Electric Power Systems Research 161 (2018) 74–85

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Frequency stabilization of hydro–hydro power system using hybrid bacteria foraging PSO with UPFC and HAE

Akhilesh Panwar[a], Gulshan Sharma[a], Ibraheem Nasiruddin[b,1], R.C. Bansal[c,*]

[a] Department of Electrical Engineering, Institute of Technology, Nirma University, Ahmedabad, India
[b] Department of Electrical Engineering, Jamia Millia Islamia University, New Delhi, India
[c] Department of Electrical Electronics and Computer Engineering, University of Pretoria, Pretoria, South Africa

ARTICLE INFO

Article history:
Received 7 October 2017
Received in revised form 17 February 2018
Accepted 29 March 2018

Keywords:
Load frequency control
Area control error
BFO
BFO-PSO
Hydrogen aqua electrolyzer unit
UPFC

ABSTRACT

This paper presents the design of proportional integral derivative (PID) based load frequency control (LFC) scheme effectively optimized through novel combination of bacteria foraging oriented particle swarm optimization (BFO-PSO) technique for a hydro dominating energy system model. The design control are implemented for 1% load disturbance in area-1 and compared with classical PID, Pessen integral rule, some overshoot, no overshoot as well as with recently published bacteria foraging optimization algorithm (BFOA) in terms of computed gains and inverse time multiplied absolute error (ITAE). The system performance for hydro energy system is sluggish and oscillatory. Hence, the further enhancement with proposed design are observed by considering the combination of unified power flow control (UPFC) in series with the tie-line and hydrogen aqua electrolyzer units installed at terminal of area-2. The system performance of the designed control is evaluated under various system investigations considering the dead-band and generation rate constraint (GRC) non-linearity and the applications results are presented to show the superiority of the proposed work.

1. Introduction

The modern power systems are bound to operate in system interconnections to satisfy the various technical and economical reasons as well as the standards set up by the different electrical utilities. The control areas are connected via tie-line in modern electric energy systems which undergo the frequency and tie-line power deviations from the standard values in the wake of load changes. The load frequency control (LFC) function is to maintain the output of system generators and so for system frequency to its acceptable limit i.e. ±0.5 Hz while maintaining the power exchange among the control areas at specified value [1–3]. The combination of frequency deviation and tie-line power exchanges among the control areas in linear form is termed as area control error (ACE). In literature, many LFC schemes have been proposed on timely basis to provide a simple and effective control for LFC of the power system.

The control technique based on conventional controllers was the earliest efforts in this area [4]. However, the proposed concept did not work well, as the gains selected were not based on some specific criterion and was totally dependent on the rich experience of the plant operator and hence proved to be an ineffective in meeting the standards of LFC under the diverse operating conditions of the system. The extensive researches have been made in the LFC and many new renewable based power generation technologies capable to improve the LFC performance such as wind power, photovoltaic (PV) for the LFC of an electrical energy system [5,6] as well as the design based on diverse control strategies i.e. optimal, model predictive and output vector feedback [7–9] are available in the literature. The LFC schemes based on optimal control provides optimum performance by minimizing the certain performance index. However, the design criterion requires availability and assessment of all the system states variables. To circumvent the drawbacks of optimal, the concepts of output vector feedback have been proposed by the researchers. The design control works sound within the permissible limits as well as requires lesser feedback states as compared to optimal LFC. In recent years, the intelligent LFC design based on fuzzy logic, artificial neural networks, multi-agent systems, genetic algorithm (GA), ant colony optimization (ACO), particle swarm optimization (PSO) and hybrid intelligent optimiza-

* Corresponding author.
E-mail addresses: akhilesh.panwar@nirmauni.ac.in (A. Panwar), gulshan.sharma@nirmauni.ac.in (G. Sharma), ibraheem_2k@qec.edu.sa (I. Nasiruddin), rcbansal@ieee.org (R.C. Bansal).
[1] Presently working at Department of Electrical Engineering, Qassim University, Kingdom of Saudi Arabia.

https://doi.org/10.1016/j.epsr.2018.03.027
0378-7796/

Nomenclature

ΔF_i	Deviation in frequency of area i (i = 1, 2) Hz
ΔP_{tie12}	Tie-line power deviation (p.u. MW)
ΔP_{gi}	Change in generation of power (p.u. MW)
ΔP_{dhi}	Change in load demand of the system (p.u. MW/Hz)
ΔP_{chi}	Change in speed changer position
ΔX_{gi}	Change in governor valve position of area i
ΔX_{ghi}	Intermediate output of hydro governor
ΔT_{ghi}	Time constant of speed governor (s)
R_i	Speed regulation parameter (Hz/p.u. MW)
T_{wi}	Hydro turbine time constant (s)
K_{ghi}	Speed governor gain
T_{phi}	Time constant of power system (s)
K_{phi}	Gain of power system
a_{12}	Area size ratio coefficient
b_i	Frequency bias constant (p.u. MW/Hz)
ACE_i	Area control error
T_{12}	Tie-line synchronizing coefficient (p.u.)
T_{hi}	Time constant associated with hydro governor of area i (s)
ΔP_{UPFC}	Change in power of UPFC
K_{AE}	Gain of HAE
T_{AE}	Time constant HAE (s)
K_{FC}	Gain of fuel cell
T_{FC}	Time constant of fuel cell (s)
n	Dimension of search space
S	Number of bacteria in the colony
N_s	Number of swim length
N_c	Number of chemotactic steps
N_{re}	Number of reproduction steps
N_e	Number of elimination and dispersal events
P_{ed}	Probability for elimination and dispersal of each bacteria
$c(i)$	Step size taken in the random direction for each tumble
C_1, C_2, R_1, R_2	PSO random parameters

tion have been applied by the researchers and power engineers worldwide to solve the LFC problem [10–14].

The GA is one of the most widely used intelligent algorithms among several other artificial algorithms and it has been successfully applied to solve the complex and nonlinear problems such as LFC. In Ref. [15], the GA is used to find the optimum parameters of LFC. In Ref. [16], the robust performance for LFC is achieved through GA using linear matrix inequalities (LMI). Despite of all, in Ref. [17] some deficiencies in GA were reported by the researchers. The performance of GA highly depends upon the nature of the objective function resulting in the premature convergence which further reduces its search capability and its performance. The issues related to the application of GA have been reduced to a great extent by the development of a new optimization technique i.e. PSO. PSO has lesser chances to get trapped on local optimum and it also has less computational time for same degree of performance.

Recently, the authors have proposed more efficient and evolutionary computation technique i.e. bacteria foraging optimization (BFO) algorithm to solve more efficiently the non-linear and complex control problems. It was developed by modeling the behavior of *Escherichia coli* bacteria present in the intestines of human beings. Due to its unique dispersal as well as elimination technique it is able to achieve favorable regions in case the involved population is smaller. These novel features of BFO overcome the drawbacks of GA and PSO i.e. entrapment in local optimum and hence improves the search capability and may proved to be an effective optimization control for LFC. In Ref. [18], the authors presented the effectiveness of BFO over GA based LFC for interconnected energy system. In Ref. [19], the problem of LFC is dealt with BFO optimized PI and its advancement over GA are demonstrated for a two-area thermal system having non-reheat turbines. The hybrid BFO-PSO was proposed in Ref. [20] to find the optimal values of PI for two-area and multi-area energy system. The superiority of the proposed algorithm is shown over PSO, BFOA, GA, craziness based PSO and over ANFIS.

From the available research work, it is observed that most of the control techniques are verified on thermal power or hydro-thermal models and the LFC literature lags with suitable and simple control design for hydro dominating energy systems as the response time of hydro turbines are much more as compared to thermal turbines due to which the LFC response of hydro dominating energy system are sluggish with sustained oscillations. Hence, the researchers and electric power engineers are avoiding this model to develop suitable control design [21].

As the modern world is moving on the way to cleaner and environmental friendly sources to generate electric power, the future emphasis is to generate more and more power from hydro, be it bulk power or micro-hydro due to which the future electrical energy system may be more complex and will consist of hydro dominating interconnected control areas. Thus, it is important to explore a simple and effective control design for such kinds of hydro dominating energy systems.

The new and fast development of power electronic industries has led to the development of flexible alternating current transmission systems (FACTS) in order to improve the performance of electric energy system and to fine control the flow of power in any direction [22]. FACTS have the ability to control active as well as reactive power and can progress the energy systems performance under sudden changes in the load demands and also ensure the quality delivery of electrical energy to the modern consumers. The application of hydrogen generative aqua electrolyzer (HAE) with fuel cell is observed to be more capable in LFC to improve the system performance as compared to other FACTS used for LFC [23]. Renewable energy sources with different energy storage can dissolve water or natural gas into oxygen and hydrogen using HAE. Finally, the produced hydrogen is compacted, stored and transported through pipelines to fuel cells. The HAE is more promising and fast to damp out the system oscillations for unstable models i.e. hydro dominates and restore the system conditions to normal value during abrupt load change of the energy system. The positive effect of HAE is restricted to the area of its installation only and it is not suggested to install it in each and every control area of energy system as it will increase the overall cost of the system. The unified power flow controller (UPFC) is a new FACTS device which can be installed in series with tie-line in order to progress the performance of electrical energy system. Thus, the coordinated operation of HAE and UPFC is used to control the system conditions of hydro dominating model in an economic and faster manner. In the view of above discussion, the novel contribution of this research article is set to;

- To propose a novel design for LFC of a two-area hydro dominating interconnected energy system based on PID control technique. The optimal gains of PID are optimized through the novel combination of hybrid bacteria foraging oriented particle swarm optimization (BFO-PSO) technique.
- The designed control is implemented for 1% load disturbance in area-1 and the application results are compared with other PID designs such as bacteria foraging optimized PID, classical PID, Pessen integral rule, some overshoot and no overshoot method.
- The performance of the proposed PID design is also evaluated considering the dead-zone of governor and through restricting