FUZZY LOGIC BASED LOAD FREQUENCY CONTROLLER

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Abstract: In power system, currently there is a tremendous increase in interconnected systems. Due to which there will be dynamic changes in tie - line power flow as well as load power. So, frequency as well as the tie - line power of the system has to be controlled to maintain steady value of system frequency. But when frequency error is made to zero, the steady state errors in the control system will give birth to errors in tie - line power. Hence, it is necessary to consider input control for the tie - line power variation. Every power generating system in an area takes Area Control Error (ACE) signal. ACE is then used as plant's output. If ACE is made zero in every area then frequency errors occurring in tie - line power also becomes zero.

This control of frequency and tie line power is achieved by implementing Fuzzy logic controller in the place of proportional, Proportional Integral (PI) and Proportional Integral Derivative (PID) controllers. This is due to the reason behind these controllers that the gain constants for conventional controllers remain constant for any load change in the system. As load can't remain same always, load value changes from time to time. In this work, a Fuzzy logic controller is designed and modeled to solve load frequency problems. Comparative analysis is performed between conventional PID controllers and Fuzzy logic controller. Simulation is performed in MATLAB/Simulink software.

Index terms- Area Control Error, frequency deviation, Fuzzy logic controller, load frequency control, PID Controller.

I. INTRODUCTION

In an electric power system, load perturbations cause disturbance in the load which leads to deviation of steady state frequency value [1]. Load frequency control (LFC) is very important concern in power system operation to supply reliable power to consumers [1], [2]. Deviation between active power generated and delivered generates frequency deviations, whereas reactive power deviations generate voltage deviations [3]. LFC ensures that system frequency is maintained at a steady state value. In general loads on the power system keep on changing so the main aim of LFC is to achieve zero frequency deviations.
Fosha and Elgerd conducted research work on load frequency control problem implementing modern control theory in the year 1970, since then research is being developed on load deviations [4], [5]. Control strategies have been proposed from control engineering to solve load frequency control problem. A developed Proportional Integral Derivative Controller has been adapted to load frequency problem in many techniques. J. Lee proposed different methods to improve the performance of PI- type fuzzy logic controller [6]. PID controllers are very popular and easy to implement have been applied for a three area power system, where are the parameters are tuned by trial and error method [7]. Later, Anwar and Pan implemented direct synthesis method to design a technique for PID controller [8]. Many Artificial intelligent controller techniques like fuzzy and Neural Control approach are also proposed in this aspect [9].

With the increase in the load demand complexity of the power system also increase. Then the performance of the conventional controller methods may deteriorate. In this work, the main aim is to compare the performance of PID Controller with Fuzzy Logic controller. Controller performance is evaluated on a single area power system.

II. RESEARCH METHOD

A. Dynamics of power system:

The block diagram representation of a single area power system is shown in Fig.1 in which $\Delta P_{ref}(s)$ is considered as the reference input signal, ΔP_L represents a load perturbation, $\Delta F(s)$ is frequency deviation from the steady state value due to variation in speed. Also, K_t is single gain factor, T_t is single time constant, $\Delta P_v(s)$ is input to the turbine, $\Delta P_t(s)$ is output from the turbine and ΔP_D is the change in load demand.

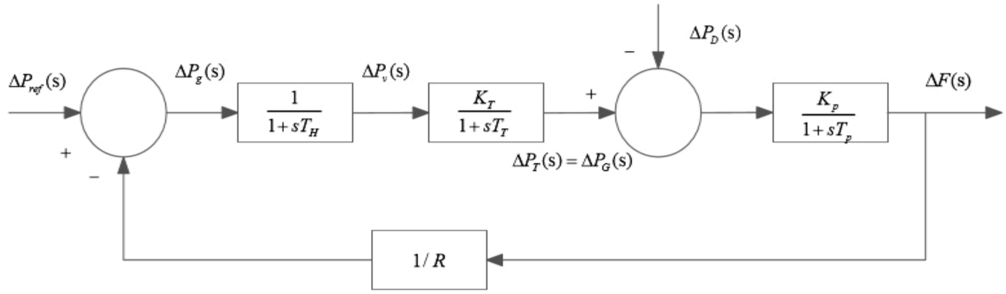

Figure 1. Block diagram of single area ALFC

Taking speed change into consideration the governor controls the opening and closing of the valve. Turbines are employed for energy conversion into mechanical power P_m and a non-reheat turbine is considered here.

B. Load Frequency Control:

The main aim here is to control load frequency through which real power oscillations can be maintained at necessary value within limits. Load Frequency Control (LFC) equipment is installed for each generator in a power system. The necessary controllers are installed in the system to monitor the operation at a particular operating condition and minor load changes are taken into consideration to maintain steady state frequency [10]. Certain assumptions are considered to linearize the mathematical equations which describe the power system operation and finally after performing mathematical modeling; a transfer function model is obtained. Here, ΔP_{ref}(s), the change in speed value setting to a constant value, ΔP_{ref}(s) = 0 is assumed.

C. System with PID controller:

In the considered single area system output frequency of generator is determined by turbine steam flow and also depends on change in load demand which is referred as electric perturbations. When electric load on the system increases suddenly, then shaft of the generator slows down its revolving speed and then finally frequency of generator decreases. Control system placed in the system detects these load variations and then a command signal is sent to steam valve to open more. Then, mechanical power produced from the turbine also increases, which balances load increment and reduces the shaft speed. Then generator frequency reduces to a normal steady state value [11].
PID controller has been used in power system operation since many decades due to its simpler and easy operation. In the present considered system, PID controller is implemented in parallel with the system to make frequency deviations zero whenever a load change is observed. Below figure 2 shows the block diagram of PID controller.

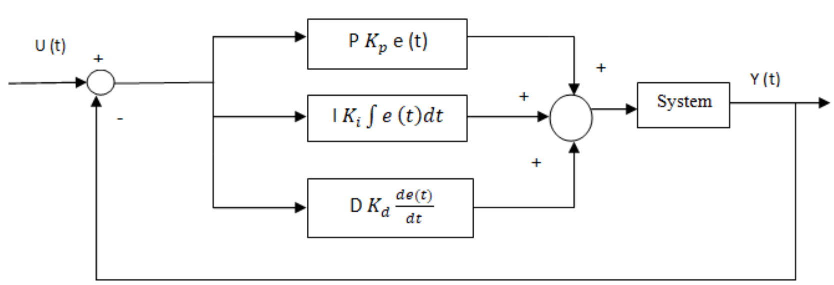

Figure 2 Block diagram of PID Controller

$$u(t) = k_p e(t) + k_i \int e(t)dt + k_d \frac{d(e(t))}{dt} \qquad (1)$$

The output of the controller is controlled based upon the above equation (1) in which k_p, k_i and k_d are the proportional, integral and differential gains respectively. These constant values are considered as k_p=2, k_i =0.8 and k_d=3 [13]. While designing a PID Controller for LFC system, main consideration is given to stability requirements so that with the proper selection of parameters the frequency deviations are reduced. PID Controller mainly focuses on reducing of steady state error by improving the dynamic response of the system.

D. Fuzzy Logic Controller (FLC) in the system:

Lofti Zadeh invented Fuzzy logic tool in the year 1965 which later became an important mathematical tool to solve concept of uncertainty. Fuzzy logic presents a soft computing technique to deal with the concept of word computing. It adjusts the plant's input variables by observing the output of the plant. It has the ability of human mechanism and presents a relationship between complexity of the system and fuzziness. Fuzzy controller adapts well even to non- linear systems also. But other controller can't adapt to non - linearity which turns to be a great advantage of fuzzy logic control [14]. The design of this controller is very easy as it doesn't involve any complex mathematical analysis. The basic block diagram of Fuzzy Logic Controller is shown in below fig. 3 [15].

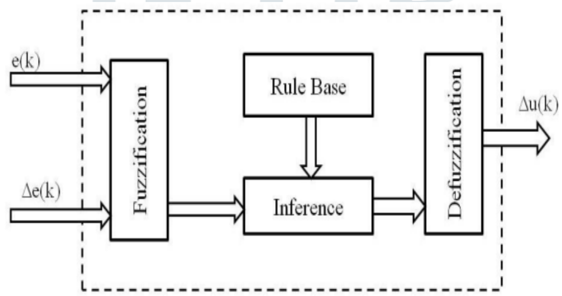

Figure 3. Block diagram of Fuzzy Logic Controller

The three main blocks of FLC controller are fuzzification module, inference engine and defuzzification module. Fuzzification module involves the process of converting numerical variables or crisp values into linguistic variables. Parameters like State error, State error derivative, state error integral come under the category of fuzzy controlled inputs. Membership function is the graphical representation of controlled inputs which define the linguistic variables. Rule base also called as rule table or decision table has fuzzy IF-THEN rules which help to map inputs to output. After implementing the IF- THEN rule set fuzzy controller easily converts crisp variables to linguistic variables using this rule base set. Fuzzy rule inference system involves two methods. They are Mamdani [16] and Sugeno [17]. Mamdani's method invented by Ebrahim Mamdani which is the most frequently used fuzzy inference system. Mamdani's method efficiently produces a single spike in output rather than distributed output. Hence, it is also called singleton output membership function. This method also enhances method of defuzzification as it simplifies the computation process. In this process, it finds out centroid of two dimensional functions. Whereas, Sugeno type of inference method is not constrained to any particular type. Sugeno type system can be employed to model any system having either linear or constant output membership function. In this system, Mamdani method is employed. The defuzzification module converts linguistic output to crisp output. Centroid defuzzification method is implemented which is represented by below equation,

$$X = \frac{\int \mu(x)xdx}{\int \mu(x)dx} \qquad (2)$$

x is the output variable and μ(x) is the membership function with respect to x.

As mentioned the main objective is to damp frequency oscillations, whenever there are zero frequency deviations which a constant value of frequency then no controller action is needed. Only when there is a difference in the frequency deviation then only control action is necessary. Hence, error e(t) and change in error ce(t) are considered as inputs to the fuzzy controller. Further, with the help of fuzzy action the generation command is monitored by changing the power generation levels.

Fuzzy rule table

Error (e) and change of error (ce) are taken as two variable input signals. Five membership functions: Negative Big (NB), Negative Small (NS), Zero (ZZ), Positive Small (PS), and Positive Big (PB) are used to convert input to fuzzy outputs. The fuzzy rule formation is called linear control rule as linear function employed here. This controller is designed with 25 rules with above mentioned five membership functions. Triangular membership function is employed for both input and output.

Table 1 Fuzzy rule base table

ce \ e	NB	NS	Z	PS	PB
NB	PB	PB	PM	NM	PB
NS	PB	PM	Z	NM	PM
Z	PM	PM	Z	NM	NM
PS	NM	NM	NM	PM	NB
PB	NM	NM	NM	PB	NB

'NM' Negative Medium

'PM' Positive Medium

'PB' Positive Big

Some of the rules mentioned in table 1 can be explained as follows,

Rule 1: If e is NB and ce is NB, then output is PB

Rule 2: If e is NB and ce is NS, then output is PB

Rule 3: If e is NB and ce is Z, then output is PM

III. SIMULATION and ANALYSIS:

A single area system is simulated using Simulink and dynamic analysis is performed to measure the frequency deviations and the prime mover response is observed with PID controller and Fuzzy Logic controller. While implementing fuzzy controller, fuzzy rules are written in the .fis file using AND function.

Case I. Single area power system with PID Controller:
PID Controller is implemented in the system with considering k_p= 2, k_i = 0.8, k_d = 3 as parameters. A step load change of 0.01 is applied in the system and the response of prime mover, the obtained frequency deviations and speed response is observed.

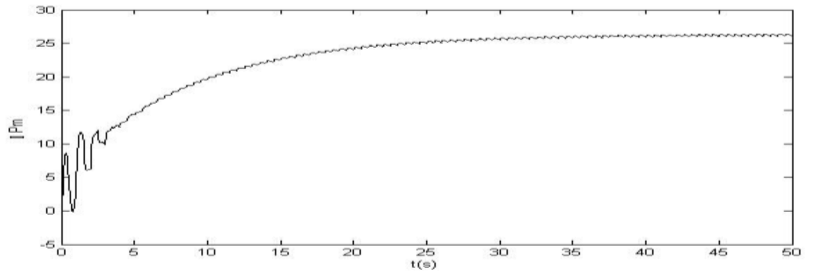

Figure 4 Step response of prime mover with PID controller

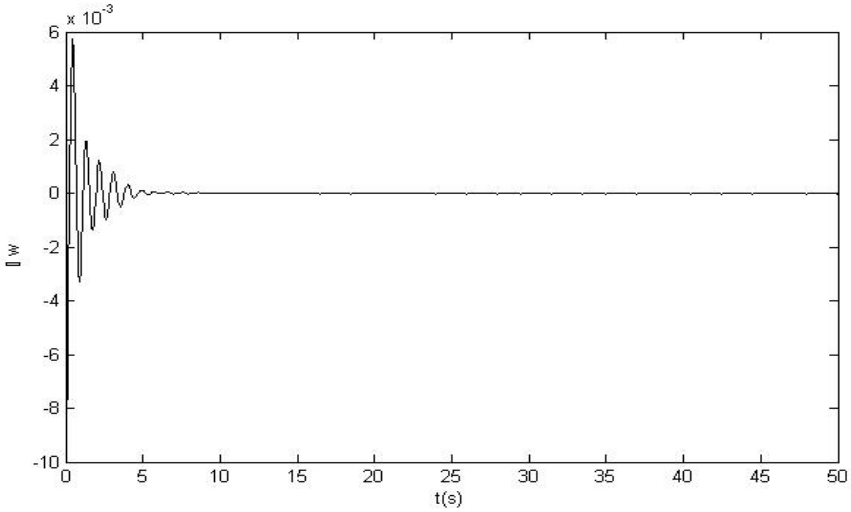

Figure 5 Speed response with step load change applied, with PID controller

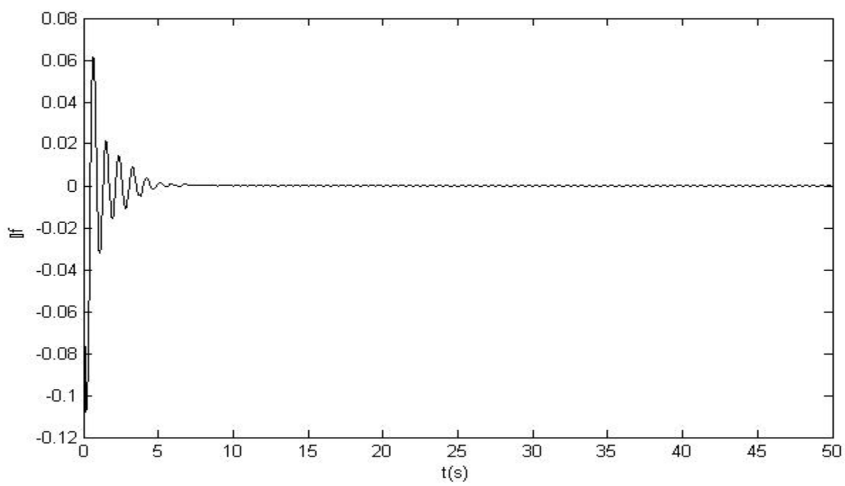

Figure 6 Frequency deviation obtained with PID controller

Figure 6 clearly shows the frequency deviations when step load change of 0.01 is applied to the system. Frequency variation is reduced and finally settled with observed settling time of 8.2sec. Also the dynamic time is equal to 5.5sec. Further, performance of the system is evaluated with fuzzy logic controller and the results are compared with PID controller.

Case II. Single area power system with Fuzzy Logic Controller:

Fuzzy Logic Controller is designed using Matlab Fuzzy Logic Toolbox and implemented in the previously designed single area power system. Fuzzy controller is implemented in the place of PID controller and the results were analyzed. Triangular membership function is considered in this work and the membership functions employed for fuzzy inputs and output is represented in below fig.7 and 8.

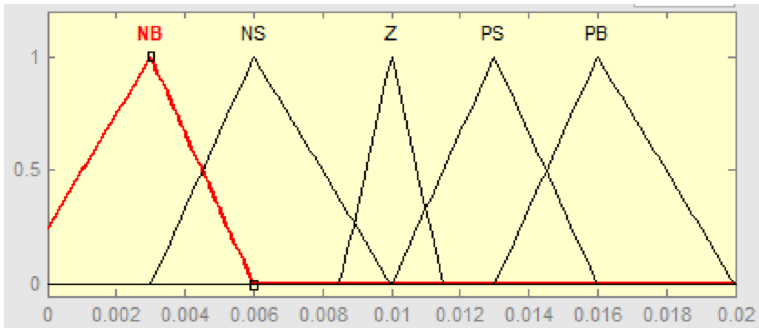

Figure 7 Membership function of input, change in input

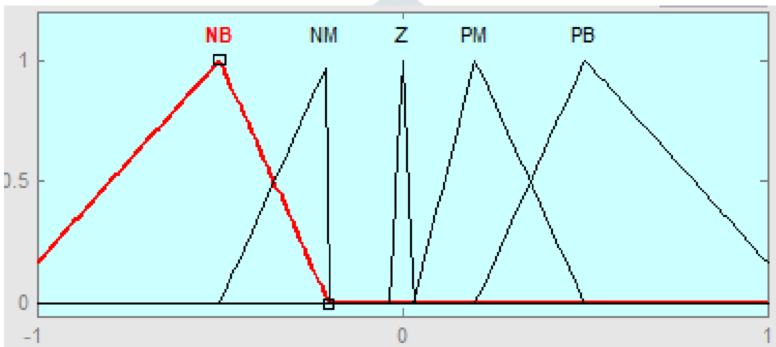

Figure 8 Membership function of output

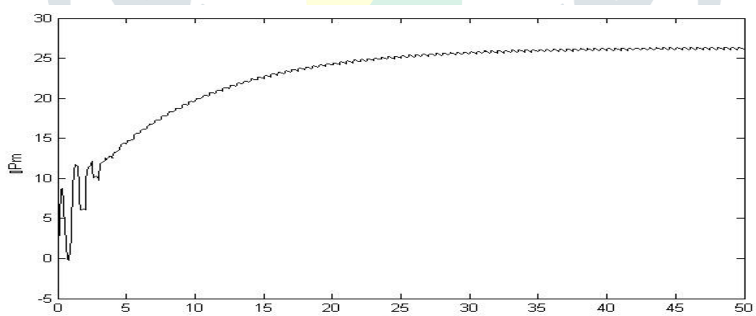

Figure 9. Step response of prime mover with Fuzzy logic controller

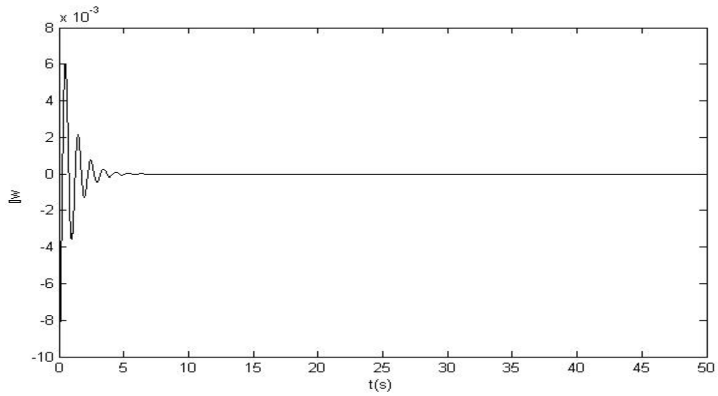

Figure 10 Speed response with step load change, applied with Fuzzy Logic controller

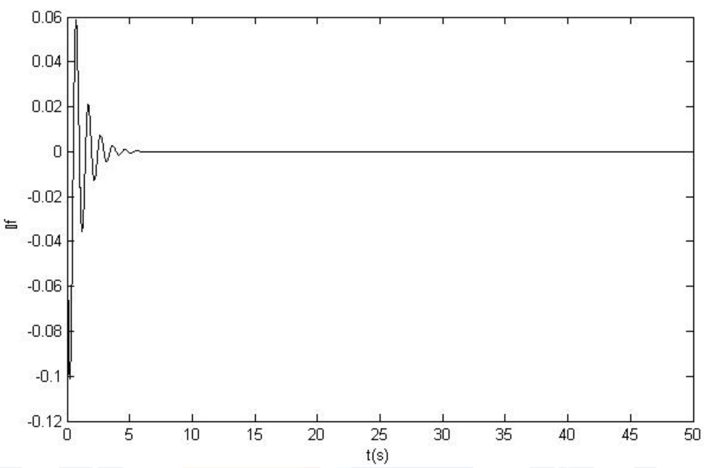

Figure 11 Frequency deviation obtained with Fuzzy Logic controller

Fuzzy logic controller is implemented in the system to improve the dynamic performance. Here, the inputs are given to fuzzy controller and the response is analyzed. From fig. 11 it is clear that the settling time is 5.5sec which is lesser than PID controller also, the dynamic time is observed at 4.4sec.

Case III. Implementation of both PID and Fuzzy logic controller:

In this case the simulation results obtained from controllers are compared. The performance of fuzzy logic controller is tested with conventional PID controller. If the frequency deviation parameter is controlled better in proposed controller than PID controller, then it is also said to be superior to conventional controller. This is clearly justified in below fig. 12 and table 2.

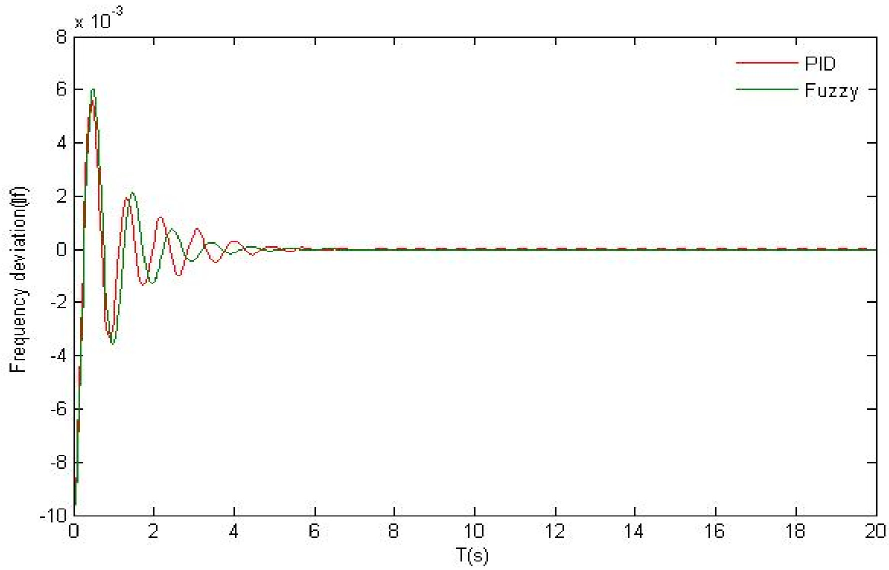

Figure 12 Frequency deviation comparison of PID and Fuzzy Controller

Table 2 Comparison of frequency deviation

Δf	**Maximum Peak (Mp)**	**Dynamic time**	**Settling time**
Fuzzy controller	0.062	4.44s	5.5s
PID controller	0.058	5.3s	8.2s

Above table 2 clearly depicts the superiority of fuzzy logic controller to conventional PID controller. As far as settling time is concerned, PID system would not settle until 8.2sec. But fuzzy system settles the parameter at 5.5sec. Similar result is obtained in dynamic time and maximum peak also. By analyzing the above circumstances it is clear that fuzzy controller delivers better control performance.

IV. Conclusion:

In this paper the performance of PID and Fuzzy logic controllers is evaluated. Simulation analysis was conducted on single area power system in MATLAB/Simulink. Modeling of prime mover, governor and load was performed based on IEEE standards. The design of this scheme has taken maximum time taken by the signal to settle, dynamic time and maximum peak value to evaluate the controller performance. And it is observed that FLC reduced the peak error within less settling time and also has less dynamic time compared with PID Controller. Due to the implementation of fuzzy rules better results have been obtained and proper reliability of the system is maintained with good quality of power supply. The analysis is carried by using time domain simulation. So, it can be concluded that Fuzzy Logic controller has better performance than conventional PID controller. Further work can be done to investigate the fuzzy logic controller performance on two area system or can be extended to multi area power system.

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