Electrical Power and Energy Systems 80 (2016) 333–346

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Pareto design of Load Frequency Control for interconnected power systems based on multi-objective uniform diversity genetic algorithm (MUGA)

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form 22 December 2015
Accepted 27 January 2016
Available online 16 February 2016

Keywords:
Multi-area power systems
Load Frequency Control (LFC)
PID controller
Generation rate constraint (GRC)
Pareto optimization
Multi-objective genetic algorithm

ABSTRACT

In this study, it is tried to employ a state-of-the-art multi-objective uniform-diversity genetic algorithm (MUGA) for Pareto optimization of PI/PID controllers in Load Frequency Control (LFC) of power systems. At first, multi objective optimization of a linear non-reheat two-area interconnected power system is conducted with respect to three conflicting objective functions. Gains of PI and PID controllers are considered as design variables while the objective functions are Integral Time multiply Absolute Error (ITAE), minimum damping ratio of dominant eigenvalues, and settling times in frequency and tie-line power deviations. To illustrate superiority of MUGA in finding optimum values of the deign variables, the proposed designs by MUGA are compared with those proposed by single and multi-objective optimization methods such as BFOA, hBFOA-PSO, and NSGA-II; the results indicate there is a noticeable improvement in response of the system. Further, robustness of the proposed designs is demonstrated by varying the system parameters from their nominal values and monitoring sensitivity of the system response to the variations. At the end, to take nonlinearities and physical constraints into account and to evaluate performance of MUGA in more complex system, a three unequal area hydro thermal system with generation rate constraints is considered.

Introduction

Interconnected power systems consist of several areas. The primary function of a power system is to generate power while frequency in each area and tie-line power exchange between areas are kept in scheduled values [1,2]. Under steady-state condition, power generation and load demand are in equilibrium but occurrence of a load change causes the equilibrium to be disturbed; consequently, values of the area frequencies and tie-line power exchanges deviate from their scheduled nominal values. This characteristic in power systems necessitates existence of a control system to restore the balance between power generation and load [3–5]. This type of control system is called Load Frequency Control (LFC) or Automatic Generation Control (AGC). In other words, LFC function is to maintain frequency and tie-line power close to the scheduled values by regulating power generation in each area in accordance with variation of load demand in the area.

Transient and steady-state properties of dynamic response along with stability are of the main performance criteria to be improved by LFC in an interconnected power system. Unfortunately, similar to most engineering design problems, these criteria conflict with each other and manipulation of controller design variables to improve a criterion causes the other criteria to deteriorate [6,7]. This characteristic of the performance criteria entails employment of an optimization method which improves all the criteria, simultaneously, for multi-objective optimization problem in a power system [5,8]. Furthermore, in different stages of controller design for a practical power system, occurrence of an intractable issue such as uncertainty in components may cause the system to diverge from its anticipated performance. In some designs, the divergence results in such drastic deterioration of the system performance that those designs will not be capable of being employed. This makes an optimization method which yields a single design, as solution of the optimization problem, highly susceptible to failure. In other words, in order to be considered

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http://dx.doi.org/10.1016/j.ijepes.2016.01.042
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Nomenclature

f	nominal system frequency in Hz
i	subscript referring to available areas
R_i	governor speed regulation parameter for ith area
T_{gi}	speed governor time constant in second for ith area
T_{ti}	turbine time constant in second for ith area
T_{ri}	reheat time constant in second for ith area
K_{ri}	steam turbine reheats coefficient for ith area
T_w	hydro turbine time constant,
K_d, K_p, Ki	electric governor derivative, proportional and integral gains, respectively
T_{Pi}, K_{Pi}	time constant and gain of power system respectively for ith area
ΔP_{tie_i}	difference between the actual tie-line power and scheduled one
B	frequency bias for ith area
K_i	controller of ith area
u_i	control signal for ith area
$K_{p_i}, K_{i_i}, K_{d_i}$	gains of PID controller of for ith area
N	derivative filter coefficient
T_{ij}	synchronizing coefficient
J	objective function
X	vector of design variables
$F(X)$	vector of objective functions
P^*	Pareto set
PF^*	Pareto front
Ω	design variable space
ε	elimination threshold

List of abbreviations

LFC	Load Frequency Control
PI	proportional plus integral
PID	proportional, integral plus derivative
GRC	generation rate constraint
ACE	Area Control Error
MUGA	Multi-objective Uniform-diversity Genetic Algorithm
BFOA	Bacteria Foraging Optimization Algorithm
PSO	Particle Swarm Optimization
hBFOA-PSO	Hybrid BOFA and PSO
NSGA-II	Non-dominated Sorting Genetic Algorithm-II

as a practical optimization process, the optimization process needs to employ an optimization method with characteristic of being able to form a set of optimum designs with respect to all considered design objectives [7,9,10]. In this regard, in current study, a state-of-the-art multi objective optimization methods is employed to address these characteristics in optimization process of controllers for multi-area interconnected power systems.

Different power systems consist of different areas with various components. Comprehensive explanation of these areas and components are expressed in [1,2]. Employment of proper structures for controllers and tuning of parameters in those controllers are of the main concerns in LFC; several controller structures employed in LFC are reviewed in [11]. Control approaches and structures including robust [12,13], adaptive [14,15], fuzzy [16,17], neural network [18,19], and PI/PID have been utilized in LFC. Among the controller structures, because of simple yet efficient structure of PI and PID controllers in practical applications, a lot of attention has been paid to these type of controllers and their performance. Parameters in PI/PID controllers need to be tuned properly, to boost efficiency of the controllers and achieve desired performance in the power systems [5,20]. In LFC, parameters tuning with the aim of improving the performance is formulated as an optimization problem. Various solutions to the optimization problem have been proposed by different meta-heuristic optimization methods such as Genetic Algorithm [8,13], Particle Swarm Optimization [17,21], Bacteria Foraging Optimization Algorithm [4,22,23], Differential Evolution [20], and Artificial Bee Colony [5].

There are single-objective optimization methods in which performance criteria are evaluated by a single objective function while there are multi-objective optimization methods in which multiple objective functions contribute to evaluate those criteria [6]. Since, usually, there is a confliction between objective functions, improvement in an objective function deteriorates the other ones. Therefore, contrary to single objective optimization, in multi objective problems, there is not a unique solution which can be considered as the best solution with respect to the all the objective functions. Multi-objective optimization of such problems is called Pareto optimization and the optimization results in a set of optimal solutions, known as Pareto optimal solutions [10,25]. There are several Pareto-based multi-objective optimization methods. MUGA [10] and NSGA-II [24] are two common methods in engineering; these methods are successors of Genetic Algorithm (GA), an optimization algorithm inspired from survival process of living organism in nature. MUGA was proposed as an alternative to NSGA-II in optimization problems with more than two objective functions [10,25].

In this study, to exploit capability of offering diverse Pareto front of non-dominated optimum designs, MUGA is employed to optimize PI/PID controllers installed in areas of multi-area interconnected power system while three conflicting objective functions, namely, integral errors, settling times of frequency and tie-line power deviations, and inverse of minimum value of damping ratios of dominant eigenvalues are considered to be minimized simultaneously. Gains in PI/PID controllers are considered as design variables. Dynamic responses of the system equipped with the PI/PID controllers proposed by current study are compared with those proposed in the literature. At the end, to take generation rate constraint (GRC) as a source of nonlinearities and physical constraints into account and to assess applicability of MUGA in more complex systems, a three unequal area hydro thermal system equipped with different PI controllers is considered.

System modeling

LFC modeling in power systems

A multi-area power system consists of several interconnected areas. In this study, block diagram of a simplified multi-area power system along with transfer functions of its components are utilized to model and represent the system. Block diagram of an area in a non-reheat linear power system is depicted in Fig. 1; each area consists of a speed governing system, a governor, a turbine, and a generator. Transfer functions of these components, as the ratio of the Laplace transform of their outputs to the Laplace transform of their inputs [27], are employed to model the components.

The speed governing system gets two input signals, ΔP_{ref} and ΔF, and generate an output signal, ΔP_G, for the actuator valve (governor) as:

$$\Delta P_G(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s). \tag{1}$$