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Simulated annealing based optimal frequency and terminal voltage control of multi source multi area system

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ABSTRACT

The article proposes optimal secondary controller for combined Load Frequency Control (LFC) and Automatic Voltage Regulation (AVR) of multi source multi area system using simulated annealing technique. When subjected to load disturbance, frequency, tie-line power and voltage fluctuations results higher oscillations. Speed governor of the system helps to match generation with the demand. But, fine tuning of frequency, tie-line power and voltage when subjected to load disturbance in multi source multi area system is achieved by secondary Proportional Integral Derivative (PID) controller. As a conventional benchmark PID controller is tuned using Zeigler Nichol's (ZN) method and further optimized using Simulated Annealing (SA) technique. The performance of the system is validated and judged using performance indices.

Introduction

In today's world, the load change is dynamic and to maintain reliable power supply is very difficult. When the end consumers demand changes, both frequency and voltage following the load is subjected to violate its limits. LFC balances the power exchange by controlling the frequency and AVR balances the machine power output by controlling the voltage [1,2]. The system would be either a single area or two area system where the researchers would have contributed their works considering mostly with linear systems [3–8]. Practically, an area would have more than one source which is connected to another area of similar nature and the system would be non-linear too.

Recently, researchers have started focusing the problems in multi source multi area system dealing LFC problems alone and handling the effect of LFC and AVR model separately [3–15]. Therefore, when load changes, the combined effect of frequency and voltage change together has to be handled while maintaining the power balance in meeting the demand. Considering non-linearities and areas operating at different capacities, the change in load would create more impact on frequency and voltage changes, falling out of limits [16,17]. This article focuses on the combined model of LFC–AVR in multi source multi area system with non-linearities under different area capacities subjected to load changes. To maintain reliable power supply under varying load conditions, the system should be retrieved at a faster rate to its nominal value of frequency and voltage. Therefore, secondary controller being flexible in nature and mostly applied toward control applications [18] is considered in this system.

In this work, Proportional Integral Derivative (PID) controller is considered for fine tuning of frequency, tie-line power flow and voltage variations to retrieve the system at a faster rate to its nominal value. As a conventional bench mark, Zeigler Nichols' (ZN) method [19] is adopted for tuning PID controller. Soft computing techniques likely as Genetic Algorithm, Ant Colony Method, Particle Swarm Optimization are proving its importance in the field of power system and helps in attaining optimized controller gains. But, these methods have the ability to get trapped in local minima whose gain values could not adapted to the system varying conditions. But, Simulated Annealing (SA) supports a unique feature of providing global optimal gain values which adapts to the system varying conditions [20,21]. Therefore in this work, the controller gains are optimized using Simulated Annealing (SA) method. The system performance is judged using performance indices [22]. Following way the sections are discussed, first section deals with the introduction and second section discusses about the model of multi source multi area system with LFC–AVR, third section discusses on secondary controller tuning methods, fourth section discusses on simulation results, fifth section ends up with the conclusion.

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Combined LFC–AVR model in multi source multi area system

In this work, the analysis is carried out on two different sources of area 1 interconnected with two different sources of area 2 via tie-line as shown in Fig. 1. LFC–AVR interacts slowly, but it helps in balancing the voltage and frequency in limits. Combined LFC–AVR model of multi source single area system is shown in Fig. 2.

The thermal power plant comprises of speed governor, governor dead band, hydraulic amplifier, boiler system, non-reheat steam turbine which imparts non-linear behavior in the system. On subjection to load disturbance, speed governor controls the steam input of the turbine according to the demand [23] whose transfer function is represented as in Eq. (2.1).

$$\Delta P_g = \Delta P_{ref1} - \frac{1}{R_1}\Delta f_1 \tag{2.1}$$

But, overlapping the valves in the hydraulic relays, backlash effects and coulomb friction caused in different governor linkages results to dead band [16,17]. To meet the generation with the demand, the turbine control valves are controlled by means of immediate control action imparted by the boiler by sensing the change in steam flow and the drum pressure. Fig. 3 shows the model of the boiler system [16,17,24].

The boiler is connected in between the hydraulic amplifier output and input of the turbine to control its valve power 'ΔP_V' w.r.t the steam flow 'ΔP_R'. The turbine power output 'ΔP_T' drives the generator which provides the electrical power to the power system is highlighted in Eq. (2.2).

$$\Delta P_T = \frac{1}{1 + sT_T}\Delta P_R \tag{2.2}$$

Similarly, hydro power plant comprises of speed governor and hydro turbine [24]. The functioning of speed governor of hydro power plant is similar to that of steam power plant. Mechanical hydro governor system is considered in the model whose reset time is given in Eq. (2.3).

$$T_R = [5.0 - (T_W - 1.0)0.5]T_W \tag{2.3}$$

where T_W is the water time constant which varies between 1 s and 4 s. The hydro governor constant T_1 is given by Eq. (2.4).

$$T_1 = \frac{R_{TD}}{R_{PD}}T_R \tag{2.4}$$

where R_{TD} is the temporary droop of the hydro governor which is given by Eq. (2.5) and R_{PD} is permanent droop which is set in the range of 0.03–0.06.

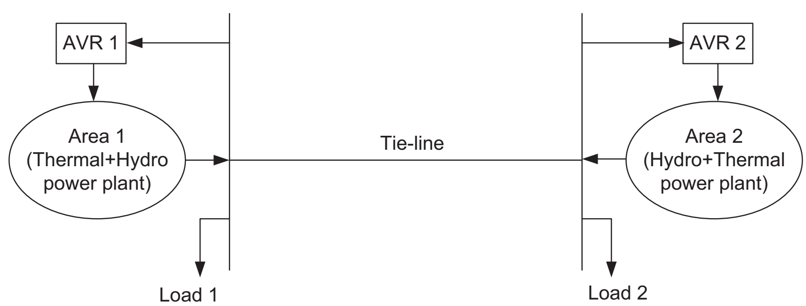

Fig. 1. Single line diagram of multi source multi area system with LFC–AVR.

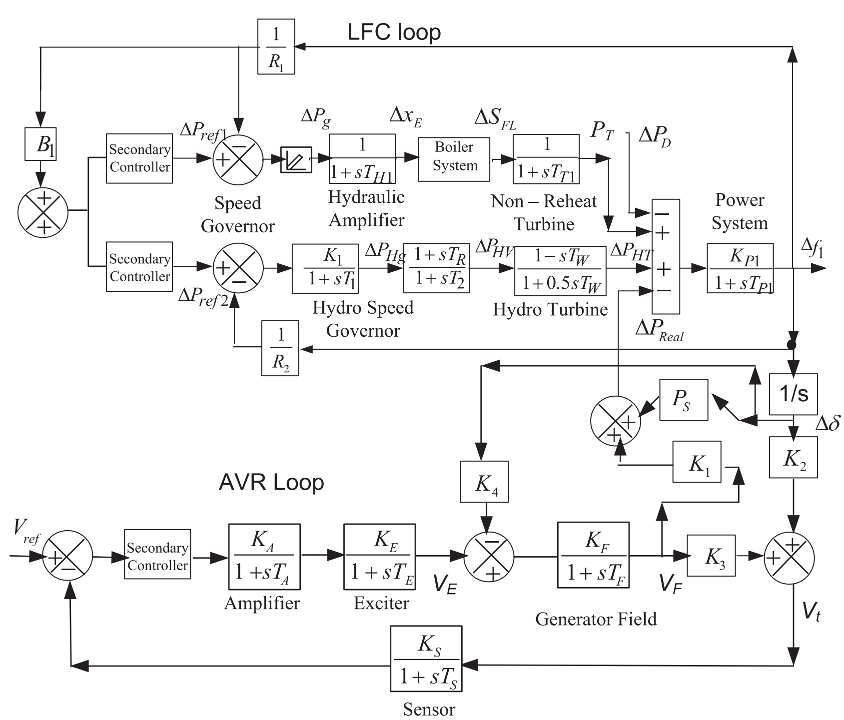

Fig. 2. Combined LFC–AVR model of multi source single area system.