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Controller parameters tuning of differential evolution algorithm and its application to load frequency control of multi-source power system

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ABSTRACT

This paper presents controller parameters tuning of Differential Evolution (DE) algorithm and its application to Load Frequency Control (LFC) of a multi-source power system having different sources of power generation like thermal, hydro and gas power plants. Initially, a single area multi-source power system with integral controllers for each unit is considered and DE technique is applied to obtain the controller parameters. Various mutation strategies of DE are compared and the control parameters of DE for best obtained strategy are tunned by executing multiple runs of algorithm for each parameter variation. The study is further extended to a multi-area multi-source power system and a HVDC link is also considered in parallel with existing AC tie line for the interconnection of two areas. The parameters of Integral (I), Proportional Integral (PI) and Proportional Integral Derivative (PID) are optimized employing tunned DE algorithm. The superiority of the proposed approach has been shown by comparing the results with recently published optimal output feedback controller for the same power systems. The comparison is done using various performance measures like overshoot, settling time and standard error criteria of frequency and tie-line power deviation following a step load perturbation (SLP). It is noticed that, the dynamic performance of proposed controller is better than optimal output feedback controller. Furthermore, it is also seen that the proposed system is robust and is not affected by change in the loading condition, system parameters and size of SLP.

1. Introduction

The problem of controlling the real power output of generating units in response to changes in system frequency and tie-line power interchange within specified limits is known as Load Frequency Control (LFC). It is generally regarded as a part of automatic generation control (AGC) and is very important in the operation and control of power systems [1,2]. Large scale power systems are normally composed of control areas or regions representing coherent groups of generators. The control area may have the combination of thermal, hydro, gas, nuclear, renewable energy sources, etc. [3]. In a practically interconnected power system, the generation normally comprises of a mix of thermal, hydro nuclear and gas power generation. However, owing to their high efficiency, nuclear plants are usually kept at base load. Gas power generation is ideal for meeting the varying load demand and are normally used to meet peak demands. Keeping in view the present power scenario, combination of multi-source generators in a control area with their corresponding participation factors is more realistic for the study of LFC.

The researchers in the world over are trying to propose several strategies for LFC of power systems in order to maintain the system frequency and tie line flow at their scheduled values during normal operation and also during small perturbations. In [4], a critical literature review on the AGC of power systems has been presented. It is noticed from literature survey, that most of the LFC works have been carried out on two area hydro-thermal or thermal–thermal systems. It is observed that, considerable research work is going on to propose better AGC systems based on modern control theory [5], neural network [6], fuzzy system theory [7], reinforcement learning [8] and ANFIS approach [9]. But, these advanced approaches are complicated and need familiarity of users to these techniques thus reducing their applicability. Alternatively, a classical Proportional Integral Derivative (PID) controller remain an engineer's preferred choice due to its structural simplicity, reliability, and the favourable ratio between performances and cost. Additionally, it also offers simplified dynamic modelling, lower user-skill requirements, and minimal development effort, which are major issues of in engineering practice. In recent times, new artificial intelligence-based approaches have been proposed to

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optimize the PI/PID controller parameters for AGC system. In [10], several classical controllers structures such as Integral (I), Proportional Integral (PI), Integral Derivative (ID), PID and Integral Double Derivative (IDD) have been applied and their performance has been compared for an AGC system. Nanda et al. [11] have demonstrated that Bacterial Foraging Optimization Algorithm (BFOA) optimized controller provides better performance than GA based controllers and conventional controllers for an interconnected power system. In [12], a modified objective function using Integral of Time multiplied by Absolute value of Error (ITAE), damping ratio of dominant eigenvalues and settling time is proposed where the PI controller parameters are optimized employed Differential Evolution (DE) algorithm and the results are compared with BFOA and GA optimized ITAE based PI controller to show its superiority. Literature survey also shows that mostly AC tie lines are used for the interconnection of multi-area power systems and lesser attention is given to AC–DC parallel tie lines. Parmar et al. have reported in [13] a multi-sources generation including thermal-hydro-gas systems, considering HVDC link connected in parallel with existing AC link for stabilizing frequency oscillation and used an optimal output feedback controller for frequency stabilization.

The growth in size and complexity of electric power systems along with increase in power demand has necessitated the use of intelligent systems that combine knowledge, techniques and methodologies from various sources for the real-time control of power systems. 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 [14]. DE uses weighted differences between solution vectors to change the population whereas in other stochastic techniques such as Genetic Algorithm (GA) and Expert Systems (ES), perturbation occurs in accordance with a random quantity. DE employs a greedy selection process with inherent elitist features. Also it has a minimum number of control parameters, which can be tuned effectively [15]. In view of the above, an attempt has been made in this paper for the optimal design of DE based classical I/PI/PID controllers for LFC of multi-area multi-unit interconnected power system. The design problem of the proposed controller is formulated as an optimization problem and DE is employed to search for optimal controller parameters. As the success of DE in solving a specific problem significantly depends on appropriately choosing trial vector generation strategies and their associated control parameter values namely the step size F, cross over probability CR, number of population NP and generations G. Hence, selection of mutation strategy and DE control parameters is an important issue and often depends on the given problem. Therefore, it is desirable to determine an appropriate strategy and its associated control parameter values for an AGC problem. Simulations results are presented to show the effectiveness of the proposed controller in providing good damping characteristic to system oscillations over a wide range of disturbance. Further, the superiority of the proposed design approach is illustrated by comparing the proposed approach with recently published optimal controller [5,13] for the same AGC system.

2. Control design of system under study

A single area system comprising hydro, thermal with reheat turbine and gas units is considered at the first instance for designing controller for the system. The linearized models of governors, reheat turbines, Hydro turbines, Gas turbines are used for simulation and LFC study of the power system as shown in Fig. 1. Each unit has its regulation parameter and participation factor which decide the contribution to the nominal loading. Summation of participation factor of each control should be equal to 1. In Fig. 1, R_1, R_2, R_3 are the regulation parameters of thermal, hydro and gas units respectively, U_T, U_H and U_G are the control outputs for of thermal, hydro and gas units respectively, K_T, K_H and K_G are the participation factors of thermal, hydro and gas generating units, respectively, T_{SG} is speed governor time constant of thermal unit in sec, T_T is steam turbine time constant in sec, K_r is the steam turbine reheat constant, T_r is the steam turbine reheat time constant in sec, T_W is nominal starting time of water in penstock in sec, T_{RS} is the hydro turbine speed governor reset time in sec, T_{RH} is hydro turbine speed governor transient droop time constant in sec, T_{GH} is hydro turbine speed governor main servo time constant in sec, X_C is the lead time constant of gas turbine speed governor in sec, Y_C is the lag time constant of gas turbine speed governor in sec, c_g is the gas turbine valve positioner, b_g is the gas turbine constant of valve positioner, T_F is the gas turbine fuel time constant in sec, T_{CR} is the gas turbine combustion reaction time delay in sec, T_{CD} is the gas turbine compressor discharge volume-time constant in sec, K_{PS} power system gain in Hz/puMW, T_{PS} is the power system time constant in sec, ΔF is the incremental change in frequency and ΔP_D incremental load change. The nominal parameters of the system are given in reference [5].

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. Derivative mode improves stability of the system and enables increase in proportional gain and decrease in integral gain which in turn increases speed of the controller response. PID controller is often used when stability and fast response are required. In view of the above, I, PI and PID structured controllers are considered in the present paper.

In the design of a modern heuristic optimization technique based controller, the objective function is first defined based on the desired specifications and constraints. The design of objective function to tune the controller is generally based on a performance index that considers the entire closed loop response. Typical output specifications in the time domain are peak overshooting, rise time, settling time, and steady-state error. Four kinds of performance criteria usually considered in the control design are the Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied Squared Error (ITSE) and Integral of Absolute Error (IAE). ISE and ITAE criterions are often used in literature for their better performance compared to IAE and ITSE criterion. ISE criterion integrates the square of the error over time. ISE will penalize large errors more than smaller ones (since the square of a large error will be much bigger). Control systems specified to minimize ISE will tend to eliminate large errors quickly, but will have to tolerate small errors persisting for a long period of time. Often this leads to fast responses, but with considerable, low amplitude, oscillation. ITAE integrates the absolute error multiplied by the time over time. What this does is to weight errors which exist after a long time much more heavily than those at the start of the response. ITAE tuning produces systems which settle much more quickly than the ISE tuning methods.