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Comparative performance analysis of teaching learning based optimization for automatic load frequency control of multi-source power systems

A.K. Barisal *

Department of Electrical Engineering, V. S. S. U. T, Burla, Odisha, India

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ABSTRACT

This paper presents a new population based parameter free optimization algorithm as teaching learning based optimization (TLBO) and its application to automatic load frequency control (ALFC) of multi-source power system having thermal, hydro and gas power plants. The proposed method is based on the effect of the influence of teacher on the output of learners and the learners can enhance their knowledge by interactions among themselves in a class. In this extensive study, the algorithm is applied in multi area and multi-source realistic power system without and with DC link between two areas in order to tune the PID controller which is used for automatic generation control (AGC). The potential and effectiveness of the proposed algorithm is compared with that of differential evolution algorithm (DE) and optimal output feedback controller tuning performance for the same power systems. The dynamic performance of proposed controller is investigated by different cost functions like integral of absolute error (IAE), integral of squared error (ISE), integral of time weighted squared error (ITSE) and integral of time multiplied absolute error (ITAE) and the robustness of the optimized controller is verified by its response toward changing in load and system parameters. It is found that the dynamic performance of the proposed controller is better than that of recently published DE optimized controller and optimal output feedback controller and also the proposed system is more robust and stable to wide changes in system loading, parameters, size and locations of step load perturbation and different cost functions.

Introduction

The purpose of an interconnected power system is to generate, exchange and control of electric energy with nominal system frequency, voltage profile and tie-line power interchange within their prescribed limits. The automatic load frequency control which is basically a part of automatic generation control plays an important role in power pool by maintaining scheduled system frequency and scheduled tie-line power in normal operation and during slow and small perturbations. The modern power system is composed of multiple sources of generation such as thermal, hydro gas and renewable energy power plants having many control areas or regions representing coherent group of generators. The area control error as the controlled output of AGC is driven to zero in order to make the frequency and tie line power deviations of control area to zeros [1,2]. The environmental drive to promote renewable energy invites new players to realistic power system with multiple sources of power generation and their corresponding participation factor are more important for the study of LFC.

Many researchers in the recent past have proposed several strategies for LFC of power systems in order to maintain the system frequency and tie line power flow at their scheduled values during normal operation and also during small perturbations. To meet the today's stringent quality requirements, accurate-tools based realistic models with faster solution speed; high degree of reliability is required. While considerable progress has been made in the development of intelligent controllers and their applications to large scale power system still remain a challenging area and a common problem. It is found in literature survey that the early work on AGC was started by Cohn [3] but the design of modern optimal controller concept for interconnected power system was initiated by Elgerd and Fosha [4]. The recent past control strategies for automatic generation control of power system are reported by Kumar and Kothari [5] which includes various control aspects for AGC system incorporating with other additional devices. The gain scheduling control method for AGC of interconnected power system was proposed by Lee et al. [6]. This control is different from

* Tel.: +91 6632430754; fax: +91 6632430204.
E-mail address: a_barisal@rediffmail.com

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other control techniques in terms of robustness to wide range of operating conditions and also easy implementation. The growth in size and complexity of electric power system due to non linear load characteristics and variable operating points has necessitated the use of intelligence based methods to address satisfactorily the performances under small perturbations. The intelligent controllers such as fuzzy logic based gain scheduling [7], two fuzzy rules for integral and proportional gains PI controller [8], adaptive fuzzy gain scheduling method [9], genetic algorithm (GA) based PI and PID controller [10], PSO based controller [11], self tuning fuzzy type PID controller [12], a reinforcement learning approach [13], adaptive neuro-fuzzy interference system (ANFIS) [14], evolutionary fuzzy PI controller [15], PSO based controller with fuzzy application [16], differential evolution (DE) algorithm based PI controller [17], optimal output feedback controller for multi-source system [18], generalized neural network approach [19], several classical controllers [20] for AGC studies in interconnected power system, were preferred by researchers from the beginning of these dates.

It is found in literature survey that most of the researchers adopt thermal–thermal or thermal hydro systems in AGC studies. Surprisingly, very few papers in literature that considers a single area [18,22] or multi-area without or with HVDC link connecting two areas [21,22] of realistic power system having generation from thermal, hydro and gas units. Mohanty et al. have considered a two area AC–DC system with parallel tie lines for frequency stabilization by using DE tuned PID controller [22] that better performs than an optimal output feedback controller [21] for similar power system. Gozde et al. proposed the usage of craziness based PSO algorithm for AGC system for an interconnected thermal power plants in the year 2011 [23]. One year after, Gozde et al. [24] again proposed the artificial bee colony based PI and PID controller parameter tuning and its superior performance compared to PSO with transient response analysis method in 2012.

There has been considerable progress in intelligent algorithm based controller research work attempting to better control for AGC systems [25]. Teaching learning based optimization (TLBO) [26] is a new optimization technique developed by Rao et al. and it has hardly been applied to tune the controller in AGC studies. The author has proposed a parameter free optimization algorithm for tuning of controller for load frequency control of the present scenario above realistic power systems having multiple sources of power generation and its superior dynamic performances are compared to that of recently published optimal controller [21] and DE tuned controller [22] for the same AGC system.

Optimal parameter combinations for the DE-tuned controller [22] are experimentally determined by conducting a series of experiments through simulation with six different DE parameter settings [17] before conducting actual simulation to collect the results. However, the proposed TLBO a parameter free algorithm is very simple in concept and easy implementation to tune the controller of AGC for the realistic power system. In the present work, a brief overview of TLBO technique with a flow chart for the sake of completeness and better reading of the paper and also request the readers to refer to [26,27] for more details of TLBO and its application.

The main investigations of the present work:

i. To propose a new nature inspired algorithm as teaching learning based optimization (TLBO) for the load frequency control of the realistic power system.
ii. To optimize the PID controller gains and study of its dynamic performances for above power system.
iii. To compare the dynamic performance of TLBO based PID controller to that of optimal controller and DE tuned controller for single area system.
iv. To compare the dynamic performance of TLBO based PID controller to that of optimal controller and DE tuned controller for multi-source multi area power system without and with HVDC link.
v. To carry out the sensitivity analysis for the proposed TLBO-PID controller with its optimum parameters and its robustness to wide changes in loading pattern and several system parameters from their nominal values and also changes in size and locations of load perturbations and different cost functions.

System investigated

Single area realistic power system

The system under study is a realistic power system which includes reheat thermal, hydro and gas generating units. The linearized model of single area system is given in Refs. [18,22] and multi area system shown in Fig. 1 for simulation and LFC study. The nominal parameters of the system are provided in Ref. [18] for single area and for multi area in appendix. Each unit has its regulation parameter and participation factor [22] which decide the contribution to the nominal loading.

Multi source multi area realistic power system with HVDC link

The two area power system interconnected by parallel AC–DC tie lines [21,22] which comprises more practical combination of generating units such as reheat thermal, hydro and gas units in each area is simulated using MATLAB Simulink. Furthermore, the generators in each area may or may not participate in the LFC task and the participation rates are not same for all participating generators. The summation of participation factors of all participating generators is equal to unity in a control area. Transfer function model of multi-source multi area with HVDC link with integral controllers is depicted in Fig. 1.

Control strategy with objective function

When designing a controller, the main purpose of controller must be foremost in all considerations. This can include system dynamics, robustness to model uncertainty, ability to follow the set point, sensitivity to measurement noise and attenuation of load disturbances. The Proportional Integral Derivative controller (PID) is the widespread and popular feedback controller used in many modern industries. The popularity of PID controllers stems in part to their wide applicability to a variety of single input single output applications. PID controller is often used when stability and fast response are required. It is reported in Ref. [22] that the DE tuned PID controller outperforms than the DE tuned PI and I controllers for multi-source multi area realistic power system. Keeping in view above, The PID controller is employed in the present paper for comparative performance analysis of similar power system.

There are four kinds of performance criteria, generally considered in the control design. These are the integral of absolute error (IAE), integral of squared error (ISE), integral of time weighted squared error (ITSE) and integral of time multiplied absolute error (ITAE). However, ITAE and ISE criterions are mostly used in AGC studies for their better performance as compared to ISTE and IAE criterion. Systems with ITAE objective functions settle more quickly than ISE method. Therefore, ITAE is a better objective function among all and considered in present paper for comparative point of view.

The objective function for multi source power system may be defined as