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FUZZY BASED LOAD FREQUENCY CONTROL OF FOUR AREA POWER SYSTEM

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Abstract— Due to the increasing load in the interconnection of the power system, power flow in tie- line and area frequency 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 integral derivative controllers. Because gain values of conventional controllers are constant, for load changes. 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 based controller is used 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.

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

I.INTRODUCTION

Generation Control (AGC) is to balance the total system generation against system load losses so that the desired frequency and power interchange with neighboring system is maintained. Any mismatch between generation and demand causes the system frequency to deviate from the nominal value. This high frequency deviation may lead to system breakdown. AGC comprises a load frequency control (LFC) loop and an automatic voltage regulator (AVR) loop interconnected power systems regulate power flows and frequency by means of an AGC. LFC system provides generator load control via frequency zero steady-state errors of frequency deviations and optimal transient behavior are objectives of the LFC in a multi-area interconnected power system.

Literature survey shows that most of earlier work in the area of LFC pertains to interconnected thermal system and relatively lesser attention has been devoted to the LFC of multi area interconnected hydro-thermal system [7]. The PID controllers are very simple for implementation and gives better dynamic response, but their performances deteriorate when the complexity in the system increases due to disturbances like load variation boiler dynamics [6], [7]. Therefore, there is need of a controller which can overcome this problem. The Fuzzy logic control approaches are more suitable in this respect. Fuzzy system has been applied to the load frequency control problems with rather promising results. [8], [9], [15]. The salient feature of these techniques is that they provide a model- free description of control systems and do not require model identification when selecting the specific number of membership function. LFC or AGC is one of the most important issues in electric power system design and operation for supplying sufficient and reliable electric power with good quality. The main aim of LFC for power system are to ensure zero steady state error for frequency deviations, to minimize unscheduled tie line power flows between neighboring control areas and to maintain acceptable overshoot and settling time on the frequency and tie line power deviation

II. MULTI AREA POWER SYSTEM

The multi area power system connected by tie-line is shown in Fig. 1. Consists of four control areas, which are connected by tie lines. In each control area, all generators are assumed to form a coherent group. The four area interconnected power system consists of two re-heat thermal turbine units and two hydro unit.

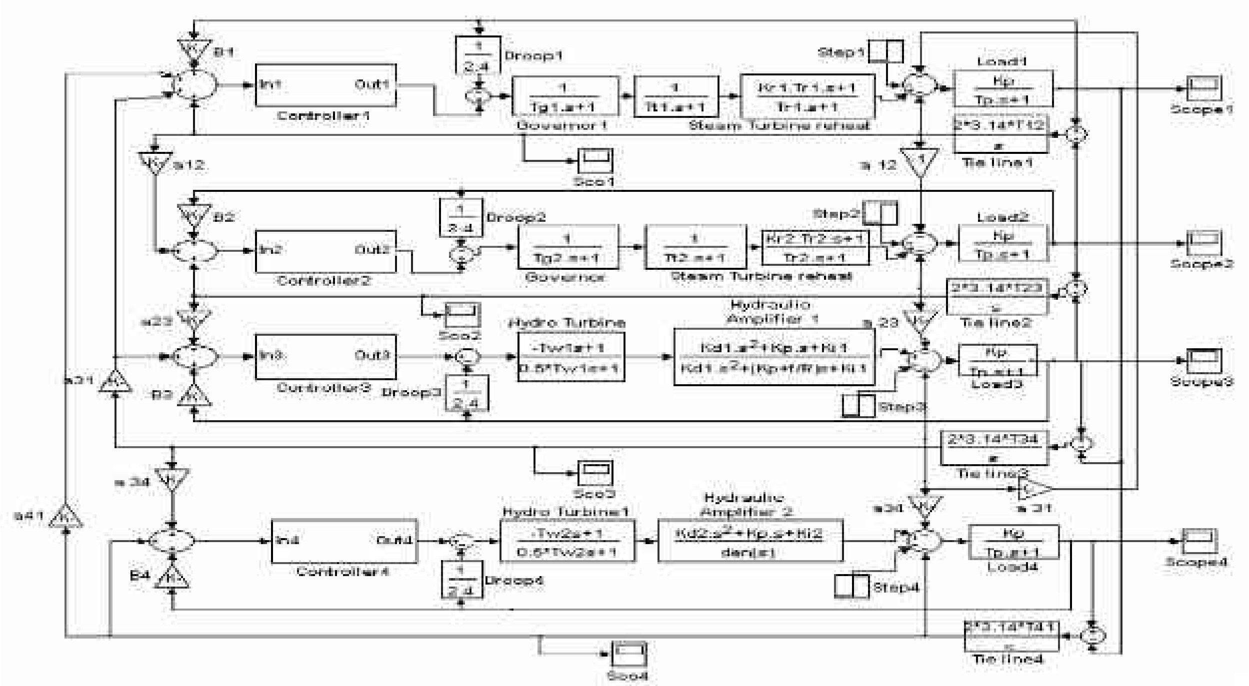

Fig. 1 MATLAB Model of four area hydro-thermal reheat power system

Modeling of the Tie-Line

Considering area 1 has surplus power and transfers to area 2.

P12 = Power transferred from area 1 to 2 through tie line.

Then power transfer equation through tie-line is given by

$$P_{12} = \frac{|V_1|.|V_2|}{X_{12}} . \operatorname{Sin}(\delta 1 - \delta 2)$$

δ1 and δ2 = Power angles of end voltages and V1 and V2 of equivalent machine of the two areas respectively.
X12 = reactance of tie line.

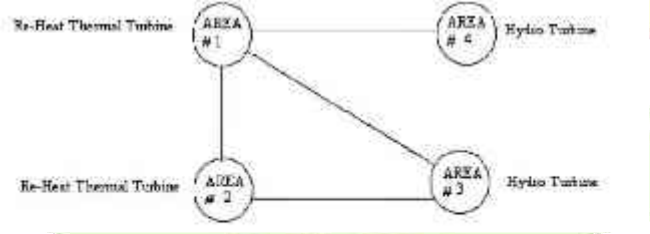

Fig 2 General Model of Four Area Power System

The order of the subscripts indicates that the tie line power is define positive in direction 1 to 2.
For small deviation in the angles and the tie line power changes with the amount i.e. small deviation in δ1 and δ2 changes by Δδ1 and Δδ 2, Power P12 changes to P12 + Δ *P*12
Therefore, Power transferred from Area 1 to Area 2 as given in [11] is

$$\Delta P_{12}(s) = \frac{2\pi T^{o}}{s}(\Delta f_1(s) - \Delta f_2(s))$$

T^0 = Torque produced

In this paper, the performance evaluation based on conventional PID method and Fuzzy control technique for four areas interconnected thermal-hydro power plant is proposed.

III FUZZY LOGIC CONTROLLER

Fuzzy logic is a thinking process or problem-solving control methodology incorporated in control system engineering, to control systems when inputs are either imprecise or the mathematical models are not present at all. Fuzzy logic can process a reasonable number of inputs but the system complexity increases with the increase in the number of inputs and outputs, therefore distributed processors would probably be easier to implement. Fuzzification is process of making a crisp quantity into the fuzzy. They carry considerable uncertainty. If the form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably fuzzy and can be represented by a membership function. Defuzzification is the conversion of a fuzzy quantity to a crisp quantity, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity. There are many methods of fuzzification, out of which smallest of maximum method is applied in making fuzzy inference system. The Fuzzy logic control consists of three main stages, namely the fuzzification interface, the inference rules engine and the defuzzification interface [15]. For Load Frequency Control the process operator is assumed to respond to variables error (*e*) and change of error (*ce*). The fuzzy logic controller with error and change in error is shown in Fig. 3.

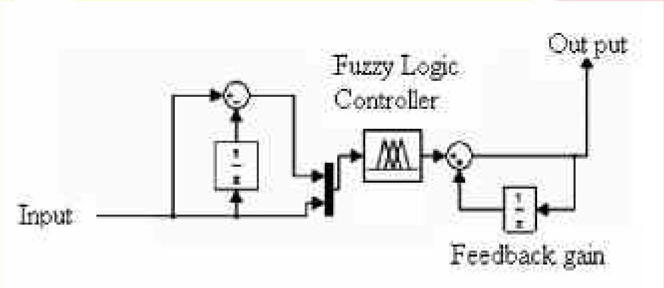

Fig. 3 Model of Fuzzy Logic Controller

The variable error is equal to the real power system frequency deviation (Δ *f*). The frequency deviation Δ*f*, is the difference between the nominal or scheduled power system frequency (*f*N) and the real power system frequency (*f*).

Taking the scaling gains into account, the global function of the FLC output signal can be written as.

$$\Delta Pc = F\,[n_e\, e(k),\ \ n_{ce}\, ce(k)]$$

where ne and nce are the error and the change in error scaling gains, respectively, and F is a fuzzy nonlinear function. FLC is dependant to its inputs scaling gains. A label set corresponding to linguistic variables of the input control signals, *e(k) and* ce(k), with a sampling time of 0.01 sec is given Attempt has been made to examine with Seven number of triangular membership function (MFs) namely Negative Big(NB), Negative Small (NS), Zero(ZZ), Positive Small(PS), and Positive Big(PB) are used. The range on input (error in frequency deviation and change in frequency deviation) i.e universe of discourse is -0.2 to 0.2 and -0.01 to 0.01. The numbers of rules are 25.

Input	e(k)				
ce(k)		NB	NS	ZZ	PS	PB
	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

TABLE I FUZZY RULE BASE

IV. SIMULATION AND RESULTS

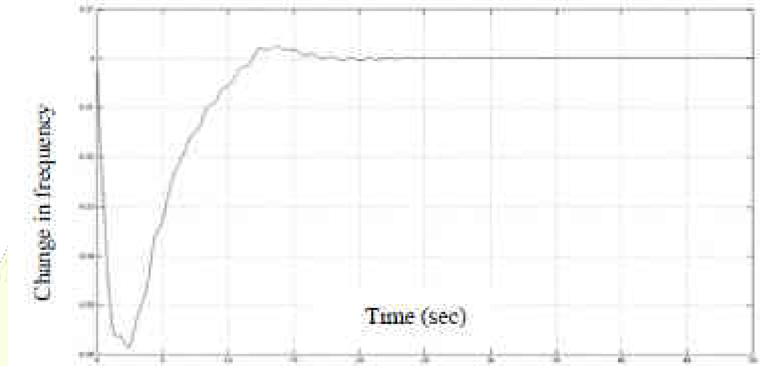

Fig. 4 Change in frequency (thermal plant) – with Fuzzy controller

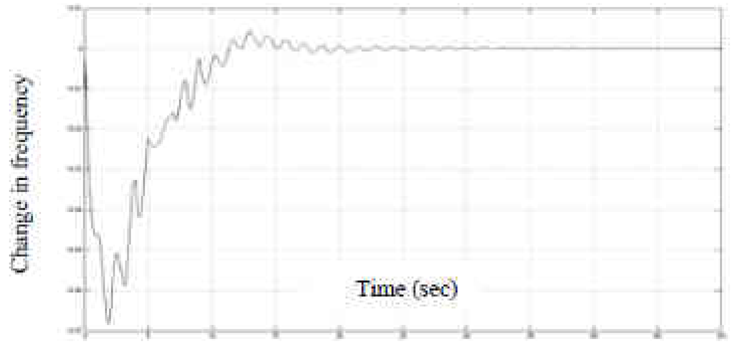

Fig. 5 Change in frequency (hydro plant) – with Fuzzy controller

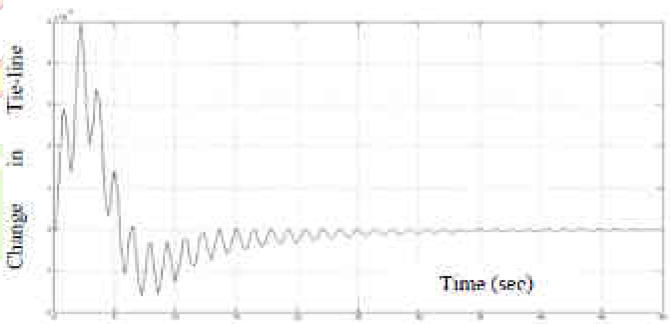

Fig.6 Change in Tie-line power (thermal plant) with Fuzzy Controller

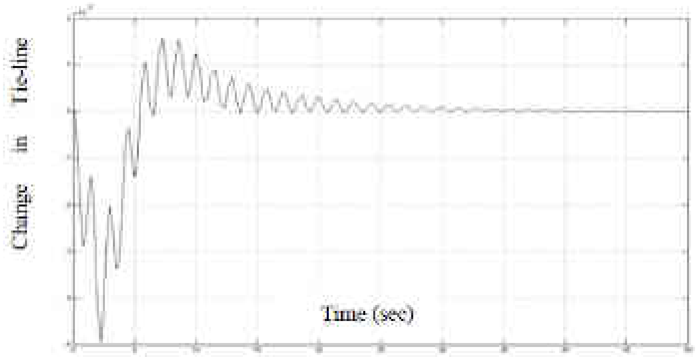

Fig.7 Change in Tie-line power (hydro plant) with Fuzzy Controller

The developed model with Fuzzy controller has been simulated and responses obtained above in Fig. 5-7 reveal that fuzzy controller further reduces the steady state error in frequency deviation and also maximum peak over shoot. The settling time is limited to 45 sec. in case of frequency deviation of thermal plant and 48 sec. for hydro plant. The deviation in the tie-line power is also limited to 45 sec. The settling time and peak over shoot is much lesser than the PID controller.

TABLE I
COMPARATIVE STUDY OF SETTLING TIME

Controller	Area1 (Sec)	Area2 (Sec)	Area3 (Sec)	Area4 (Sec)	Thermal-thermal (Sec)	Hydro thermal (Sec)
PID	60	60	60	50	62	60
FUZZY	45	45	45	48	40	45

TABLE II
COMPARATIVE STUDY OF PEAK OVERSHOOTS

Controller	Area1 (Sec)	Area2 (Sec)	Area3 (Sec)	Area4 (Sec)	Thermal-thermal (Sec)	Hydro thermal (Sec)
PID	-0.049	-0.049	-0.0057	-0.062	0.005	-0.0042
FUZZY	-0.059	-0.06	-0.068	-0.065	0.005	-0.012

By varying 1% step load, the above responses reveals that the steady state error in dynamic change in requency and tieline power are reduced to zero and settling time and peak overshoot is plotted and tabulated in Table I and Table II.

V. CONCLUSIONS

In this paper, automatic generation control of four area interconnected hydro thermal power system is investigated. In order to demonstrate the effectiveness of proposed method, the control strategy based on fuzzy and conventional PID technique is applied. The performance of proposed controller is evaluated through the simulation. The results are tabulated in Table I and II respectively. Analysis reveals that the proposed technique gives good results and uses of this method reduce the peak deviation of frequencies, tie-line power, time error and inadvertent interchange. It can be concluded that fuzzy controller with sliding gain provides better settling performance than conventional PID one. Therefore, the control approach using Fuzzy concept is more accurate and faster than PID control scheme even for complex dynamical system.

VI APPENDIX

Parameters are as follows:
f = 50 Hz, $R_1 = R_2 = R_3 = R_4$ =2.4 Hz/ per unit MW, T_{gi}= 0.08sec,
T_{pi}=20 sec; $P_{tie, max}$ = 200 MW ; Tr = 10 sec ; Kr = 0.5,
$H_1 = H_2 = H_3 = H_4$ =5 sec ; P_{ri}=2000MW, T_{ti} = 0.3sec ;
$K_{p1} = K_{p2} = K_{p3} = K_{p4}$ = 120 Hz.p.u/MW ;K_d =4.0;
Ki = 5.0 ; Tw = 1.0 sec; D_i =8.33 * 10_{-3} p.u MW/Hz.;
$B_1 = B_2 = B_3 = B_4$=0.425 p.u. MW/hz; a_i=0.545;
a=2*pi*T_{12}=2*pi*T_{23}=2*pi*T_{34}=2*pi*T_{41}=0.545,
delP_{di}= 0.01

where
i: Subscript referring to area (i=1,2,3,4)
f : Nominal system frequency
H_i: Inertia constant;
ΔP_{Di} : Incremental load change
ΔPg_i : Incremental generation change
T_r : Reheat time constant
T_g: Steam governor time constant;
K_r : Reheat constant,
T_t : Steam turbine time constant; B_i: Frequency bias constant
R_i : Governor speed regulation parameter
T_{pi} : 2Hi / f * Di, K_{pi}: 1/ Di
K_t: Feedback gain of FLC
T_w : Water starting time, ACE : Area control error
P: Power, E : Generated voltage
V: Terminal voltage, δ Angle of the Voltage V
$\Delta \delta$: Change in angle, ΔP: Change in power
Δf : Change in supply frequency;
ΔPc: Speed changer position
R: Speed regulation of the governor
K_H : Gain of speed governor
T_H : Time constant of speed governor
K_p : 1/B= Power system gain
T_p: 2H / B f_0 = Power system time constant

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