Performance analysis of FL, PI and PID controller for AGC and AVR of a Two-Area Power System

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Abstract- Present work deals with the combination of automatic generation control (AGC) with automatic voltage regulator control (AVR) and the implementation of PI, PID and fuzzy logic controller for two area system. The purpose of the AGC is for balancing the system's total generation against system load and losses. If any mismatch between generation and demand occur the system frequency may deviate from preset value. Thus, high value of frequency deviation may lead to failure of the system. The role of AVR is to hold terminal voltage magnitude of the generator at a preset level. The interaction between frequency deviation and voltage deviation is analyzed and studied in this paper. System performance and operation has been evaluated at various loading disturbances. In this paper we deal with the design, implementation and operation performance of fuzzy logic controller with the combined loop of AGC & AVR for interconnected power system. The fuzzy controller is implemented in order to control the area control error calculation of AGC & excitation of AVR, which determines the deficit or extra generation that has to be corrected. Simulation results (using MATLAB/SIMULINK) shows that the proposed modified fuzzy control offers better performance than PI and PID controllers at different operating conditions.

Index Terms- Automatic Generation Control (AGC), Automatic Voltage Regulator (AVR), Area Control Error (ACE), Frequency Response, Voltage Response, Fuzzy logic(FL) controller, PID controller.

I. INTRODUCTION

With the AGC loop, the load changes will result in a steady-state frequency change, depending on the governor speed regulation. Hence, to reduce the frequency deviation to zero, we must provide a reset action. The reset action is achieved by introducing an integral controller to act on the load reference setting to change the speed reference point. The integral (I) controller increases the system type by one which forces the steady state frequency deviation to zero. Automatic Generation Control (AGC) is very important issue in power system operation and control for supplying sufficient and both good quality and reliable electric power [1].

The generator excitation system maintains generator voltage and hence, controls the reactive power flow in the power system. A change in the real power demand affects essentially the system frequency, whereas a change in the reactive power affects mainly the voltage magnitude in the power system. There is a weak interaction between voltage and frequency controls to justify their analysis separately. The sources of reactive power are generators, capacitors, and reactors. The reactive power of generator is controlled by field excitation. Other methods for improving the voltage profile in the electric transmission systems are static Var control equipment, switched capacitors, transformer load tap changers, step voltage regulators. The important means of generator reactive power control is the generator excitation control using automatic voltage regulator (AVR). The role of an AVR is to maintain the terminal voltage magnitude of synchronous generator at a specified level [2].

By the proportional integral (PI) control approach zero steady-state error in the frequency of the system is achieved, but exhibits relatively poor dynamic performance which results in large overshoot, transient frequency oscillations and also relatively large transient settling time. In this paper, the fuzzy logic is effectively used to change the integral gain (K_i) of AGC settings automatically to restore nominal system frequency for various wide-range load changes [6-8]. The terminal voltage magnitude drops due to the increase in reactive power load. The potential transformer senses the voltage magnitude on one phase and it is compared with DC set point signal. The amplified error signal controls the exciter field and increases the exciter terminal voltage. This increases the generator field current and generated emf. The reactive power generation is increased to a new balanced level, increasing the terminal voltage to the desired value and hence, obtaining the system balance [9]. This paper presents a development of voltage control of AVR or excitation system by using a self-tuning fuzzy proportional integral and differential (PID) controller to overcome the appearance of nonlinearities and uncertainties in the systems. The self-tuning fuzzy PID controller is the combination of a PID controller and fuzzy controller [11]. Development of AGC for frequency stabilization [3] using fuzzy controller is also presented.

II. INTERCONNECTED POWER SYSTEM

Power systems have complex structures and also they consist of many different control blocks most of which are non-linear. Power systems are basically divided into control areas which are connected by transmission lines called tie-lines as shown in Fig.(1). All generators are supposed to constitute a coherent group in each control area. In the interconnected power systems, it is seen that each area needs its system frequency and tie line power flow to be controlled and to maintain them in the prescribed limits. The speed of the response is limited by the natural time lags of the turbine and the system itself. The relationship between the speed and load can be adjusted by changing a load reference set point input. A case study is presented by considering a two area power system [4].

2.1. Area control error

Area Control Error is defined by,

$$ACE_i = CP_{ij} + B_i * C_f \qquad (1)$$

Where,
i -control area for which ACE is being measured
CP_{ij} -power interchange in areas i and j
B_i- control area frequency bias coefficient
C_f- deviation in frequency

The ACE is an error signal consisting of two factors. 1st factor represents the error in the scheduled tie flows. The 2nd factor is inter-area assistance in generation from control area to prevent large deviation of interconnection frequency. ACE represents the generation versus load mismatch for the control area. The ACE indicates instant at which the total generation must be lowered or raised in a control area. A general criterion can be given about which AGC is considered ‘good’. Since ACE is directly influenced by random load variations, this criterion can be treated statically by specifying that the standard deviation of ACE should be small and ACE should not be allowed to ‘drift’. This means that the integral of ACE over appropriate time should be small. A ‘drift’ in ACE has the cumulative effect of creating system time errors or inadvertent interchange errors [5].

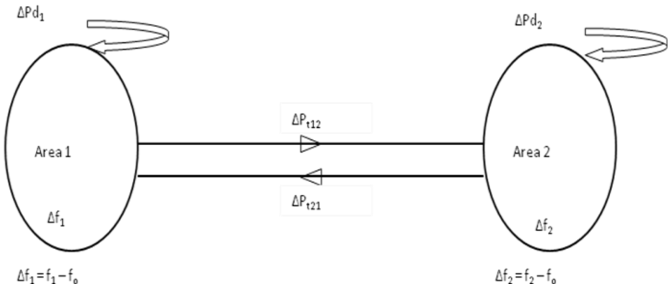


Fig.1: Two area interconnected power system

III. FUZZY LOGIC CONTROLLER

Conventional control methods cannot provide desired results because power system dynamic characteristics are complex and variable. Advanced controller can be replaced with conventional controller to get fast and good dynamic response in load frequency problems. Fuzzy Logic Controller (FLC) as shown in Fig.(2) can be more useful in solving large scale of controlling problems with respect to conventional controller which are slower. Fuzzy logic controller is designed to minimize fluctuation on system outputs. There are many studies on power system with fuzzy logic controller.

There are three principal elements to a fuzzy logic controller:
(i) Fuzzification module (Fuzzifer)
(ii) Rule base and Inference engine
(iii) Defuzzification module (Defuzzifier)

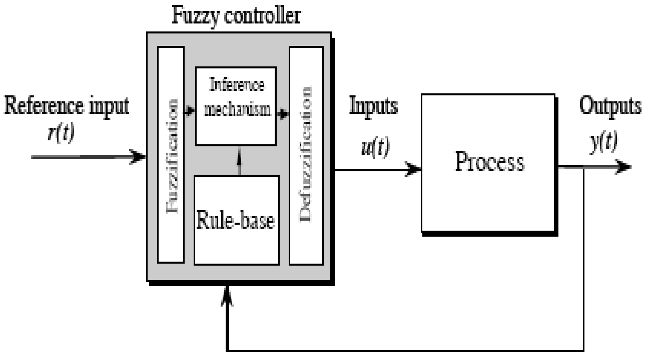


Fig.2: Fuzzy logic controller

Fuzzy control is based on a logical system called fuzzy logic. It is much close in spirit to human thinking than conventional logical systems. Complexity and Multi-variable nature of power system limits the conventional control method, to provide satisfactory solutions. The FLC is to handle the reliability, robustness and nonlinearities associated with power system controls. Due to this fuzzy logic controller becomes adaptive and nonlinear in nature having a robust performance under parameter variations with the ability to get desired control actions for complex uncertainty, and nonlinear systems without their mathematical models and parameter estimation [3,5,10].

The error ‘e’ and change in error (Δe) are inputs to the fuzzy logic controller. These two inputs signals are converted to fuzzy numbers first in fuzzifier using seven membership functions. The fuzzy rules are interpreted as if ACE is NB and d(ACE)/dt is NS then the output is PM. The Triangular membership functions are used for both the inputs and output signals.

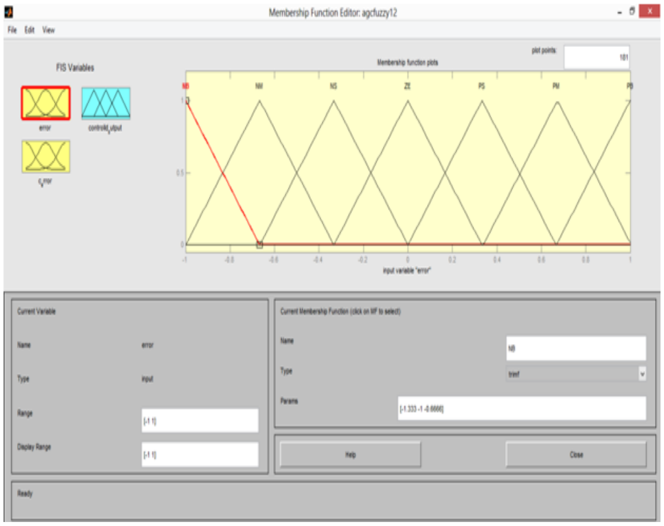
The rule table for fuzzy with AGC and AVR is as shown in Table 1 and Table 2.

3.1. Membership functions for AGC for the fuzzy variable of the proposed FLC

Fuzzy control rules are constructed by using the control experience of operator having experiences about automatic generation control of the interconnected power system. There are two controllers, fuzzy ACE1 and fuzzy ACE2 as shown in Fig.3 and Fig.4. Each of the controllers has the Negative Big NB, Negative Medium NM, Negative Small NS, Zero ZE, Positive Big PB, Positive Medium PM, Positive Small PS for both the change in area control error d(ACE)/dt and area control error ACE [5].

The rules are interpreted as follows, if ACE is NB and d(ACE)/dt is NS then the output is PB. The triangular membership functions are used for both the inputs and output. The Defuzzification method employed is the center of area method [8].

The membership functions for input and output are shown in Fig.3, 4 and Fig 5. Rule viewer and Surface viewer of AGC block in FLC is shown in Fig.6 and Fig.7.



Current Variable

Name error

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name NB

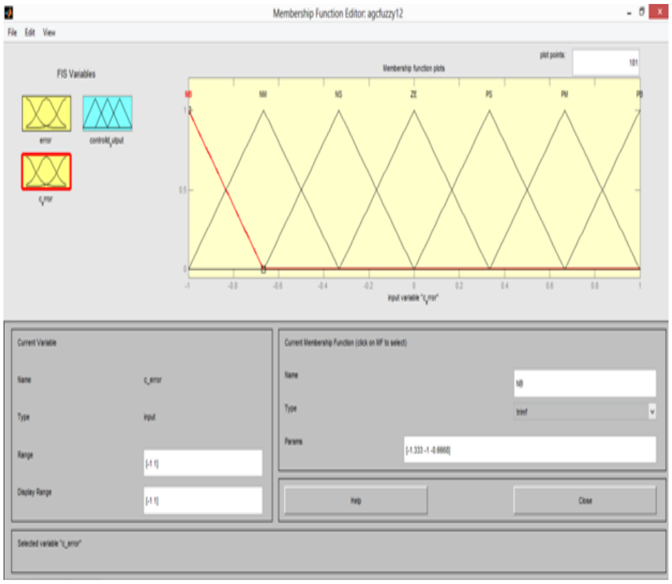
Type trimf

Params [-1.333 -1 -0.6668]

plot points: 181

Ready

Fig 3: Membership function editor for input1 of FLC



Current Variable

Name c_error

Type input

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name NB

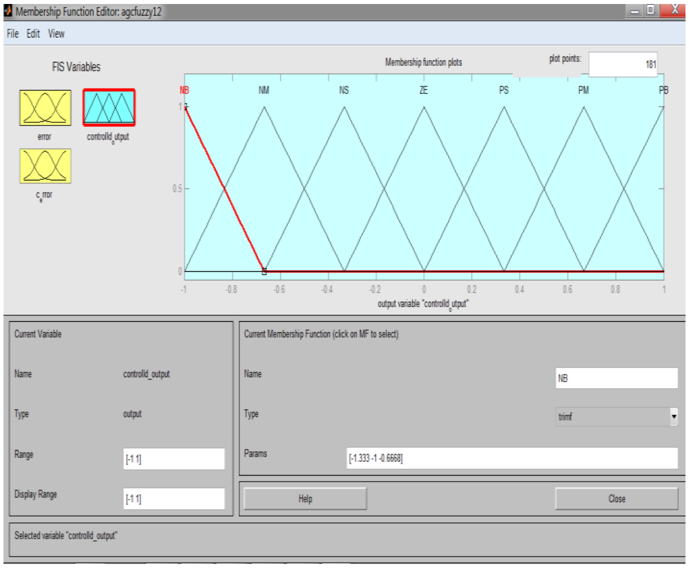
Type trimf

Params [-1.333 -1 -0.6668]

plot points: 181

Selected variable "c_error"

Fig 4: Membership function editor for input2 of FLC



Current Variable

Name controlld_output

Type output

Range [-1 1]

Display Range [-1 1]

Current Membership Function (click on MF to select)

Name NB

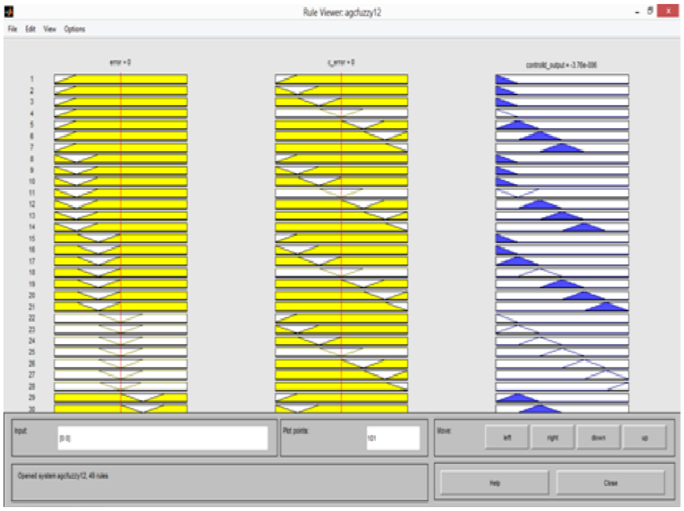
Type trimf

Params [-1.333 -1 -0.6668]

plot points: 181

Selected variable "controlld_output"

Fig 5: Membership function editor for output of FLC

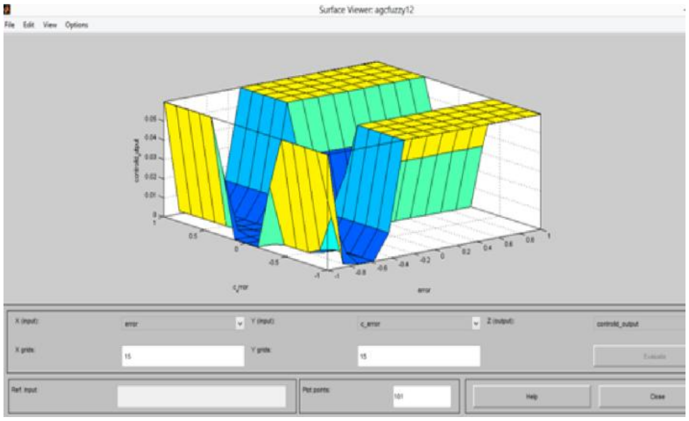


Input: [0 0]

Plot points: 101

Opened system agcfuzzy12, 49 rules

Fig 6: Rule viewer of AGC block in FLC



X (input): error

Y (input): c_error

Z (output): controlld_output

X grids: 15

Y grids: 15

Ref. Input:

Plot points: 101

Fig 7: Surface viewer of AGC block in FLC

TABLE 1: FUZZY RULE TABLE FOR AGC

		AREA CONTROL ERROR (ACE)						
		NB	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
d/ dt of A C E	**NB**	PB	PB	PB	PB	PM	PM	PS
	NM	PB	PM	PM	PM	PS	PS	PS
	NS	PM	PM	PS	PS	PS	PS	ZE
	ZE	NS	NS	NS	ZE	PS	PS	PS
	PS	ZE	NS	NS	NS	NS	NM	NM
	PM	NS	NS	NM	NM	NM	NB	NB
	PB	NS	NM	NB	NB	NB	NB	NB

TABLE 2: FUZZY RULE TABLE FOR AVR

	NB	NM	NS	Z	PS	PM	PB
NB	Z	PS	PM	NS	NM	PS	NM
NM	PS	Z	PS	PM	NS	NM	PS
NS	PM	PS	Z	PS	PM	PS	PM
Z	PS	PM	PS	Z	NS	NM	PS
PS	PS	PS	PM	NS	Z	NS	NM
PM	NS	PM	NS	NM	NS	Z	NS
PB	NM	NS	NS	NS	NM	NS	Z

IV. SIMULATION AND RESULTS

Testing was done on each of the individual blocks of the AGC system and AVR system. The design and simulation of problem is done in MATLAB Simulink environment. The following simulations were performed in order to investigate the performance of the proposed fuzzy logic controller over the conventional integral controller.

The simulation block diagram for AGC and AVR interconnection for single area using fuzzy logic controller is shown Fig.8 and the AGC and AVR for two areas interconnected using fuzzy logic controller is shown Fig.9. The change in frequency v/s time and change in voltage v/s time for single area is shown in Fig.10 and 11 respectively.

Frequency deviation of AGC_AVR in area-1 using FLC, PI and PID in two area interconnected system is shown in Fig.12. The Voltage response of AVR for two area using FLC and PID are shown in Fig.13 and 14.

Comparison of dynamic responses of FLC, PI and PID are shown in Table 3. The various assumptions used for AGC, AVR, PI and PID simulation are shown in Table 4, 5 and 6 respectively.

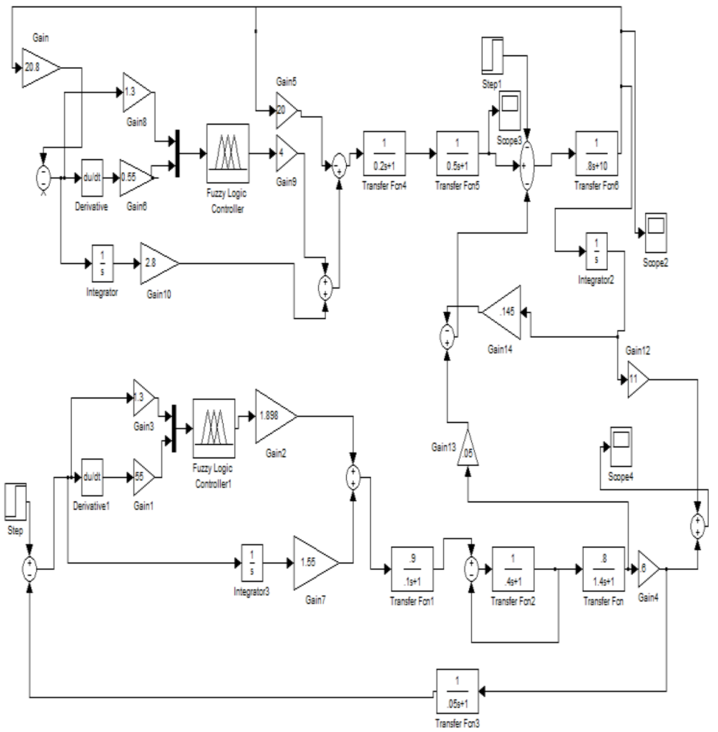


Fig.8: AGC and AVR interconnection for single area using fuzzy logic controller

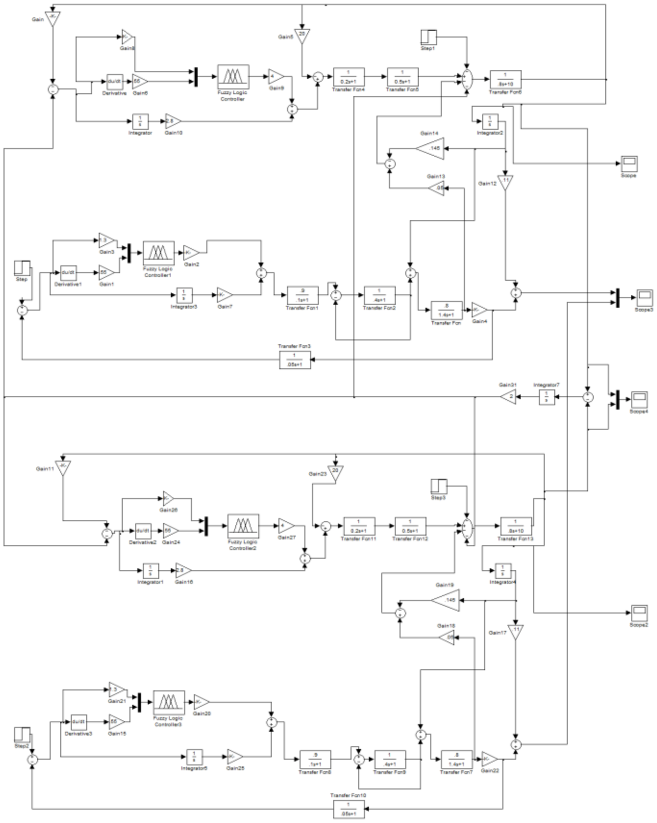


Fig.9: AGC and AVR for two areas interconnected using fuzzy logic controller.

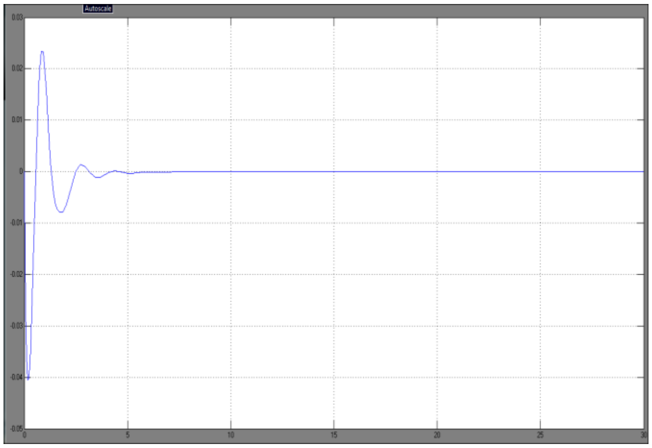


Fig.10: Frequency deviation of AGC using FLC in single area.

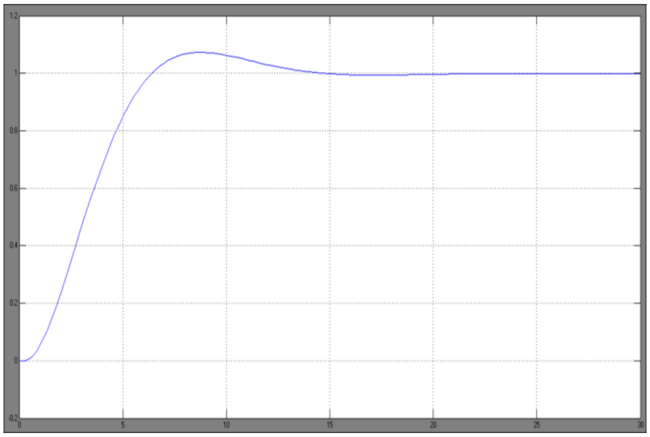


Fig.11: Voltage response of AVR using FLC in single area.

TABLE 3: COMPARISON OF DYNAMIC RESPONSES OF PI, PID AND FLC

CONTROLLER	FREQUENCY DEVIATION			
	SETTLING TIME (SEC)		MAXIMUM OVERSHOOT	
	AGC	AVR	AGC	AVR
FLC	12	12	$-3.5*10^{-3}$	1.1
PID	18	15	$-3.5*10^{-3}$	1.05
PI	31	30	$-4*10^{-3}$	1.0

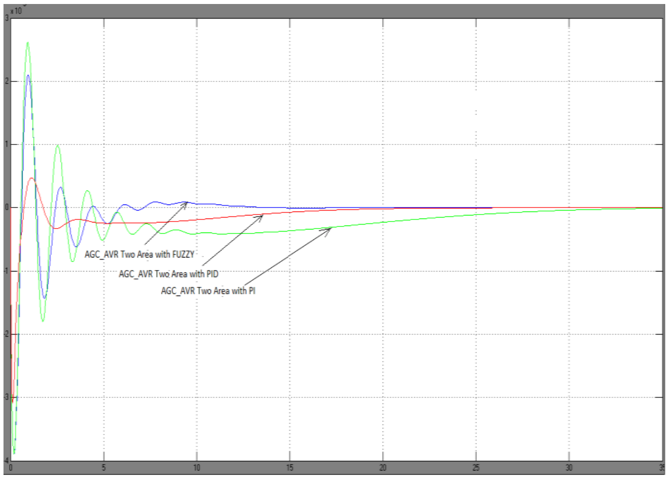


Fig.12: Frequency deviation of AGC_AVR in area-1 using FLC, PI and PID in two area interconnected system.

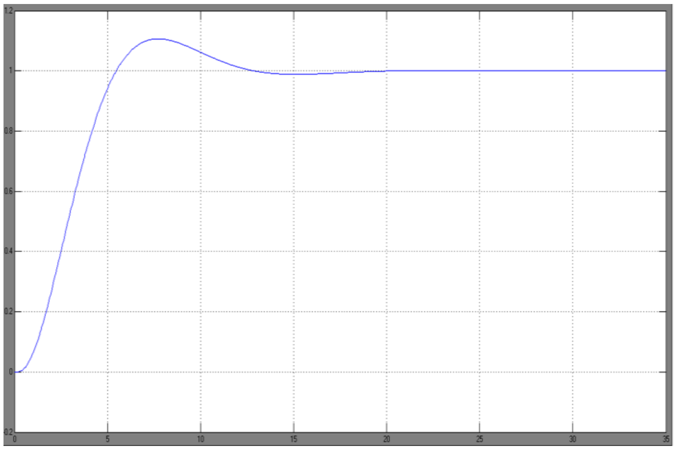


Fig.13: Voltage response of AVR using FLC in two area interconnected system.

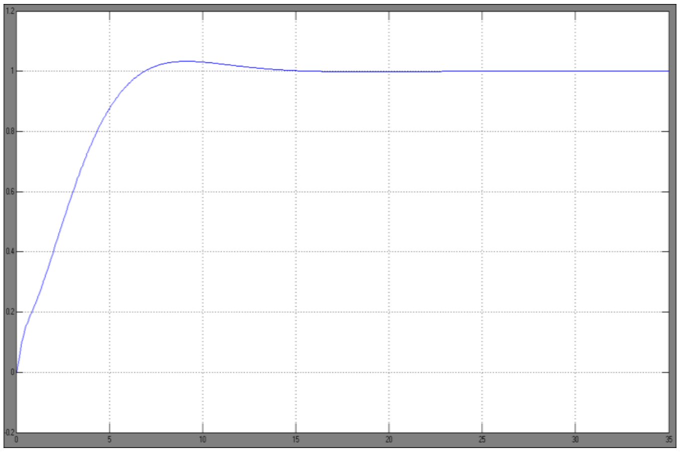


Fig.14: Voltage response of AVR using PID in two area interconnected system.

The assumptions used for AGC, AVR and PID simulations are shown in Table 4,5 and 6 respectively.

TABLE 4: ASSUMPTIONS MADE IN THE SIMULATION RUNS FOR AGC

Governor speed regulation	R_1=0.051
Frequency bias factors	D_1=0.62
Inertia constant	H_1=5
Base power	1000MVA
Governor time constant	T_{sg1}=0.2 sec
Turbine time constant	T_{t1}=0.5 sec
Constant	K=0.159
Nominal frequency	F_1=50 Hz
Load change	P_{LI}=50 MW
Load disturbance in per unit (area)	$(P_{LI})_{p.u}$=0.05PU

TABLE 5: ASSUMPTIONS MADE FOR AVR

Quantity	**Gain**	**Time constant**
Amplifier	9	0.1
Exciter	1	0.4
Generator	1	1.0
Sensor	1	0.05

TABLE 6: ASSUMPTIONS MADE FOR PID

Quantity	**Gain**
PID controller	Kp=1.2 Ki=1.8 Kd=1
PI controller	Kp=1.0 K_i=1.8

V. CONCLUSION

The PI, PID and FL controller approach in AGC and AVR in an interconnected power system has been implemented. The fuzzy logic approach with integral gain scheduling yields overall better performance regarding transient responses in comparison to the conventional controller. The settling time is reduced to a great extent with the Fuzzy logic mode of scheduling. The gain scheduling approach yields automatic, self-adjusting outputs irrespective of widely varying uncertain off-nominal conditions. The computational burden and memory have been reduced.

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