RESEARCH ARTICLE OPEN ACCESS

Load Frequency Control of Multi Area System using Integral-Fuzzy Controller

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ABSTRACT
The power system is interconnected to enhance the security and reliability. With large interconnected system, unexpected external disturbances, parameter uncertainties and the model uncertainties make big challenges for stability of system. Load Frequency Control (LFC) deals with the control of real power and frequency of the system. The LFC is used to reduce the transient deviations in the power system. It limits the frequency within limits and controls the tie-line exchange power. Various controllers are used for this purpose. Recently Artificial Intelligence Techniques such as Artificial Neural Network (ANN), fuzzy logic, Genetic Algorithm etc. are used for the designing of controllers. These controllers provide a faster response and are flexible to adjust according to system conditions. In this paper, I have designed integral controller which is conventional method for Load Frequency Control and Artificial Intelligence Technique based Fuzzy Logic controller to deal with the Load Frequency Control Problem for Multi-area System. The simulation of the system is done with MATLAB. These controllers provide a robust system which is more stable and reliable and helps the system to regain its normal state after any disturbance.
***Keywords* -** Load Frequency Control, Integral control, Fuzzy Logic.

I. INTRODUCTION

Power systems convert natural energy into electric power and transmit this power to load centers. For optimized performance of electrical equipment, good quality of power is required which means a nearly constant voltage and frequency of the supply. During the transportation of electrical power through transmission lines both the active power and the reactive power balance must be maintained between generating end and load end. Thus the input to the generators must be continuously maintained according to the varying demand of active power so that the frequency is balanced in the system. As we see that the frequency is dependent on the active power while the voltage is highly dependent on the reactive power. The problem of controlling active power and so the frequency of the system is known as "Load Frequency Control". It is also known as generation control or *P-f* control.

In an interconnected power system consisting of many areas, following controller designing and tuning techniques which includes use of Conventional and Artificial Intelligence Techniques are used for the purpose of load frequency control. Various controllers have been designed for LFC. These work includes the design of conventional Integral controllers. Conventionally Proportional Integral (PI) controllers are used. The Proportional Integral Derivative (PID) Controllers were also designed with enhanced properties for LFC. This controller attempts to minimize the error by adjusting the process control output. Fuzzy logic based controllers are widely used for the LFC. These are based on the fuzzy set theory which takes fuzzy variables. This controller analyzes the system based on some rule base defined and gives the corresponding output. The output is much improved by using fuzzy logic. Artificial Neural Network based controllers are also used widely these days for the purpose of LFC. These controllers are based on pattern recognition and classification. The algorithms used are back propagation, orthogonal least square etc. There are controllers based on the combination of above mentioned techniques such as Neuro-Fuzzy based controllers, PID-Fuzzy based controllers etc. the output performance of the system is much improved after the application of such controllers in the system.

In this paper, I have study and design the load frequency control of a multi area system using conventional integral controller, fuzzy logic and combination of these two controllers. A comparison between these controller systems is taken into consideration to provide the better response of the power system for Load Frequency Control. The power system under consideration is modeled and tested in MATLAB/Simulink and the response of the system is noted. After the application of the integral controller and the fuzzy logic controller in the system, we will be requiring the faster response of the system with less percent overshoot, less delay time, less settling time etc. The aim of these controllers is to restore the frequency to its nominal value in the shortest time possible whenever there is change in demand. It should be coupled with minimum frequency transients and zero- steady state error.

II. LOAD FREQUENCY CONTROL

The LFC controls the loading of the generators of the system at normal frequency. The frequency of a system remains constant or under nominal conditions when active power generation and its demand remain in balanced condition. Due to change in load, there is a deviation in the frequency of the system from the nominal frequency, known as frequency error Δf. This error signal is used by the load frequency control system to change the generation to bring the system under normal condition. The LFC system control the inlet valve opening of the prime movers according to change in loading condition of the system. For large systems and multi area systems automatic control devices or controllers are used in loop of LFC system. The first and foremost task of LFC is to keep the frequency constant against the randomly varying active power loads, which are also known as unknown external disturbance.

II.I Mechanism

When the load demand varies on generating unit, unbalance between the real power input and output occurs. This difference between input and output of real power is supplied by the stored kinetic energy of rotating parts of that unit.

$$\text{Kinetic Energy (KE)} = \frac{1}{2}\, I\, \omega^2$$

Where, I = moment of inertia of rotating part.
ω = angular speed of rotating part.

The kinetic energy, angular speed and frequency are directly proportional to each other. The frequency change is given by Δf and is sensed by a speed-governor system. This value is fed back through a feedback control system to control the position of inlet valve of prime mover so as to maintain balance between input and output of real power. Thus in this way frequency variation is controlled in the system. So the Load frequency control loop senses the change in frequency Δf and change in tie line power ΔP_{tie} which gives the change in rotor angle of the system □ and the change in this angle due to change in loading conditions i.e. Δ□ is need to be corrected for the balance of system. These error signals are given to prime mover for an increment in torque. The prime mover changes the generator output by ΔP_g which in turn bring the values of Δf and ΔP_{tie} within the specified limits.

Another task of the LFC is to regulate the tie-line power exchange error. In order to improve the fault tolerance limit of the whole power system, these different areas of generating units are connected through tie-lines. The tie-line power induces a new error into the control problem of tie-line power exchange error. When a sudden active power load changes in an area, the area gets this power via tie-lines from other areas. But the area that is subjected to the load change should balance it on its own and without external support. Otherwise there would be economic conflicts between the GENCOS and TRANSCOS of areas. Hence each area requires a separate load frequency controller to regulate the tie-line power exchange error so that all the areas in an interconnected power system can set their set-points accordingly. A major problem with the interconnection of the power systems results in huge increase in both the order of the system and the number of the tuning controller parameters. Thus when we model such complex power systems, the model and parameter approximations cannot be avoided. Therefore, the requirement of the LFC is to be robust against the uncertainties of the system model and the variations of system parameters in real.

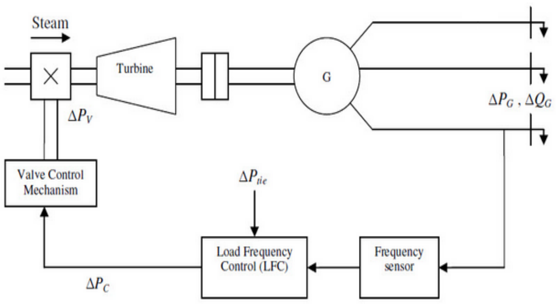

Fig 2.1 Schematic Diagram of Load Frequency Control

The schematic diagram of a Load Frequency Control is shown in figure 2.1

III. DYNAMICS OF GENERATION SYSTEM

III.I Generator

For LFC, we focus on the frequency output of the generator instead of the energy transformation. Swing equation for synchronous machine is-

$$\frac{2H}{\omega_s}\,\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e$$

For small speed change,

$$\frac{d\Delta\frac{\omega}{\omega s}}{dt} = \frac{1}{2H}\left(\Delta P_m - \Delta P_e\right)$$

Taking Laplace transformation

$$\Delta\Omega(s) = \frac{1}{2Hs}\left(\Delta P_m(s) - \Delta P_e(s)\right)$$

III.II Load

For a composite load, the speed-load characteristics is given by the equation

$$\Delta P_e = \Delta P_L + D\Delta\omega$$

Where, $\Delta P_L(S)$ = Load change independent of frequency
$D\Delta\omega$ = Load change dependent on frequency

$$D = \frac{\%\ change\ in\ load}{\%\ change\ in\ frequency}$$

III.III Turbine

The transfer function of non-reheat turbine is given by

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{\tau_t s}$$

Where τ_{ts} = Time constant. Its value lies between 0.2 to 2 seconds.

III.IV Speed governing system

From speed governor characteristics,

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega$$

The relation between ΔP_g and ΔP_v is

$$\Delta P_v = \frac{1}{1+\tau_g}\Delta P_g(s)$$

III.V Tie lines

The equation representing tie line is given as

$$\Delta P_{tie}(s) = \frac{1}{s}T_{ij}\left(\Delta F_i(s) - \Delta F_j(s)\right)$$

Where ΔP_{tie} = tie line exchange power between two areas
T_{ij} = tie line synchronizing torque between two areas.

III.VI Area control error

The Area Control Error (ACE) can be defined as

$$ACE_i = \sum_{j=1\ldots n, j\neq i} \Delta P_{tie\ ij} + B_i\Delta F_i$$

Where B_i = frequency response characteristic for area

The output of each generation area is given by ACE. All the frequency errors and tie line power errors will be zero if we can make the ACE as zero.

III.VII Parallel operation

The power generating units are connected in parallel for their operation. The equations related to such condition are given as

$$M_{eq} = \sum_{i=1\ldots n} M_i$$

$$D_{eq} = \sum_{i=1\ldots n} D_i$$

$$B_{eq} = \sum_{i=1\ldots n}\frac{1}{R_i} + \sum_{i=1\ldots n} D_i$$

Where M_{eq} = Equivalent generator inertia constant
D_{eq} = Load damping constant
B_{eq} = Frequency Response characteristic

IV. INTEGRAL CONTROLLER

The integral controller used for the purpose of LFC is comprised of a frequency sensor and an integrator. The work of frequency sensor is to sense the change in frequency or frequency error (Δf) of the system due to load change or fault condition. This frequency error signal is then fed to the integrator. This frequency error which is given as the input to integrator is known as "Area Control Error" (ACE). Thus we can say that ACE is the frequency change of an area which is given to integral control action loop to bring the system in steady state and keep frequency error as zero i.e. ACE = Δf.

Thus the integrator work as

$$\Delta P_c = -k_i\int \Delta f\,.dt$$

Where ΔP_c = Power command signal
K_i = integral gain constant.

The signal ΔP_c is given as input to speed changer and makes it move according to the stability requirement. The integral gain constant controls the rate of integration and so the speed response of the control loop of the system. The block diagram for a system having integrator and frequency sensor is shown in figure 4.1

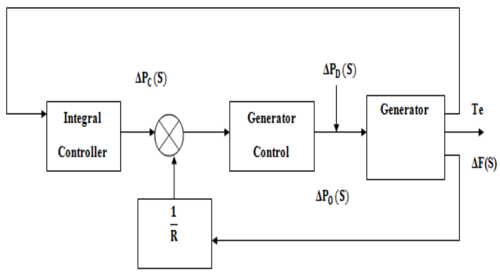

Fig 4.1 Block Diagram of Integral Controller

In this figure,

R = speed regulation feedback parameter
$\Delta P_G(s)$ = incremental changes in generation
$\Delta P_D(s)$ = incremental changes in load
$\Delta F(s)$ = incremental changes in frequency

V. FUZZY LOGIC CONTROLLER

The fuzzy logic controller works in a same way as human by adjusting the input signal to system based on the changes in output parameters. The fundamental fuzzy logic control approach consist of four elements-

1. Fuzzification
2. Interference system
3. Rule base
4. Defuzzification

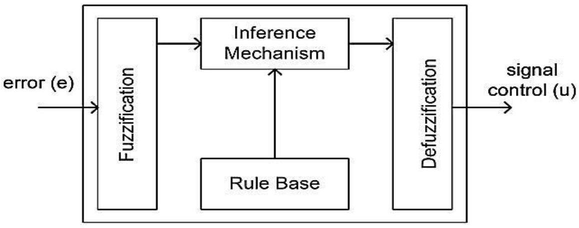

Fig 5.1 Block Diagram of Fuzzy Logic

Fuzzification is the process of changing crisp value to a fuzzy value. This fuzzy value carries uncertainty in it. This value is represented by membership functions. Fuzzy control loop consist of fuzzy reasoning and rule base to give the decisions. Knowledge Base defines the parameters and variables of the fuzzy set. Defuzzification is the process of changing the fuzzy values to a crisp value. It is basically interpreting fuzzy set membership degrees into decision or real value.

The Fuzzy logic based Load frequency controller is designed with two inputs. One input is Area Control Error and second input is differential of ACE. The output signal is the change of the control signal. For designing the controller, Mamdani type fuzzy interference engine has selected and centroid method is used for defuzzification. The membership function gives the range upto which an input belongs to a fuzzy set. We have use triangular membership functions are used for both input and output of the fuzzy logic controller. Five membership functions are being used with the set of 25 rule base to define the control problem of LFC. These are given in table 5.1

TABLE 5.1: FUZZY RULES

		ACE				
$\dot{}$		M	N	O	P	Q
A	M	N	N	N	N	O
	N	N	N	N	O	P
C	O	N	O	O	P	P
	P	O	O	P	P	P
E	Q	O	P	P	Q	Q

NB : Negative Big, NS : Negative Small, Z : Zero, PS : Positive Small. PB : Positive Big

The membership functions for the controller are shown in figure 5.2

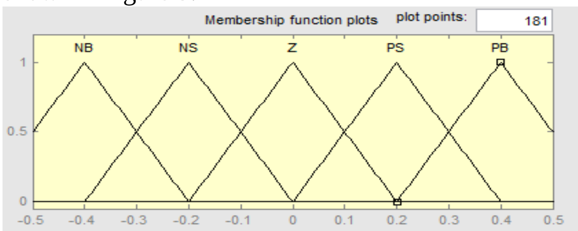

Fig 5.2 Membership Function Diagram of Fuzzy Controller

These membership functions are used to describe the linguistic variables. If-Then statement is used for designing the control rules. This system is then implemented in the actual system to enhance the performance of the system.

VI. SIMULATION AND RESULT

The four area system consisting of Thermal Power systems with non-reheat type turbine are simulated. This system is connected with integral controller, fuzzy controller and a combination of integral fuzzy controller. The response of the system is taken with 1% of variation in frequency in each Area. The frequency deviation and tie-line power value for different area is as shown in figures. The steady state error is eliminated in the system with Tie-Line Bias Control. The combination of tie line power error and frequency are used to make ACE linear.

The response of four area system without any controller and with 1% frequency deviation in each area is shown in figure 6.1. The tie line power variation is shown in figure 6.2. The frequency response of the system with integral controller is shown in figure 6.3 and its tie line power is shown in figure 6.4. The system response with fuzzy controller is shown in figure 6.5 and 6.6. The system frequency deviation and tie line power with combined integral and fuzzy logic based controller is shown in figure 6.7 and 6.8.

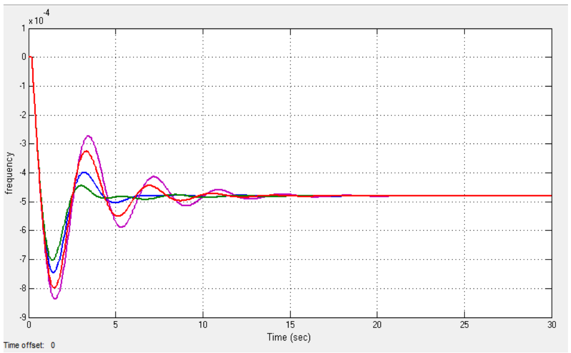

Fig 6.1 Frequency response of four area system

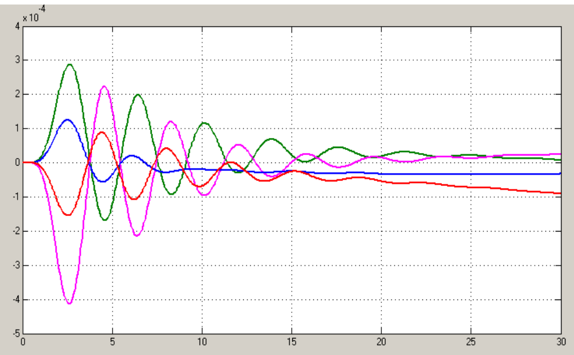

Fig 6.2 Tie line power of four area system

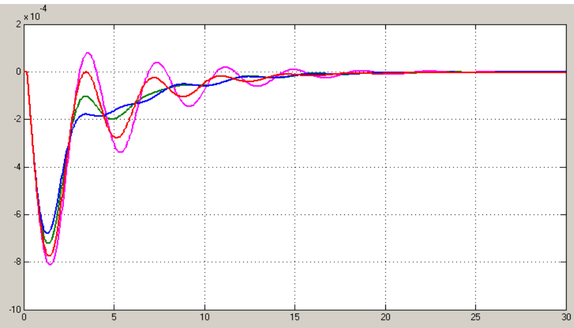

Fig 6.3 Frequency Response of Four Area System with Integral Controller

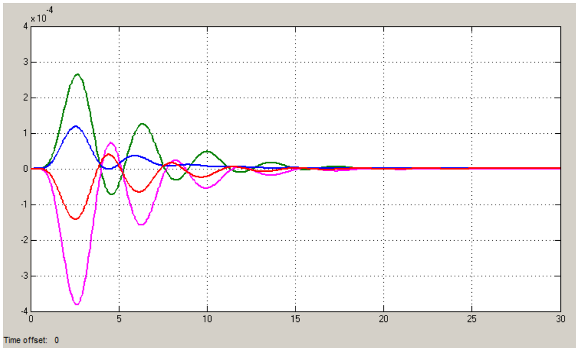

Fig 6.4 Tie Line Power of Four Are System with Integral Controller

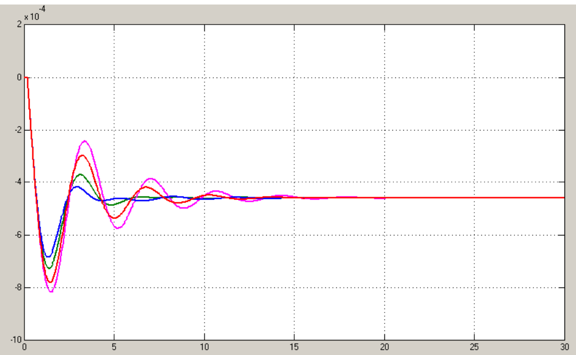

Fig 6.5 Frequency response of four area system with Fuzzy Controller

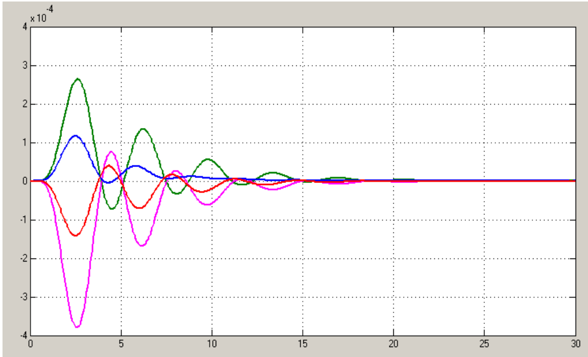

Fig 6.6 Tie Line Power of Four Area System with Fuzzy Controller

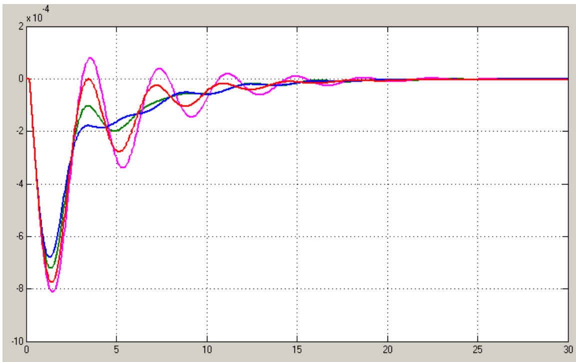

Fig 6.7 Frequency Response of Integral-Fuzzy Controller

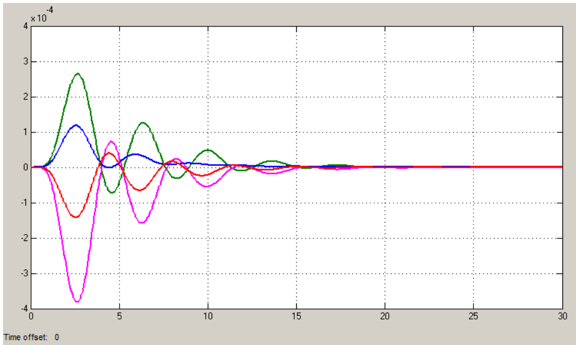

Fig 6.8 Tie line Power with Integral Fuzzy Controller

VII. CONCLUSION

In this paper, a multi area power system is designed. This area is simulated with the help of MATLAB. Then I have designed integral controller and fuzzy logic based controller for this system. The controllers are designed such that whenever some disturbance in frequency response or fault occurs in the system, then the system would be able to regain its original normal operating condition in least time. This makes the system more stable and reliable. When the system is simulated with MATLAB with Integral controller, we observed that the system is able to regain its nominal operating condition with zero steady state error. This improves the safety of the system and makes system more reliable. Now, when the fuzzy logic controller is connected in the system, the system regains its normal operating condition in same duration. With using fuzzy logic based controller, the system stabilizes with less settling time but there is a little deviation from the nominal frequency and with the application of integral with fuzzy controller, the system stabilizes in less settling time with zero steady state error. Hence the system response is improved.

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