Engineering Science and Technology, an International Journal 19 (2016) 113–134

HOSTED BY

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: http://www.elsevier.com/locate/jestch

Full Length Article

# Automatic generation control of multi-area power systems with diverse energy sources using Teaching Learning Based Optimization algorithm

Rabindra Kumar Sahu *, Tulasichandra Sekhar Gorripotu, Sidhartha Panda

*Department of Electrical Engineering, Veer Surendra Sai University of Technology (VSSUT), Burla, Odisha 768018, India*

A R T I C L E I N F O

*Article history:*
Received 18 May 2015
Received in revised form
13 July 2015
Accepted 20 July 2015
Available online 14 August 2015

*Keywords:*
Automatic Generation Control (AGC)
Boiler dynamics
Teaching Learning Based Optimization (TLBO) algorithm
Generation Rate Constraint (GRC)
Governor Dead Band (GDB)
Proportional-Integral-Double Derivative (PIDD) controller

A B S T R A C T

This paper presents the design and analysis of Proportional-Integral-Double Derivative (PIDD) controller for Automatic Generation Control (AGC) of multi-area power systems with diverse energy sources using Teaching Learning Based Optimization (TLBO) algorithm. At first, a two-area reheat thermal power system with appropriate Generation Rate Constraint (GRC) is considered. The design problem is formulated as an optimization problem and TLBO is employed to optimize the parameters of the PIDD controller. The superiority of the proposed TLBO based PIDD controller has been demonstrated by comparing the results with recently published optimization technique such as hybrid Firefly Algorithm and Pattern Search (hFA-PS), Firefly Algorithm (FA), Bacteria Foraging Optimization Algorithm (BFOA), Genetic Algorithm (GA) and conventional Ziegler Nichols (ZN) for the same interconnected power system. Also, the proposed approach has been extended to two-area power system with diverse sources of generation like thermal, hydro, wind and diesel units. The system model includes boiler dynamics, GRC and Governor Dead Band (GDB) non-linearity. It is observed from simulation results that the performance of the proposed approach provides better dynamic responses by comparing the results with recently published in the literature. Further, the study is extended to a three unequal-area thermal power system with different controllers in each area and the results are compared with published FA optimized PID controller for the same system under study. Finally, sensitivity analysis is performed by varying the system parameters and operating load conditions in the range of ±25% from their nominal values to test the robustness.



## 1. Introduction

Automatic Generation Control (AGC) plays an important role in the large scale multi-area interconnected power systems to maintain system frequency and tie-line powers at their nominal values. Due to sudden disturbances or some other reasons if the generated active power becomes less than the power demand, the frequency of generating units tends to decrease and vice versa [1,2]. This causes the system frequency to deviate from its nominal value which is undesirable. To damp out the frequency deviation quickly and to keep the tie-line power at its scheduled value, AGC concept is used. However, the constant frequency cannot be obtained by the speed governor alone. So, a control system is essential to cancel the effects of the sudden load changes and to keep the frequency at the nominal value [3–5].

Over the past decades, the researchers in the world over are trying to understand the AGC problem using several control strategies and optimization techniques and the database is scanty. The concepts of optimal control theory [6], Integral [7], Proportional-Integral [8], Proportional-Integral-Derivative [9], Integral-Double Derivative [10], Fractional Order PID [11] and Proportional-Integral-Double Derivative [12] have been applied and their performance has been compared for an AGC problem. Daneshfar and Bervani [13] have suggested the multi-objective optimization problem (MOP) approach and Genetic Algorithm (GA) technique is used to tuned PI controllers for multi-area power systems. Gozde et al. [14] have used Artificial Bee Colony (ABC) optimization technique to study the dynamic performance of AGC in a two-area interconnected thermal power system. Ali and Abd Elazim [15] have optimized the gains of PID controller using BFOA technique for LFC problem and they have compared it with Ziegler Nichols (ZN) and GA optimization techniques. Dash et al. [16] have the applied cuckoo search algorithm for AGC of a three-area thermal system with single reheat turbine considering Generation Rate Constraints. Mohanty et al. [17] have applied Differential Evolution (DE) algorithm based PID controller for multi-area multi-source power system. Recently, Sahu et al. [18] have applied hybrid firefly algorithm and pattern search optimization technique with PID controller in AGC problem. It is

* Corresponding author. Tel.: +91 9439702316, fax: +91 6632430204.
*E-mail address:* rksahu123@gmail.com (R.K. Sahu).
Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2015.07.011
2215-0986/

observed from literature survey that, most of the work was confined to reheat thermal plants, hydro plants and relatively lesser attention has been devoted to wind, diesel generating units. As conventional sources are exhausting day by day, now it is essential to make use of non-conventional sources such as solar and wind energy at favorable locations [19].

It is clear from literature survey that the performance of the power system depends on the controller structure and the optimization techniques employed to optimize the controller parameters. Classical techniques of determining the optimum gains of the controllers may fail to give optimal solution while solving harder constrained problems with large number of variables or in a large search space. To overcome such difficulties evolutionary algorithms (EAs) are used for searching near-optimum solutions to problems. Hence, proposing and implementing new controller approaches using high performance heuristic optimization algorithms to real world problems are always welcome.

In this proposed work optimum values of PIDD controller gains are obtained by using Teaching Learning Based Optimization (TLBO) algorithm. The performance of many optimization techniques depends on proper selection of certain control parameters. In Particle Swarm Optimization (PSO) algorithm the control parameters influencing performance are inertia weight (w), social and cognitive parameters ( $c_1$ and $c_2$ respectively), in Differential Evolution (DE) algorithm the control parameters are scale factor ($F$) and crossover rate ($CR$). Selection of these parameters plays a very crucial role in the performance of the algorithms. However TLBO algorithm does not require any controlling parameter. Since it is a parameter free algorithm, it is simple, effective and faster which motivates many researchers to use this algorithm in their own research area. TLBO algorithm proposed by Rao et al. [20] is a recently developed evolutionary optimization technique which does not require any control parameter.

Having known all this, in the present work, it is planned to carry out a methodical simulation study, to evaluate the performance of the proposed PIDD controller with TLBO algorithm. Simulation results are compared with some recently published works based on Firefly Algorithm (FA) [18], hybrid Firefly Algorithm and Pattern Search (hFA-PS) algorithm [18], Bacteria Foraging Optimization Algorithm (BFOA) [15], Genetic Algorithm (GA) [15] and conventional Ziegler Nichols (ZN) [15]. It is observed that TLBO optimized PIDD controller for the proposed two-area power system gives better dynamic performance in terms of settling time, overshoot and undershoot. In addition the proposed approach is extended to multi-area multi-source power systems. The better system performance is achieved with TLBO optimized PIDD controller compared to others. Further a three unequal-area thermal power system is considered. Results obtained are compared with that of a recently published work proposed by Padhan et al. [21]. Robustness test is performed by varying the operating load condition and system parameters in the range of ±25% from their nominal values.

## 2. Materials and methods

### 2.1. Two-area power system model

A two-area non-reheat interconnected thermal power system as shown in Fig. 1 is considered. 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 AGC [8,15,22]. In Fig. 1, $B_1$ and $B_2$ are the frequency bias parameters; $ACE_1$ and $ACE_2$ are area control errors; $u_1$ and $u_2$ are the control outputs from 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 seconds; $\Delta P_{G1}$ and $\Delta P_{G2}$ are the governor output command (p.u.); $T_{T1}$ and $T_{T2}$ are the turbine time constant in seconds; $\Delta P_{T1}$ and $\Delta P_{T2}$ are the change in turbine output powers; $\Delta P_{D1}$ and $\Delta P_{D2}$ are the load demand changes; $K_{P1}$ and $K_{P2}$ are the power system gains; $T_{P1}$ and $T_{P2}$ are the power system time constant in seconds; $T_{12}$ is the synchronizing coefficient in p.u.; $\Delta P_{Tie}$ is the incremental change in tie line power (p.u.); $\Delta F_1$ and $\Delta F_2$ are the system frequency deviations in Hz. The relevant parameters are given in Appendix A.

### 2.2. Controller structure and objective function

Classical PID controllers are used in most of the industrial processes due to their simple and robust design, low cost, and effectiveness for linear systems. However, the classical PID controllers are usually not effective due to their linear structure, especially, if the processes involved are higher order, time delay systems and

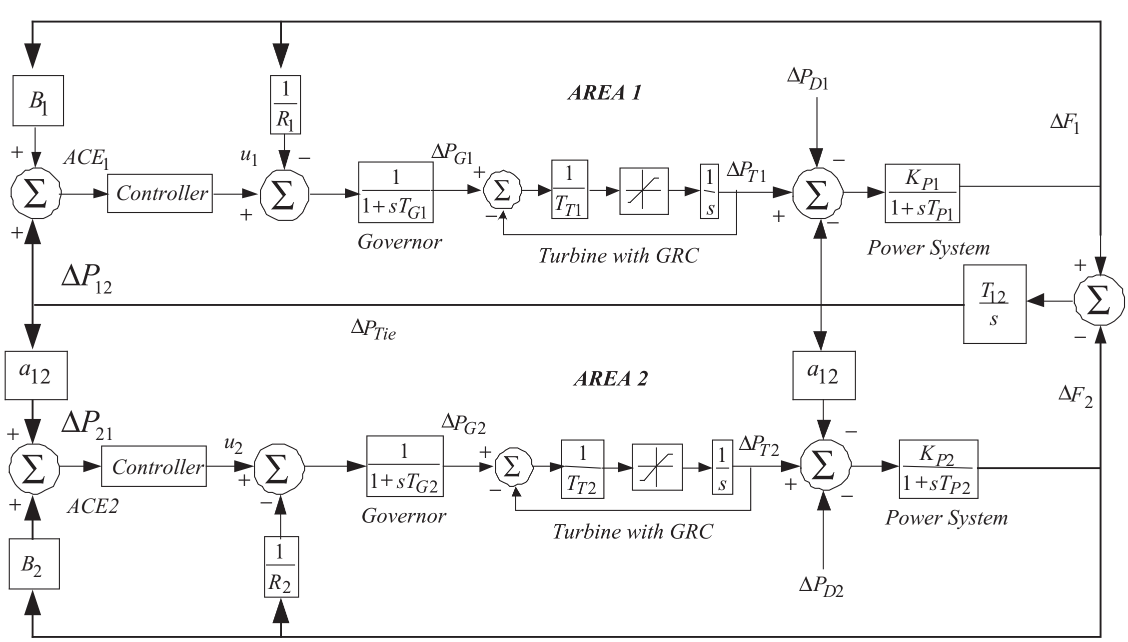


**Fig. 1.** Transfer function model of two-area non-reheat thermal power system.