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Analysis of AGC and AVR for Single Area and Double Area Power System Using Fuzzy Logic Control

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ABSTRACT: In this paper the study of AGC and AVR taken together. In the power system it is require maintaining the frequency and voltage in a tolerable limit. but due to sudden load variation it is difficult to maintain them in a prescribe limit; so it is necessary to take some control action for this automatic generation control for frequency and automatic voltage regulator for voltage is used. The AGC is used for balancing system generation against system load and losses. Further the role of the AVR is used to maintain terminal voltage of the synchronous generator in order to keep the bus bar voltage in a tolerable limit. By using MATLAB software of version R2010$_{a,}$ the analysis of frequency deviation and voltage variation with time is done for a single area system. By using the controller it can be seen that the deviation of frequency response and voltage is minimized. In this paper the comparison of a conventional controller like PI, PID is done with fuzzy logic controller, and we find that fuzzy controller is better than the conventional controller.

KEYWORDS: Automatic Voltage Regulator (AVR), Automatic Generation Control (AGC), Fuzzy logic – Proportional-Integral-Derivative controller (FPID), Proportional-Integral-Derivative controller (PID), Proportional-Integral controller (PI), Automatic Control Error (ACE).

*I.*INTRODUCTION

One of the most serious problems in a large inter connected power system is to maintain the change of voltage and frequency profile in a definite limit. In this paper, a single and double area power system is considered in which AGC and AVR; both are considered separately. As the frequency depends on the real power generation so for frequency control, we use AGC, and the magnitude of the voltage depends on the reactive power, and it is maintained at its normal value by using AVR. Electric field provided through slip ring and brushes by using dc generators mounted on the same shaft as the rotor of the synchronous machine. However, in a modern excitation system ac generator is used with rectifier, and this is known as brush-less excitation. There are many sources of reactive power some of this are generators, capacitors, and reactors and the reactive power is controlled by using excitation. Electric transmission voltage profile is maintained healthy by using a tap changer transformer; switched capacitor, a step voltage regulator and static vary control equipment. Automatic load frequency control (ALFC) maintains the frequency constant by adjusting the speed of the prime mover of a generating station[1]. The AVR provided for maintain the voltage profile of the bus voltage in a tolerable limit by improving the excitation of the generator. AVR loop is used for providing reactive power balance at a generator bus it means a voltage is maintained at the required level [2]. Many control strategies are used such as PI controllers, decentralized controllers, optimal controllers and adaptive controllers are designed for controlling real and reactive power output. Intellectual computing methods like fuzzy logic (FLC). Genetic algorithms (GA), particle swarm optimization (PSO) are applied for maintain the frequency and voltage control of a synchronous generator [3]. In this paper, a single and double area is considered is which we have used both the AVR and AGC for controlling voltage and frequency at a desired level, in this the conventional controller like PID; PI is compared with fuzzy, and fuzzy-PID controllers; we see that the intelligent controller is better than the conventional controller. By using the mat lab software we have analysis the change of frequency with respect to time and the change of governor power of AGC and voltage with time of AVR. The parameters like settling time, rise time, and steady-state error of the frequency, voltage and power are desired to be zero [4].

II. AUTOMATIC GENERATION CONTROL

If the load on the system is increased then, there is a drop in frequency because the governor speed goes down, for adjusting the speed to a set point it is required to increase the speed of a governor. As the speed change diminishes; the error signal becomes smaller, and the governor speed is made constant. However, it is impossible to fix the governor speed to a set point because the load is varying with time; therefore, we use a control system with an integrator. The control mechanism analyses the change and make corrections accordingly to remove offsets. The ability of system to come back to its normal value this control action is called reset point. So the AGC is a scheme which restores the frequency to its nominal value automatically [5, 6]. In Fig. 1 the AGC for single area is shown, the AGC consist of a governor system which provides a signal to the turbine to adjust its speed to maintain the frequency constant.

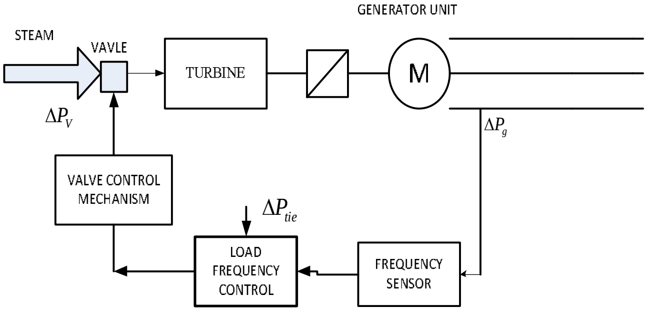

Fig. 1 Block diagram of Automatic load frequency control

A. Modelling of automatic generation control for single area:

The main parts consist as Governor, prime mover load and inertia model; are described as following:

Governor model: the command ΔP_g is transformed by hydraulic amplifier to the steam valve position ΔP_V [7]. The T_g is governor time constant, the transfer function of governor is

$$\frac{\Delta P_V(s)}{\Delta P_g(s)} = \frac{1}{1+T_g s} \tag{1}$$

Prime mover model: The prime mover is used for producing mechanical power; it may be steam for steam turbine, water wall for hydraulic turbine. The model of prime mover ΔP_m relates the mechanical power output to change in steam valve value ΔP_v the transfer function is

$$\frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+T_t s} \tag{2}$$

Load and inertia model: The motor load is sensitive to the frequency change; it can be analysis by speed load characteristic.

$$\frac{\Delta w(s)}{\Delta P_m - \Delta P_l} = \frac{1}{2H+D} \tag{3}$$

Frequency bias factor: The frequency biased factor is sum of frequency sensitive load change (D) and speed regulation.

$$B = \frac{1}{R} + D \tag{4}$$

By using above Eqn. (1 – 4) the automatic generation block diagram can be formed which is shown Fig. 2.

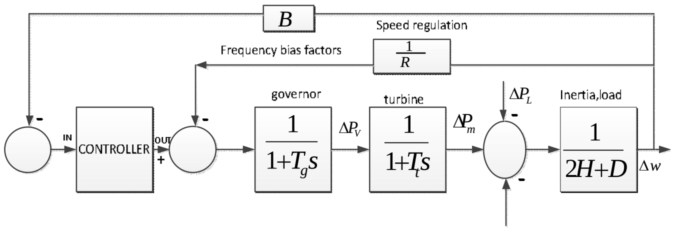

Fig. 2 Block diagram of Automatic generation control for single area system

B. Modelling of automatic generation control for double area

Let two areas represented by an equivalent generating unit interconnected by a lossless tie line with reactance X_{tie}

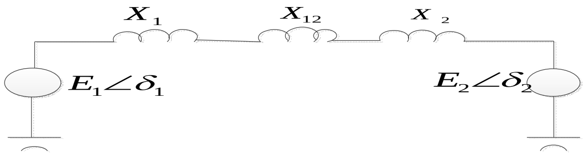

Fig. 3 Network for a two area power system

During the normal operating condition the real power transferred over the tie line is given and shown in Fig. 3.

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin \Delta\delta_{12} \tag{5}$$

Consider a small deviation in a tie line power ΔP_{12} the equation for this is given as consider for a initial rotor angle δ_0

$$\Delta P_{12} = \frac{dP_{12}}{d\delta_{12}} \tag{6}$$

The synchronous power coefficient is given by Eqn. (7).

$$P_S = \frac{|E_1||E_2|}{X_{12}} \cos \Delta\delta_{12} \tag{7}$$

Consider a load change ΔP_{L1} in area1at time of steady state the deviation in frequency is consider to be same it means

$$\Delta w = \Delta w_1 = \Delta w_2 .$$

$$\begin{aligned} \Delta P_{m1} - \Delta P_{m2} - \Delta P_{l1} &= \Delta w D_1 \\ \Delta P_{m2} + \Delta P_{12} &= \Delta w D_2 \end{aligned} \tag{8}$$

The change in mechanical power is determined by using the governor speed characteristic is given as

$$\Delta P_{m1} = \frac{-\Delta w}{R_1}, \Delta P_{m2} = \frac{-\Delta w}{R_2} \tag{9}$$

$$\Delta w = \frac{-\Delta P_{l1}}{B_1 + B_2}, \Delta P_{12} = \frac{B_2}{B_1 + B_2}(-\Delta P_{l1}) \tag{10}$$

Tie-Line Bias Control: The tie-line bias control is used to maintain frequency and power at a pre-specified value where in each area manages its own load. The conventional LFC is based on the tie line bias control; in which each area is trying to reduce error to zero. The area control error is given by (ACE)

$$ACE_1 = \Delta P_{12} + B_1 \Delta w_1, ACE_2 = \Delta P_{21} + B_2 \Delta w_2 \tag{11}$$

By using the above Eqn. (11), the block diagram can be made as given below of a two area interconnected power system is shown in Fig. 4 as shown below.

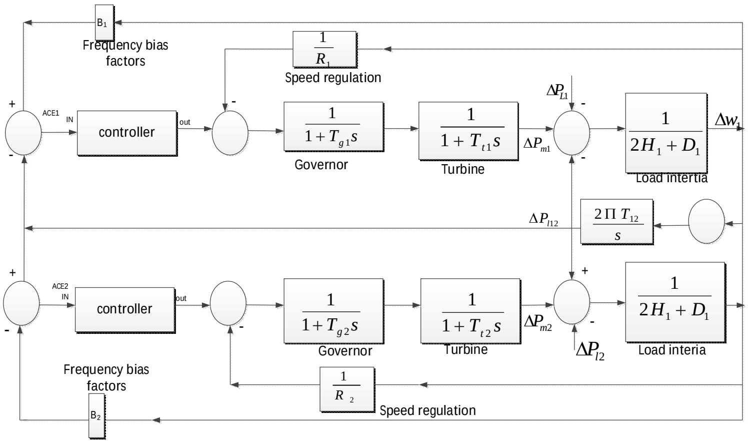

Fig. 4 Block diagram of ALFC for two area power system

III. AUTOMATIC VOLTAGE REGULATOR

AVR is an important part of a synchronous generator. The AVR is used for regulating the terminal voltage of the synchronous generator, whenever, there is a sudden drop in voltage due to accidents, faults or frequent changes in loading. The AVR improves the transient stability of a system. In this paper; the reference voltage is compared with the stepped down transformed and rectified terminal voltage [8]. In Eqn. (12), the error signal is the difference of terminal voltage (v_{ref}) and reference voltage (v_t).

$$e(t) = v_{ref} - v_t \tag{12}$$

The working of AVR can be understood by Fig.5, the voltage is sensed by the potential transformer of one phase. This voltage is rectified and compare with a DC preset point. The amplified error signal controls the exciter field and increases the exciter terminal voltage. Thus increase in generator field current which increases the generator EMF. Thus reactive power generation is increased which result in the voltage to be increased.

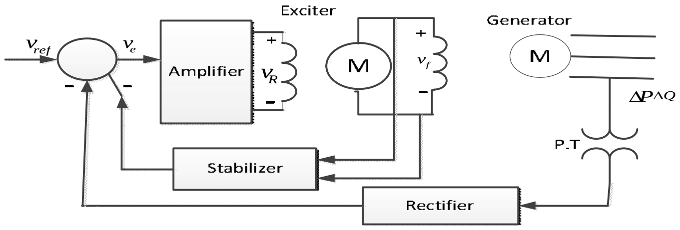

Fig. 5 Block diagram of Automatic voltage regulator

A. Modelling of automatic voltage regulator:

Amplifier model: In the above Fig. 5; it can see amplifier, the amplifier may be magnetic amplifier, rotating amplifier or modern electronic amplifier, and it is denoted by k_A the typical range of it is 10 to 400.the amplifier time constant is very small is given by 0.02 to 0.1 sec. the transfer function of amplifier model is

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{I + T_A s} \tag{13}$$

Exciter model: The transfer function of a exciter is represented by a Exciter time constant T_E and gain is given by k_A .the time constant of exciter is very small.

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1 + T_E s} \tag{14}$$

Generator model: The synchronous machine generated EMF is a function of magnetization curve, and its terminal voltage is dependent on generator load. k_G May vary between0.7 to 1 and T_G be 1 to 2 seconds from full load to no load.

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1+T_G s} \tag{15}$$

Sensor model: Sensor sensed voltage through a potential transformer the T_R time constant of sensor is assuming a range from 0.01 to 0.06.

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1+T_R s} \tag{16}$$

By using the above Eqns. (5 – 8), the block diagram is made shown in Fig. 6 as shown below.

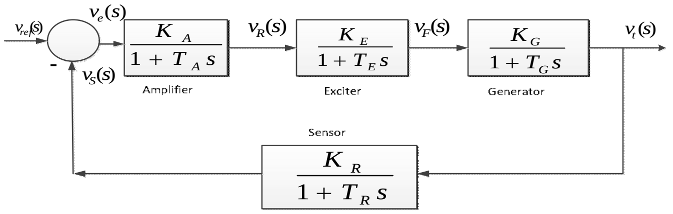

Fig. 6 Block diagram of automatic voltage regulator

From the above block diagram we can write open loop transfer function which is given as:

$$KG(S)H(S) = \frac{K_A K_E K_G K_R}{(1+T_A s)(1+T_E s)(1+T_G s)(1+T_R s)} \tag{17}$$

And the closed loop transfer function relating the generator terminal voltage $V_t(s)$ to the reference voltage $V_{ref}(s)$ is

$$\frac{v_t(s)}{v_{ref}(s)} = \frac{K_A K_E K_R K_G (1+T_R s)}{(1+T_A s)(1+T_E s)(1+T_G s)(1+T_R s)+K_A K_E K_G K_R} \tag{18}$$

IV.CONVENTIONAL CONTROLLER

A. PI controller

The proportional plus integral controller has two output signals one is related to the error signal and other is related to the integral of error signal [8, 9]. The equation of PI controller is given as

$$K_p\left[1+\frac{1}{T_i s}\right] \tag{19}$$

Where K_p is the gain of the controller, T_i is the time constant of the integral controller.

B. PID controller

The propositional plus integral plus derivative controller has three output signals, the proportional controller results in decrease of rise time but increases the oscillation, derivative controller reduced the oscillation by providing the proper damping which improves the transient performance and stability and integral controller reduces the steady state error to zero[10]. The equation of PID controller is given as

$$K_P\left[1+\frac{1}{T_p s}+T_d s\right] \tag{20}$$

Where K_p is a gain for controller and T_p and T_d are the time constant.

V. FUZZY LOGIC CONTROL

The conventional controller is unable to give proper dynamic response when compared with intelligent controller. In this paper fuzzy logic is used for controlling the voltage and frequency response of power system fuzzy logic controller mainly consists of four components (1) Fuzzification inference (2) knowledge base (3) Decision making (4) Defuzzification inference [11-14]. The fuzzy Fuzzification inference measures the input variables and converts them into linguistic variables [15, 16]. By knowledge base we are able to define the rules which are necessary to produce the output. By this human being thinking is converted into reasoning without using any mathematical equation [17]. The Defuzzification inference converts the linguistic variables into the desired value output. The block diagram of fuzzy logic controller is shown in Fig. 7

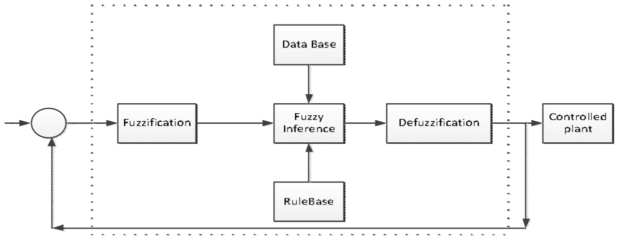

Fig. 7 Block diagram of fuzzy logic controller

Membership function used for designing of fuzzy logic controller for AGC is given below in Fig. 8.

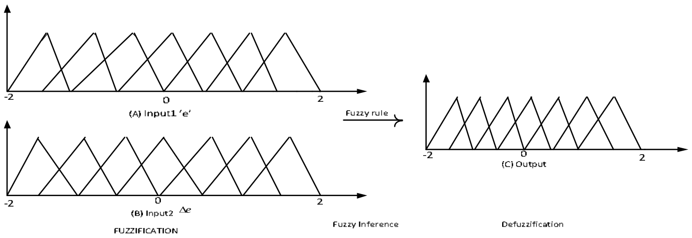

Fig. 8 Membership function for FLC

The rule base for AGC and AVR is shown in Table 1 the combinational exploration in rules is given by X=Y^{m}. Where X is the number of rule=number of linguistic values for each input variables and m=number of input variables[18]. in this paper Y =7, and m=2, hence the no of rule for AGC it means X= 49, similarly for AVR Y=7.and M=2, hence X=49.rule base can be written as if (input1 is VVN) or (input2 is VVN) then (output is VVN),if (input1 is VVN) or (input2 is VN) then (output is VVN),if (input1 is VVN) or (input2 is VVP) then (output is ZE) the short form stands for VVN-Very very negative VN-very negative, N-negative, ZE-Zero, P-positive, VP-very positive, VVP-Very very negative[19, 20].

.Table 1. Rule base for AGC

Derivative of error signal, $\Delta\dot{e}$	Error Signal Δe						
	VVN	VN	N	ZE	P	VP	VVP
VVN	VVN	VVN	VN	VVN	VN	N	ZE
VN	VVN	VVN	VVN	VN	N	ZE	VP
N	VVN	VVN	VN	N	ZE	P	VP
ZE	VVN	VN	N	ZE	P	VP	VVP
P	VN	N	ZE	P	VP	VVP	VVP
VP	N	ZE	P	VP	VVP	VVP	VVP
VVP	ZE	VP	VP	VVP	VVP	VVP	VVP

VI. SIMULATION RESULT

The conventional controller is compared with fuzzy controller it is find that fuzzy controller is better than conventional controller. In this paper the analysis of a single and double area power system for AGC and AVR is done, the simulation result are obtained by using mat lab software[21]. The proposed Fuzzy PID is compared with conventional PID,PI for both single and double area and it is found that Fuzzy PID result is better[22]. the frequency response for single area is shown in Fig. 9,and the power deviation and terminal voltage deviation is shown in Fig. 10-11, the summary of simulated result for frequency deviation and power deviation, terminal voltage deviation is shown in Table 2 - 4, and frequency deviation for double area is shown in Fig. 12-13,voltage deviation is shown in Fig. 14-15, and power deviation is shown in Fig. 16, Table 7-11 consist of summary of frequency deviation, terminal voltage and power deviation, in this way it can be seen that the frequency comes to steady state by some time, similarly the voltage response at the terminal of generator and the power response with respect to time comes to steady state. The data used is given in Table 5 - 6 for AGC and AVR, respectively. The table shows the settling time rise time steady state error, the fuzzy logic controller with PID controller is better as compare to conventional controller.

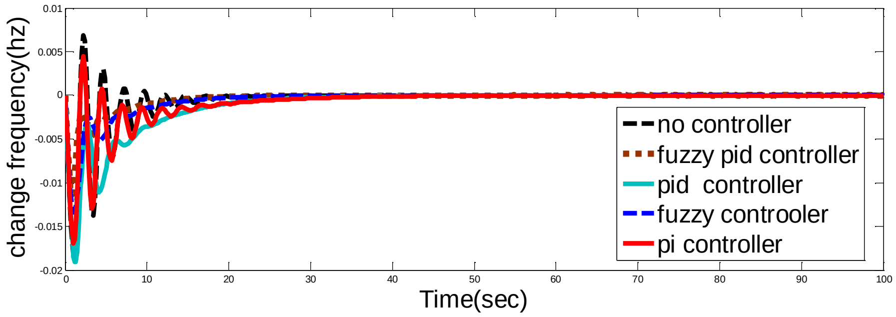

Fig. 9 Frequency deviation for single area system

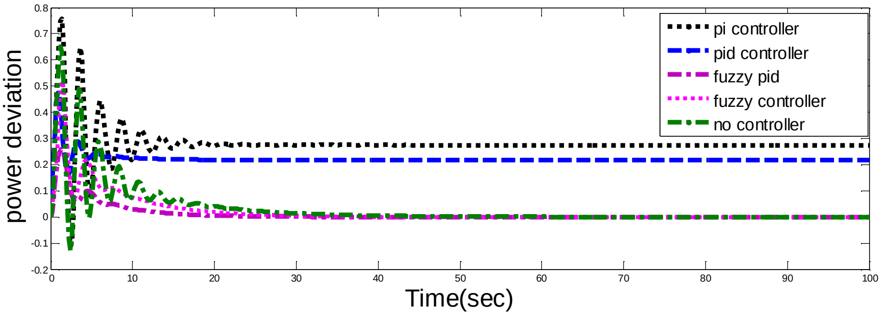

Fig. 10 power deviations for single area power system

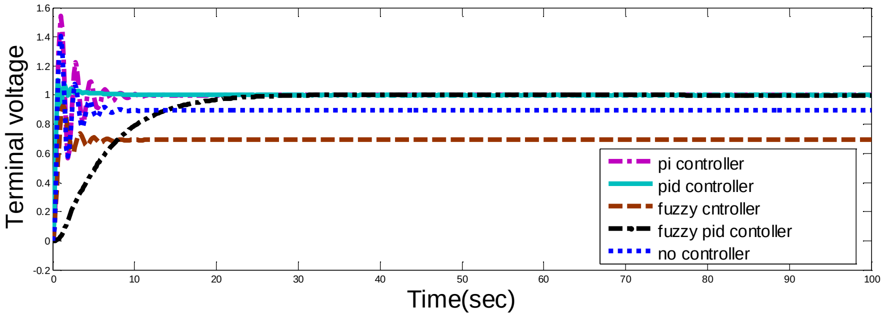

Fig. 11 Terminal voltage for single area power system

Table 2. Summary of frequency deviation for single area power system

Types of controller	% overshoot	Settling time(sec)	Steady state error
Without controller	4.4×10^{-3}	51	0.2
Fuzzy PID controller	-2.5×10^{-3}	24	0
Fuzzy controller	-1.2×10^{-3}	29	0
PID controller	-1.960	28	0
PI controller	6.8×10^{-3}	31	0

Table 3. Summary of power deviation for single area power system

Types of controller	% overshoot	Settling time	Steady state error
Without controller	1.4067	14	0.2
Fuzzy PID controller	0	22	0.0024
Fuzzy controller	0.9276	14	0.3
PID controller	1.1017	15	0
PI controller	1.548	22	0

Table 4. Summary of Terminal voltage for single area power system

Types of controller	Percentage overshoot	Settling time	Steady state error
Without controller	0.6851	58	0.4
Fuzzy PID controller	0.2579	22	0
Fuzzy controller	0.4875	24	0
PID controller	0.4971	24.4	0.2169
PI controller	0.757	38	0.28

Table 5. Data used for AGC in double area power system model

Parameter of double area power system	Area – 1	Area-2
Governor speed regulation $[1/R]$	20	16
Frequency bias factor $[D]$	0.6	0.8
Inertia constant $[H]$	5	4.0
Bass power	1000MVA,	1000MVA
Governor time constant $[T_g]$	0.2	0.3
Turbine time constant $[T_t]$	0.5	20.6
Load change $[\Delta P_l]$	50 MW	

Table 6. Data used for Automatic voltage control

Block of AVR	Gain	Time constant
Amplifier	9	0.1
Exciter	1	0.4
Generator	1	1.0
Sensor	1	0.05

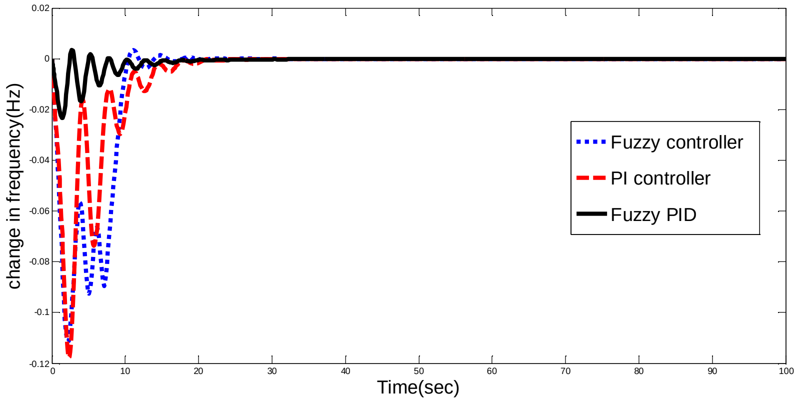

Fig. 12 Frequency deviation (Δf_1) for area-1

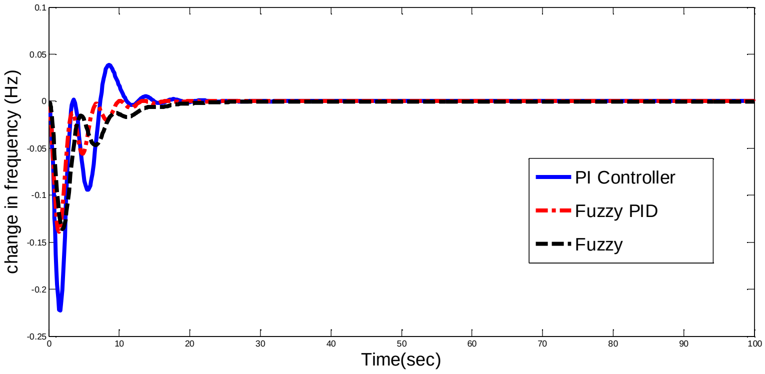

Fig. 13 Frequency deviation (Δf_2) for area2

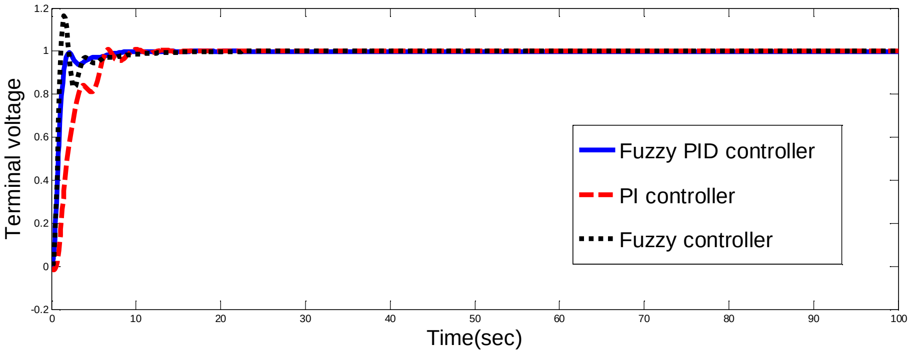

Fig. 14 Terminal voltage response for area-1

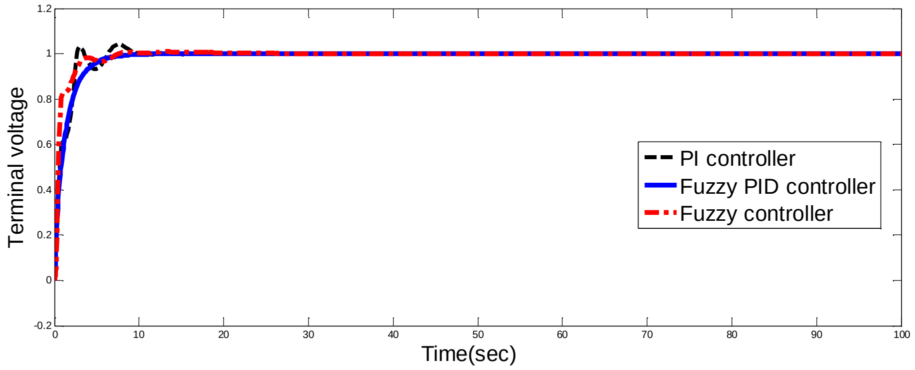

Fig. 15 Terminal voltage response for area2

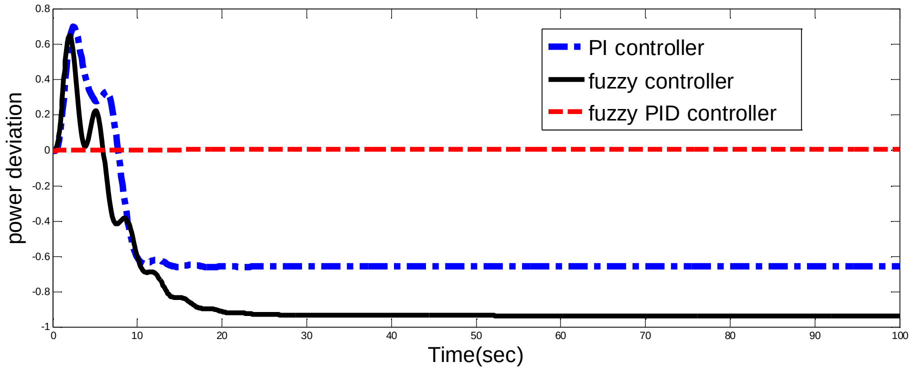

Fig. 16 Power deviation for area12

Table 7. Summary of frequency deviation of area-1

Types of controller	Settling time	% overshoot	Steady state error
PI controller	32	0.0035	-0.001
Fuzzy controller	25	0.0034	0.0
Fuzzy PID controller	23	-0.0161	0.0

Table 8. Summary of frequency deviation of area-2

Types of controller	Settling time	% overshoot	Steady state error
PI controller	40	-0.013	0.0
Fuzzy controller	27	0.03	0.0
Fuzzy PID controller	20	-0.0124	0.0

Table 9. Summary of Terminal voltage area-1

Types of controller	Settling time	% overshoot	Steady state error
PI controller	20	1.17	0.0
Fuzzy controller	18	0.995	0.0
Fuzzy PID controller	12	0.91	0.0

Table 10. Summary of terminal voltage of area-2

Types of controller	Settling time	% overshoot	Steady state error
PI controller	28	1.005	0.001
Fuzzy controller	15	1.035	0.0

Fuzzy PID controller	10	0.9	0.0

Table 11. Summary of power deviation (ΔP_{tie}) of area-12

Types of controller	Settling time	% overshoot	Steady state error
PI controller	32	1.001	-0.6
Fuzzy controller	28	0.7	-0.4
Fuzzy PID controller	18	0.2	-0.005

VII. CONCLUSION

In this paper, single-area and double-area power system models are considered for analysis. The responses like change in frequency, power deviation and terminal voltages are observed. The system response with proposed fuzzy controller is compared to the conventional controller and found that the intelligent controller is better than the conventional controller. The analysis of AGC and AVR is done together, by using the controller with reduced steady-state error, settling time; peak overshot of frequency response in AGC and terminal voltage in AVR. In both analyses fuzzy controller is better than the conventional controller.

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