

Intelligent Controllers for Load Frequency Control of Two-Area Power System

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Abstract: This paper considers the problem of load frequency control using intelligent controllers. Three types of turbines, namely the non-reheat steam turbine, reheat steam turbine and hydraulic turbine, are considered. Two-area power systems undergoing sudden load changes in each area are implemented and analysed. The objective is to eliminate errors due to the disturbances in both frequency and tie-line power so as to ensure an economic power generation. PID, Fuzzy Logic and ANN-NARMA-L2 compensating schemes are designed and successfully simulated. In all the three cases, steady-state errors present in the systems are removed. The results obtained are promising and show the satisfactory performance of the intelligent controllers in achieving load frequency control.

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1 INTRODUCTION

The objective behind an electric power system is to generate and supply electrical energy to consumers at nominal system frequency and voltage magnitude defined by a certain power quality standard (Ragini et al. 2015). Starting from the generation of real and reactive power at the generators until its utilization by the customers, the generated power must be balanced with the load demand. The real power and reactive power which correspond to frequency and voltage equilibrium are crucial for a good power quality (Zhang 2009). The nominal frequency of a system is dependent on the balance between the load demand and the generated real power. When the generated power is less than the load demand, the speed and thus the frequency of the generating units start to decrease. The contrary occurs when the generated power is greater than the load demand thereby causing wastage of resources (Ragini et al. 2005). Normally, the load demand varies randomly depending on the customers' need and this indeed affects the frequency and the voltage of the system. The latter therefore requires certain control actions which are carried out by the automatic voltage regulator (AVR) and LFC; these two compensators are implemented on each alternator in a power system for both voltage and frequency control (Saadat 1999).

A power system has many interconnected utilities forming a grid and the transfer of power is done via the tie-lines. As the frequency of the system decreases, the speed governor for each generator will provide the primary speed control so as to match the system power generation with the load demand. However, this primary control action is not enough to restore back the frequency. A secondary control action is required to remove any deviation in frequency and maintains the tie-line power flow by adjusting the generators' output. This secondary control action is known as LFC.

Both the primary and secondary controls form part of the automatic generation control (AGC). The transient responses of the primary and secondary controls are in the range of seconds and minutes respectively (Tan 2011). Though in an

interconnected network the area that is subjected to a load change will obtain energy from the other areas via the tie-lines, the concerned area should be able to restore the equilibrium prior to the load change without any external help. Otherwise, the power swings occurring due to transient disturbances in one area can induce power swings in adjacent areas via the tie-lines. Therefore, each area requires a controller that will not only restore the frequency to its standard value but also remove any error in the tie-line power flow (Zhang 2009).

In the last decades, engineers have turned towards artificial intelligence techniques in order to ensure continuous power flow. Many artificial intelligence techniques have been adapted to LFC with Fuzzy Logic and Artificial Neural Network (ANN) being the most common ones. Even a combination of these two intelligent techniques to form a hybrid Neuro-Fuzzy controller has been adapted to power systems (Shree and Kamaraj 2015).

There are several ANN controllers; one of them is NARMA-L2 which is the easiest one to compute. Though automatic control scheme has gained much popularity over the years due to the advances in technology, the PID controller is still being implemented in more than 90% of industrial control systems. This is because it provides a simple yet efficient solution that no other controllers can attain (Ang et al. 2005). Moreover, several optimization techniques like Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO), Backtracking Search Algorithm (BSA) and Multiple Tabu Search (MTS) that are available to tune the parameters of the PID proved to yield better responses than the conventional tuning methods (Ragini et al. 2005; Pothiya et al. 2006; Omar et al. 2013; Ismail and Mustafa Hassan 2012).

2 POWER SYSTEM MODEL

The power system model includes the power generating system with three different types of turbine, and the

interconnection of a network by means of the tie-line. The transfer function of each unit of a power generating system is derived for the development of the single-area power system model which is then extended to the two-area model with the introduction of interconnection units.

The two-area power system model is shown in Fig.1. LFC is provided by the controller such that zero error is obtained in both frequency and tie-line power flow. Since the area control error (ACE) output consists of both the frequency deviation and tie-line power error as given by (1), once it has output zero automatically the errors in the frequency and the tie-line power will be eliminated. Hence, it is fed as input to the controller.

$$ACE_i = \sum_{j=1, \dots, n, j \neq i} \Delta P_{tie\ ij} + B_i \Delta f_i \quad (1)$$

Where

ACE_i : Area control error of area i

$\Delta P_{tie\ ij}$: Tie-line net power flow between area i and j

Δf_i : Frequency deviation in area i

B_i : Frequency response characteristic of area i (Zhang 2009)

The transfer function of each turbine is as given by (2):

2.1 Non-Reheat Steam turbine

$$G_{NR}(s) = \frac{1}{1 + sT_{CH}} \quad (2)$$

T_{CH} : Constant time delay between the change in the valve opening position and the mechanical torque of the turbine

2.2 Reheat Steam turbine

$$G_R(s) = \frac{1 + sF_{HP}T_{RH}}{(1 + sT_{CH})(1 + sT_{RH})} \quad (3)$$

T_{RH} : Time constant of the reheater

F_{HP} : Rating of the high pressure stage with respect to total generated mechanical power of turbine

2.3 Hydraulic turbine

$$G_H(s) = \frac{1 - T_w s}{1 + s(T_w/2)} \quad (4)$$

T_w : Water starting time which varies with the load

In order to provide a stable control performance during the transient state, a transient droop compensator is to be added to the governor for this type of turbine so that a fast transient response is obtained. Once the system has reached the steady-state, the normal droop is exhibited. The transfer function of the compensator is described as given by (5):

$$G_C(s) = \frac{1 + sT_R}{1 + s(R_T/R_P)T_R} \quad (5)$$

R_P : Permanent droop

T_R : Reset time

R_T : Temporary droop

The turbines' transfer function is obtained based on the change in mechanical power output of the turbine ΔP_{mech} against the valve/gate opening position ΔP_V (Kundur 1994). A load disturbance of 0.07p.u was added to Area-1 of each system whilst that of Area-2 was set to 0.05p.u. The verification of the systems' stability followed up by means of the root locus method. After the simulation of the stable systems over a time interval of 100s, the design of the compensators was carried out. The parameters used for each generating unit can be found in Appendix I.

3 COMPENSATOR DESIGN

3.1 PID

In this paper, the PID function block in Simulink was chosen for the design and simulation processes. $U(s)$ is the output of the controller and $E(s)$ is the error input. The parameters K_p , K_i and K_d represents the gains of the proportional, integral and differential terms of the PID (Ang et al. 2005). The gains of the PID were found by trial and errors by tuning the three PID terms.

3.2 Fuzzy Logic

The Fuzzy Logic controller performs similar tasks as a human operator by adjusting the input variables just by looking at the output of the plant (Altas and Neyens 2006). The four processes of the Fuzzy Logic system are: fuzzification, rule base set up, decision-making by means of an inference mechanism and defuzzification. The schematics of the implemented Fuzzy Logic can be found in the technical report by Jantzen(1998).

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