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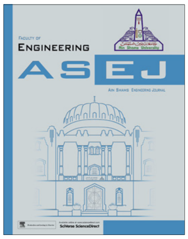

ELECTRICAL ENGINEERING

Automatic generation control with thyristor controlled series compensator including superconducting magnetic energy storage units

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Superconducting Magnetic Energy Storage (SMES)

Abstract In the present work, an attempt has been made to understand the dynamic performance of Automatic Generation Control (AGC) of multi-area multi-units thermal–thermal power system with the consideration of Reheat turbine, Generation Rate Constraint (GRC) and Time delay. Initially, the gains of the fuzzy PID controller are optimized using Differential Evolution (DE) algorithm. The superiority of DE is demonstrated by comparing the results with Genetic Algorithm (GA). After that performance of Thyristor Controlled Series Compensator (TCSC) has been investigated. Further, a TCSC is placed in the tie-line and Superconducting Magnetic Energy Storage (SMES) units are considered in both areas. Finally, sensitivity analysis is performed by varying the system parameters and operating load conditions from their nominal values. It is observed that the optimum gains of the proposed controller need not be reset even if the system is subjected to wide variation in loading condition and system parameters.

1. Introduction

Load Frequency Control (LFC) is a very important issue in modern power system operation and control for supplying sufficient and reliable electric power with good quality. The main goal of the LFC is to maintain the system frequency of each area and the tie line power within tolerable limits with variation in load demands [1]. For power balance, the power generated should match with the total load demanded and associated system losses. However the load demands fluctuate randomly causing a mismatch in the power balance and thereby deviations in the area frequencies and tie-line powers from their respective scheduled values, called Automatic Load Frequency Control (ALFC) [2,3]. Due to the complexity of the modern power system, superior intelligent control design is essential. Literature study reveals that several control strategies have been proposed by many researchers over the past decades for LFC of power system. Many control and optimization techniques such as classical, optimal, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fuzzy Logic Controller (FLC), and Artificial Neural Network (ANN), have been proposed for LFC [4–9]. Design of a controller for

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AGC can be divided into two groups. In the 1st group the controller gains are tuned by a suitable optimization algorithm. In the 2nd group researchers have adopted self-tuning techniques with the help of neural network and fuzzy logic. Fuzzy logic controllers have been successfully used for analysis and control of non-linear system in the past decades. Yesil et al. [10] have used a self-tuning fuzzy PID type controller for load frequency control of a two-area interconnected system. Khuntia and Panda [11] have used ANFIS approach for AGC of a three area system. Ghosal [8] have used PSO optimization technique to optimize the PID controller gain for a fuzzy based LFC. These methods provide good performances but the transient responses are oscillatory in nature. Fuzzy logic based PID controller can be successfully used for all non-linear system but there is no specific mathematical formulation to decide the proper choice of fuzzy parameters (such as inputs, scaling factors, membership functions, and rule base). Normally these parameters are selected by using certain empirical rules and therefore may not be the optimal parameters. Improper selection of input–output scaling factor may affect the performance of FLC to a greater extent.

To get an accurate insight into the AGC problem, it is necessary to include the important physical constraints in the system model. The major physical constraints that affect the power system performance are Generation Rate Constraint (GRC) and time delay. The Flexible AC Transmission System (FACTS) controllers [12] play a crucial role to enhance power system stability in addition to control the power flow in an interconnected power system. Several studies have explored the potential of using FACTS devices for better power system control since it provides more flexibility. A Superconducting Magnetic Energy Storage (SMES) is capable of controlling both active and reactive power simultaneously. SMES unit with small storage capacity can be essential not only as a fast energy compensation device for power consumptions of large loads, but also as a stabilizer of frequency oscillations [13]. TCSC is one of the FACTS controller which is enhanced the power system dynamics, power transfer capability of transmission lines and dynamic stability [14].

It obvious from the literature survey that the performance of the power system not only depends on the controller structure but also depends on the artificial optimization technique. Hence, proposing and implementing new high performance heuristic optimization algorithms to real world problems are always welcome. Differential Evolution (DE) is a population-based direct search algorithm for global optimization capable of handling non-differentiable, non-linear and multi-modal objective functions, with few, easily chosen, control parameters [15,16]. However, the success of DE in solving a specific problem crucially depends on appropriately choosing trial vector generation strategies and their associated control parameter values namely the step size F, crossover probability CR, number of population NP and generations G [17].

In view of the above, a Differential Evolution (DE) optimized fuzzy PID controller is proposed for Load Frequency Control (LFC) of multi-area multi-units thermal–thermal power system with the consideration of reheat turbine, Generation Rate Constraint (GRC) and time delay. The superiority of the proposed approach is shown by comparing the results with GA for the same power system. Further, TCSC is employed in series with the tie-line in coordination with SMES to improve the dynamic performance of the power system. Finally, sensitivity analysis is carried out by varying the loading condition and system parameters.

2. Materials and methods

2.1. System under study

The system under investigation consists of two area interconnected thermal power system as shown in Fig. 1. Area 1 comprises two reheat thermal power units. Area 2 comprises two non-reheat thermal units. In Fig. 1, B_1 and B_2 are the frequency bias parameters; ACE_1 and ACE_2 are area control errors; R_1, R_2 and R_3, R_4 are the governor speed regulation parameters in pu Hz for area 1 and area 2 respectively; T_{G1}, T_{G2} and T_{G3}, T_{G4} are the speed governor time constants in sec for area 1 and area 2 respectively; T_{T1}, T_{T2} and T_{T3}, T_{T4} are the turbine time constant in sec for area 1 and area 2 respectively; ΔP_{D1} and ΔP_{D2} are the load demand changes; ΔP_{Tie} is the incremental change in tie line power (p.u); K_{Ps1} and K_{Ps2} are the power system gains; T_{Ps1} and T_{Ps2} are the power system time constant in sec; T_{12} is the synchronizing coefficient and ΔF_1 and ΔF_2 are the system frequency deviations in Hz. To get an accurate insight into the AGC problem, it is essential to include the important inherent requirement and the basic physical constraints and include them model. The important constraints that affect the power system performance are Generation Rate Constraint (GRC), and Time delay. In view of the above, the effect of GRC and Time delay are included to a power system model. Time delays can degrade a system's performance and even cause system instability. In a power system having steam plants, power generation can change only at a specified maximum rate. In thermal power plants, power generation can change only at a specified maximum/minimum rate known as Generation Rate Constraint (GRC). In the present study, a GRC of 3%/min for reheat and 10%/ min for non-reheat thermal units are considered [18,19]. Also in the present study, a time delay of 50 ms is considered [20]. The relevant parameters are given in Appendix A.

2.2. Control structure and objective function

To control the frequency, fuzzy PID controllers are provided in each area. The structure of fuzzy PID controller is shown in Fig. 2 [21,22].

The error inputs to the controllers are the respective area control errors (ACE) given by:

$$e_1(t) = ACE_1 = B_1\Delta F_1 + \Delta P_{Tie} \tag{1}$$

$$e_2(t) = ACE_2 = B_2\Delta F_2 - \Delta P_{Tie} \tag{2}$$

Fuzzy controller uses error (e) and derivative of error ($\dot{e}$) as input signals. The outputs of the fuzzy controllers u_1 and u_2 are the control inputs of the power system i.e. the reference power settings ΔP_{ref1} and ΔP_{ref2}. The input scaling factors are the tuneable parameters K_1 and K_2. The proportional, integral and derivative gains of fuzzy controller are represented by K_P, K_I and K_D respectively. Triangular membership functions are used with five fuzzy linguistic variables such as NB (negative big), NS (negative small), Z (zero), PS (positive small) and PB (positive big) for both the inputs and the output. Membership functions for error, error derivative and FLC out-