© 2016 IJSRSET | Volume 2 | Issue 2 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Theme Section : Engineering

Load Frequency Control of Two Area Interconnected Systems Using Fuzzy PI Controller

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Abstract

The automatic generation control (AGC) problem of large interconnected power systems have been studied by considering the whole power system as a group of control areas. A control area may be described as a power system, a part of a system, or a combination of systems for which a common generation control scheme is capable of handling the control aspects of the system. This paper improves the stability of AGC of two area interconnected Thermal-Thermal (T-T) power system. The operation of the proposed controller in the presence of generator rate constraints is compared with those of conventional PI controller in two area interconnected T-T power system.

Keywords : Automatic Generation Control, PI Controller, Load Frequency Control

I. INTRODUCTION

The electrical interconnections within each control area are supposed to be very strong, whereas the ties between areas are weak. However, all generators in a control area operate coherently or swing in unison, which is characterized by a single frequency. In normal steady-state operation, each control area of a power system should strive to meet its own load demand. Simultaneously, each control area of a power system should participate in regulating the frequency of the system [1-2].

An electric energy system must be preserved at a desired operating level characterized by nominal frequency and electric potential profile and this is accomplished by close control of real and reactive powers, generated through the controllable source of the arrangement. Therefore, the control issue in power systems can be decoupled into two independent problems. One is about the active power and frequency control, whereas the other is about the reactive power and voltage control [3]. The active power and frequency control is mentioned to as Load Frequency Control (LFC) or AGC. A large frequency deviation can damage equipment, degrade load performance, cause the transmission lines to be overloaded and can impede with system protection schemes, ultimately leading to an unstable condition for the power system [4].

Therefore, the main job of AGC is to hold the frequency constant against the arbitrarily varying active power loads, which are likewise referred to as unknown external disturbance. Another job of the AGC is to regulate the tie-line power exchange error. A typical large-scale power system is composed of various areas of generating units. To bring down the monetary value of electricity and to improve reliability of power supply, these generating units are connected via tie-lines [5]. The usage of tie-line power imports a new error into the control problem, i.e., Tie-line power exchange error. When a sudden active power load change occurs in an area, the area will obtain energy via tie-lines from other areas.

II. INTERCONNECTED THERMAL SYSTEM

Power systems are interconnected for economy and continuity of power supply. For the interconnected operation, fuel costs, generation limits, tie line capacitors, spinning reserve allocation and area commitments are important considerations. Compared to stand alone power system, interconnected networks have special features that need to be addressed such as load sharing, frequency error minimized and reliable power supply. Interestingly, if the number of interconnections is more, the total inertia is increased, thereby reducing the oscillations. While interconnecting two or more stand-alone power system, it should be noted that:

- Generators in two areas have same power rating.
- All areas are connected through tie-line.
- Each area regulates its own load variations.

A. Control Area

An interconnected power system can be divided into a number of load frequency control pools known as control area.

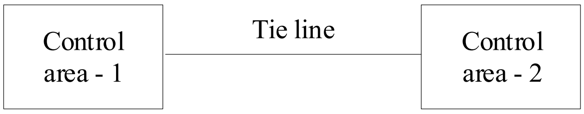


Figure 1: Tie Line

Each control area is connected by tie-line. Figure1 represent the control area 1 and control area 2 connected through tie line. As per the existing standards and policies [6], a control area is defined as a part or a combination of several power systems under common control for which a single area control is defined. The primary goal of control area concept is to provide optimal interconnected operation.

- Under normal condition, each control area should have the capacity to meet its own load from its generation capacity plus the scheduled interchange between neighbouring areas.
- Under emergency condition, the power can be drawn from the spinning reserves of all the neighbouring areas due to the sudden loss of generation.

B. Tie-Line

A multi area interconnection is comprised of region, or areas that are interconnected by tie-line. Tie-lines have the benefit of providing inter area support for abnormal condition on overall as the transmission parts for contractual energy exchanges between the areas. In nonlinear tie line bias control of interconnected power systems [7], the area boundaries are determined by the tie-line metering for AGC and contractual billing purpose.

A mode of LFC in which Area Control Error (ACE) is a function of the net interchange error and frequency related biases.

The function of the tie line bias control is as follows:

- Causing each area to absorb its own load changes.
- Making each area to do its share of system frequency control.

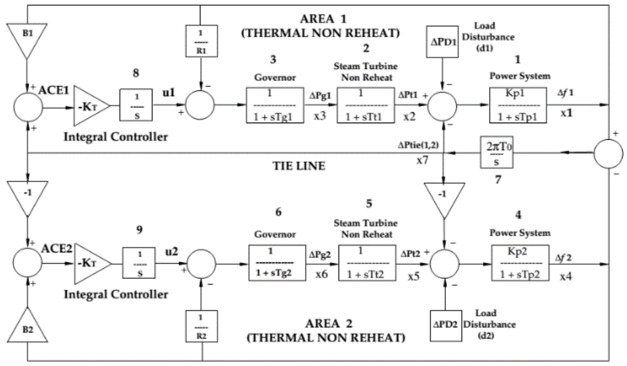


Figure 2: Two area thermal-thermal (non-reheat) system with integral controller

- Determining the steady state response of an area to a remote load change, after the initial governing response and pending absorption of the load change by the remote area.

Interconnected power generation is optimum, when each control area has the tie line bias set to Area Frequency Response Characteristics (AFRC). The basic equation relates tie line modeling for area 1,

$$\Delta P_{tie} = \frac{2\pi T_{12}}{s}\left(\Delta F_1 - \Delta F_2\right)$$

Where, T_{12} represents the synchronizing co-efficient or tie line strength, ΔF_1 and ΔF_2 represent the frequency deviation in area 1 and 2 respectively. On the other hand, for area 2;

$$\Delta P_{tie21} = -\Delta P_{tie12}$$

Therefore, if two areas are interconnected, algebraic sum of tie line power is zero. In other words, if area 1 delivers power, same amount is received by area 2 and vice versa.

C. Non-Linearities

In the view of exact modeling, all non-linearities associated with governor should be included. In this context, governors have dead-band effect, which is important for speed control under small disturbances. The effects of governor dead band on analog AGC were studied [8].

The multi-area power system consists of interconnection of several power systems. Each area of the power system consists of speed governing system, turbine, and generator. In this work, each area of a single non-reheat turbine is considered. Perturbed model of a two area T-T (non-reheat) power system with controller scheme is shown in Figure 2.

Each area has three inputs and two outputs. The inputs are the controller input ΔP_{ref} (also denoted as u), load disturbance ΔP_D and tie-line power error ΔPtie. The outputs are the generator frequency ΔF and ACE, given by;

$$ACE = B\Delta F + \Delta P_{tie} \qquad (1)$$

where B is the frequency bias parameter.

To simplify the frequency-domain analyses, transfer functions are used to model each component of the area. Turbine is represented by the transfer function [9] as;

$$G_T(s) = \frac{\Delta P_T(s)}{\Delta P_V(s)} = \frac{1}{1 + sT_T} \qquad (2)$$

From [1-2], the transfer function of a governor is

$$G_G(s) = \frac{\Delta P_V(s)}{\Delta P_G(s)} = \frac{1}{1 + sT_G} \qquad (3)$$

The speed governing system has two inputs ΔP_{ref} and ΔF, with one output ΔPG(s) given in [9],

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \qquad (4)$$

The generator and load are represented by the transfer function [5];

$$G_P(s) = \frac{K_{PS}}{1 + sT_{PS}} \qquad (5)$$

where K_{PS} = 1/D and T_{PS} = 2H/f D. The generator load system has two inputs ΔPT(s) and ΔPD(s), with one output ΔF(s) as given in [5];

$$\Delta F(s) = G_P(s)\left[\Delta P_T(s) - \Delta P_D(s)\right] \qquad (6)$$

III. CONVENTIONAL PI CONTROLLER

The conventional PI controller is the simplest method of control and widely used in industries. Proportional plus Integral Controller increases the speed of response.

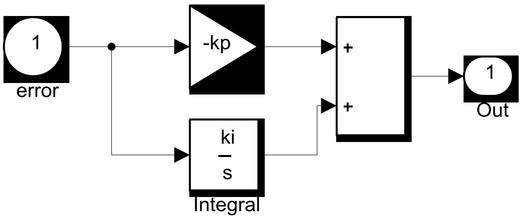


Figure 3: Block diagram of PI controller

It produces very low steady state error. In this paper, ACE is given as input to PI controller and output is taken into the system. General equation of the PI controller is;

$$U(s) = K_P E(s) + \frac{K_i}{s} E(s) \tag{7}$$

where Kp is proportional gain, K_i is the integral gain, E(s) is the controller input and U(s) is the controller output. Figure 3 shows the block diagram of PI controller. Ziegler Nichols' method of tuning is adopted to find the optimum value of Kp and Ki values. Table.1 shows the gain and ISE values of PI controller.

Table.1 Gain values of PI controller

Controller	Kp	Ki	ISE
Conv PI	0.85	0.06	777.6886

IV. PSO ALGORITHM

Particle swarm optimization algorithm was introduced by Kennedy and Eberhart in 1995, as inspired from fish schooling and birds flocking, is a powerful yet simple optimization algorithm that can perform extensive exploration of the problem space. Besides, it does not rely on derivative information to guide the search toward the problem solution. Particle swarm optimization and some of its variants have been proposed and successfully applied to economic dispatch problems with piecewise quadratic cost functions [10, 11-13].

The PSO algorithm is based on the behavior of individuals of a swarm developed by Kennedy and Eberhart. Its roots are in zoologist-modeling of the movement of individuals (i.e., fish, birds, and insects) within a group. It has been noticed that members of the group seem to share information among them to lead to increased efficiency of the group. The particle swarm optimization algorithm searches in parallel using group of individuals similar to other AI-based heuristic optimization techniques. Each individual corresponds to a candidate solution to the problem. Individuals in a swarm approach to the optimum through its present velocity, previous experience and the experience of its neighbours. In a physical n-dimensional search space, the position and velocity of individual i are represented as the velocity vectors. Using these information individual i and its updated velocity can be modified under the following equations in the particle swarm optimization algorithm. The flowchart of the particle swarm optimization is shown in Figure 4.

$$x_i^{k+1} = x_i^{(k)} + v_i^{(k+1)} \tag{5}$$

$$v_1^{k+1} = v_i^k + \alpha_i\left(x_i^{lbest} - x_i^{(k)}\right) + \beta_i\left(x_i^{gbest} - x_i^{(k)}\right) \tag{6}$$

Where,

$x_i^{(k)}$ is the individual i at iteration k

$v_i^{(k)}$ is the updated velocity of individual i at iteration k

$\alpha_i ; \beta_i$ are uniformly random numbers between [0,1]

x_i^{lbest} is the individual best of individual i

x^{gbest} is the global best of the swarm

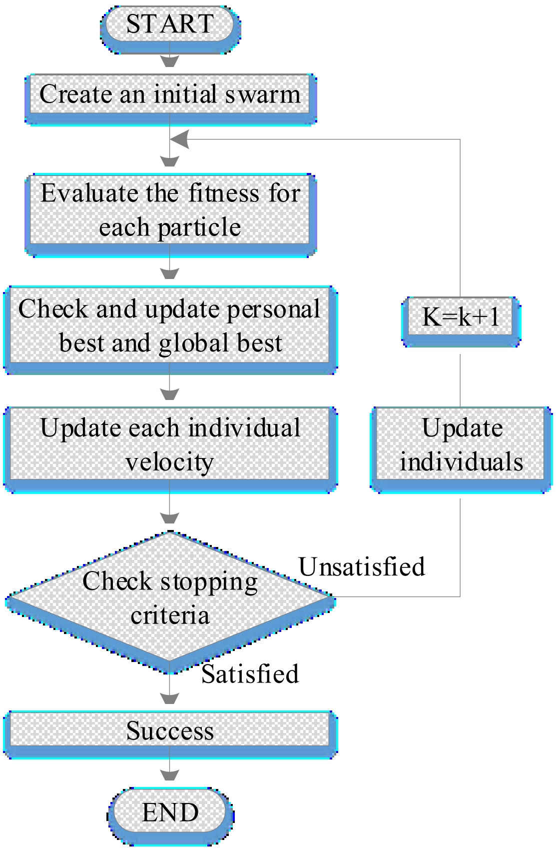


Figure 4: Flowchart of the PSO algorithm

V. FUZZY - PI CONTROLLER

The fixed value of K_p and K_i in a PI controller produces a sudden change in frequency. Online tuning of K_p and K_i in a PI controller can conquer this problem. It necessitates the Fuzzy Gain Scheduling controller for online tuning of K_p and K_i [14]. Fuzzy logic controllers (FLCs) have been an interesting and good alternative in a variety of power system applications [15]. Their advantages are robustness, a non-requirement of a mathematical model and acceptance of non-linearity. In order to implement the FLC algorithm in an interconnected power system, frequency deviation is sensed and given to the fuzzy gain scheduling controller. In a Fuzzy Gain Scheduling controller, Fuzzy logic module is considered as a self-tuning module for parameters K_p and K_i in PI controller. The Fuzzy PI controller considers the major contribution of this paper. Figure 5 shows the fuzzy logic control and Figure 6 shows the fuzzy membership functions of the proposed system. Table.2 shows the fuzzy membership functions.

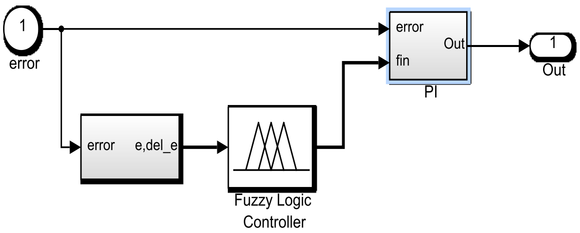
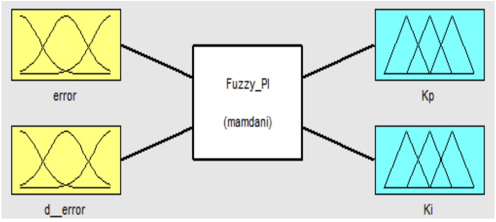
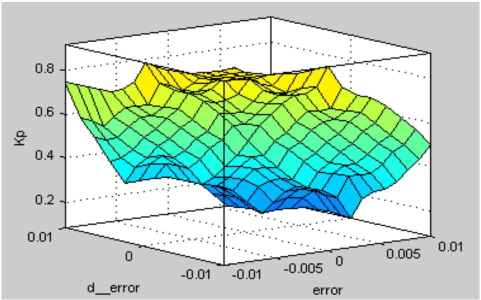


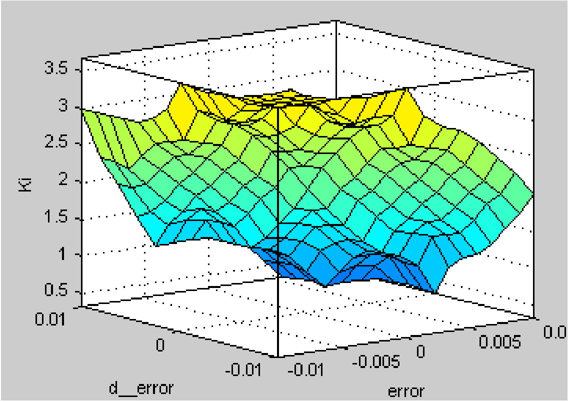
Figure 5: Simulink model of fuzzy PI control



(a) Proposed Fuzzy PI Controller Structure



(b) Fuzzy Rule surface for Proportionality gain



(c)Fuzzy Rule surface for Integral gain

Figure 6: Fuzzy membership functions

Table 2 Fuzzy Rule

	NB	NS	Z	PS	PB
NB	PB	PB	PS	PS	Z

NS	PB	PS	PS	Z	NS
Z	PB	PS	Z	NS	NS
PS	PS	Z	NS	NS	NB
PB	Z	NS	NS	NB	NB

NB – Negative Big, NS – Negative Small, Z – Zero, PS – Positive Small, PB – Positive Big

VI. SIMULATION RESULTS

Two area T-T interconnected system simulations were analyzed using MATLAB / Simulink software. The system has been analysed with conventional PI controller and fuzzy gain scheduled PI controller. The simulated results are shown in Figs.7-9.

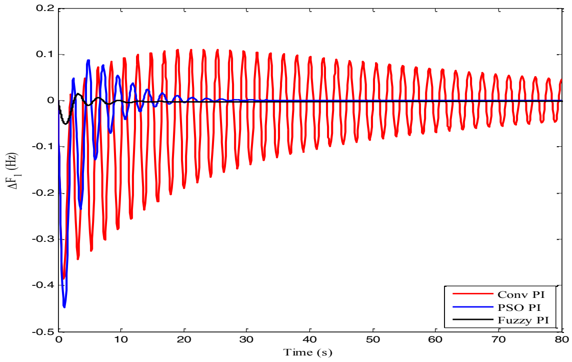


Figure 7: Frequency deviation in area 1 at nominal load condition of two area thermal non-reheat power system

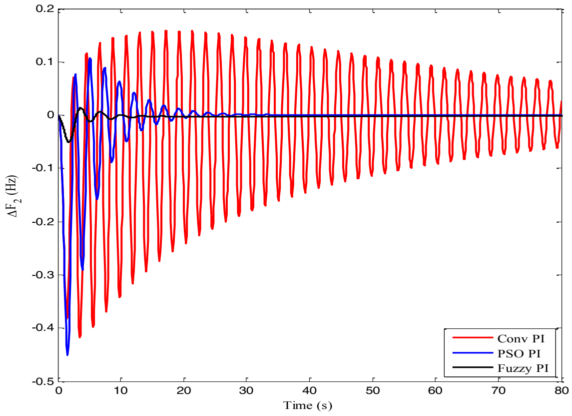


Figure 8: Frequency deviation in area 2 at nominal load condition of two area thermal non-reheat power system

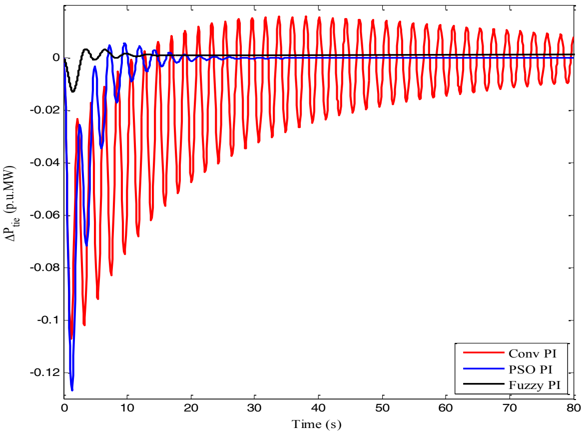


Figure 9: Tie line power deviation at nominal load condition of two area thermal non-reheat power system

Figures 7, 8 and 9 show the simulated responses of Frequency deviation in area 1, Frequency deviation in area 2 and Tie line power deviation at nominal load condition of two area thermal non-reheat power system respectively. From the figures it is observed that the response of fuzzy gain tuned PI controller settled very fast with less shoot as compared with conventional PI controller.

VII. CONCLUSION

Model of two area interconnected non-reheat thermal-thermal power system has been developed with various control strategies. The state equations and control equations have been successfully obtained. Fuzzy PI controller with Load Frequency Control of interconnected power system consisting of areas with different characteristics have been successfully designed and developed. The operations of the proposed controller have been projected and compared with conventional PI controller. It has been demonstrated that the Fuzzy PI controller can be successfully developed and its performance is very much superior to other control strategies under simultaneous load disturbances.

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