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Variable structure fuzzy gain scheduling based load frequency controller for multi source multi area hydro thermal system

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ABSTRACT

In this paper, variable structure fuzzy gain scheduling is proposed for solving the load frequency control problem of multi source multi area hydro thermal power system. The two control areas are connected via tie line. Each area comprises of both hydro and thermal power plant. The area frequency and tie line power oscillates during load variations are controlled by primary governor controller and secondary Proportional Integral (PI) controller. The PI controller gains are tuned using Ziegler Nichols' (ZN) method and Genetic Algorithm (GA). ZN method is for conventional bench marking and GA is based on search in the space. In both the methods, the gain values of PI controllers are fixed for any system changes and it is not acceptable. This problem is overcome by scheduling the gain based on system changes using Fuzzy Logic. Finally, Variable Structure System of switching P to PI controller during transient to steady state is integrated with fuzzy gain scheduling. On evaluating all the controller performance based on performance indices, variable structure fuzzy gain scheduling provides better response for multi source multi area hydro thermal power system.

1. Introduction

The power system became highly complex due to rapid growth of industries. The active power demand of industries keeps varying, which leads to change in system frequency. It is corrected with the help of Load Frequency Controller (LFC). The power system will lose its stability if LFC does not work. An effective, fast acting LFC is required to maintain the system stability during load variations. The controller is developed with the help of transfer function model. The transfer function model of power system is furnished by Elgerd [1–3] and is used by many researchers [4–6,9–19]. In transfer function model developed by Elgerd, the control area has only the thermal power station and all the generators are in unison operation. But in real world, a control area contains different generating stations. So, the transfer function model of control area would contain different sources [7,8].

In the past three decades, the two area power system either thermal - thermal or hydro – thermal type is considered [9–11]. In which one of the area is thermal and other will be hydro or thermal. They are interconnected via tie line. But in actual practice, each area will have both hydro and thermal power plants. Such multi source multi area system is considered in this paper. In LFC, the speed governor which acts as primary controller matches the supply with the demand and the secondary controller does the fine tuning of frequency and tie line power.

Though, there are many advanced controllers in recent days, Proportional Integral (PI) controller still has its importance as secondary controller in LFC [12–15]. The gain values are tuned using many methods like Ziegler Nichols'(ZN) [20], Genetic Algorithm (GA) etc. [14–16]. In these methods, the gains values are fixed for any system changes. For effective control, the gains values are to be varied with respect to the changes in system. This can be achieved using Fuzzy Gain Scheduling (FGS) [21–26]. Along with the variable gain, the proportional controller is to be predominant during transient period and integral controller during steady state period. This is achieved by Variable Structure System (VSS) controller [27–31].

In this paper, multi source multi area system is considered in which each area contains both hydro and thermal power plant. It is explained in Section 2. The secondary PI controller is tuned using ZN method for conventional, genetic algorithm for optimal search and FGS for variable gain. These tuning methods are explained in Section 3. Later, switching from P to PI controller during transient to steady state is achieved using VSS controller is explained in Section 4. The Performance of all these controllers are simulated, compared and optimal controller for multi source multi area hydro thermal power system is identified in Section 5.

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2. System model

The multi source multi area hydro thermal power system is shown in Fig. 1 has two control areas. Both the areas have both hydro and thermal power plants. Each area would be subjected to load variations. These two areas are connected via tie line for power transfer between areas to improve reliability and stability [1–3].

The transfer function model of Fig. 1 is shown in Fig. 2. In the transfer function model, both the areas are of 2000 MW capacity operating at 1000 MW at 50 Hz. For this operating condition, the power system is modeled.

The thermal power plant in both the areas consists of speed governor acting as a primary controller. It helps to match generation with the demand by controlling the steam input to the turbine. The reference power setting of the governor is varied by the secondary controller for fine tuning of the frequency. The speed governor equation is

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

Hydraulic amplifier acts against high pressure steam into the turbine based on governor. The mathematical representation of hydraulic amplifier is:

$$\Delta P_H = \frac{1}{1 + sT_H}\Delta P_g \tag{2}$$

The governor controls the steam input to the non-reheat turbine acting as a prime mover for the generator which in turn supplies energy to the power system. Non-reheat turbine is expressed as:

$$\Delta P_T = \frac{1}{1 + sT_T}\Delta P_H \tag{3}$$

The operation of the hydro power plant is similar to thermal power plant. The speed governing mechanism of hydro power plant with hydraulic amplifier is represented as:

$$\Delta P_{HV} = \left(\frac{K_1}{1 + sT_1}\right)\left(\frac{1 + sT_R}{1 + sT_2}\right)\Delta P_{ref} - \frac{1}{R}(\Delta f) \tag{4}$$

Hydro turbines used in hydro power plants has different characteristics from thermal turbines and is represented by:

$$\Delta P_{HT} = \frac{1 - sT_w}{1 + 0.5sT_w}\Delta P_{HV} \tag{5}$$

The turbine output power becomes an input to the generator for feeding electrical power to the power system. The generator along with the power system with the load disturbance is expressed as:

$$\Delta P_T - \Delta P_D = \frac{K_p}{1 + sT_p}\Delta f \tag{6}$$

The power is transferred between the areas via tie line and is represented by:

$$\Delta P_{tie12} = \frac{2\Pi T}{s}(\Delta f_1 - \Delta f_2) \tag{7}$$

During load disturbances, each area faces frequency deviation apart from tie line power deviations. As per Cohn control strategy [1,32], each area should share the control of tie line power deviations based on its capacity and also fine tune the system frequency. Cohn control strategy followed in this paper is represented by:

$$\mathrm{ACE} = \Delta P_{tie12} + \beta\Delta f \tag{8}$$

The Area Control Error (ACE) is the input for the secondary controller which in turn controls the reference power setting of the governor.

3. Tuning of secondary PI controller

In control systems, PI controller is used as a generic control feedback loop mechanism [33,34]. The proportional term reduces the transient behavior of the system and the integral term eliminates steady-state error, thereby improves the stability of the system. The PI controller is implemented as secondary controller in LFC, which sets the reference power setting of the governor present in each plant of the respective area. The PI secondary LFC controller is expressed by:

$$\Delta P_{ref} = \left(K_p + \frac{K_i}{s}\right)\mathrm{ACE} \tag{9}$$

In this paper, the gain values of PI controller are tuned using ZN method, genetic algorithm and fuzzy gain scheduling.

3.1. ZN method

The PI tuning proposed by Ziegler and Nichols [20] is a standard method developed empirically through the simulation of a large number of process systems to provide a simple rule. In this method, the process is kept under closed loop proportional (*P*) control, the gain of the *P* controller at which the loop oscillates with constant amplitude being referred as the ultimate gain (K_{cu}). The ultimate gain is the gain at which the loop is at the threshold of instability. Ultimate period (T_u) is the period during the sustained oscillations produced at the ultimate gain. The higher the ultimate gain, it is easier to control the process loop. PI controller gain is tuned using the parameters K_{cu} and T_u.

3.2. Genetic algorithm

The GA is basically a search algorithm to find the optimal value based on the concept of natural selection and genetic inheritance [35,4]. It searches an optimal solution to the problems by manipulating a population of string that represents different potential solutions. A string structure in GA represents each parameter. This is similar to the chromosome structure in natural genes. The

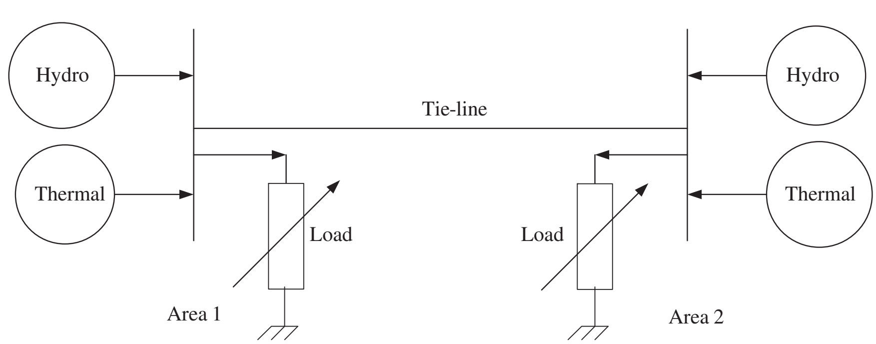

Fig. 1. Multi source multi area hydro thermal power system.