"I hereby declare that I have read through this report entitled "A Critical Analysis of PID Tuning Methods for Automatic Voltage Regulator system" and found that it complies the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering"

Signature: ....

Supervisor's Name: IR. Fauzal Naim Bin Zohedi.

Date: ....

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

Faculty of Electrical Engineering

UNIVESITI TEKNIKAL MALAYSIA MELAKA

2018

I declare that this report entitled “A Critical Analysis of PID Tuning Methods for Automatic Voltage Regulator system” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: ....
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Date: ....

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.

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].

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

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.

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:

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.

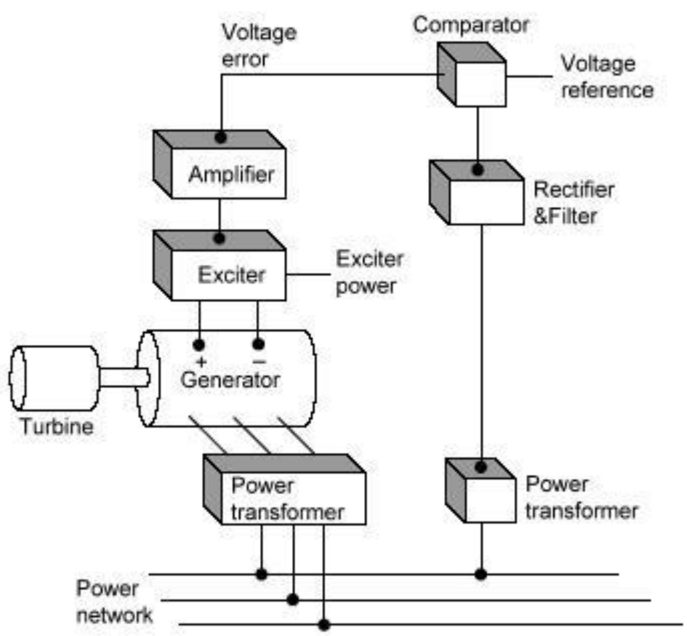

Figure 2-1: The Real Model of The AVR System

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

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).

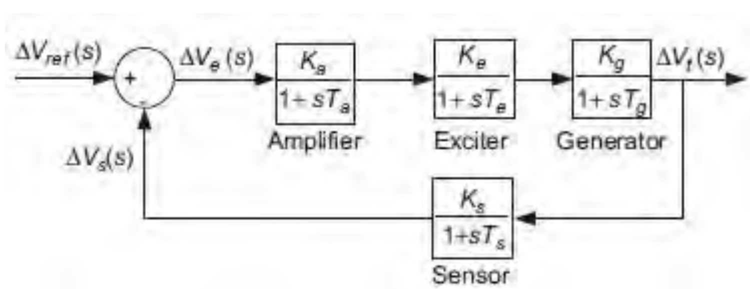

Figure 2-2: Model of the Automatic Voltage regulator (AVR)

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

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

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

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

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

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

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].

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]:

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

WhereK_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].

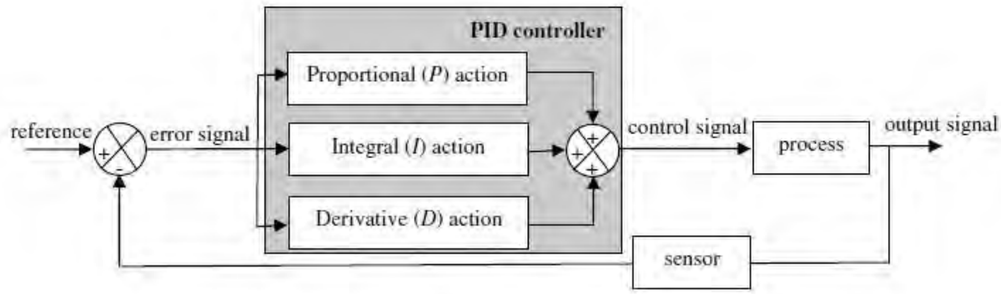

Figure 2-3: Closed Loop Block Diagram of PID Controller

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].

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].

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].