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Design of biogeography optimization based dual mode gain scheduling of fractional order PI load frequency controllers for multi source interconnected power systems

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ABSTRACT

This paper presents the effect on application of biogeography optimization (BBODMFOPI) based dual mode gain scheduling of fractional order proportional integral controllers for load frequency control (LFC) of a multi source multi area interconnected power systems. This controller has three parameters to be tuned. Thus, it provided one more degree of freedom in comparison with the conventional proportional integral (PI) controller. For proper tuning of the controller parameters, Biogeography-Based Optimization (BBO) was applied. BBO is a novel evolutionary algorithm which involves the methodology of making the system effectively by using mathematical techniques. The dual mode concept is also incorporated in this work, because it can improve the system performance. In this work, simulation investigations were taken out on a two-area power system with different generating units. The simulation results show that the proposed biogeography optimization based dual mode gain scheduling of fractional order PI controllers, provide better transient as well as steady state response. It is also found that the proposed controller is less sensitive to the changes in system parameters and robust under different operating condition of the power systems.

Introduction

Load frequency control (LFC) is a fundamental part in power system operation and control. The continuous monitoring is needed for the sufficient supply and uninterrupted power. In order to ensure good quality and reliability to the consumers and to obtain the above understood criteria, it is mandatory to interconnect all the power system which includes thermal and hydro, gas system [1]. LFC deals with the problem of delivering the demanded power to the load with minimum transient oscillation. The current scenario of the power system is the interconnection of different power plants. Stand alone power system is basically a dynamic device, and has the tendency to become unstable after a severe disturbance. Thus, there is a need for an effective invention and restraint to maintain its stability. Further, an effective control system is required for interconnected operations. But the problem in the interconnected power system is dampened out the frequency and tie line power oscillations. If no adequate damping is provided, the oscillations may persist for a long time, causing disintegration of system [2].

A number of control strategies have been employed in the design of load–frequency controllers in order to achieve better dynamic performance [2–10]. Among the various types of load frequency controllers, the most widely employed is the simple conventional controllers. These conventional controllers for LFC are still popular with the industries because of their simplicity, easy realization, low cost, and robust nature. The conventional proportional plus integral control strategy, which is widely used in the power industry, is to take the integral of the area control error (*ACE*), which is a linear combination of net-interchange and frequency errors as the control signal. Generally, the conventional approach using the proportional plus integral controller results in relatively large overshoots in transient frequency deviations. Further, the settling time of the system frequency deviation is also relatively long [3].

Although, conventional controllers are well known for their simplicity and are widely used in LFC as secondary controllers, but there is no guarantee that such controllers would provide the best dynamic response under realistically constrained conditions like generation rate constants (GRC). It has been seen that the basic approaches of classical controllers are not effective in achieving

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Nomenclature

List of symbols

f	area frequency in Hz
i	subscript referred to area i (1–2)
P_{ei}	the total power exchange of area i in p.u. MW/Hz
P_{Di}	area real power load in p.u. MW
P_{ci}	area speed changer output in p.u. MW
X_e	governor valve position in p.u. MW
$P_{g\ i}$	incremental generation change in area i p.u. MW
K_P, K_I	electric governor proportional and integral gains respectively
T_P	area time constant in seconds
R	steady state regulation of the governor in Hz/p.u. MW
T_g	time constant of the governing mechanism in seconds
k_r	reheat coefficient of the steam turbine
T_r	reheat time constant of the steam turbine in seconds
T_t	time constant of the steam turbine in seconds
β_i	frequency bias constant in p.u. MW/Hz
ACE	area controller error
B	bias constant
ISE	integral square error
N	number of interconnected areas
Δ	incremental change of a variable
Δf_i	incremental change in frequency of area i in Hz
ΔP_G	change in generated power
ΔP_D	change in load demand
ΔP_c	change in speed governor
T_P	power system time constant
$\Delta P_{tie\ i\text{–}j}$	incremental change in tie line power connecting between area i and area j in p.u.
N	number of interconnected areas
s	laplace frequency variable
BBO	Biogeography based optimization
S^{max}	maximum species count
SIV	suitability index variable
SI	suitability index
$\underline{E}_{BBO}$	maximum possible emigration rate
$\underline{I}_{BBO}$	maximum possible immigration rate
$\underline{n}_{BBO}$	number of species
$\underline{\lambda}_{BBO}$	immigration rate
$\underline{\mu}_{BBO}$	emigration rate
$\underline{k}_{BBO}$	number of species in $\underline{k}$th island
w/o	without

Superscript

T	transpose of a matrix

Subscripts

i, j	area indices (i, j = 1,2,...,N)

good dynamic performances when selected to wide changes in magnitude of step load perturbation [3]. In the past, the focus has been to optimize the gains of conventional controller using various optimization techniques [11–13]. Many research works have been carried out considering the fuzzy logic controller (FLC) and supervised artificial neural network (ANN) controller in LFC. However, in case of FLC, a considerable computational time is required for the database to be examined and more time is required for the database for training the ANN controller in supervised learning [8,14,15].

Recently fractional-order (FO) dynamic systems and controllers, which are based on fractional-order calculus, have been gaining attention in several research communities since the last few years. In fractional-order proportional–integral (FOPI) controller, integral operation is usually of fractional order; therefore, besides setting the proportional and integral constants K_P, K_I. We have one more parameter: the order of fractional integration λ. Finding an optimal set of values for K_P, K_I and λ to meet the user specifications for a given process plant calls for real parameter optimization in three-dimensional hyperspace [16–19].

It is well known that if the control law employs an integral control, the system will have no steady-state error. However, it increases the type of the system by one. Therefore, the response with the integral control is slow during the transient period. In the absence of integral control, the gain of the closed loop system can be increased, significantly to improve the transient response since the proportional plus integral control does not eliminate the conflict between the static and dynamic accuracy. The conflict be resolved by improving the principle of dual mode control [20].

Numerous intelligent optimization techniques such as genetic algorithm (GA), particle swarm optimization (PSO), bacterial foraging optimization, and firefly algorithm are successfully applied to solve the LFC problems and are available in the literatures [2,3,6]. The complexity of LFC problems reveals the necessity for development of more efficient algorithms in order to accurately minimize the error signal to zero.

Recently, a Biogeography based optimization (BBO) algorithm has been suggested for solving optimization problems [21,23]. It is based on the mathematics of biogeography that studies the geographical distribution of biological organisms. In this approach, problem solutions are represented as islands or habitats and the sharing of features between solutions is represented as immigration and emigration between islands. Since its founding, it has been applied to a variety of power system optimization [21–26]. In this work Biogeography based optimization (BBO) technique is utilized to tune the Dual Mode FOPI controller parameters.

In view of the above, the objectives of the present work are:

- To design and apply a new Biogeography based dual mode gain scheduling of fractional order PI controllers for multi source interconnected power systems.
- To study the performance of the BBODMFOPI controller under random load pattern and higher magnitude of step load perturbation.
- To study the further impact of capacitive energy storage (CES) unit on the same momentary performance.
- To check the robustness of the proposed controller through sensitivity analysis.
- To check the robustness of the proposed controller for different operating conditions of the power system.

Mathematical linearized model of multi source interconnected power systems

Model description

The power system considered in this work consists of two generating areas. Each area comprises of reheat thermal, hydro and gas generation units. The block diagram description of reheat thermal, hydro and gas plants are shown in Fig. 1. Because the system is exposed to a small change in load during its normal operation, the linear model will be sufficient for its dynamic representation.