Fuzzy Logic Based Automatic Load Frequency Control of Multi-Area Power Systems

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Abstract— **now days due to the increase in the interconnection of the power system, load as well as power flow in tie-line are varying dynamically. So there is a need of robust control of both systems frequency and tie-line power flows. This robust control can be attained using fuzzy logic controller rather than the conventional proportional, proportional integral and proportional integral derivative controllers. Because gain values of conventional controllers are constant, for load changes. Load can't be constant, load changes time to time but gain values of conventional controllers are constant. In order to overcome the drawbacks of the conventional controllers, many techniques have been proposed in literature. In this work, fuzzy logic base controller is considered for load frequency control problem. The required rules are executed depending upon the load variation to minimize the error. In fuzzy logic controller, triangular membership function is used for making the rule base, because triangular membership function gives easy way to make the rule base compared to other membership functions. The system simulation is realized by using Matlab/Simulink software.**

Index Terms*— Automatic Load Frequency Control, PI, PID Fuzzy Logic Controller and Matlab/Simulink Software,** ***AGC.

I. INTRODUCTION

In recent years, power systems have more complicated and Non-linear configurations. Many industrial establishments are affected by operating point variations [1]. Electricity sector and end user are concerned about power quality reliability, efficiency and energy future. There are many reasons about increasing concerns on power quality. The microprocessor based equipment and power electronic devices are more sensitive to power quality. On the other hand, an electric network consists of many interconnected subsystems. If a fault occurs in a subsystem, disturbances and interruptions adversely affecting power quality take place in the power system. Any disharmonies between energy generation and demand cause frequency deviations. Thus, significant frequency deviations lead to system blackouts [2]. Power system loads are usually variable so that controller system must be designed to provide power system quality. Interconnected power systems regulate power flows and frequency by means of an automatic generation control (AGC). AGC is a feedback control system adjusting a generator output power to remain defined frequency [3]. AGC comprises a load frequency control (LFC) loop and an automatic voltage regulator (AVR) loop. LFC system provides generator load control via frequency [3]. Zero steady-state -errors of frequency deviations and optimal transient behavior are objectives of the LFC in a multi-area interconnected power
system [4]. So far there are many studies about load frequency control of interconnected power systems. The aim is a design of feedback controller to realize desired power flow and frequency in multi-area power systems.

In literature, control strategies based on conventional and fuzzy logic controller are proposed [5]. Several authors suggest variable-structure systems, various adaptive control techniques and Riccati equation approach for load a frequency controller design [6, 7]. There are many studies about different control strategies having advantages and disadvantages [1, 2, 5, 8-10]. In Reference [9], a load frequency control using a conventional PID controller is applied and it is emphasized that the controller performance is better than others. However, if a power system structure has nonlinear dynamics and parts, the system operating point varies and conventional controllers needing system model must not be used. In Reference [5], a modified dynamic neural networks controller is proposed. It is determined that the proposed controller offers better performance than conventional neural network controller. In Reference [2], for a single area system and two areas interconnected power systems, artificial intelligence techniques are purposed for the automatic generation control and the comparison is performed between intelligent controllers and the conventional PI and PID controllers. In Reference [10], a robust decentralized control strategy is used for Load frequency control for four area power systems to obtain robust stability and better performances. In References [1, 8], power system load frequency control is realized by fuzzy logic controller.

II. FOUR-AREA POWER SYSTEM

Power systems have variable and complicated characteristics and comprise different control parts and also many of the parts are nonlinear [8]. These parts are connected to each other by tie lines and need controllability of frequency and power flow [4]. Interconnected multiple-area power systems can be depicted by using circles. A simplified four area interconnected power system used in this study, each area can be represented as equivalent generating unit and interconnected through lossless tie-lines with some reactance. As simplified four-area interconnected power systems as shown in Fig. 1 [6].

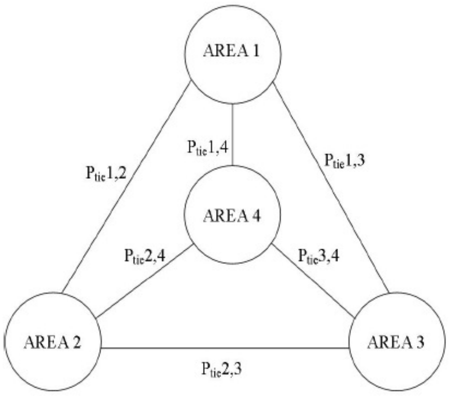

Fig 1 Four-area electric power system with interconnections

In Fig. 2, a four-area interconnected system block diagram is depicted. The system frequency deviation Δf_i, the deviation in
the tie-line power flow $\Delta P_{tie,i}$, load disturbance ΔP_{Di}. The system parameter values are given in Appendix.

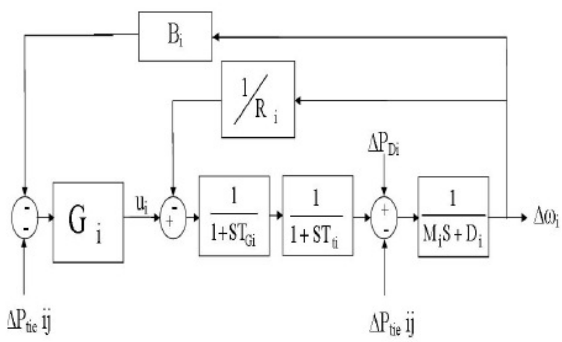

Fig 2 **Block** diagram for one area of system (i[th] area)

A four-area electric power system is considered as a test system and shown in Figure 1. The block diagram for each area of interconnected areas is shown in Figure 2. The parameters in Figure 2 are defined as follows:

Where,

$i = 1, 2, 3, 4.\ j = 1, 2, 3, 4$ and $i \neq j$

Δ : Deviation from nominal value
$M_i=2H$: Constant of inertia of i^{th} area
D_i: Damping constant of i^{th} area
R_i : Gain of speed droop feedback loop of i^{th} area
T_{ti} : Turbine Time constant of i^{th} area
T_{Gi} : Governor Time constant of i^{th} area
G_i : Controller of i^{th} area
ΔP_{Di} : Load change of i^{th} area
$B_i=(1/R_i)+D_i$: Frequency bias factor of i^{th} area
ΔP_{tie} ij : Tie power interchange from i^{th} area to j^{th} area

III. FUZZY LOGIC CONTROLLER

Since power system dynamic characteristics are complex and variable, conventional control methods cannot provide desired results. Intelligent controllers can be replaced with conventional controllers to get fast and good dynamic response in load frequency control problems [12]. If the system robustness and reliability are more important, fuzzy-logic controllers can be more useful in solving a wide range of control problems since conventional controllers are slower and also less efficient in nonlinear system applications [8, 13, 14]. Fuzzy logic controller is designed to minimize fluctuation on system outputs [15]. There are many studies on power system with fuzzy logic controller [16-18]. FLC designed to eliminate the need for continuous operator attention and used automatically to adjust some variables the process variable is kept at the reference value. A FLC consists of three sections namely, fuzzifier, rule base, and defuzzifier as shown in Fig 3.

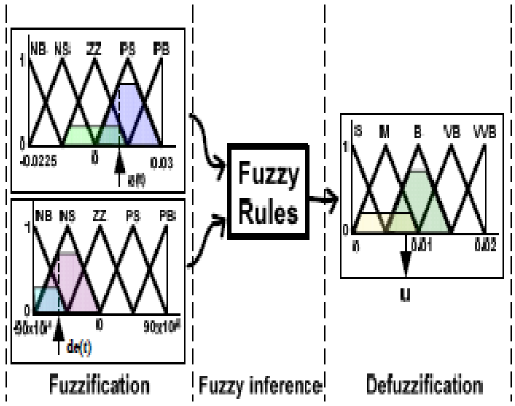

Fig 3 Fuzzy inference system for FLC.

The error, e and change in error, de are inputs of FLC. Two input signals are converted to fuzzy numbers first in fuzzifier using five membership functions: Positive Big (PB), Positive Small (PS), Zero (ZZ), Negative Small (NS), Negative Big (NB), Small (S), Medium (M), Big (B), Very Big (VB) and Very Very Big (VVB). Triangular membership functions are used in this paper since it is easier to intercept membership degrees from a triangle. Then they are used in the rule table shown in Table I to determine the fuzzy number of the compensated output signal. Finally, resultant united fuzzy subsets representing the controller output are converted to the crisp values using the central of area (COA) defuzzifier scheme. The FLC parameters are chosen on the basis of a trial and error study of the control.

TABLE I FUZZY RULES DECISION TABLE FOR FLC

		ė				
		NB	NS	ZZ	PS	PB
e	NB	S	S	M	M	B
	NS	S	M	M	B	VB
	ZZ	M	M	B	VB	VB
	PS	M	B	VB	VB	VVB
	PB	B	VB	VB	VVB	VVB

The main fuzzy reasoning blocks and the defuzzification process of the FLC used in this study are given in Fig. 4. The FLC used here is developed in Matlab/Simulink environment for multipurpose use as a control tool. With some simple modifications it can be used to control different systems. More detailed information about the Matlab/Simulink modeling of the FLC used here can be found in [19, 20].

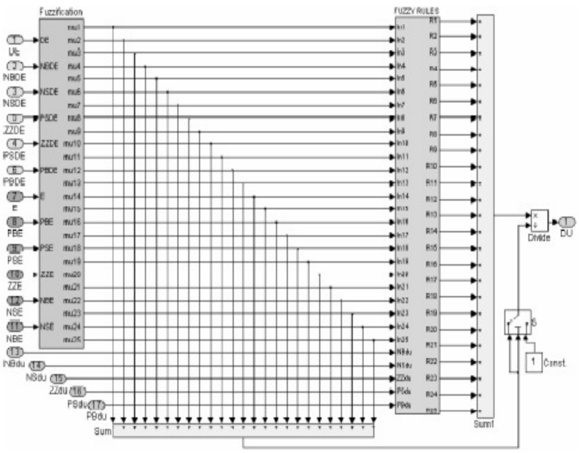

Fig 4 Fuzzy reasoning representing the process from fuzzification to defuzzification

IV. SIMULATION RESULTS

The system dynamic performance is observed for three different controller structures, PI (Proportional + Integral), PID and Fuzzy logic controller. The simulation results are shown in Figs. 5-8 in this study.

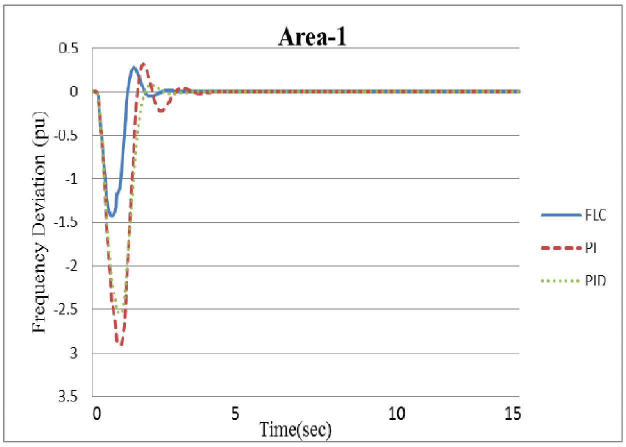

Fig 5 Dynamic response of Area 1

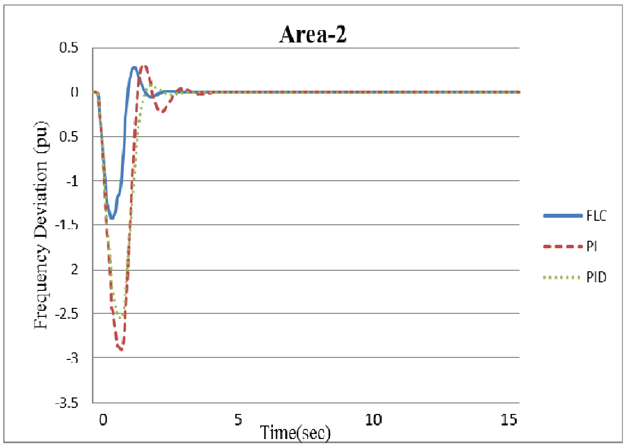

Fig 6 Dynamic response of Area 2

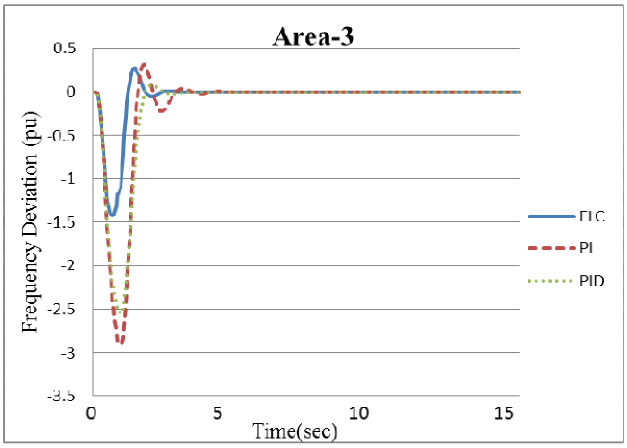

Fig 7 Dynamic response of Area 3

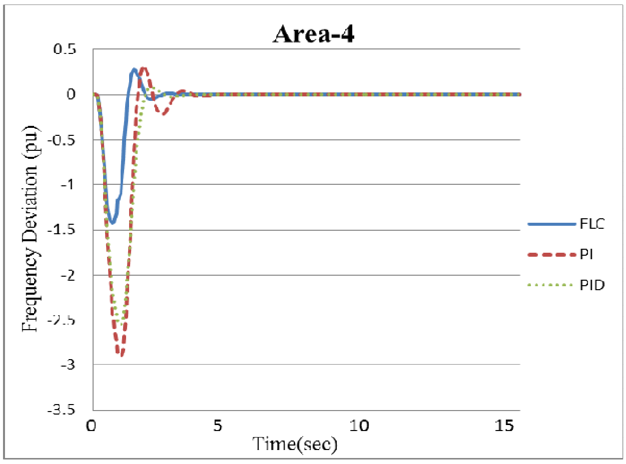

Fig 8 Dynamic response of Area 4

V. CONCLUSION

In this paper, a fuzzy logic controller technique is designed for automatic load frequency control of four-area interconnected power systems. The system dynamic performances are observed via using different controllers.

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APPENDIX

The typical values of system parameters for the nominal operating condition are as follows:

1st area parameters
T_{T1}=0.03 T_{G1}=0.08 M_1=0.1667 R_1=2.4
D_1=0.0083 B_1=0.401 T_{12}=0.425 T_{13}=0.500
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1st area parameters
T_{T1}=0.03 T_{G1}=0.08 M_1=0.1667 R_1=2.4
D_1=0.0083 B_1=0.401 T_{12}=0.425 T_{13}=0.500
T_{14}= 0.400

2nd area parameters
T_{T2}=0.025 T_{G2}=0.091 M_2=0.1552 R_2=2.1
D_2=0.009 B_2=0.300 T_{21}=0.425 T_{23}= 0.455
T_{24}= 0.523

3rd area parameters
T_{T3}=0.044 T_{G3}=0.072 M_3=0.178 R_3=2.9
D_3=0.0074 B_3=0.480 T_{31}=0.500T_{32}= 0.455
T_{34}=0.600

4th area parameters
T_{T4}=0.033 T_{G4}=0.085 M_4=0.1500 R_4=1.995
D_4=0.0094 B_4=0.3908 T_{41}= 0.400 T_{42}= 0.523
T_{43}=0.600

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