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Load Frequency Control of Two Area Interconnected Power System Using Conventional and Intelligent Controllers

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ABSTRACT
The load on the power system is always varying with respect to time which results in the variation of frequency, thus leading to load frequency control problem (LFC). The variation in the frequency is highly undesirable and maximum acceptable variation in the frequency is ± 0.5hz. In this paper load frequency control is done by PI controller, which is a conventional controller. This type of controller is slow and does not allow the controller designer to take into account possible changes in operating conditions and non-linearity's in the generator unit. In order to overcome these drawbacks a new intelligent controller such as fuzzy controller is presented to quench the deviations in the frequency and the tie line power due to different load disturbances. The effectiveness of the proposed controller is confirmed using MATLAB/SIMULINK software. The results shows that fuzzy controller provides fast response, very less undershoot and negligible peak overshoots with having small state transfer time to reach the final steady state.

***Keywords* –** PI controller, Fuzzy controller, Two area power system, load frequency control, MATLAB SIMULINK

I. Introduction

In order to keep the system in the steady-state, both the active and the reactive powers are to be controlled. The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency with in permissible limits.

Changes in real power mainly affect the system frequency, while the reactive power is less sensitive to the changes in frequency and is mainly dependant on the changes in voltage magnitude. Thus real and reactive powers are controlled separately. The load frequency control loop (LFC) controls the real power and frequency and the automatic voltage regulator regulates the reactive power and voltage magnitude [11]. Load frequency control has gained importance with the growth of interconnected systems and has made the operation of the interconnected systems possible. In an interconnected power system, the controllers are for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits [12].

II. Reasons for keeping frequency constant

The following are the reasons for keeping strict limits on the system frequency variations. The speed of AC motors is directly related to the frequency. Even though most of the AC drives are not much affected for a frequency variation of even 50±0.5Hz but there are certain applications where speed consistency must be of higher order. The electric clocks are driven by synchronous motors and the accuracy of these clocks is not only a function of frequency error but is actually of the integral of this error. If the normal frequency is 50Hz, and the turbines are run at speeds corresponding to frequency less than 47.5Hz or more than 52.5Hz the blades of the turbine are likely to get damaged. Hence a strict limit on frequency should be maintained [1] . The system operation at sub normal frequency and voltage leads to the loss of revenue to the suppliers due to accompanying reduction in load demand [13] .It is necessary to maintain the network frequency constant so that power stations run satisfactorily in parallel.

The overall operation of power system can be better controlled if a strict limit on frequency deviation is maintained. The frequency is closely related to the real power balance in the overall network. Change in frequency [2-6], causes change in speed of the consumers' plant affecting production processes.

III. Mathematical Modeling

3.1 Complete Block Diagram Representation of Load Frequency Control of an Isolated Power System.

The complete block diagram representation of an isolated power system comprising turbine, generator, governor and load is obtained by combining the block diagrams of individual components.

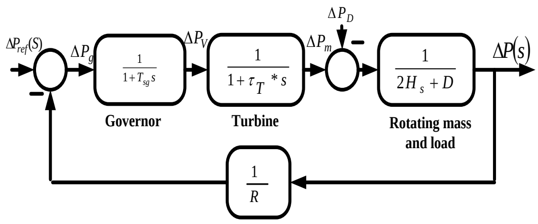

Fig 3.1 Block Diagram Representation of Load Frequency Control of an Isolated Power System

IV. 4. Two Area Load Frequency control

An extended power system can be divided into a number of load frequency control areas interconnected by means of tie-lines. Let us consider a two-area case connected by a single tie-line.

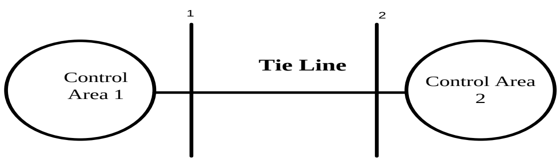

Fig 4.1 Two Area with Tie-Line Connection

The control objective is now to regulate the frequency of each area and to simultaneously regulate the tie-line power as per inter-area power contracts. As in the frequency, proportional plus integral controller will be installed so as to give steady state error in tie-line power flow[7-10] as compared to the contracted power.

Each control area can be represented by an equivalent turbine, generator and governor system. Symbols with suffix 1 refer to area 1 and those with suffix 2 refer to area 2. In an isolated control area case the incremental power (ΔP_G-ΔP_D) was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Since a tie-line transports power in or out of an area, this must be accounted for in the incremental power balance equation of each area.

Power transported out of area 1 is given by

$$P_{tie1} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1 - \delta_2) \ldots\ldots\ldots\ldots\ldots 4.1$$

Where, δ_1, δ_2 are power angles of equivalent machines of two areas. For incremental changes in δ_1 and δ_2 , the incremental tie line power can be expressed as

$$\Delta P_{tie1}(pu) = T_{12}(\Delta\delta_1 - \Delta\delta_2) \ldots\ldots\ldots \ldots\ldots\ldots\ldots 4.2$$

$$\text{Where } T_{12} = \frac{V_1 V_2}{P_{r1} X_{12}} \cos(\delta_1^0 - \delta_2^0) \ldots\ldots\ldots\ldots 4.3$$

is a synchronizing coefficient. Since incremental

power angles are integrals of incremental frequencies, we can write above equation as follows

$\Delta P_{tie1} = 2\pi T_{12} (\int \Delta f_1 \, dt - \int \Delta f_2 \, dt) \ldots\ldots\ldots\ldots 4.4$

Where Δf_1 and Δf_2 are incremental frequency changes of areas 1 and 2 respectively. Similarly, the incremental tie-line power out of area 2 is given by

$\Delta P_{tie2} = 2\pi T_{21} (\int \Delta f_2 \, dt - \int \Delta f_1 \, dt) \ldots\ldots\ldots\ldots 4.5$

$$\text{Where } T_{21} = \left(\frac{P_{r1}}{P_{r2}}\right) T_{12} = a_{12} T_{12} \ldots\ldots\ldots\ldots 4.6$$

The power balance equation for area 1 is given by,

$$\Delta P_{G1} - \Delta P_{G2} = \frac{2H_1}{f_0}\frac{d}{dt}(\Delta f_1) + B\Delta f + \Delta P_{tie,1} \ldots 4.7$$

Taking the Laplace form of the above equation and arranging them we get,

Let

$$\Delta F(s) = [\Delta P_{G1}(s) - \Delta P_{G2}(s) - \Delta P_{tie1}(s)] * \frac{K_{ps1}}{1 + T_{ps1} s} \ldots 4.8$$

$K_{ps,1} = 1/B_1$ and $T_{ps,1} = 2H_1 / B_1 f^0$

Also,

$$\Delta P_{tie1}(s) = \frac{2\Pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] \ldots 4.9$$

$$\Delta P_{tie2}(s) = -\frac{2\Pi a_{12} T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] \ldots 4.10$$

In two-area power system [14-17], inorder that the steady state tie line power error be made zero, another integral control loop must be introduced to integrate the incremental tie-line power signal and feed it back to the speed changer. This is accomplished by defining ACE as a linear combination of incremental frequency and tie-line power. Thus, for control area 1,

$ACE_1 = \Delta P_{tie1} + b_1 \Delta f_1$ 4.11

Taking the Laplace transform of the above equation, we get

$ACE_1(s) = \Delta P_{tie1} + b_1 \Delta F_1(s)$……………………4.12

Similarly, for control area 2,

$ACE_2(s) = \Delta P_{tie2} + b_2 \Delta F_2(s)$……………………4.13

The complete block diagram of two-area load frequency control is shown below. For the steady state error to be zero, the change in tie-line power and the frequency of each area should be zero. This can be achieved by integration of ACEs in the feedback loops of each area.

V. Different types of controllers

5.1 PI controller

A controller in the forward path, which changes the controller output corresponding to the proportional plus integral of the error signal is called PI controller. The PI controller increases the order of the system, increases the type of the system and reduces steady state error tremendously for same type of inputs.

5.2 Fuzzy controller

In control systems, the inputs to the systems are the error and the change in the error of the feedback loop, while the output is the control action. The general architecture of a fuzzy controller is depicted in Fig 5.3[1]. The core of a fuzzy controller is a fuzzy inference engine (FIS), in which the data flow involves fuzzification, knowledge base evaluation and defuzzification.

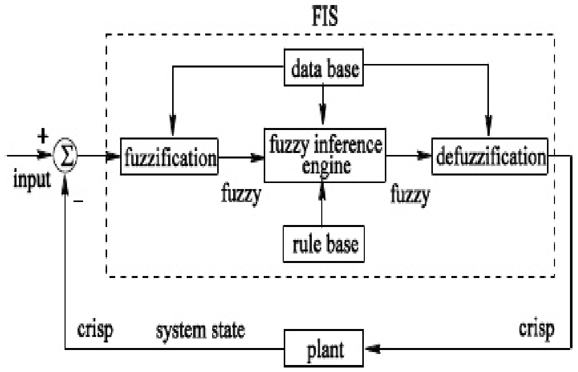

Fig 5.1 Structure of fuzzy logic controller

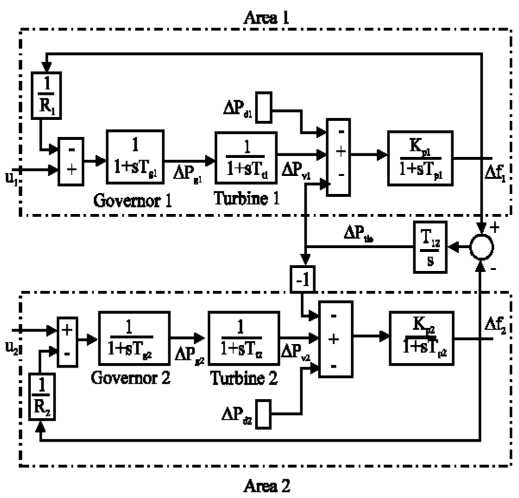

Fig 5.2 Complete block diagram of two- area LFC

VI. 6. Simulation results of two-area LFC

6.1 Two-area LFC without and with PI Controllers

The two-area LFC is also implemented using MATLAB SIMULINK with and without PI controllers and also with FUZZY controller. The following are the specifications of simulation.

For Control Area 1

- Gain of speed governor $K_{sg} = 1$
- Gain of turbine $K_t = 1$
- Gain of generator load $K_{ps} = 120$
- Time-constant of governor $T_{sg} = 0.08$
- Time-constant of turbine $T_t = 0.28$
- Time-constant of generator load $T_{ps} = 18$

For Control Area 2

- Gain of speed governor $K_{sg} =1$
- Gain of turbine $K_t =1$
- Gain of generator load $K_{ps} =100$
- Time-constant of governor $T_{sg} =0.1$
- Time-constant of turbine $T_t =0.28$
- Time-constant of generator load $T_{ps} =20$

The simulation block diagrams and their results are as follows.

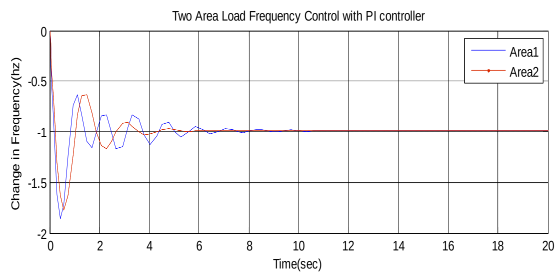

Fig 6.1 Response of two-area LFC without controller

Now the simulation is done with controllers. The results are as follows.

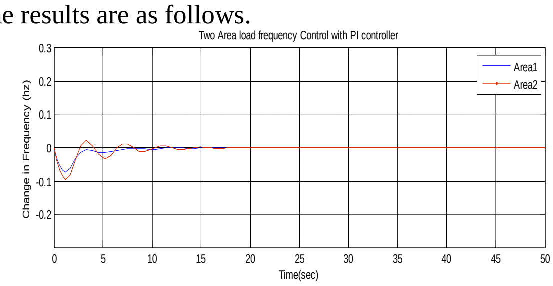

Fig 6.2 Response of two-area LFC with PI controller

6.2 Simulation using FUZZY Controller

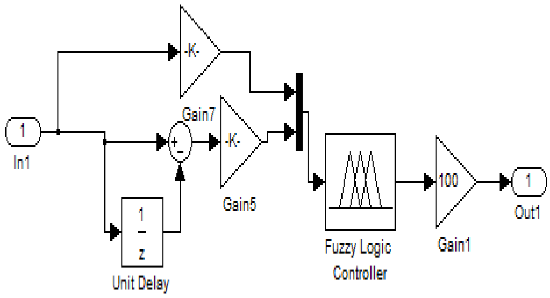

Fig 6.3 Simulation block diagram of Subsystem

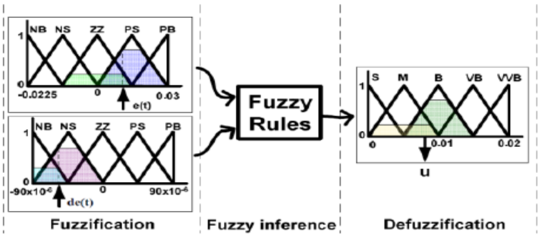

Fig 6.4 Fuzzy inference system for two area fuzzy controller

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Table 1. Rules for two area fuzzy controller

		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

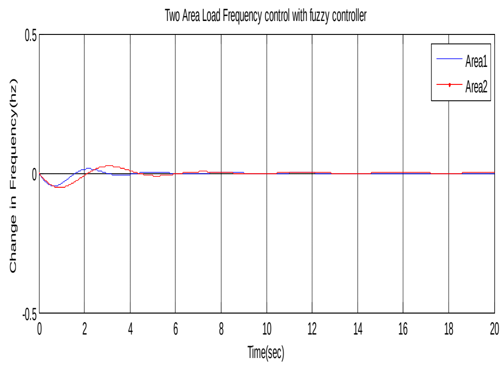

Fig 6.5 Response of two-area LFC with FUZZY controller

Table.2 Comparison between PI and Fuzzy controllers

Area	Parameter	Without any controller	With PI Cont-roller	With Fuzzy Cont-roller
1	Peak Overshoot (hz)	1.8	0.07	0.05
	Settling Time(sec)	Never settles down to steady state value	7	3
2	Peak Overshoot (hz)	1.75	0.09	0.07
	Settling Time (sec)	Never settles down to steady state value	17	5

6.3 Observations of Two-Area LFC

The steady state error in the response of two-area LFC with PI controller is almost zero when compared with the response obtained without controller. Comparing Fig 6.1, 6.2 it can be seen that the performance using PI controller is better than that of not using any controller. From Fig 6.5 it is observed that by using FUZZY controller, the steady state error, settling time and peak-overshoot are reduced which is preferred.

VII. CONCLUSION

The system frequency should be maintained constant and it will be undesirable if the limits exceed. In order to maintain the frequency constant and to make the steady state error zero, we used different types of controllers like PI and FUZZY in our paper. By using these controllers, the steady state error, settling time and peak-overshoot are reduced. Also the performance is compared between the controllers. From the observations in the previous sections, it can be concluded that performance of Multi-area Load Frequency Control using FUZZY controller is much better than that of PI controller because by using PI controller, only the steady state error is reduced but by using FUZZY controller, settling time and the peak-overshoot are also reduced. The frequency change can also be reduced by using other advanced techniques. Some of those techniques are Particle Swarm Optimization (PSO) method, Genetic Algorithm method, using Artificial Neural Network (ANN)[5] method.

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