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Automatic generation control of multi-area power system using multi-objective non-dominated sorting genetic algorithm-II

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ABSTRACT

Controllers design problems are multi objective optimization problems as the controller must satisfy several performance measures that are often conflicting and competing with each other. In multi-objective approach a set of solutions can be generated from which the designer can select a final solution according to his requirement and need. This paper presents the design and analysis Proportional Integral (PI) and Proportional Integral Derivative (PID) controller employing multi-objective Non-Dominated Shorting Genetic Algorithm-II (NSGA-II) technique for Automatic Generation Control (AGC) of an interconnected system. To minimize the effect of noise in the input signal, a filter is employed with the derivative term. Integral Time multiply Absolute Error (ITAE), minimum damping ratio of dominant eigenvalues and settling times in frequency and tie-line power deviations are considered as multiple objectives and NSGA-II is employed to generate Pareto optimal set. Further, a fuzzy-based membership value assignment method is employed to choose the best compromise solution from the obtained Pareto solution set. The proposed approach is first applied to a linear two-area power system model and then extended to a non-linear power system model by considering the effect of governor dead band non-linearity. The superiority of the proposed NSGA-II optimized PI/PID controllers has been shown by comparing the results with some recently published modern heuristic optimization approaches such as Bacteria Foraging Optimization Algorithm (BFOA), Genetic Algorithm (GA) and Craziness based Particle Swarm Optimization (CPSO) based controllers for the similar interconnected power systems.

1. Introduction

The main objective of a power system utility is to maintain continuous supply of power with an acceptable quality to all the consumers in the system. The system will be in equilibrium, when there is a balance between the power demand and the power generated. There are two basic control mechanisms used to achieve power balance; reactive power balance (acceptable voltage profile) and real power balance (acceptable frequency values). The former is called the automatic voltage regulator (AVR) and the latter is called the automatic load frequency control (LFC) or Automatic Generation Control (AGC). For multi area power systems, which normally consist of interconnected control area, AGC is an important aspect to keep the system frequency and the interconnected area tie-line power as close as possible to the intended values [1]. The mechanical input power to the generators is used to control the system as it is affected by the output electrical power demand and to maintain the power exchange between the areas as planned. AGC monitors the system frequency and tie-line flows, calculates the net change in the generation required according to the change in demand and changes the set position of the generators within the area so as to keep the time average of the ACE (Area Control Error) at a low value. ACE is generally treated as controlled output of AGC. As the ACE is adjusted to zero by the AGC, both frequency and tie-line power errors will become zero [2].

The researchers in the world over trying to employ several strategies for AGC of power systems to maintain the system frequency and tie line flow at their scheduled values during normal operation and also during disturbance conditions. A critical literature review on the AGC of power systems has been presented in Ref. [3] where different control techniques pertaining to AGC problem have been discussed. There has been considerable research work attempting to propose better AGC systems based on modern control theory [4], neural network [5], fuzzy system theory [6], reinforcement learning [7] and ANFIS approach [8]. However, these approaches require complex controller structure and in depth knowledge of users thus reducing their applicability. On the other hand a classical Proportional Integral Derivative (PID) controller and its variants remain an engineer's preferred choice due to its structural simplicity, reliability, and the favorable ratio between performances and cost. Beyond these benefits, it also offers simplified dynamic modeling, lower user-skill requirements, and

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minimal development effort, which are issues of substantial importance in engineering practice. New artificial intelligence-based approaches have been proposed recently to design a PI/PID controller for AGC system. Several classical controllers structures such as Integral (I), Proportional Integral (PI), Integral Derivative (ID), PID and Integral Double Derivative (IDD) have been applied and compared in Ref. [9] for an AGC system. Nanda et al. [10] have shown that bacterial Foraging Optimization Algorithm (BFOA) optimized controller provides better performance as compared to classical and GA based controllers for an interconnected power system. Ali and Abd-Elazim [11] have recently presented a BFOA based Proportional Integral (PI) controller which provides better performance as compared to that with GA based PI controller in two area non-reheat thermal system. Gozde and Taplamacioglu [12] proposed a gain scheduling PI controller for an AGC system consisting of two area thermal power system with governor dead-band nonlinearity. The authors have employed a Craziness based Particle Swarm Optimization (CPSO) with different objective functions to minimize the settling times and standard error criteria.

It clear from literature survey that the performance of the system not only depends on the artificial techniques employed but also on controller structure and selection of objective function. For the design of a modern heuristic optimization technique based PI/PID controller, the objective function is first defined based on the desired specifications and constraints. The selection of objective function to optimize the controller parameters is usually based on desired performance requirement. Typical output specifications in the time domain are peak overshooting, rise time, settling time, and steady-state error. Performance criteria that are usually reported in literature are the Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied by Squared Error (ITSE) and Integral of Absolute Error (IAE). It has been shown that the ITAE provides better responses as compared to other criteria [13]. The integral action of ITAE ensures that the integral of the frequency and tie-lines errors are minimized and time multiplier makes certain that the settling times in these deviations are minimized. Also, in a power system, it is required that all modes be stable and all electromechanical oscillations be damped out as quickly as possible i.e. the damping ratios of dominant eigenvalues should be maximized as much as possible [1,2]. Now it is difficult to design a controller to satisfy above multiple design objectives which are conflicting in nature. Design of such a controller is indeed a multi-objective optimization problem. In these types of multi-objective problems generally there is no single solution that is the best when measured on all objectives and so several trade-off solutions (called the Pareto optimal set) are usually preferred [14].

Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) proposed by Deb et al. [15] is promising algorithm to solve multi-objective problems. The advantages of NSGA-II over NSGA are that it has a better sorting algorithm, incorporates elitism and sharing parameter need not be chosen a priori. In view of the above, an attempt has been made in this paper for the optimal design of NDGA-II based PI/PID controller for AGC of two area interconnected power system. To eliminate the effect of noise in the input signal, a filter is provided with the derivative term and the value of filter coefficient is also optimized. The design objectives are minimizations of integral errors and settling times of frequency and tie-line power deviations and maximization of damping ratios of dominant eigenvalues. The design problem is formulated as a multi-objective optimization problem and NSGA-II is employed to generate Pareto optimal set of solutions from which the designer can choose a solution according to the requirement. A fuzzy-based membership value assignment method is employed to select the best compromise solution from the obtained Pareto solution set. Further, robustness analysis is carried to show the robustness of the proposed NSGA-II optimized PID controller under wide changes in system parameters. Finally, the proposed design and analysis is extended to a non-linear power system by considering the effect of governor dead band non-linearity. The advantage of the proposed design approach is demonstrated by comparing the results with some recently published single objective optimization approaches such as BFOA, GA and CPSO techniques for the similar interconnected power systems.

2. System modeling

The system under investigation consists of two area interconnected power system of non-reheat thermal plant as shown in Fig. 1. Each area has a rating of 2000 MW with a nominal load of 1000 MW. The system is widely used in literature for the design and analysis of automatic load frequency control of interconnected areas [11]. In Fig. 1, B_1 and B_2 are the frequency bias parameters; AEC_1 and AEC_2 are area control errors; u_1 and u_2 are the control outputs form the controller; R_1 and R_2 are the governor speed regulation parameters in p.u. Hz; T_{G1} and T_{G2} are the speed governor time constants in sec; ΔP_{V1} and ΔP_{V2} are the change in governor valve positions (p.u.); ΔP_{G1} and ΔP_{G2} are the governor output command (p.u.); T_{T1} and T_{T2} are the turbine time constant in sec; ΔP_{T1} and ΔP_{T2} are the change in turbine output powers; 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. The relevant parameters are given in Appendix A.

Each area of the power system consists of speed governing system, turbine and generator as shown in Fig. 1. Each area has three inputs and two outputs. The inputs are the controller input ΔP_{ref} (denoted as u_1 and u_2), load disturbances (denoted as ΔP_{D1} and ΔP_{D2}), and tie-line power error ΔP_{Tie}. The outputs are the generator frequency deviations (denoted as ΔF_1 and ΔF_2) and Area Control Error (ACE). To simplify the frequency-domain analyses, transfer functions are used to model each component of the area. For detailed equations, the readers are suggested to refer [2].

3. The proposed approach

3.1. Controller structure

The proportional integral derivative controller (PID) is the most popular feedback controller used in the process industries. It is a robust, easily understood controller that can provide excellent control performance despite the varied dynamic characteristics of process plant. As the name suggests, the PID algorithm consists of three basic modes, the proportional mode, the integral and the derivative modes. A proportional controller has the effect of reducing the rise time, but never eliminates the steady-state error. An integral control has the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control has the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. Proportional Integral (PI) controllers are the most often type used today in industry. A control without derivative (D) mode is used when: fast response of the system is not required, large disturbances and noises are present during operation of the process and there are large transport delays in the system. PID controllers are used when stability and fast response are required. Derivative mode improves stability of the system and enables increase in proportional gain and decrease in integral gain which in turn increases speed of