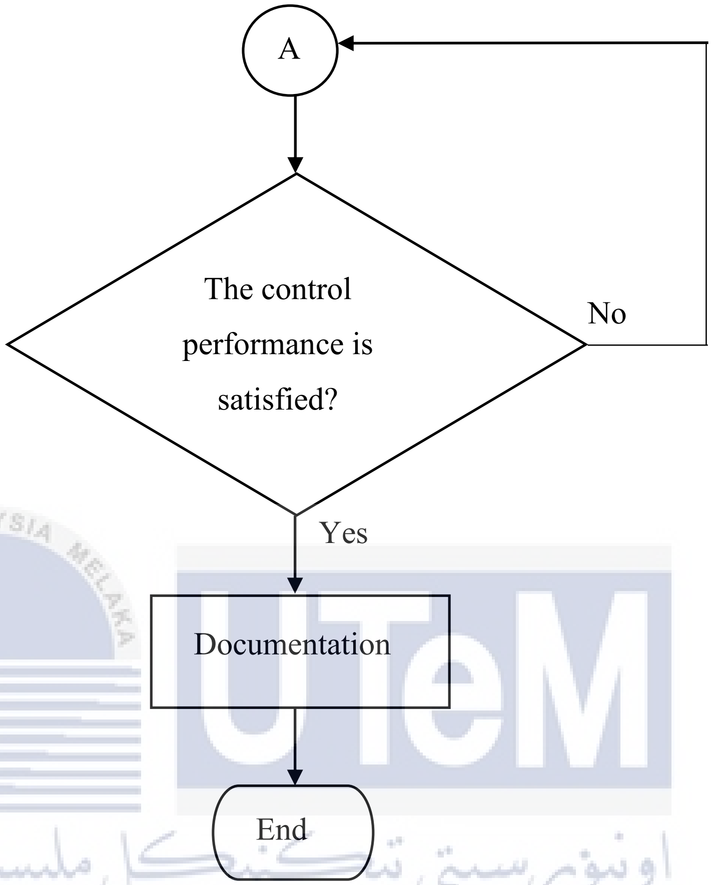
3.2 Flow Chart of Project Methodology





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3.3 Mathematical Model of AVR System

The AVR system mainly consists of four components amplifier, exciter, generator and sensor respectively. Figure 3.1 shows the AVR model block diagram with PID controller and the AVR components arrangement [22][19].

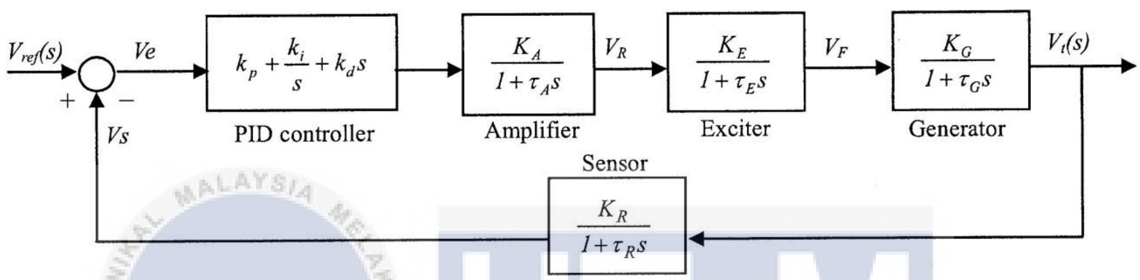

Figure 3-1: Block Diagram of An AVR System With A PID Controller

Based on Table 2.1 the transfer function of the system can be derived by using algebra feedback form.

$$G_{AVR} = \frac{\frac{K_A}{1+T_A s} \times \frac{K_E}{1+T_E s} \times \frac{K_G}{1+T_G s}}{1+\frac{K_R}{1+T_R s} \times \frac{K_A}{1+T_A s} \times \frac{K_E}{1+T_E s} \times \frac{K_G}{1+T_G s}} \tag{3.1}$$

The AVR transfer function parameters can be selected from Table 2.2. Thus, the transfer function of the AVR system without a controller is

$$GAVR = \frac{V_T(s)}{V_{ref}(s)} = \frac{0.1s+10}{0.0004s^4+0.045s^3+0.555s^2+1.51s+11} \tag{3.2}$$

3.4 Mathematical Model of PID Tuning Methods

The PID controller is widely used in many control applications in term of its simplicity of design and implementation. The PID controller is utilized to improve the Time response by decreasing the steady-state error, reducing overshoot, increasing speed of rise and settling time. The proportional, integral, derivative controller defined by equation:

$$G_C(s) = K_P + K_d s + \frac{K_i}{s} \tag{3.3}$$

A proportional gain K_p decreases the rise time whereas the effect of an integral gain K_i is eliminating or reducing the steady-state error. The function of derivative gain K_d is to improve or enhance the transient response and stability of the system other than reducing the overshoot. Table 3.1 describes and summarizes the effects of PID controller gainsK_p,K_i and K_d on a closed-loop system[11].

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Table 3-1: Effect of PID gains to system performance.

Controller Gain	**Overshoot**	**Settling Time**	**Rise time**	**Steady-State Error**
Proportional gain K_p	Increase	Decrease	decrease	Decrease
Integral gain K_i	Increase	Decrease	Small change	Eliminate
Derivative gain K_d	Decrease	Minor changes	Small change	Minor changes

3.4.1 Mathematical Calculation of Ziegler Nichols

The parameters of PID controller are computed by Ziegler Nichols by using the following procedures:

i. Setting the values of gain K_i and K_d to zero.
ii. Increasing the value of K_p until the ultimate gain K_{cr} is reached, which makes the system oscillates sustainably.
iii. Measuring the T (time) for one cycle as labeled in figure 3.2.
iv. Substituting the values of ultimate gain and time for one cycle in formulas stated in Table 2.3 to get the parameters values of PID controller.

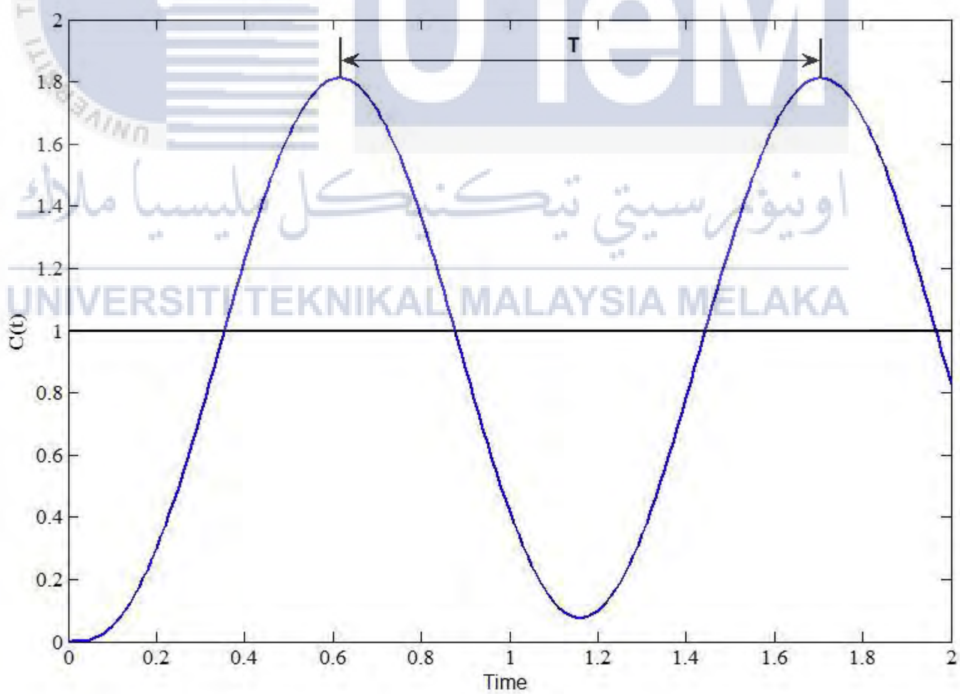

Figure 3-2: Sustained Oscillation Waveform

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3.4.2 Theoretical of Manual Tuning Method

The PID controller parameters can be tuned by the manual tuning methods in order to get the satisfied performance. In this method, the mathematical is not required[20]. The procedures of manual tuning method are as follow:

i. Setting all gains to zero.
ii. Increasing gain $\mathrm{K_p}$ until the oscillations of the system are oscillated regularly
iii. Increasing gain $\mathrm{K_d}$until the oscillations are eliminated.
iv. Repeating steps 2 and 3 until the increasing of gain $\mathrm{K_d}$does not prevent the oscillations.
v. Setting K_P and K_d to the last stable values.
vi. Increasing the gain $\mathrm{K_i}$until oscillations desired is obtained.

3.4.3 Mathematical Calculation of COHEN COON

In C-C PID tuning method, there are some values need to be determined in order to obtain the parameters values as illustrated in Figure 3.3[20].

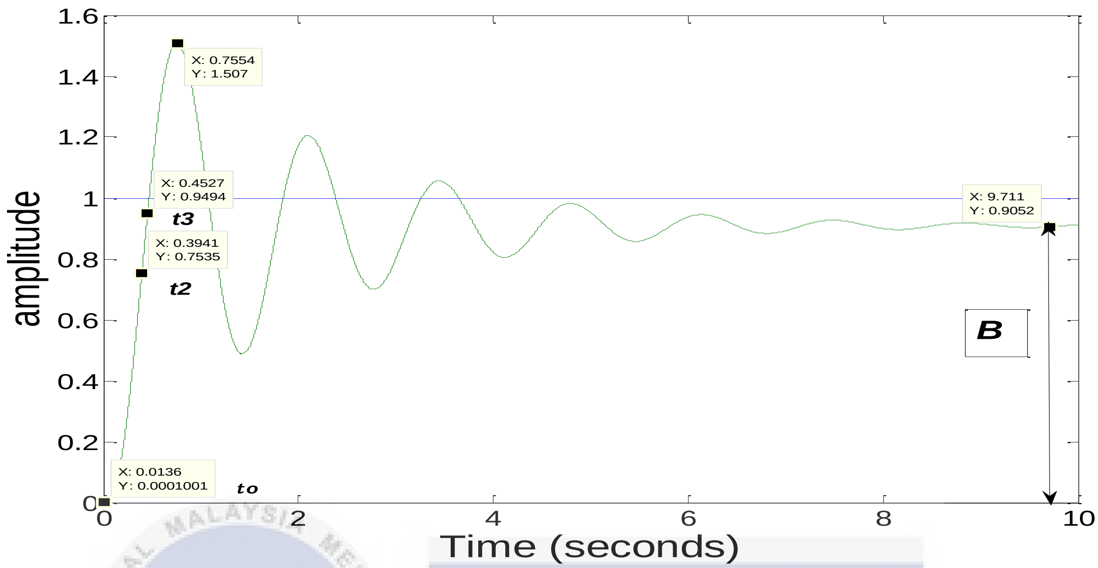

Figure 3-3: Parameters Values of t_0, t_2 and t_3

t_0 = Initiated time (0s)

t_2 = Half time of peak point(1.4s)

t_3 = 63.2% of peak point time (1.467s)

B = Obtain from steady state error line (0.9052)

A = Input value (1)

The pervious values are used to calculate thet_1,τ ,τ_{del}, K and R in following formulas:

$$t_1 = \frac{t_2 - ln(2)t_3}{1 - ln(2)} \tag{3.4}$$

$$\tau = t_3 - t_1 \tag{3.5}$$

$$\tau_{del} = t_1 - t_0$$ (3.6

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$$K = \frac{B}{A} \tag{3.7}$$

Then, substitute these t_1, τ, τ_{del}, K and R in formulas in table 2.4 to get the PID parameters.

3.4.4 Mathematical Calculation of C-H-R

The parameters of PID controller according C-H-R to are computed by using the following procedures[23]:

i. Obtaining the response of AVR system without PID controller.
ii. Determining the equivalent time constant *T*, equivalent dead time *L* and inflection point K_m values as illustrated in Fgure 3.
iii. Substituting these values *L*, *T* and K_m in formulas of Table 2.6 to get the PID controller parameters.

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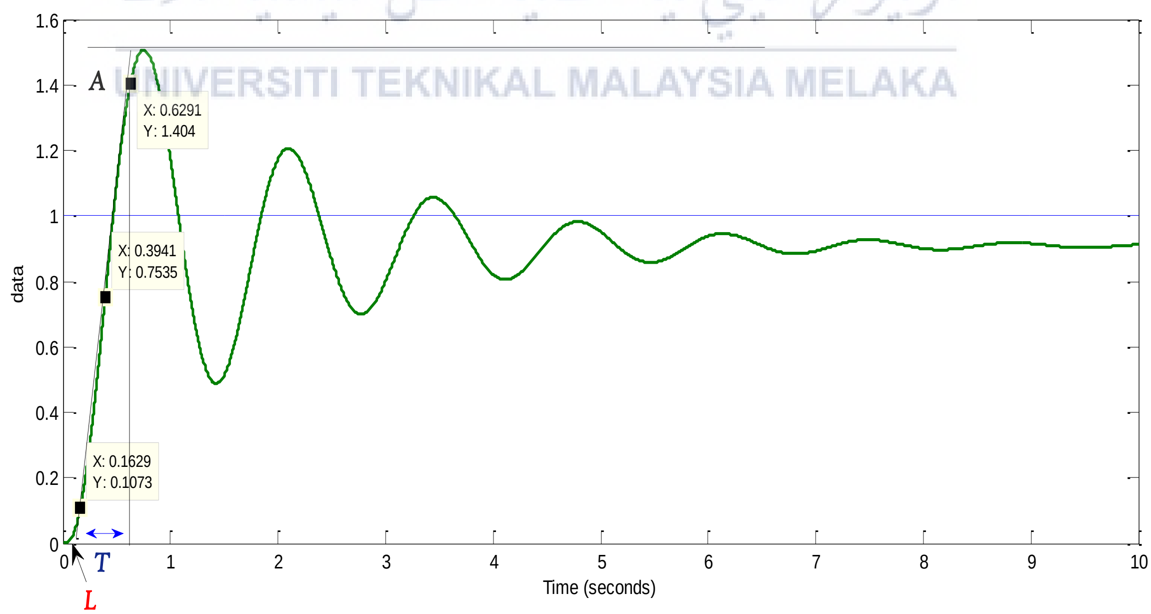

Figure 3-4:Variable Values of *L*, *T and* K_m

From the above figure3.4 the values obtain are:

L = 0.1629

T = 0.3941

K_m = 0.6291

3.5 MATLAB /Simulation Software

Simulink is tool in MATLAB software and it is an environmentally block diagram for Model-Based Design and multidomain simulation. It helps design of system-level, automatic code generation, simulation, and verification of embedded systems continuous test and. The graphical editor, customizable block libraries, solvers for modeling system and simulating dynamic system is provided by Simulink tool. Further, It is enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis[24].

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In this project, MATLAB software is used to simulate the PID tuning methods of the AVR model to validate the controller. The results obtain from the simulation will be compared with each other to state the better performance method in term of the settling time, raise time, overshooting and steady-state error. The simulation of AVR system with PID controller is shown in figure 3.3.

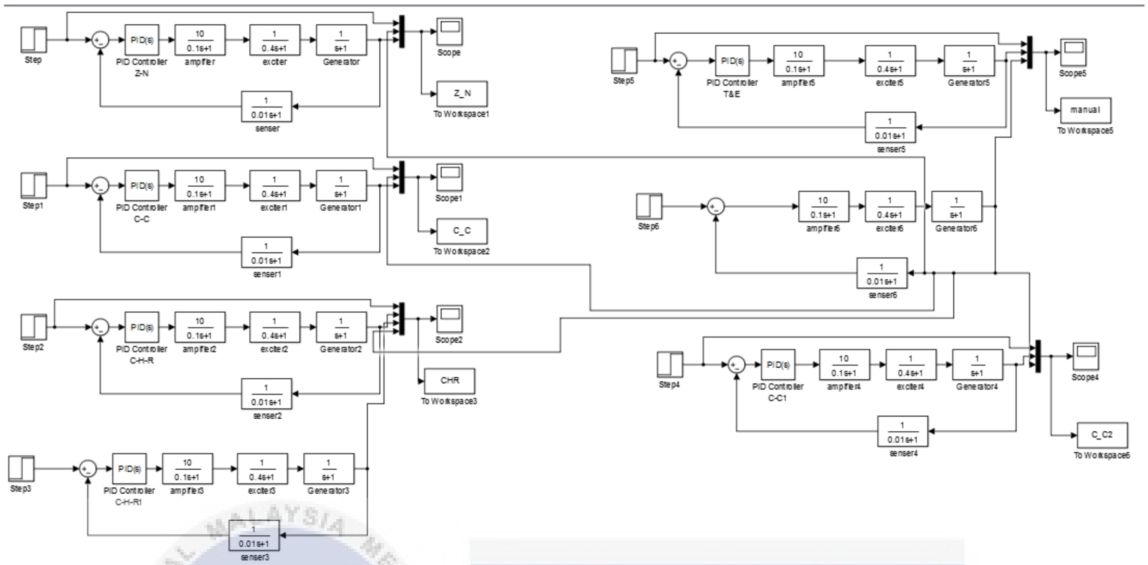

Figure 3-5: The Simulink Modeling of AVR System with PID Controller

3.6 Mathematical Model of Time Response

The time response is a plot or an equation that explain the performance of the system. The time response consists of settling time, raise time, overshooting and steady-state error. It is a combination of transient response and steady-state error. Figure 3.4 illustrate the time response contains[25].

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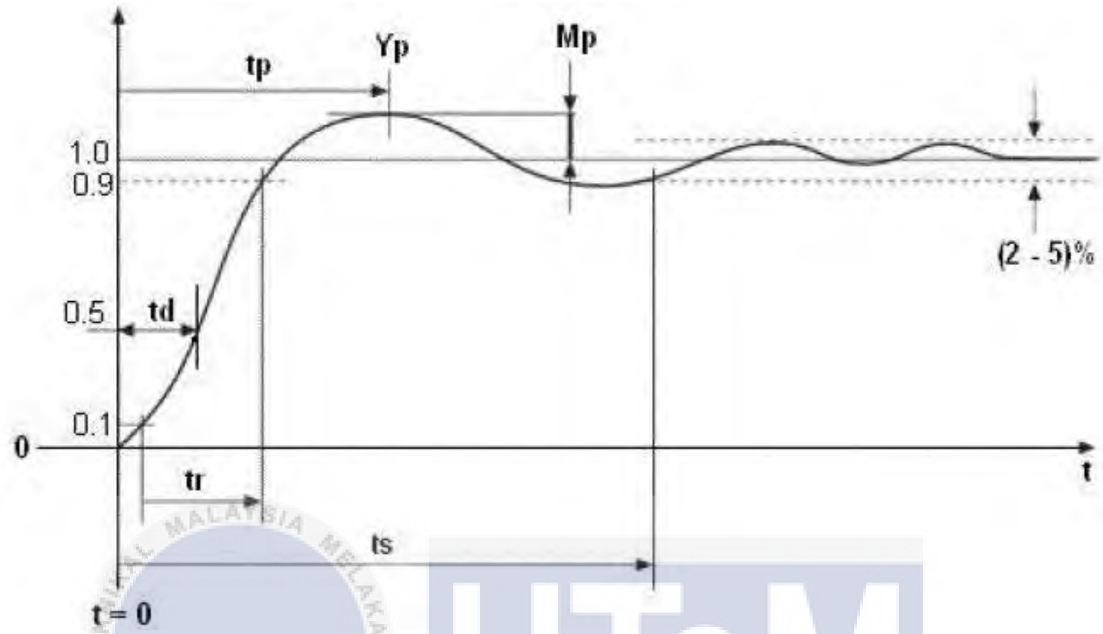

Figure 3-6: Illustration of Time Response.

Peak Time (T_p): is the required time to reach the maximum value.

Rise Time (T_r): is the required time for response to rise from 0.1 to 0.9 of its final value.

Settling Time (T_s): is the required time for response to reach and stay within two percent of its final value.

Percent of Overshoot (OS %): is the difference between the peak response and steady state response.

Steady-State Error (e_{ss}): is indication of error between the desired output and actual input.

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CHAPTER 4

RESULT

In this chapter, the result will be discussed to show the effect of PID controller by various PID tuning methods for AVR system. The results are obtained by using the Simulink tool in MATLAB program, and then it will be compared and discussed in term of time response. Figure 4.1 shows the performance of PID controller for AVR system. The green ripple is the performance of AVR without controller whereas the other ripples are AVR performance with PID controller tuned by Ziegler Nichols, Cohen coon, CHR and manual tuning methods. Regarding to these ripples we can notice the affection of PID tuning methods to an AVR system

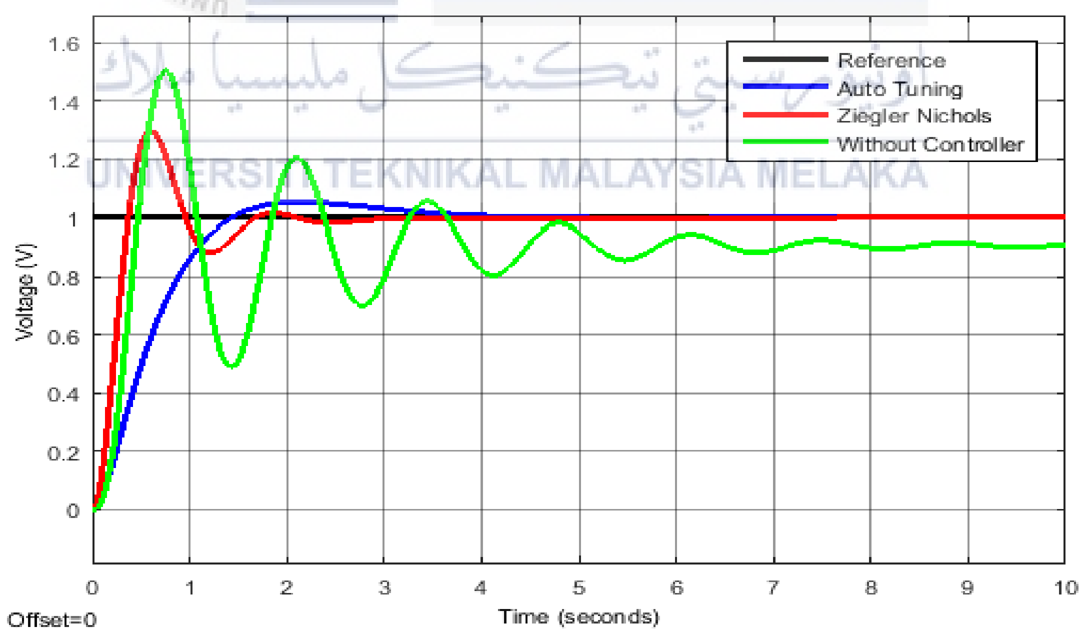

Figure 4-1: PID Control Performance For AVR

4.1 Result and Discussion

The result of each PID tuning methods will be discussed in individually by comparing with original system and finally the transient response parameters are combined in one tables and analyzed together.

4.1.1 Zeigler Nichols Method

Figure 4.2 shows the performance of PID controller tuned by Ziegler Nichols method for AVR system.

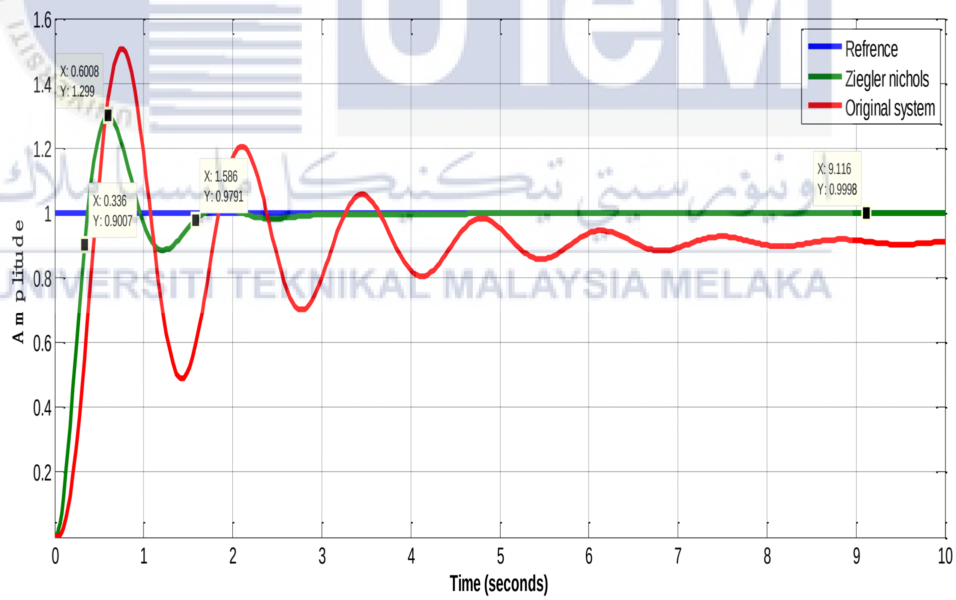

Figure 4-2:PID Z-N Performance for AVR

According to the Figure 4.2, the performance of the Z-N tuning method for PID controller is obviously improved compared to the performance of the original AVR system. Whereas, the transient responses of the Z-N tuning method achieved better performance in terms of faster rise and settling times, lower overshoot and approximately eliminated steady-state error as stated in Table 4.1.

Table 4-1 Transient response analysis values of PID Z-N method

Time response / method	T_s	T_r	OS%	e_{ss}
Ziegler Nicolas	1.589s	0.2512s	29.84	0.0001
Original system	9.108	0.2812	59.2	0.1

4.1.2 Manual Tuning Method

The result performance of Manual PID tuning methods for AVR system is shown in Figure 4.3.

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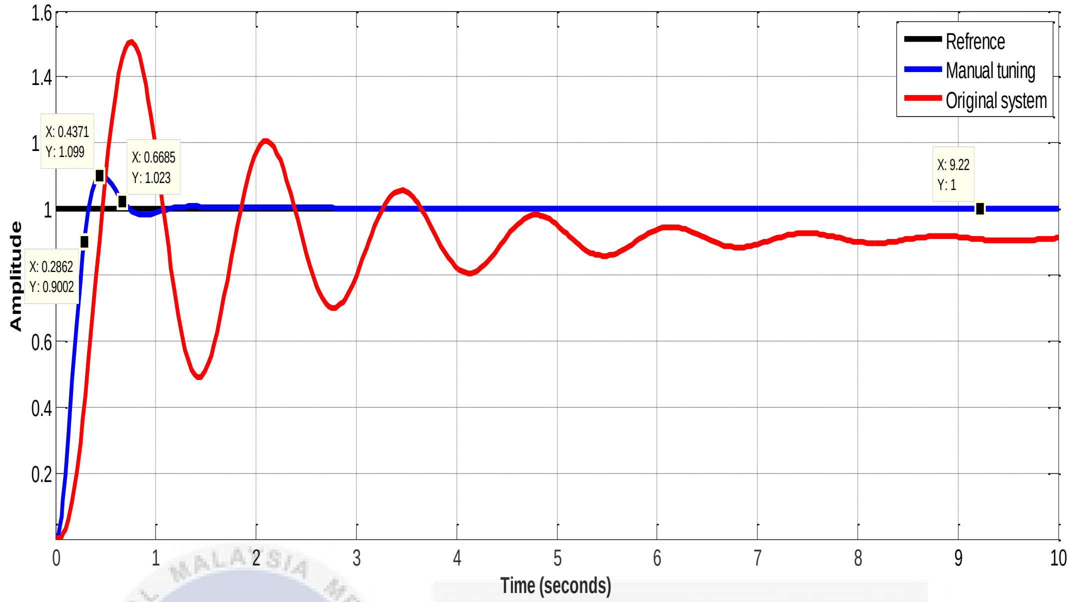

Figure 4-3: PID Manual Tuning Performance for AVR

The simulation result of PID controller as shown in Figure 4.3 displays transient response of Manual tuning method for AVR system. The performance of AVR system tuned by has greatly improved compared to the original system performance. Hence, the Manual tuning method has short settling and rise time, low overshoot and zero steady state error as tabulated in Table 4.2

Table 4-2: Transient response analysis values of manual method

Time response / **method**	T_s	T_r	**OS%**	e_{ss}
Manual tuning	0.6854s	0.2176s	10.11	0
Original system	9.108	0.2812	59.2	0.1

4.1.3 Cohen coon (C-C) Method

The result performance of AVR system tuned by C-C method PID controller shows in Figure 4.4.

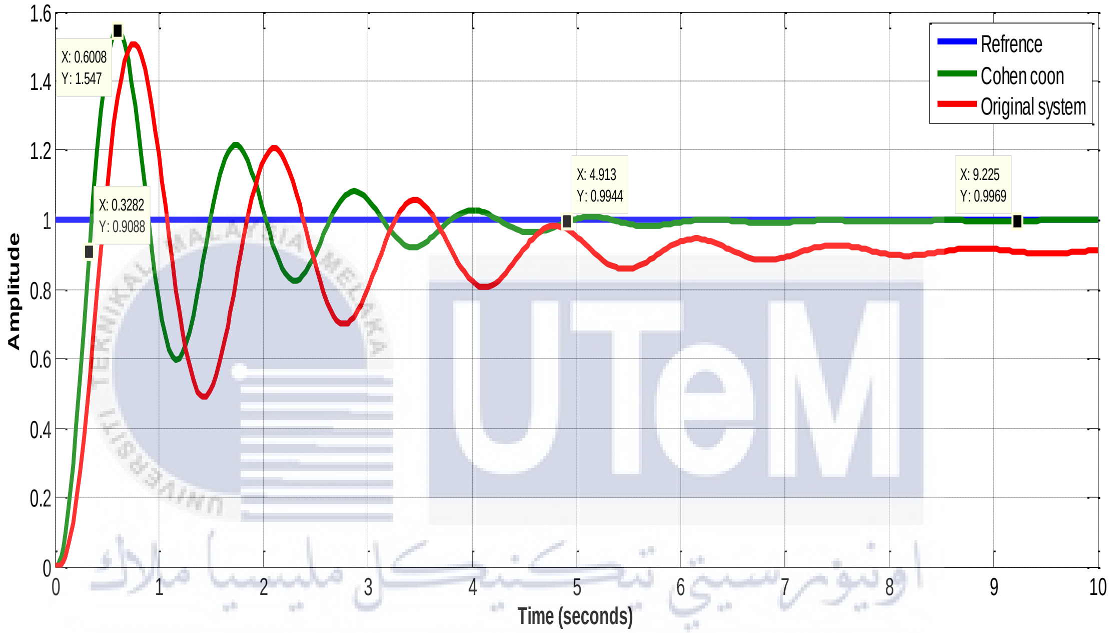

Figure 4-4: PID C-C Performance for AVR

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Regarding to Figure 4.4, the simulation result of PID C-C tuning method compared to the original AVR system performance. The transient responses of Cohen coon tuning method and AVR original system have approximately similar overshoot and rise time whereas the C-C tuning method has lower settling time and considered eliminated steady-state error as stated in Table 4.3.

Table 4-3:Transient response analysis values PID C-C method

Time response / method	T_s	T_r	OS%	e_{ss}
Cohen coon	4.918s	0.2237s	54.59	0.001
Original system	9.108	0.2812	59.2	0.1

4.1.4 Cohen coon C-C2

The Figure 4.5 shows the result performance of AVR system controlled by PID controller. The controller has been tuned by C-C2 method in another way where the Half time of peak point t2 and 63.2% of peak point time t3 have multiplied by two.

According to result of simulation in Figure 4.5 of AVR system tuned by PID C-C2 tuning method, the transient response of C-C2 tuning method has lower overshoot than the original system and Cohen coon C-C. In contrast, the C-C2 tuning method has nearly similar rise time with the original system and Cohen coon. In addition, the settling times of C-C2 tuning method and Cohen coon are almost closed to each other, while the original system has higher settling time. The steady-states errors of both C-Cs are approximately eliminated compared to the original system as stated in Table 4.4

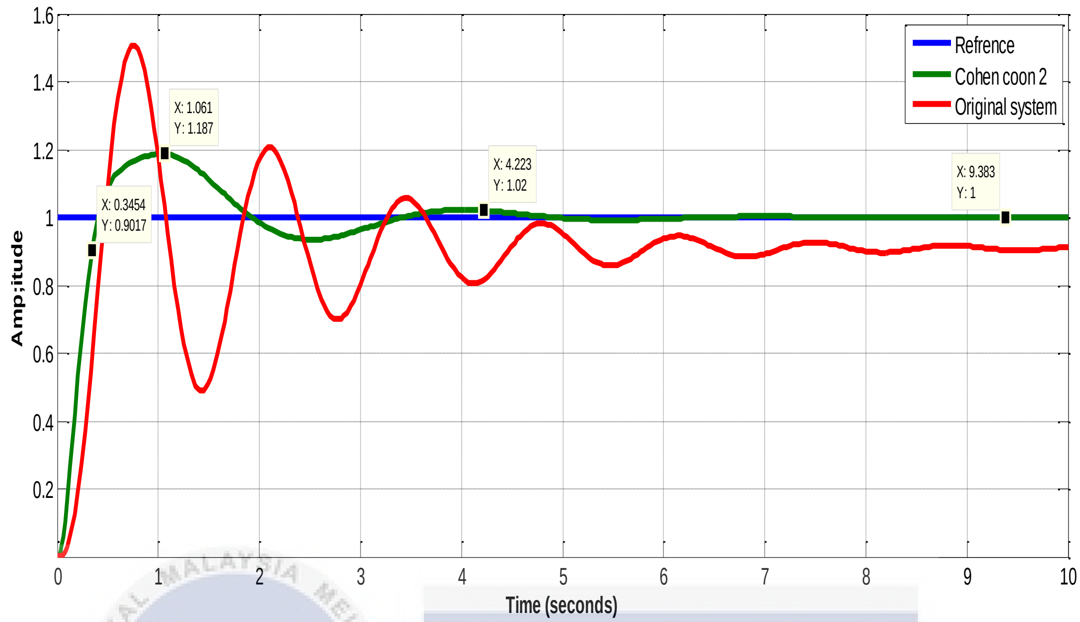

Figure 4-5: PID C-C2 Performance for AVR

Table 4-4: Transient response analysis values PID C-C2 method

Time response / method	T_s	T_r	OS%	e_{ss}
Cohen coon	4.918s	0.2237s	54.59	0.001
Cohen coon 2	4.2223s	0.2683s	18.81	0.0002
Original system	9.108	0.2812	59.2	0.1

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4.1.5 Chien, Hrones and Reswich C-H-R Zero and 20 Percecnt

The result performance of C-H-R PID tuning method for AVR system is shown in Figure 4.6 in both “quickest response with 20% overshoot” and “quickest response without overshoot”.

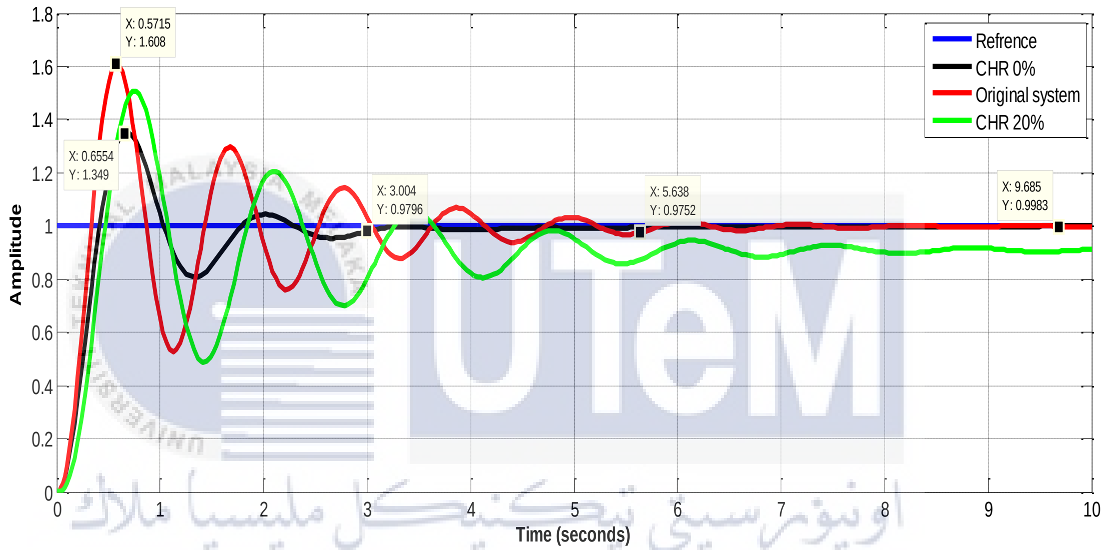

Figure 4-6: PID C-H-R 0% & 20% Performance for AVR

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The performance result of simulation of PID C-H-R tuning method for the AVR system shows the transient responses of both CHR 0% and 20% overshoot as shown in Figure 4.6. The CHR 0% overshoot has the lowest settling time and overshoot compared to CHR 20% overshoot and original system. On the other hand, the CHR 0% and 20% overshoot have nearly similar rise time in comparison with original AVR system. The steady-state error CHR 0% and 20% overshoot is almost eliminated as stated in Table 4.5

Table 4-5: Transient response analysis values PID C-H-R method

Time response / method	T_s	T_r	OS%	e_{ss}
Zero overshoot	3.0076s	0.2743s	35.3	0.001
20% overshoot	5.6807s	0.211s	61.2	0.002
Original system	9.108	0.2812	59.2	0.1

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4.2 Summary of Results

The implementation of various PID tuning methods have been implemented for the automatic voltage regulator system successfully and the results have been discussed in term of settling time T_s,rise time T_r ,overshoot OS% and steady-state errore_{ss} . All the pervious performance results have been compared with the original performance of the AVR system to show the effectiveness of PID tuning methods for the system as stated in Table 4.6. Further, the results performance of PID tuning methods have compared and analyzed together based on transient response to find out the most effective and capable method for the AVR system as illustrated in subsequent Figures.

Table 4-6: Comparison of all PID tuning methods performance

Time response / method	T_s	T_r	OS%	e_{ss}
Original system	9.108	0.2812	59.2	0.1
Ziegler Nicolas	1.589s	0.2512s	29.84	0.0001
Manual tuning	0.6854s	0.2176s	10.11	0
Cohen coon	4.918s	0.2237s	54.59	0.001
Cohen coon 2	4.2223s	0.2683s	18.81	0.0002
Zero overshoot	3.0076s	0.2743s	35.3	0.001
20% overshoot	5.6807s	0.211s	61.2	0.002

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4.2.1 Settling Time Analysis

The Figure 4.7 illustrates the settling times of all the PID tuning methods used to enhance the performance of AVR system. Additionally, the analyzed results of settling time showed a large range amongst all identified PID tuning methods. Thus, Manual tuning method has achieved the shortest settling time among all methods.

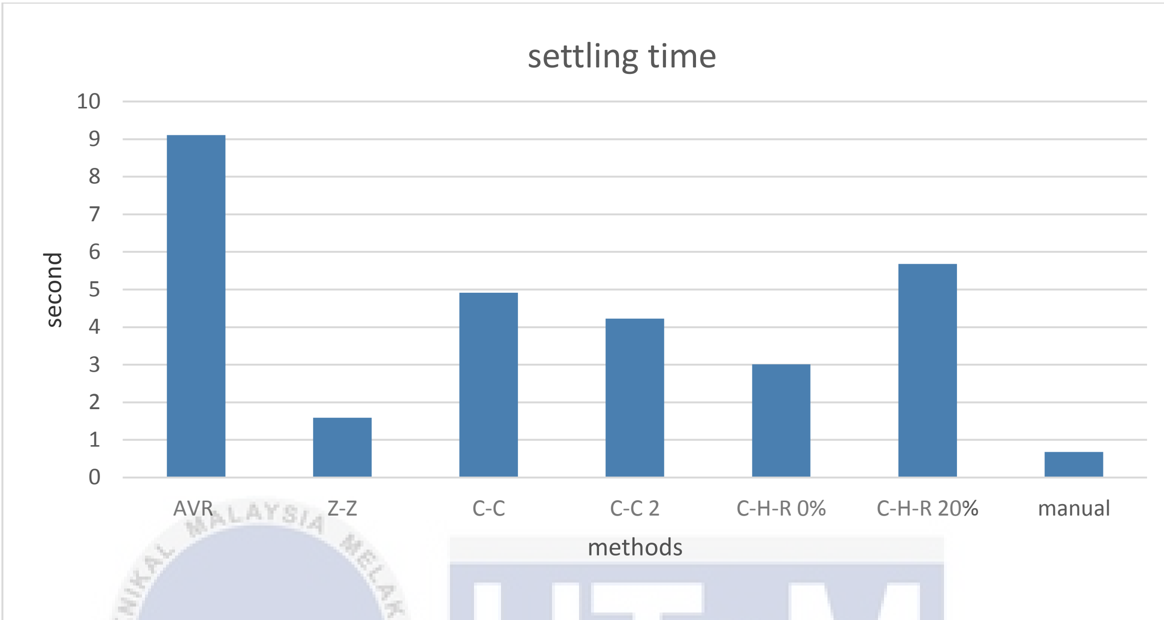

Figure 4-7:Analysis of Settling Time of All Results

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4.2.2 Rise Time Analysis

The comparison of rise time amongst the used PID tuning methods for the AVR system has shown in Figure 4.8. However, the results of rise time are ranged between 0.21s and 0.28s where they are nearly closed values. Hence, the C-H-R and Manual methods approximately recorded the shortest rise times respectively.

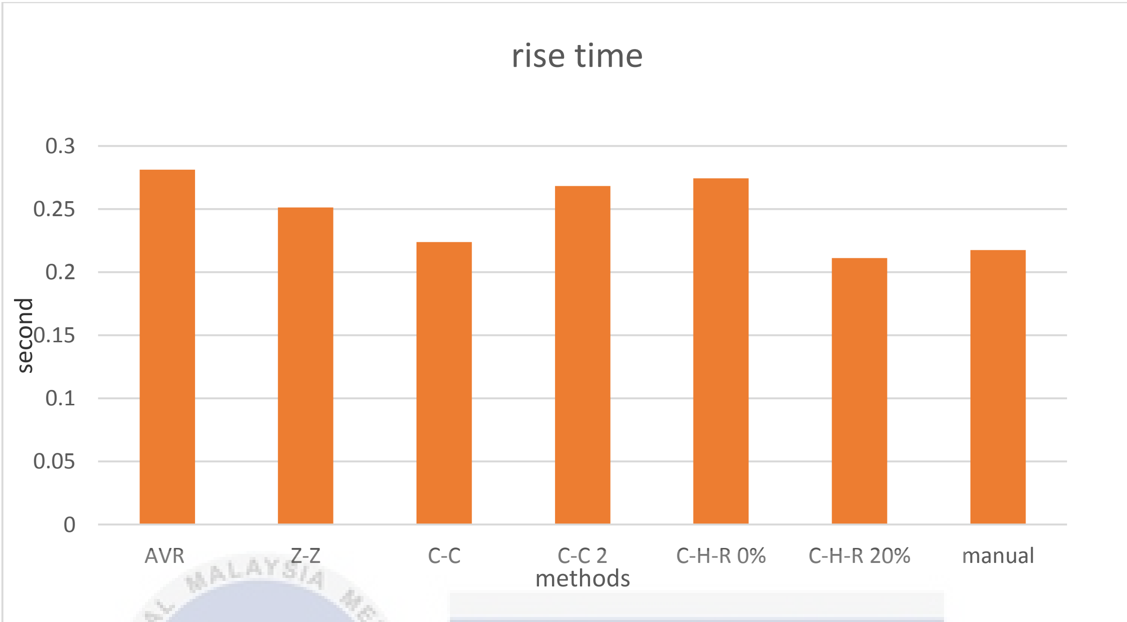

Figure 4-8: Analysis of Rise Time of All Results

4.2.3 Overshoot Analysis

The analysis of overshoots of PID tuning methods for AVR system is showed in Figure 4.9. Furthermore, the values of all overshoots have recorded different range of decreasing among the PID tuning methods. Consequently, Manual and Cohen coon2 methods have accomplished the lowest overshoot compared to others PID tuning methods.

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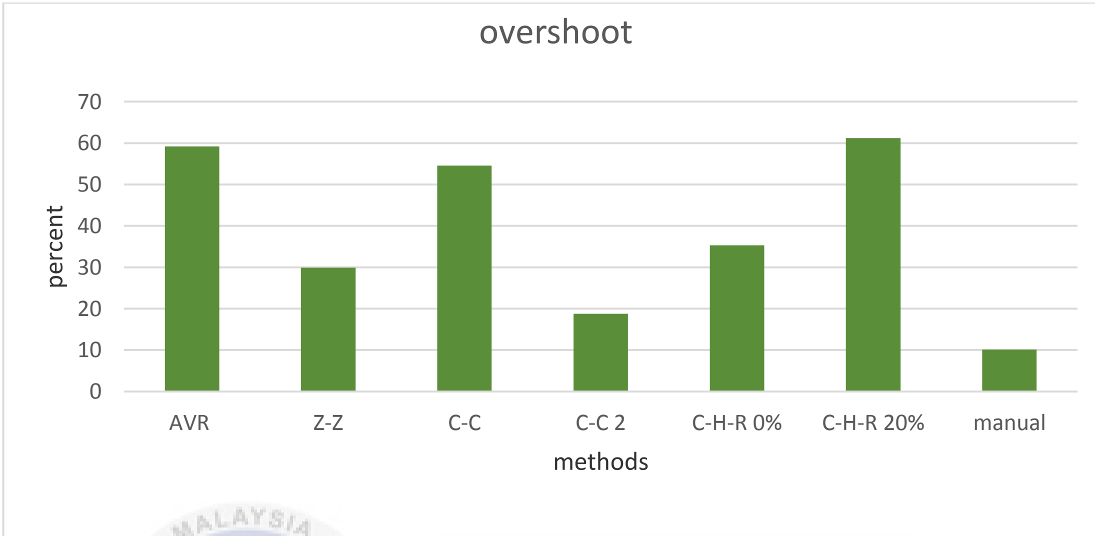

Figure 4-9: Analysis of Overshoot of All Results

4.2.4 Steady-State Error Analysis

The Figure 4.10 illustrates the analysis of PID tuning methods in term of steady-state error. Generally, the steady state error of all methods has considerably eliminated whereas steady-state error of Manual tuning method has eliminated totally.

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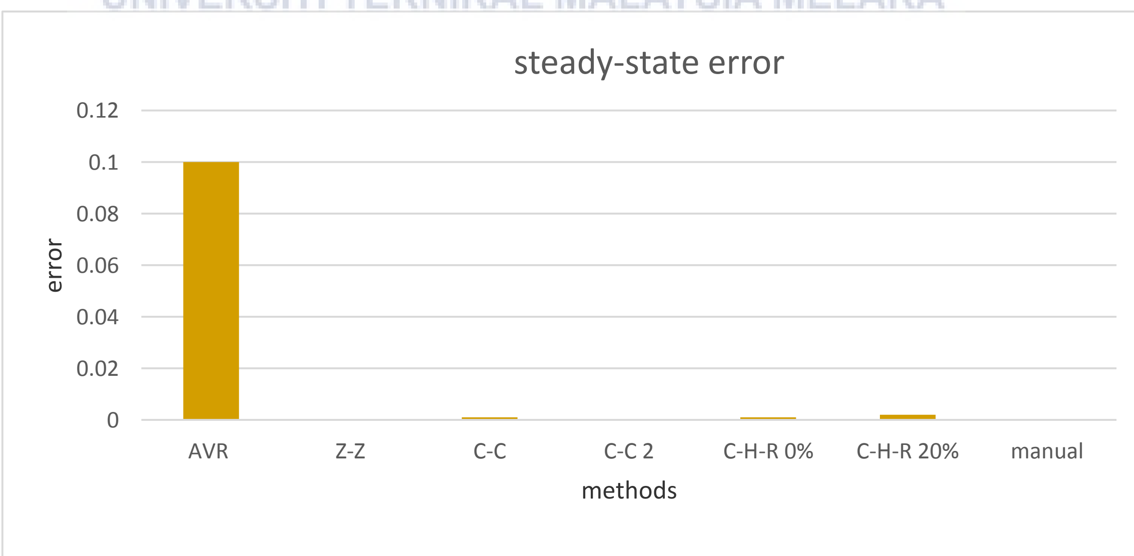

Figure 4-10: Analysis of Steady State Error f All Results

4.2.5 A Critical Analysis for AVR System

The critical analysis for the AVR system is stand for the stability and the number of peaks in impulse response respecting to input response. For that reason, A system is stable if every bounded input produces a bounded output[26]. Figure 4.11 illustrate the different types of stability for impulse response.

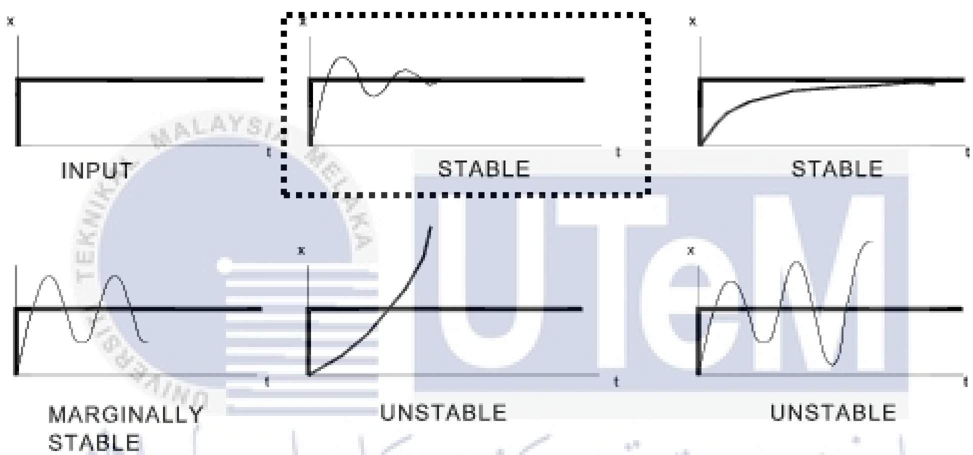

Figure 4-11: Stability Types for Impulse Response

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According to dashed rectangular in Figure 4.11, all PID tuning methods have achieved this type of stability by referring to figures [4.2-4.6]. Also, the steady state errors have an important role in the stability of system where they have been approximately eliminated. In the term of peaks numbers, all PID tuning methods have decreased the peaks numbers compared to the original system as shown in Figure 4.12. hence, the much number of peaks will affect the life span of the system performance.

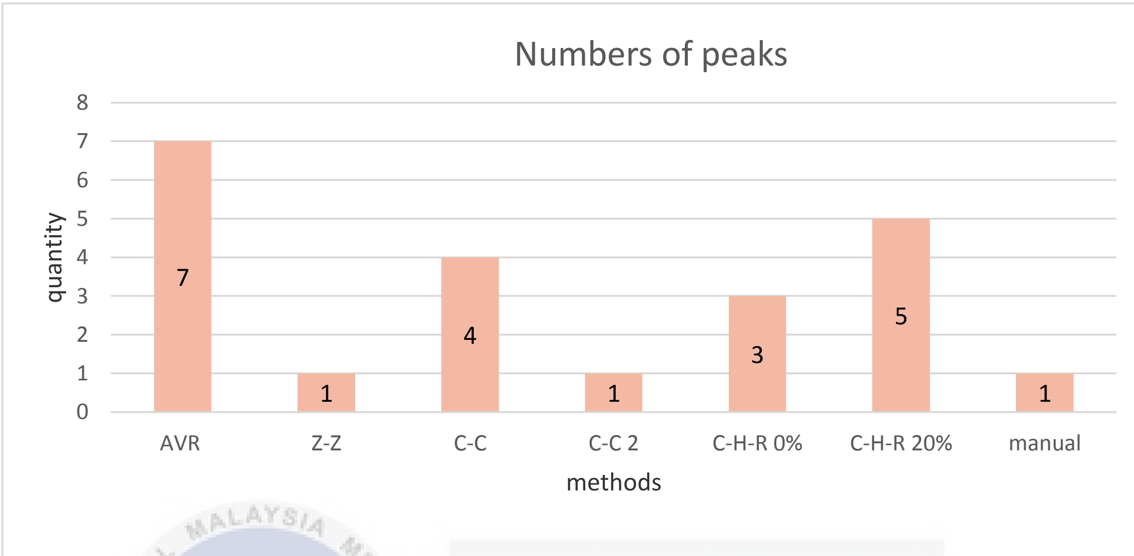

Figure 4-12: Numbers of peaks for each method

To summarize, one of the more significant findings to emerge from this study is that manual tuning method is most effective and capable PID tuning methods for the AVR system since it has more features in term of the shortest settling time $\boldsymbol{T_s}$, reasonable rise time $\boldsymbol{T_r}$, acceptable overshoot OS% and eliminated steady-state error $\boldsymbol{e_{ss}}$. Further, the manual tuning method has achieved the stability criteria and reduced the peaks number from seven peaks to one peak. Nevertheless, this method requires long time to obtain the satisfied performance.

CHAPTER 5

CONCLUSION and FUTURE WORK

5.1 Conclusion

As a conclusion, the AVR system is significant device since its role to keep the magnitude of voltage at constant level and save the apparatus from unexpected change in input supply. The model of AVR system has been investigated and PID controller has been designed by manual, Ziegler Nichols Z-N, Cohen coon and C-H-R methods for AVR system. Regarding to the simulation of AVR model with PID controller, the result shows the manual has the better performance based on the time response compared to others tuning methods and AVR original system without controller.

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5.2 Future Work

The future work for this project are:

i. Design and analyze PID controller by different tuning methods for AVR system.
ii. Control the AVR system by fuzzy logic controller and others controller.
iii. Analyze the result performance of tuning methods in term of time response and number of ripples.
iv. Compare the result performance of AVR system controlled by different controller to state the most competent for AVR system.

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