DESIGN AND PERFORMANCE ANALYSIS OF TUNING CONVENTIONAL CONTROLLERS AND FUZZY CONTROLLER PID APPROACH FOR AUTOMATIC VOLTAGE REGULATOR

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Abstract- This paper presents analysis of time response of Automatic Voltage Regulator for effective voltage control, with stabilizer and Fuzzy Proportional Integral Derivative Controller using a fast computing MATLAB Simulation. In this paper, a simulation study is carried out to understand the operation of voltage controller by developing models in SIMULINK. The simulation study helps students to understand the principle and challenges behind voltage controller.
Keywords— Automatic Voltage Regulator, PI controller, PID controller and Fuzzy-PID controller

I. INTRODUCTION

Power system is a combination of generation, transmission and distribution networks and loads. The active and reactive power demands from different loads vary continuously. The change in real power demand affects the frequency while the change in the reactive power affects the voltage [1]. Automatic voltage regulator plays a vital role in power system in order to regulate the output voltage at a nominal constant voltage level. The main functions of AVR are to detect terminal voltage, compare with the voltage setter and regulate field current via the exciter. The stability of the AVR system is of great concern because it can seriously affect the security of the power system. The excitation system must contribute for the effective voltage control and enhancement of the system stability. It must be able to respond quickly to a disturbance enhancing the transient stability and the small signal stability [2]. In the power system, the excitation system maintains the effective voltage control for reactive power flow and enhancement of the system stability. Three principal control systems directly affect a synchronous generator: the amplifier, exciter and generator control. In most modern systems the automatic voltage regulator (AVR) is to hold the terminal voltage magnitude of a synchronous generator at a specified level. An increase in reactive power load of the generator is accompanied by a drop in the terminal voltage. The voltage magnitude is sensed through a potential transformer on the phase. This voltage is rectified and compared to DC set point. The amplified error signal controls the exciter field and increases exciter terminal voltage. To solve these control problems, which are explained above, an Automatic Voltage Regulator (AVR) system is applied to power generation units. The AVR system is a closed loop control system that provides terminal voltage at the desired value. The A VR controls the terminal voltage by adjusting the exciter voltage of the generator. This increases generated EMF. Because of the high inductance in the generator field winding, it is difficult to make rapid changes in field current. This introduces a considerable lag in the control function and is one of the major obstacles to be overcome in designing a regulating system [3-4]. In this paper, fuzzy logic control of Automatic Voltage Regulator is constructed with fuzzy logic and its performances are evaluated and compare with no controller, PI controller, PID controller and fuzzy controller. The purpose of this work is the development of a different controller of AVR technique.
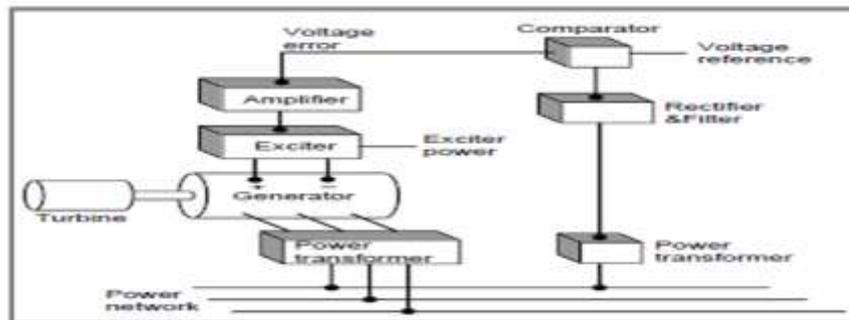
II. AUTOMATIC VOLTAGES REGULATOR

Operation of energy systems is growing rapidly at this time both in science and technology as well as in the industrial world. These developments felt also the supplier of electrical power (PLN) to regulate its supply to the load. This can be seen with the use of well control equipment in the

generation, substation or distribution substation. Control equipment for the generation are usually used to regulate the supply of active and reactive power. Load changes occur very influential on changes in the frequency and voltage. Rise and fall of frequency dependent active power changes, so does the voltage depending on changes in reactive power. This situation opens the mind to the engineers particularly in the field of power systems to find a solution. One of the solutions in managing change in reactive power load in order to use AVR generator voltage stays constant, however, cannot regulate steady-state error due to the dynamic response, because it takes control device that is capable of eliminating [5-6]. An AVR system is used in synchronous generator to hold the magnitude of terminal voltage at a specified level. AVR composes of four main components which are amplifier, exciter, generator and sensor. The simple schematic diagram of an AVR as shown in figure 1.
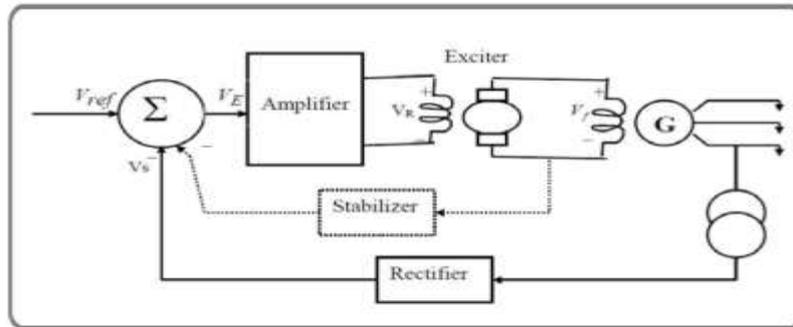
Figure 1 Automatic Voltage Regulator schematic diagram

An increase in the reactive power load of the generator is accompanied by a drop in the terminal voltage magnitude. The voltage magnitude is sensed through a potential transformer. This voltage is rectified and compared to a dc set point signal. The amplified error signal controls the exciter field and increases the exciter terminal voltage. Thus, the generator field current is increased, which results in an increase in the generated emf. The reactive power generation is increased to a new equilibrium, raising the terminal voltage to the desired value and Real model of Automatic Voltage Regulator controller is show in figure 2.

Figure 2 Real model of Automatic Voltage Regulator controller

III. MATHEMATICAL MODELING

An AVR system is used in synchronous generator to hold the magnitude of the terminal voltage at a specified level. It composes of four main components which are named as amplifier, exciter, generator and sensor. Mathematical modeling of these components needs to consider their transfer functions However, nonlinear conditions are not considered in this study.

Amplifier Model

The excitation amplifier magnetic amplifier, rotating amplifier, or modern electronic amplifier. gain K_A and a time constant τA as in transfer function given below

$$\frac{V_R(S)}{V_e(S)} = \frac{K_A}{1+ \tau_A \; s} \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . (1)$$

Exciter Model

The exciter of the synchronous generator is the main component in the AVR loop. The main function of exciter is to provide dc current to the field of synchronous generator. The exciter transfer function is given by

$$\frac{V_F(S)}{V_R(S)} = \frac{K_E}{1 + \tau_E \, s} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

Generator Model

The synchronous machine generated emf is a function of the machine magnetization curve and its terminal voltage is dependent on the generator load. The generator transfer function is given by

$$\frac{V_t(S)}{V_F(S)} = \frac{K_G}{1 + \tau_G \, s} \quad \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

Sensor Model

The voltage is sensed through a potential transformer and, in one form, it is rectified through a bridge rectifier. The sensor is modeled by a simple first order transfer function, given by

$$\frac{V_S(S)}{V_T(S)} = \frac{K_R}{1 + \tau_R \, s} \quad \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

The block diagram of an AVR is shown in figure 3 and AVR system data is given in table 1.
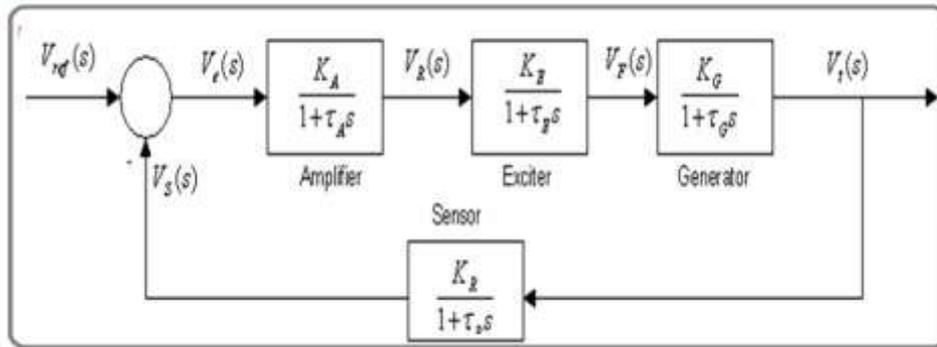

Figure 3 Block diagram Automatic Voltage Regulator system

Table 1. Transfer function of AVR component [7]

Model name	Transfer Function	Parameter Limits	Nominal Values
PID CONTROLLER	$Kp + \frac{K_i}{s} + sKd$	$0.0001 \le K_P, K_I, K_D \le 1.0$	$K_P\,2.1$ $K_I = 0.25$ $K_D = 0.02$
INTEGRAL CONTROLLER	$Kp + \frac{K_i}{s}$	$0.0001 \le K_P, K_I, \le 1.0$	$K_P = 1.8$ $K_I = 0.5$
AMPLIFIER	$\frac{V_R(S)}{V_e(S)} = \frac{K_A}{1 + \tau_A \, s}$	$10 \le K_A \le 40$ $0.02 \le \tau_A \le 1.0$	$K_A = 10$ $\tau = 0.1$
EXCITER	$\frac{V_F(S)}{V_R(S)} = \frac{K_E}{1 + \tau_E \, s}$	$1 \le K_E \le 10$ $0.4 \le \tau_E \le 1.0$	$K_E = 1$ $\tau = 0.4$
GENERATOR	$\frac{V_t(S)}{V_F(S)} = \frac{K_G}{1 + \tau_G \, s}$	$0.7 \le K_G \le 1$ $1.0 \le \tau_G \le 2$	$K_G = 1$ $\tau = 1$
SENSOR	$\frac{V_S(S)}{V_T(S)} = \frac{K_R}{1 + \tau_R \, s}$	$0.001.0 \le \tau_G \le 0.06$	$K_R = 1$ $\tau = 0.01$

IV. PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLING TECHNIQUES

The PID controller is generally used in industry because it is easy to implement and can control the plant optimally [8-9]. The block diagram of Proportional Integrative Derivative (PID) controller is shown in Figure 4.
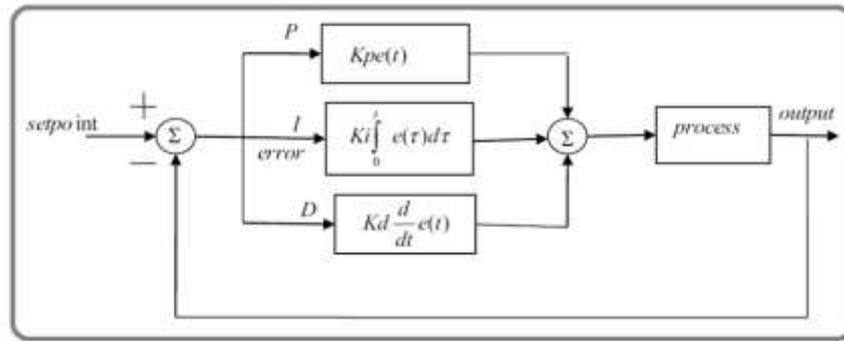
Figure 4 Block diagram representation of a PID controller

The PID controller is the most common form of feedback. The PID control method is most flexible and simple method. This method is more popular among all control methods. In the process control, more than 95% are of control loop are of PID type, most loops are actually PI control. PID controllers are today found in all areas where control is used. The controllers come in many different forms [10]. A Proportional–Integral– Derivative (PID) controller is a three-term controller that has a long history in the automatic control field, starting from the beginning of the last century. P-I-D controller has the optimum control dynamics including zero steady state error, fast response (short rise time), no oscillations and higher stability. The necessity of using a derivative gain component in addition to the PI controller is to eliminate the overshoot and the oscillations occurring in the output response of the system. One of the main advantages of the PID controller is that it can be used with higher order processes including more than single energy storage. In order to observe the basic impacts, described above, of the proportional, integrative and derivative gain to the system response. The tuning parameters are

(a) Proportional Gain (Kp)

Larger values typically mean faster response since the larger the error, the larger the Proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

(b) Integral Gain (Ki)

Larger values imply steady state errors are eliminated more quickly. The trade-off is larger overshoot: any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

(c).Derivative Gain (Kd)

Larger values decrease overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

The effects of each of controller parameters, K_p, K_i, and K_d on a closed-loop system are summarized in the table below 2.

Table 2.1: Effect of controller parameters

Closed Loop Response	Rise Time	Overshoot	Settling Time	Steady State error
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	No Change

V. STRUCTURE OF FUZZY CONTROLLER

Today, there are number of products in the market which are controlled by fuzzy logic [11-12] in which different types of FLC are used, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical

instrumentation, decision-support systems, and portfolio selection, the block diagram of the fuzzy logic controller is shown in Figure 5.
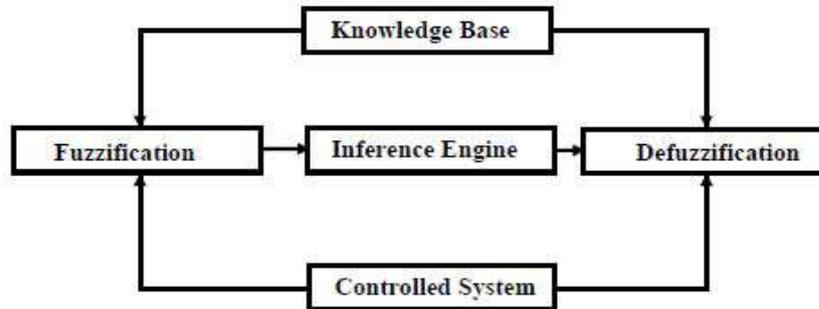

Figure 5 Structure of Fuzzy Controller

In general this type of FLC contains four main parts, two of which perform transformations; which are:

1) Fuzzifier (2) Knowledge base (3) Inference engine (4) Defuzzifier.

Fuzzification measures the values of input variable and converts input data into suitable linguistic values. Knowledge base consist a database and provides necessary definitions, which are used to define linguistic control rules. This rule base characterized the control goals and control policy of the domain experts by means of a set of linguistic control rules. Decision-making logic or inference mechanism is main part of a FLC. It has the capability of simulating human decisionmaking based on fuzzy concepts and of inferring fuzzy control actions employing fuzzy implication and the rules of inference in fuzzy logic. Defuzzification is a scale mapping, which converts the range of values of output variables into corresponding universe of discourse and also yields a nonfuzzy control action from an inferred fuzzy control action. This transformation is performed by Membership Functions (MF). In FLC, number of MF and their shapes are initially determined by use

Design of Fuzzy Logic Controller

In this paper, only two fuzzy membership functions are used for the two inputs error e and change in error membership functions for the output parameter are show here NH means Negative High, NS Negative Small ZE means Zero and PS means Positive Small. In output membership function NH is negative High, NS is negative small, ZE is zero, PS is positive small and PH is positive High. Figure 6, Figure 7 , Figure 8 , Figure 9 are fuzzy FIS, fuzzy error, fuzzy change of error and fuzzy rules (25) and output response are KP.KI,KD are show in figure 10, Figure 11 and Figure 12.
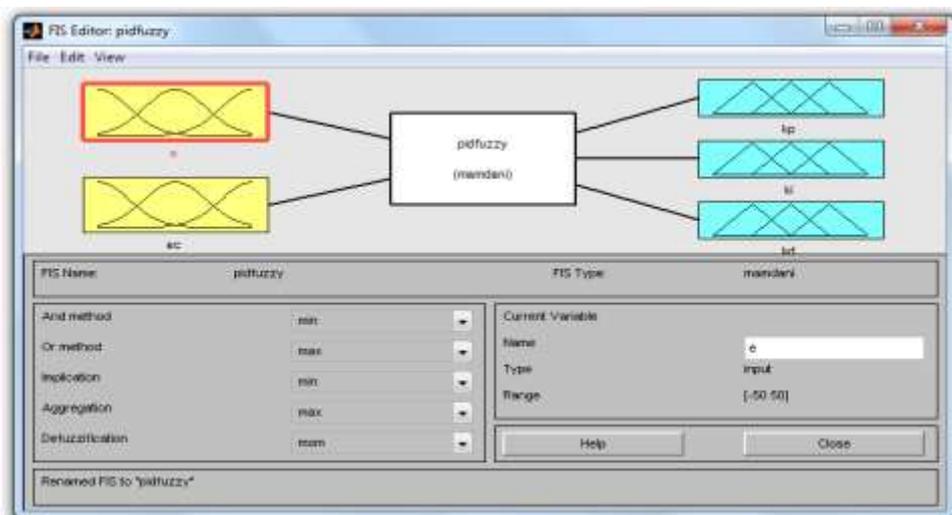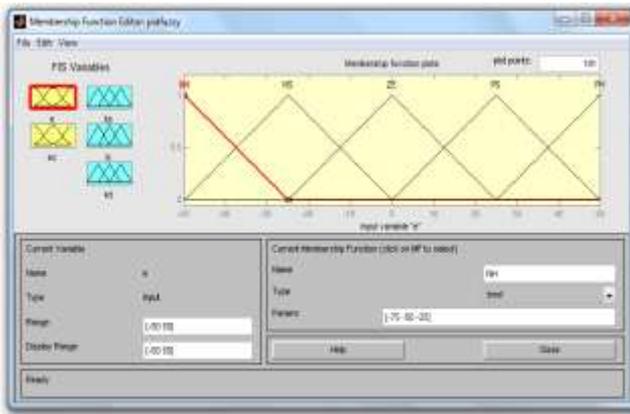

Figure 6 fuzzy FIS
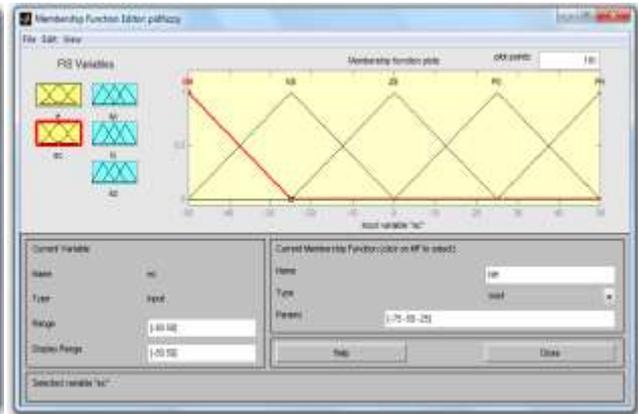
Figure 7 fuzzy error

Figure 8 fuzzy change of error
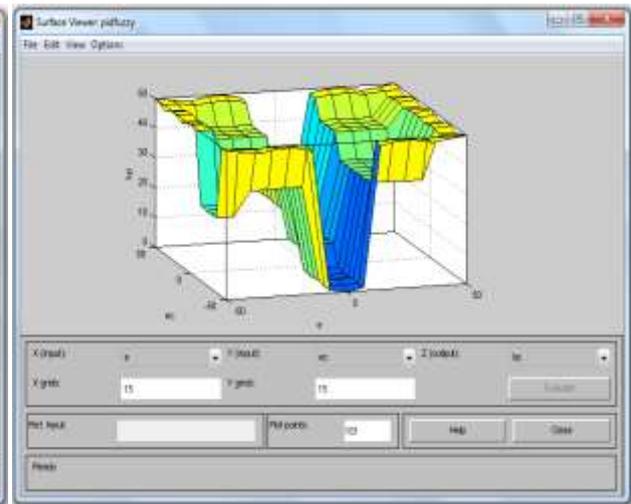

Figure 9 fuzzy rules (25)

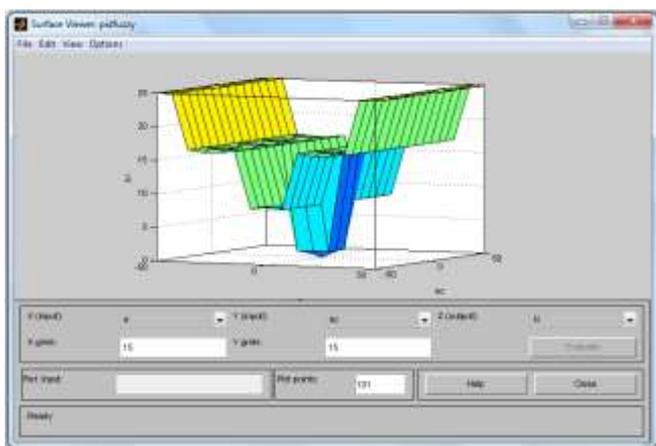

Figure 10 output response of KP
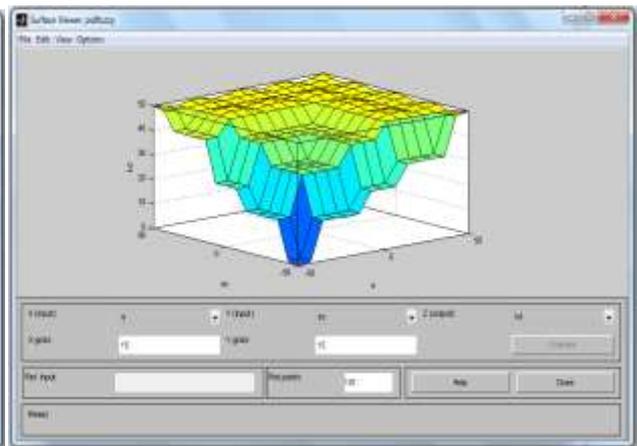

Figure 11 output response of KI

Figure 12 output response of KI

VI. RESULTS OF AVR SYSTEM

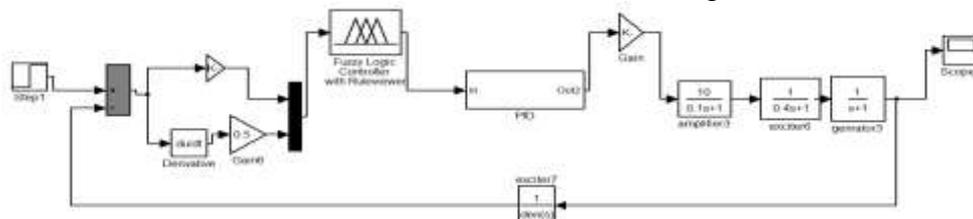The FUZZY-PID AVR MATLAB SIMULINK model is show in figure 13

**Figure 13 Fuzzy-PI AVR Matlab Simulink Model**

Response of output AVR System under study AVR system tune with-out Controller response figure 14, PI-response AVR tune controller figure 15, PID response AVR tune controller figure 16 and fuzzy-PID response AVR tune controller is shown in Fig 17 and combined all controller AVR tune response is show in figure 18.
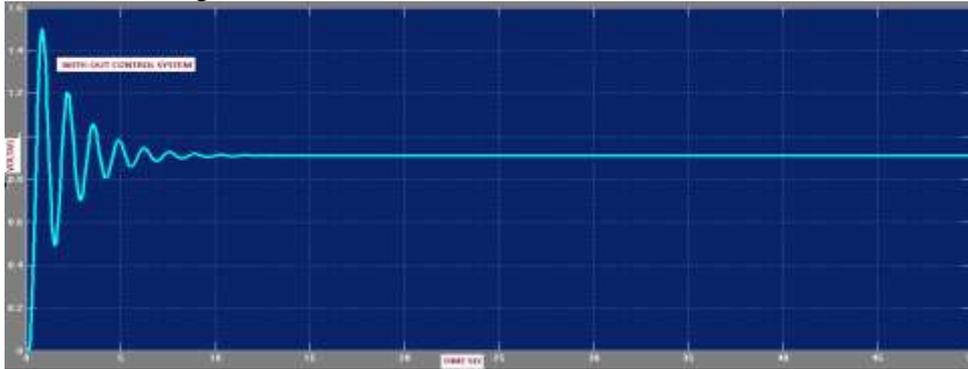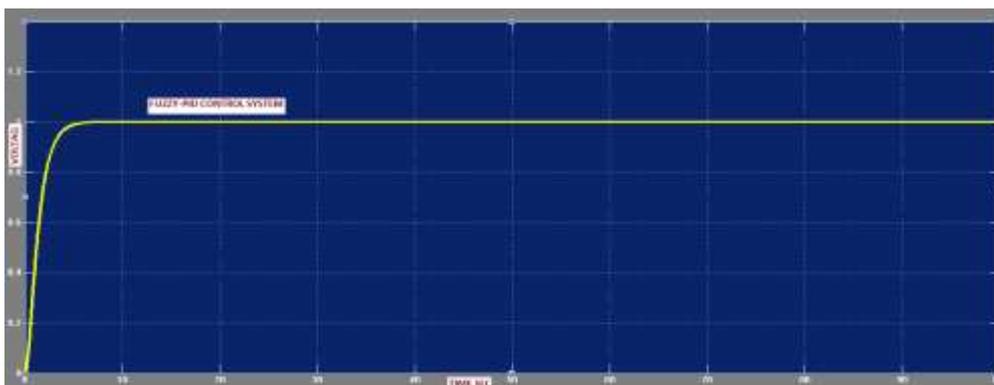

Figure 14 AVR system response with-out tune
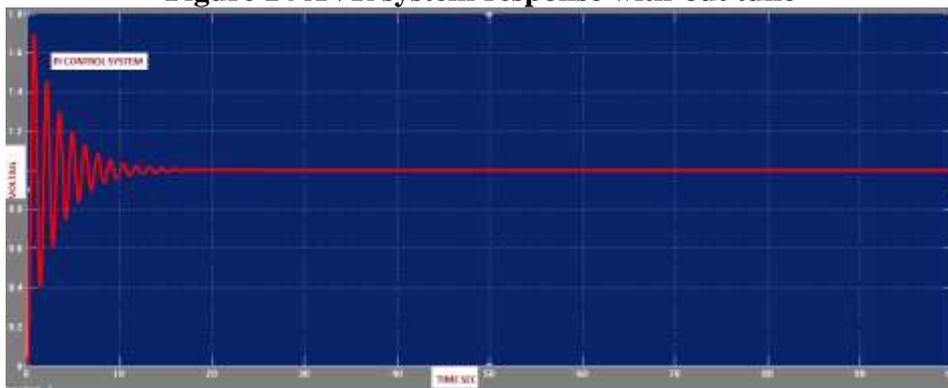
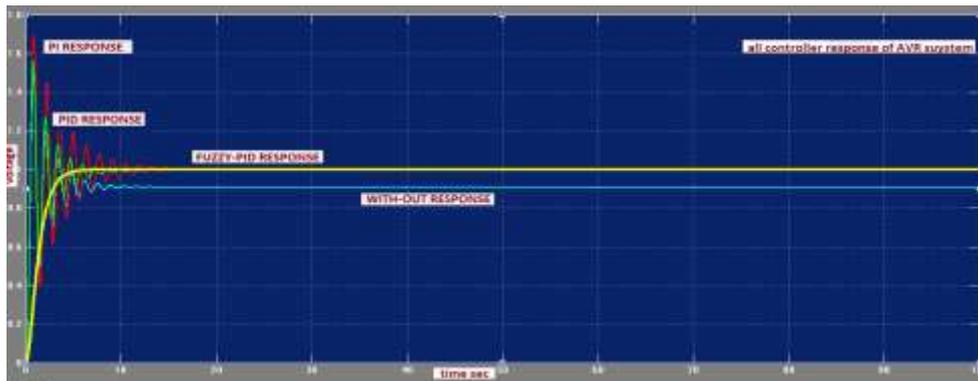**Figure 15 AVR system output response with PI TUNE**
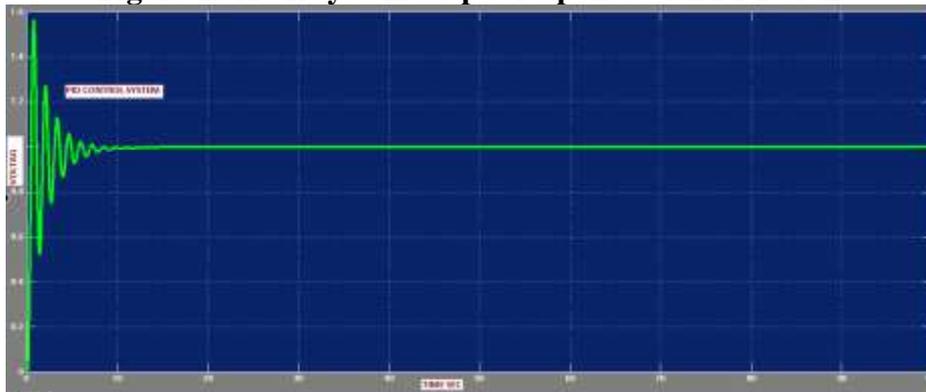
Figure 16 AVR system output response with PID TUNE

Figure 17 AVR system output responses with FUZZY-PID TUNE

Time response parameters settling time and Peak Amplitude for with-out Controller response, with PI-response controller, PID response controller and fuzzy-PID response for AVR SYSTEM is given bellow.

Figure 18 ALL Controller AVR system output response

Table 3 Automatic voltage regulators all controller response

Parameter controller	Peak amplitude	Settling time	System Response
Without Controller response of AVR System	Unstable	Unstable	Unstable
PI- Controller response of AVR System	1.69 sec	11.9 sec	More Oscillation
PID- Controller response of AVR System	1.60 sec	9.74 sec	Oscillation
FUZZY-PID Controller response of AVR System	**1.00 sec**	**5.0 sec**	**No Oscillation**

It is clear from fig 18 and table 3, The FLC controller has not percentage overshoot but without controller, with pi controller and with PID controller has percentage overshoot. The settling time is the time that taken to reach from steady state, for this output response the FLC-PID is better controller than other controller because settling time and peak amplitude is less than other controller and no oscillation with FUZZY PID controller response.

VII. CONCLUSION

In this research paper, the purpose of comparative analysis of the various responses of the AVR system, we simulate all the four MATLAB Simulink models i.e. without controller AVR, PI controller AVR, PID controller AVR and using with FLC-PID Response AVR. Then we combine all the four responses in a single plot. It's clear from the results that without controller are unstable response and PI and PID controller response is more overshoot and oscillation but FUZZY-PID controller is no oscillation response with stable response so Fuzzy logic controller is somewhat intelligent than PI and PID controller.

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