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Design and analysis of multi-source multi-area deregulated power system for automatic generation control using quasi-oppositional harmony search algorithm

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A B S T R A C T

The present article focuses on the study of automatic generation control (AGC) of a realistic power system having a distinct combination of multi-area multi-source generating units in each control area under deregulated framework. An attempt is made in this paper to integrate reheat thermal, hydro and gas generating unit in a single control area and, then, extended this combination to five control areas. In this work, six reheat thermal, six hydro and three gas generating units are taken into account for the modeling of five-area power system. Some important physical constraints like time delay, governor dead band and generation rate constraint are imposed in the power system dynamics to get an accurate perception of the deregulated AGC subject. The highlighting features of the present work are to model, simulate, optimize and co-relate their inter-related dynamic performances for the purpose of AGC study. For such a complex AGC model, the vital role of the proposed quasi-oppositional harmony search (QOHS) algorithm, as an optimizing tool, is signified while solving the AGC problem in deregulated regime. The simplicity of the structure and acceptability of the responses of the well-known proportional–integral–derivative controller, inherently, enforces to employ in this work. The three classes of extensive deregulated cases (in the presence of load following and physical constraints) are demonstrated by examining the closed loop performance of the studied model. The simulation results show that the designed power system model may be a feasible one and the proposed QOHS algorithm may be a promising optimization technique under these circumstances.

Introduction

General

The modern power system is composed of multiple generating sources such as thermal, hydro and renewable energy power plants having many control areas or regions represents coherent group of generators. The present situation enforces to promote new sources of power generation, invites new players in the realistic power system with multiple sources of power generation and their corresponding area participation factors (*apf*) also play an important role in the study of load frequency control (LFC) [1]. The contribution of thermal, hydro and gas generating units have distinct role in the performance evaluation of automatic generation control (AGC) of power system. These three generating units have distinct characteristics, different class of contributions and different modeling concepts which have increased the level of interest to apprehend their individual role in the AGC performance.

In AGC phenomena, the performance of power system depends on the existing balance between the available total generation and the consumed load associated with the system losses. Any deviation between these two is classified by the change in frequency deviation. Thus, it may be justified that frequency control is one of the important aspect of AGC, treated as an elementary part of discussion and the most profitable service of AGC [2]. AGC design strategies have, recently, becomes an area of prominent research owing to the increase in power exchange through tie-lines and environmental and economical reason after deregulation [3].

Literature review

Most of the contributions, outcomes and insights presented so far for the AGC work, lie in the beneath of observing and controlling both the frequency and tie-line power deviation profiles during the

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normal/abnormal condition (usually, by the variation in load). These two terms dignify the AGC synthesis for the evaluation of applied techniques. The composite mixture of these two terms, known as area control error (*ACE*), is utilized by a dynamical controller in order to satisfy the desired AGC performance [4].

With the passage of time, the structure of classical interconnected power system has been shifted to deregulated domain. The initial contribution, in the domain of deregulation, has been perceived by Kumar et al. [5,6]. In their cited works, they have (a) presented the deregulated electric industry, (b) suggested the modifications required in the conventional AGC system to study the load following aspects and (c) described the simulation models and various bilateral cases. In the same vein, Donde et al. [7] have presented an AGC model of two-area thermal power system reflected by bilateral contracts on the dynamics.

The recent studies have unfolded that the structure of power system is changing due to significant contribution of hydro power system. The inclusion of gas power plant, in addition to, hydro power system in line with existing power, has increased the level of interest in the analysis of AGC subject. In recent time, the study of multi-sources in single- and multi-area power system in deregulated AGC regime has revamped the total AGC scenario. The contribution of hydro turbine, in opposite to thermal system owing to deregulated AGC work, has been addressed by Demiroren and Zeynelgil in [8]. Nanda et al. [9] has applied the bacterial foraging (BF) algorithm in a multi-area power system, imposed by generation rate constraint (GRC). Hybrid particle swarm optimization (PSO) based optimization of deregulated multi-area AGC system has been carried out by Bhatt et al. [10]. Golpira and Bevrani [11] have designed a realistic AGC model of three control area power system using genetic algorithm (GA). A small load perturbed LFC model of a combined cycle gas turbine power plant has been studied in [12] by using the firefly algorithm (FA). Mohnathy et al. [13] have analyzed AGC model of single-area and, then, extended to multi-area multi-source power system by using differential evolution (DE) algorithm. An application of teaching learning based optimization (TLBO) algorithm in connection to LFC of multi-source power system by incorporating thermal, hydro and gas power plant may be found in [14]. Dash et al. [15] have studied the multi-area thermal system with the provision of single reheat turbine and GRC by using the bat algorithm (BA). The implementation of FA with an online wavelet filter in the AGC model of unequal three area reheat thermal power system including the physical constraints (such as time delay, dead zone, boiler dynamics, GRC and high frequency noise components) has been carried out in Naidu et al. [16]. Debbarma et al. [17] have focused on the solution to multi-area AGC problem of power system by using FA.

The above discussions reveal that ample attentions have been paid by the various researchers in deregulated AGC field having multi-source generating units. A sequence-wise study reveals that the applied algorithms have shown improved results and may be used to solve the AGC problem of multi-unit multi-area power system. Inspired by the above study, the present work utilizes unequal five control areas having the distinct combinations of multi-sources such as reheat thermal, hydro and gas generating units for deregulated AGC study. To make the study more realistic one, important physical constraints such as GRC, time delay and governor dead band are also included in the designed power system model.

Motivations behind the present work

Literature survey highlights a number of AGC models that have been implemented in deregulated power domain having multiple generating units. These systems are only the basic AGC models to study the applied AGC techniques. However, most of the AGC models are based on thermal system. A very few papers are related to hydro power system or the combination of these two [8]. In the new AGC paradigm, a control area may have a variety of generating sources like thermal, hydro and gas energy sources and, therefore, representing a control area by thermal or hydro system dynamics only may not result in a good design of LFC system.

In most of the articles, a simplified yet controlled approach is adopted while neglecting important physical constraints simultaneously or in a part [14]. It may be noted that the effect of governor dead band, practical limits on the incremental rate of turbine output (say GRC) and delay associated with the signal processing/ communication channels are often either neglected or studied separately. In the presence of GRC and governor dead band, the system becomes highly non-linear (even for a small load perturbation) and, hence, in an actual power system, the performance of the designed controller is, significantly, degraded by increasing overshoot and settling time [9,16]. On the other hand, communication delay/time delay has become a significant challenge in the AGC synthesis/analysis owing to the (a) restructuring, (b) expanding of physical set up, (c) enhancing functionality and (d) increasing complexity of power systems. In the control system design, it is well-known that time delays may degrade the system performance and, even, cause system instability [3]. In the overall analysis, the impacts of these three physical constraints, all-together, are the missing index in deregulated AGC study of power system. Considering all the dynamics, frequency control synthesis/analysis would be, really, a useful idea. However, to get an accurate perception of the AGC subject, it is necessary to (a) consider the important inherent requirements and the basic constraints imposed by the physical system dynamics and (b) model them for the sake of actual performance evaluation.

As concerned to the adopted optimization algorithms in the literature (like the BF [9], PSO [10], GA [11], FA [12], DE [13], TLBO [14] and BA [15]) are restricted to its utilization in the basic AGC models providing ideal environment with or without imposing physical constraints which, in turn, affects the AGC performances. Literature survey reveals that the earlier used optimization methods are not tested to a more realistic power system model considering time-delay, governor dead band and GRC, all-together, as imposed in real-time power system under deregulated regime.

In the field of optimization techniques, harmony search (HS) algorithm (HSA) is an emerging meta-heuristic optimization algorithm [18]. Along with HSA, a few modified variants of HSA have been also introduced in the literature for enhancing its optimization performance. Valian et al. [19] have presented an improved HSA by introducing an idea of swarm intelligence technique to solve continuous optimization problems. Pan et al. [20] have proposed HSA with dynamic sub-harmony memories to minimize the total weighted earliness and tardiness penalties. Chatterjee et al. [21] have proposed oppositional-based HSA for the solution of combined economic and emission dispatch problem of power system.

The reported work shows that evolutionary optimization techniques have played a significant role in the various faces of deregulated AGC power system. The present work utilizes a more complete AGC model and, then, the quasi-oppositional HS (QOHS) algorithm [22] is applied to optimize the controller gains of the studied power system model with an aim for its substantial improvement as far as AGC performance of the deregulated five-area power system model is considered by incorporating all possible physical constraints prevailing in real-time power system.