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Original Research Article

A modified harmony search algorithm for solving load-frequency control of non-linear interconnected hydrothermal power systems

Mojtaba Shivaie [a,*], Mohammad G. Kazemi [b], Mohammad T. Ameli [a]

[a] Department of Electrical & Computer Engineering, Shahid Beheshti University, A.C., Tehran, Iran
[b] Sama Technical and Vocational Training College, Islamic Azad University, Gachsaran-Branch, Gachsaran, Iran

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ABSTRACT

In this paper, a new method is presented to solve the load-frequency control of non-linear power systems. In the proposed methodology, a two-area interconnected hydrothermal power system is considered to optimal adjustment parameters of Proportional-Integral-Derivative (PID) controller. In order to illustrate the usefulness of the newly proposed method, the obtained results are compared with the determined results of genetic algorithm. The cost function of problem is also proposed based on the Integral of Time-multiplied Absolute value of the Error (ITAE) in the optimization process along with frequency bias factor to improve system response. The proposed controller is optimized by a new music-inspired algorithm, named modified harmony search algorithm (MHSA). The MHSA is a recently developed optimization algorithm which imitates the music improvisation process. In this process, the Harmonists improvise their instrument pitches searching for the perfect state of harmony. The newly developed method has been implemented on a two-area interconnected hydrothermal system with three different scenarios to show the feasibility and effectiveness of the proposed method. Simulation results demonstrated the sufficiency of the newly developed method in the load-frequency control, when compared with other methods; and therefore, it can be beneficial for the real-world power systems.

Introduction

Literature review and motivations

In general, the dynamic behavior of electric power plants is heavily influenced by disturbances and, in particular, by changes in the operating point. Load frequency control (LFC) is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. The main goal of the LFC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area power system [1]. During the last decades, many technical papers have been dealt with the LFC in power system literature by using linear models, such as [2–4]. In Ref. [2], a LFC model is studied by using linear feedback. In Ref. [3], a new approach is reported for optimal control of power systems. In another study [4], an artificial neural network-based approach is proposed for optimal control of power systems. On the other hand, many studies have been performed for non-linear control of generator, governor and power system, such as [5–7]. One thing that must be highlighted in the aforementioned approaches is that the control time of power systems is a long time. Therefore, in this paper, with a new point of view, an innovative method is proposed for load-frequency control, which can both reduce control time and decrease value of frequency deviation during dynamic performance of power systems. By developing of industrial controllers, Proportional-Integral-Derivative (PID) controllers is still one of the most popular controllers, and many technical papers have been accomplished for optimal and automatic adjusting of the PID parameters [8–10]. In addition, different performance criteria have been used for evaluating the performance of controlled power systems. In some Refs., Integral of Absolute Error (IAE) [11–12] and other Refs., Integral of Square Error (ISE) [11] have been used. Integral of Time Multiplied Square Error (ITSE) has been investigated in Ref. [13]. Integral of Time multiplied Absolute Error (ITAE) has been used in Refs. [13–14].

In this paper, then, a new approach is addressed for non-linear load-frequency control of interconnected hydrothermal power systems by using a modified harmony search algorithm (HSA). The modified HSA is used to optimize the PID parameters. In addition, to adjust PID controller, the ITAE is used as cost function. The ITAE criterion is chosen due to it can determine a good weight for error signal in terms of time. This issue can reduce settling time in the lowest value and damp fluctuations, quickly [12]. In the proposed

* Corresponding author. Tel.: +98 912 531 8241; fax: +98 23 33460958.
E-mail address: m_shivaie@sbu.ac.ir (M. Shivaie).

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Nomenclature

The main notation used throughout the paper is stated below for quick reference.

D	Damping coefficient
H	Inertia constant
$H_G(s)$	Transfer function of governor
$H_T(s)$	Transfer function of steam turbine
K_r	Reheat factor
K_p, K_i, K_d	Parameters of the PID controller
$K_{p,i}$	Proportional coefficient in area i
$K_{I,i}$	Integral coefficient in area i
$K_{D,i}$	Derivative coefficient in area i
R	Drop of unit in [Hz/p.u. MW]
T_G	Time constant of governor
T_T	Time constant of thermal turbine
T_r	Time constant of reheat
T_w	Time constant of hydro turbine
$(x'_G)_{\max}$	Maximum allowable speed of governor
$(x'_G)^{obtainted}_{\max}$	Maximum calculated speed of governor
$(x_G)_{\max}$	Maximum allowable displacement of governor
$(x_G)^{obtainted}_{\max}$	Maximum calculated displacement of governor
β_i	Frequency bias factor for each area
ΔP_D	Changes of the load
ΔP_G	Changes of the governor
ΔP_T	Changes of the turbine
Δf	Frequency deviation
ΔP_{tie}	Tie-line power deviation
ΔPC_i	Control relationship of the LFC

method, the Area Control Error (ACE) is also defined and computed on the basis of the feedback in each area; and therefore, control action is performed to set the ACE in zero value. As a result, frequency and tie power among areas are kept in the specified values. The newly proposed method uses a Frequency Bias Factor (FBF) for each area to provide a proportion of the error of frequency over the error of tie power.

Aims and contributions

In order to the best of our knowledge, the main contributions of this paper in comparison with the previous papers in the context of LFC problem are threefold:

(1) To consider a new optimal method to solve of the LFC problem in a two-area non-linear interconnected hydrothermal power system;
(2) To increase the flexibility of method in order to improve system response by considering the ITAE function and the FBF in the optimization process;
(3) To takes into account a new and robust modified music-inspired optimization algorithm to overcome the difficulties in solving LFC problem and determine the optimal final solution.

Paper organization

The remainder of this paper is organized into five sections. Section "Load-frequency problem formulation" describes LFC model of thermal and hydro power systems. Also, solution algorithm of the proposed LFC is presented in Section "Solution algorithm". Simulation results and case studies are demonstrated and discussed in Section "Simulation and case studies". Finally, Section "Conclusions and future research" is devoted to conclusion remarks.

Load-frequency problem formulation

In the present paper, a non-linear two-area interconnected hydrothermal power system is investigated, which structure of the system along with load frequency controller is shown in Fig. 1 [2,17–18]. In order to investigate the dynamic behavior of the thermal governor turbine system with reheat, the transfer functions have been defined according to Eqs. (1) and (2) [8,10].

$$H_G(s) = \frac{0.8 - \frac{0.2}{\pi}s}{1 + T_G s} \tag{1}$$

$$H_T(s) = \left(\frac{1 + K_r T_r s}{1 + T_r s}\right) \cdot \left(\frac{1}{1 + T_T s}\right) \tag{2}$$

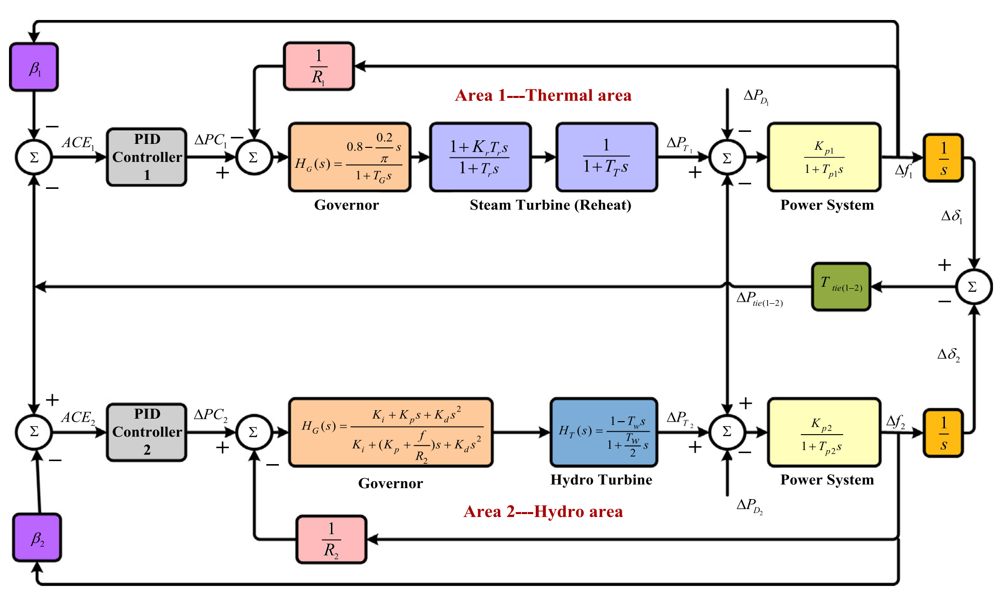

Fig. 1. Block diagram of a two-area interconnected hydrothermal power system.