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Design and Analysis of Fuzzy Pid Controller for Multi Area Reheat Thermal Power System

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Abstract: Automatic generation control in electric power system operation is a most common issue presently due to its growing size, varying structure, addition of non conventional energy sources and distributed generators to meet the rising demand. This paper depicts that, the application of fuzzy logic control in automatic generation control. A two area thermal power system considering reheat steam turbine with Generator rate constraints is modeled and the system is simulated for three different speed regulations. The response from conventional Proportional Integral (PI) controller, Proportional Integral Derivative (PID) controller with Fuzzy PID controller is compared. The proposed Fuzzy PID Controller can generate best dynamic performance for a step load change of 0.01puMW. The system simulation is realized by using MATLAB software.

Key words: Automatic Generation Control · Frequency Deviation · Fuzzy Logic Controller · MATLAB · Proportional Integral Controller · Proportional Integral Derivative Controller

INTRODUCTION

In recent years, major changes have been established into the structure of power system due to its growing size, emerging renewable energy resources, environmental constraints and complexity of power system. Area load changes and abnormal fault conditions affect the system frequency and scheduled power interchange between areas. So Automatic Generation Control (AGC) is one of the essential control problems in inter connected power system design to normalize the system frequency and Tie-line power interchange within the scheduled limits. If these values deviated from their limits, they cause unnecessary disturbances in the power system [1-5]. For example, the frequency deviation will affect the power system operation, protection, reliability, efficiency, degrading load performance, over loading of transmission lines and triggering of protection devices.Two major control loops with which the majority of large generators are equipped in the power system are the Automatic Generation Control (AGC) or Automatic Load Frequency control (ALFC) and the Automatic Voltage Regulator (AVR). The AGC which is the key focus of this paper maintains the system frequency and tie line power interchange within the limits. If these load frequency changes not managed correctly, then the system leads to blackout. AGC has two control loops which are primary control loop and secondary control loop. Under normal operating conditions, the small frequency deviation can be attenuated by primary control loop. But fine tuning of frequency deviation, secondary control is required to get the nominal values of frequency.Conventional PI, PD, PID controllers are used as secondary control [6-7]. By tuning the proportional, integral and derivative gains, the desired dynamic response of the power system can be achieved. But the Area Control Error cannot be reached at a minimum value in the integrated multi area power system. So studies are carried out with intelligent controllers to achieve smallest amount of Area Control Error [8-20]. Fuzzy Logic controller will give not only the desired dynamic performance but the Area Control Error to a minimum value [8-10]. Fuzzy logic PI controllers were used to damp oscillations resulted from the step load perturbations [8]. The AGC system performance was estimated with nonlinear neural network controller using generalized neural structure to yield better system dynamic performance than individual neurons [12]. Genetic algorithm can be used for load frequency control for two area interconnected power system [13-16]. Evolutionary algorithm based controller for load

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frequency problem is also observed [17]. Literature survey shows that the conventional and intelligent controller have been designed and experienced, only with one speed regulation parameter. To emphasize the controller suitability it is better to test the system for more speed regulation parameters. While including the fuzzy PID controller the dynamic performance of the system can be enhanced with faster response.

Automatic Load Frequency Control in Single Area System: In single area system, the mechanical power produced by the turbine depends on the steam flow, which will then be transformed to electrical power by synchronous generator. Therefore, the frequency of current and voltage waveforms at the generator output mainly depends on steam flow. So the frequency can be changed by varying the steam injection which involves the adjustment of control valve at the steam flow pipe. Assume an unexpected increase in load, which decreases the speed of the synchronous generator. Due to reduction in the speed the frequency gets reduced. But the frequency should be maintained within its tolerable limit in order to avoid system blackout [1]. The primary control loop senses the load change and adjusts the control valve in order to increase the steam injection to the turbine blades. This will increase the mechanical power output of the turbine according to the load change taken place. Then the speed of the synchronous generator is increased and then brings back the frequency to its nominal value. In secondary control loop the governing mechanism wants to execute a reset action that can be done by integrating the frequency error, which is the difference between the designed reference speed and actual rotating speed and thereby feeding it into the control valve mechanism. This in turn opens the inlet valve to compensate for the speed change and increases the mechanical input to the generator [2, 3].

Automatic Load Frequency Control of Two Area System: The power system with two control areas interconnected by tie line is called as two area power system. Each area supplies its user pool and the tie line allows electric power to flow between areas. Therefore, the load change in one of the areas affects the frequency of other area, as well as the power flow on the tie line. During normal operation, the real power transferred over the tie line is shown in equation 1.

$$P_{12} = \frac{|E_1|\ |E_2|}{(X_{12})\sin\delta_{12}} \tag{1}$$

Where $X_{12}=X_1+X_{tie}+X_2$, $\delta_{12}=\delta_1-\delta_2$ and δ_1, δ_2 are the angles of end voltages E_1 and E_2. Due to some load disturbances, the tie line power deviation

$$\Delta P_{12} = T^o\left(\Delta\delta_1 - \Delta\delta_2\right) \tag{2}$$

In Equation (2) T^o represents the synchronizing coefficient of the tie line. The tie line power flow appears as a load increase in one area and a load decrease in the other area, depending on the direction of the flow. The direction of the flow is indicated by the phase angle difference, if $\Delta\delta_1>\Delta\delta_2$, the power flows from area 1 to area 2. For a sudden load change in area1, the change in frequency is shown in equation 3 and the tie line power change is shown in equation 4. The Area Control Error in area1 and area2 is shown in equation 5 and 6 [18].

The Area Control Error in area1 and area2

$$ACE_1 = \Delta P_{12} + B_1\Delta w_1 \tag{5}$$

$$ACE_2 = \Delta P_{21} + B_2\Delta w_2 \tag{6}$$

The main objective of this paper is to design a fuzzy PID controller to reduce the area control error and to test the two area thermal power system with three different speed regulation parameters.

Power System Model for Investigation: The two area thermal power system connected with an AC tie line is considered. Each area is included with reheat steam turbine with the generator rate constraint of 3% per minute. A step load disturbance is given in area1 and the simulation results for the frequency deviation in area1 and area2 is observed for various values of speed regulation. The tie line power deviation response following the step load change is also observed. Figure 1 shows the simulink diagram for two area thermal power system including Generator rate constraints [19].

The PD controller could add damping to a system and reduces the rate of change of error where the steady state error is not affected. The PI controller could improve the relative stability and reduces the steady state error but increases the oscillations. This leads to the motivation of using a PID controller, so that the best features of each of the PI and PD controllers are utilized. First the system is simulated with conventional PI and PID controller. The control signal from PI and PID controller is given in equation 7 and 8.

For PI controller the control signal is

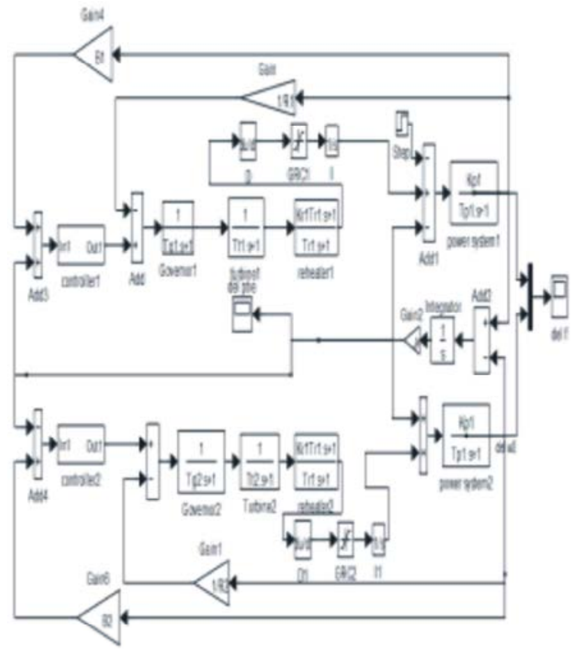

Fig. 1: Simulink model for two area thermal power system including Generator Rate Constraints.

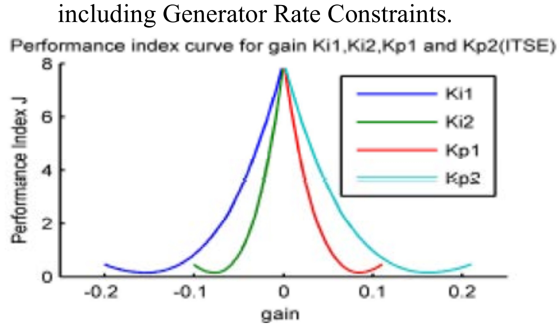

Fig. 2: Performance index curve for gains in PI controller.

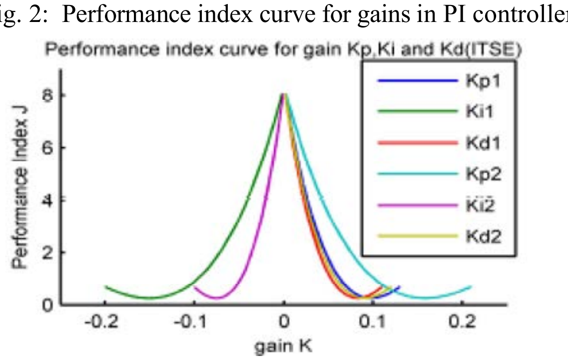

Fig. 3: Performance index curve for gains in PID controller.

$$u(t) = K_p ACE(t) + K_i \int ACE(t)dt \quad (7)$$

For PID controller the control signal is

$$u(t) = K_p ACE(t) + K_i \int ACE(t)dt + K_d \frac{d(ACE(t))}{dt} \quad (8)$$

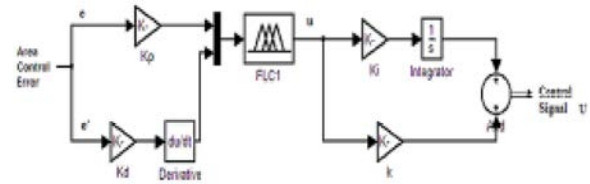

Fig. 4: Struture of fuzzy PID controller.

where Kp, Ki and Kd are the proportional gain, integral gain and derivative gain of the PID controller respectively and ACE(t) is the area control error signal.

In control system design and analysis or for optimal control purposes, performance indices are calculated to be used as quantitative measures to evaluate a system's performance, where a control system is judged as an optimum system when the system parameters are adjusted so that the index used in the design reaches its minimum value, while constraints of the controlled system are respected. The commonly used indices are integral of the square of the error (ISE), integral of the absolute value of the error (IAE), integral of the time multiplied by the squared error (ITSE) and integral of the time multiplied by the absolute error (ITAE). The ITSE method, which will be implemented in this paper, to optimize the gain values of PI and PID controller. The performance index J is given by the following equation 9 [20].

$$J = \int (\Delta f_1 2 + \Delta f_2 2)_{tdt} \quad (9)$$

The performance index curve for obtaining the gain values of PI controller PID controller for speed regulation R=2.4 Hz / puMW are shown in Figure 2 and Figure 3 respectively.

The conventional controller is then replaced with proposed fuzzy PID controller and the dynamic response is observed for three different values of speed regulation in order to emphasize the effectiveness of proposed fuzzy PID controller. Figure4 shows the structure of the fuzzy PID controller.

Fuzzy Modelling

Fuzzification: Fuzzification is the process of transforming real valued variable into a fuzzy set value. The real input value for a two area power system is the area control error and rate of change area control error. The triangular membership function with seven linguistic variables using Mamdani type fuzzy inference system is used in this study. The linguistic variables are NL (Negative Large), NM (Negative medium), NS (Negative Small), ZE (Zero Error), PS (Positive small) PM (Positive Medium) and PL (Positive Large).

Table 1: Rule base for fuzzy controller

	Rate of change of ACE						
ACE	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NM	NM	NS	Z
NM	NL	NL	NM	NM	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PM	PL	PL
PL	Z	PS	PM	PM	PL	PL	PL

Fig. 5: Rule view for fuzzy PID controller.

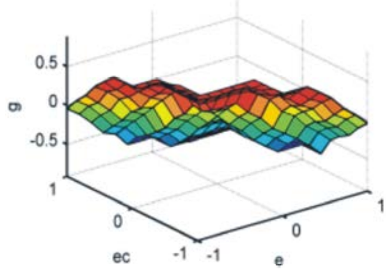

Fig. 6: Surface view for fuzzy PID controller.

Rule Base: The rule base consists of fuzzy if-then rules. A Fuzzy rule may contain fuzzy variables and fuzzy subsets characterized by membership function. For example if the value of Area Control Error (ACE) is NL and the rate of change of area control error is [d(ACE)/dt] NL, then the output control signal is NL. With these fuzzy variables and membership functions, a total of 49 rules are formed. The rule base is given in the Table 1. The rule view for fuzzy PID controller is shown in Figure 5 and the surface view is shown in Figure 6.

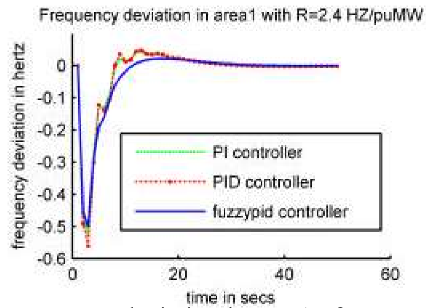

Fig. 7a: Frequency deviation in area1 of two area system with a step load disturbance given in area1 for R=2.4 HZ/puMW.

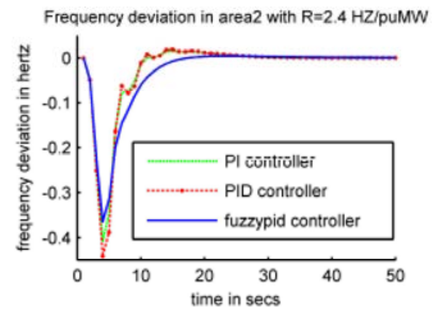

Fig. 7b: Frequency deviation in area2 of two area system with a step load disturbance given in area1 for R=2.4 HZ/puMW.

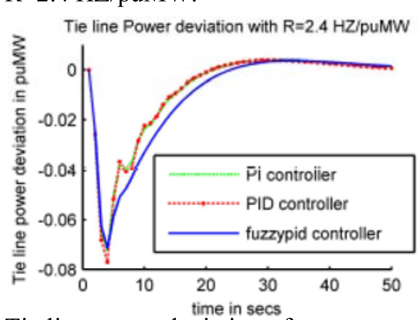

Fig. 7c: Tie line power deviation of two area system with a step load disturbance given in area1 for R=2.4 HZ/puMW.

Defuzzification: Defuzzification converts the output fuzzy variable to a crisp value, so that it can be used for real time control. The centroid method of defuzzification is employed here. The membership function, rule base and method of defuzzification combinally determine the controller performance.

Simulation Results: Frequency deviation of area1, area2 and Tie line power deviation with PI, PID and fuzzy PID controller following a step load disturbance in area 1 with speed regulation R= 2.4 HZ/puMW is shown in Figures 7a, 7b and 7c. Figures 8a, 8b and 8c shows the response for R= 4 HZ/puMW and Figures 9a, 9b and 9c

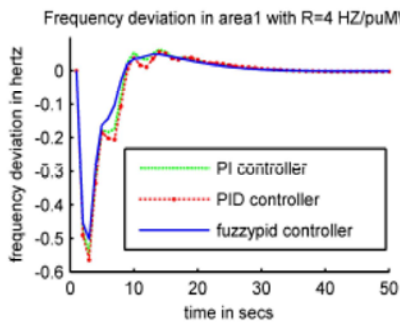

Fig. 8a: Frequency deviation in area1 of two area system with a step load disturbance given in area1 for R=4 HZ/puMW.

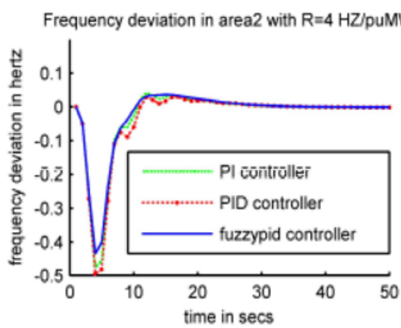

Fig. 8b: Frequency deviation in area2 of two area system with a step load disturbance given in area1 for R=4 HZ/puMW.

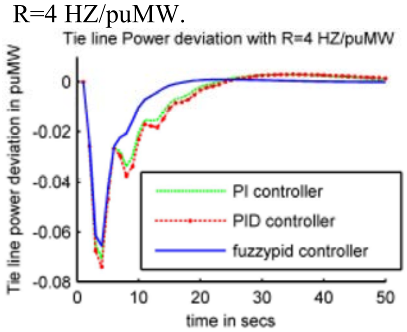

Fig. 8c: Tie line power deviation of two area system with a step load disturbance given in area1 for R=4 HZ/puMW.

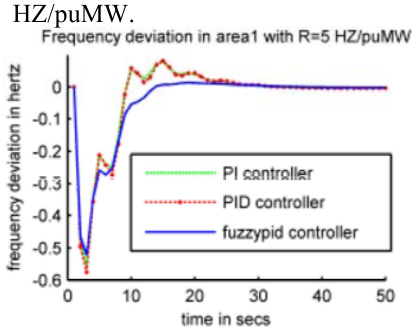

Fig. 9a: Frequency deviation in area1 of two area system with a step load disturbance given in area1 for R=5 HZ/puMW.

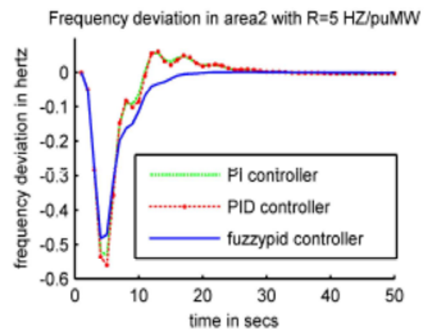

Fig. 9b: Frequency deviation in area2 of two area system with a step load disturbance given in area1 for R=5 HZ/puMW.

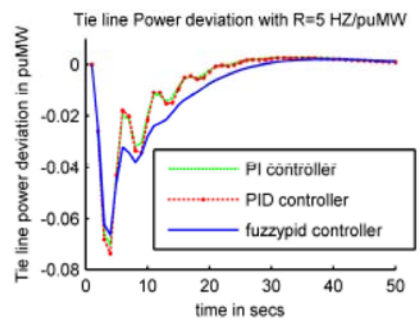

Fig. 9c: Tie line power deviation of two area system with a step load disturbance given in area1 for R=5 HZ/puMW.

shows the response for R= 5 HZ/puMW. For the two area system with fuzzy PID controller the time response specifications such as peak overshoot, undershoot and settling time of the frequency and tie line power deviation curves has less values as compared to conventional PI and PID controller with speed regulation R= 2.4 HZ/puMW, R= 4 HZ/puMW and R= 5 HZ/puMW.

CONCLUSIONS

In this study, Automatic generation Control of two area system with reheat turbine thermal system in each area including generator rate constraints is employed. The performance of PI, PID and Fuzzy PID controller is shown in the simulation results for three different values of speed regulation. From the results, it is observed that while using the Fuzzy PID controller the frequency and tie line power deviation has less settling time, less peak over shoot and peak under shoot as compared to conventional PI and PID controller. Hence by using the fuzzy PID controller the dynamic stability of the system is increased.

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