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Full Length Article

A novel quasi-oppositional harmony search algorithm for AGC optimization of three-area multi-unit power system after deregulation

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ABSTRACT

The present work addresses a decentralized, well tested three-area multi-unit power system for its automatic generation control (AGC) after deregulation which is characterized by price-based market operation. To match with the actual deregulated environment, as prevailing in the real one, the market structure is kept generic enough enabling to capture all possibilities occurring in real-time day-to-day power environment. In accordance to the modifications, as done in the investigated three-area power system model, the concerned objective is to intensify the deregulated AGC operation followed by load disturbances. At the present platform, three different classes of case study results are postulated for the studied test system. The first two illustrate the behavior of unilateral and bilateral based power contract transactions while the third one considers the contract violation case as it exists in present time. The contractual agreement, instituted by DISCO participation matrix, is initialized to address the power transaction contracts. In this work, a novel quasi-oppositional harmony search (QOHS) algorithm is explored and presented its significances in deregulated AGC operation. In the second phase of investigation, fast acting Sugeno fuzzy logic technique is explored for on-line, off-nominal operating conditions. For analysis purpose, both the qualitative and the quantitative aspects of the proposed QOHS are presented in reference to genetic algorithm (GA). Additionally, the sensitivity analysis is also performed to evaluate the performance of the proposed QOHS based controller. Simulation work reveals that the proposed QOHS may be, effectively, worked out to order to improve the deregulated AGC performance. It is also being observed that the proposed QOHS outperforms the GA in sense of deregulated AGC operation of power system.

1. Introduction

1.1. General

At present, the electric power industry is, largely, in the control of vertically integrated utilities (VIUs) which have their own generation–transmission–distribution systems. It supplies powers to the customers as per automatic generation control (AGC) criteria. One VIU is, usually, interconnected to other VIUs and this interconnection is always at the transmission voltage level [1]. When concerning AGC control strategy, the conventional *tie-line bias control* concept is adopted where a single utility company has its own one control area and, hence, may locate the control error according to its own desire [2]. After the huge success of AGC in VIUs, the concept of price-based market operation is the missing index that has changed the entire structure of the power industry. In view of this, a new deregulated power system has evolved, although keeping all essential ideas the same as per AGC. The purpose is to orient a price-based operation, supervised by AGC and classified by the new market structure.

In essence, deregulation is collective sums of market policies, economic benefits as well as good qualities of services that may be used for the optimum benefits of the customers. Functionally, the process of deregulation starts with the emergence of independent generation companies (GENCOs), distribution companies (DISCOs), transmission companies and independent service operator (ISO) [3]. These independent entities have to play distinct roles in AGC domain and, therefore, have to model differently.

In deregulated AGC system, load following may be the most important aspect of observation. Corresponding to this, the deviation in frequencies and the tie-line power flow profiles might be the mysterious questions of a priori importance. At the instant application of load demands, the most influenced state (affected part) is the actual generated powers of the GENCOs. The GENCOs generated

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profiles, at the steady state of each control area, must reach their desired values according to their participation factors as decided for the DISCOs load demands.

In this new challenging paradigm, AGC must have a deep sense of responsibly to overcome the contractual effects as made concerning quality services [4]. The root of success of deregulation lies in the fact that a DISCO has the complete freedom to contract, individually, with any GENCO in its own control area and/or to other areas for the transaction of powers which is supervised by the ISO. The path of these power transactions is followed by the DISCO participation matrix (DPM) [5].

1.2. Literature review

Interconnected power system modelling, its control strategies and operational behavior play important roles in deregulated power system operation and control. Over the last few decades, significant amounts of in depth discussions have been attributed in connection to interconnected power systems (viz. VIUs) regarding AGC performance study. A major portion/contribution of these research works are addressed in References 4 and 6.

The crucial role of AGC is continuing in the domain of deregulated power system oriented by price-based operation and accounting various bilateral policies. In view of this, the necessary modifications as required in the conventional AGC system to study the load following deregulated operation have been reported in References 4 and 7. In these two works, the difference between the AGC operation in VIUs (conventional paradigm) and the horizontally integrated industry (new paradigm) has been highlighted. Also, the deregulated AGC model, its control strategies and various deregulated cases have been unveiled.

The recently reported works on deregulated AGC domain reveal that significant numbers of optimization techniques have been used, classified by different theories (*i.e.* mathematical computational techniques, optimal control concepts, evolutionary optimization algorithms etc.) to enhance the AGC performance of deregulated power system. AGC optimization using mathematical computational techniques have been reported in References 8 and 9. In these two research works, an iterative procedure in view of finding the proportional-integral-derivative (PID) controller gains has been introduced. Also, the analytical expressions have been derived for finding the boundaries of equality constraints set on proportional-integral (PI) gains. The formulation and the solution of multi-objective AGC problem in deregulated environment using the mixed H_2/H_∞ control approach have been reported in Reference 10. A deregulated AGC model, oriented by multi-stage fuzzy-PID controller, has been suggested in Reference 11. The impacts of internal model control method in deregulated AGC domain have been studied by Tan et al. [12]. Likewise, the significance of linear active disturbance rejection control method has been investigated for load frequency control (LFC) issue after deregulation in Reference 13. The assessment of dynamic reliability for bilateral contract of electricity providers has been presented by Ding et al. [14]. AGC simulation of deregulated multi-area power system has been carried out by Bhatt et al. [15] using hybrid particle swarm optimization (PSO) algorithm. Likewise, the performance of a fractional-order PID controller in deregulated power market has been evaluated in Reference 16 by using the bacteria foraging optimization algorithm (BFOA).

1.3. Motivations behind the present work

Literature survey divulges that a number of AGC techniques have been proposed in deregulated power system. These techniques have, significantly, contributed in the initial development of deregulated AGC operation. But, at the same time, no sophisticated methods have been proposed in AGC formulation due to some inherent drawbacks as prevailing in the adopted techniques.

The good choices of initial condition and the selection of derivative gain play crucial roles in the iterative method that affect the AGC performance [9,17]. The fuzzy-PI controller does not produce satisfactory dynamic responses. However, the fuzzy-PID controller produces somewhat better AGC results but, at the same time, requires a three-dimensional rule base which is difficult to design [18]. All in one, the intelligence-based PID controller is a once-for-all method, which means that once the optimization is completed, the parameters are hard to re-tune. Control system based tuning methods need to use full states of a control area (as the feedback input signal) which is, in reality, a difficult task as some of them lead to high-order controllers while the others are too complex to be understood [13,19].

Reflecting to optimization techniques, both the binary coded genetic algorithm (GA) and the real coded GA has received considerable attention as optimization tool by the researchers' pool for several engineering applications. However, these two techniques are susceptible to the choice of mutation probability and crossover ratio. The generated solutions may stick to suboptimal solutions [15]. PSO is developed through the simulation of bird flocking in multi-dimensional search spaces. Empirical studies, performed on PSO, indicate that even when the maximum velocity and acceleration constants are correctly defined, the particles may still diverge *i.e.*, go to infinity (a phenomena known as "*explosion*" of the swarm). BFOA is based on chemotactic movement of virtual bacterium models *i.e.* instituted by trial solutions of the optimization problem. During the process of chemotaxis, the performance of BFOA depends on random search direction that may lead to delay in reaching the global solutions. Also, the number of parameters, as used in BFOA for searching the total solution space, is higher than GA and, hence, the possibility of trapping into local minima is higher than GA.

The problem of concern is that optimized controller gains as obtained so far by the application of various optimization techniques are not close to their global optimal solutions. These controller gains exhibit unsatisfactory dynamic responses and, directly, affect the AGC performance. It may also be inferred that the earlier adopted methods are not convenient in deregulated AGC system owing to their own problems and limitations. Moreover, recently developed optimization techniques have not been used in deregulated AGC domain that may satisfy the multi-objective AGC problems (such as stability, robustness, optimal performance etc.) up to a satisfactory level.

To overcome the above mentioned difficulties, a new evolutionary population based searching technique is proposed. In this paper, an approach (harmony search (HS) algorithm (HSA)) based on musical improvisation process is presented in order to solve AGC problem. HSA is a derivative-free real parameter optimization algorithm and may be used in various fields of engineering applications [20,21]. Along with HSA, a few modified variants of HSA have been also proposed for enhancing its solution accuracy and convergence profile speed. Mahdavi et al. [22] have presented an improved HSA by introducing an idea of constant parameters so as to, dynamically, tune its key parameters. Omran and Mahdavi [23] have proposed a global best HSA by utilizing the concept of swarm intelligence. Pan et al. [24] have proposed a self-adaptive global best HSA for solving continuous optimization problems. Banerjee et al. [25] have proposed oppositional-based HSA for reactive power compensation of an autonomous power system model.

The behavior of a synchronous generator in connection to AGC of power system depends on many factors. These are: (a) its position in the network, (b) the operating conditions, (c) the network topology and (d) the generation schedule. Usage of a desired optimization technique yields a distinct set of controller gains for different operating conditions. Under drastic change in operating