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Multi area AGC scheme using imperialist competition algorithm in restructured power system

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ABSTRACT

This paper is focused on optimization based design methodology and application of PID controller in restructured, competitive electricity market environment, for AGC problem. The paper compares two search algorithms for designing of PID controller used for AGC in multiarea power system. The optimal parameters of PID controller have been determined with the use of Imperialist Competitive Algorithm (ICA). A deregulated scenario has been considered to develop the model of the multiarea AGC scheme. This paper presents that the ICA tuned PID (ICA-PID) controller can optimally regulate the generators output and can provide the best dynamic response of frequency and tie-line power on a load perturbation. The performance of proposed controller has been checked on 2-area thermal power system and 3-area thermal-hydro power system with the consideration of generation rate constraint (GRC). The results obtained by ICA-PID controller and genetic algorithm tuned (GA-PID) controller have been compared on the basis of performance parameters (settling time and oscillations). It is seen that ICA-PID controller shows the better performance as compared to GA-PID controller.

1. Introduction

AGC is used to maintain zero steady state errors in deviation of system frequency and tie-line power exchange to other areas. The conventional AGC scheme for isolated and interconnected power system has been discussed in [1–3]. For the improvement in the efficiency of the operation of power system, it has been restructured according to open market system, which consists Gencos (generation companies), Transcos (transmission companies), Discos (distribution companies), and ISO (independent system operator). ISO is an independent agent which procures various ancillary services for stable and secure operation of a power system [4,5]. AGC is one of the most important ancillary services among all. The main goal of this ancillary service is to provide a balance between generation and load demand of each area and maintain the frequency and tie-line power flow within the specified limit. In deregulated power system, poolco-based transactions, bilateral transactions, and a combination of poolco and bilateral i.e. mixed transactions are used for various contracts between Discos and Gencos [6–8]. Various load frequency control issues related to deregulation is reported in [9].

The increasing complexities in power system encouraged researchers to explore appropriate control algorithms for AGC. Various control strategies, such as optimal control [10,11], variable structure control [12,13], adaptive and self-tuning control [14,15], robust control [16–18] etc. have been discussed in the literature for AGC scheme. PID controller has a simple structure and widely used in AGC scheme to control the frequency and the tie-line power. The literature reveals that the different methods have been proposed to determine the parameters of a PID controller. A variety of optimization algorithm have been reported to find the optimal parameters of PID controller such as Fuzzy logic (FL) [19–24], genetic algorithm (GA) [25,26], bacterial foraging [27,28], particle swarm optimization (PSO) [29,30] etc. In addition to these, ICA may be used as an alternate tuning method due to its global search and stable convergence characteristics. ICA is inspired by the socio political idea [31]. In recent years, ICA has been successfully applied to the different control processes or optimization problems, some of them are the economic dispatch problem [32], power system stabilizer [33], oil flow rate [34], reactive power dispatch [35] and tuning of PID controller [36–39].

According to the recent literature available, the controller designed using ICA has capability of handling parameter

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uncertainty, possess robustness and eliminate steady state errors efficiently. It also gives better stability [33–39]. The versatility and efficient performance of this technique in different areas motivated us to investigate its implementation to the problem of AGC under deregulated environment. It is seen that ICA-PID controller works well, provides stability and ensured good dynamic performance of AGC in restructured environment.

In present study, ICA algorithm is used to determine the optimal parameters of a PID controller for multiarea AGC scheme in deregulated environment. Poolco and bilateral transactions have been considered between the areas. Disco participation matrix (DPM) is used for implementation of various contracts. Mean square error (MSE) of area control error (ACE) is considered as a performance index (objective function) for this optimization problem. The proposed controller is tested on 2-area thermal power system [6], and 3-area thermal-hydro power system considering GRC [40]. The performance of ICA-PID controller has been compared with GA-PID controller. The convergence characteristic of ICA shows the higher convergence rate than GA. Results show that ICA-PID controllers have reduced settling time and oscillations in dynamic response of frequency, tie-line power and change in generation as compared to PID controllers optimized by GA.

2. System modeling

Any mismatch between real power generation and load demand, give rise to area control error (ACE) [7]. Coefficients that distribute ACE to several Gencos are known as ACE participation factors (αpf). Power system satisfactory operation requires the removal or minimization of ACE. In a deregulated electricity market different transactions can take place such as poolco based transaction, bilateral transaction and the combination of these two transactions [8]. Poolco based transaction does not change the scheduled tie-line exchange, but the bilateral transaction can change the tie-line exchange which can modify the ACE.

The net tie-line power flow from an area-i can be represented as given below,

$$\Delta Ptie_{i-schd} = \Delta Ptie_i + \sum_{\substack{j=1 \\ i \neq j}}^{n} D_{ij} - \sum_{\substack{j=1 \\ i \neq j}}^{n} D_{ji} \quad (1)$$

where, D_{ij} and D_{ji} represent the demand of the Disco of area-j and area-i from the Genco of area-i and area-j respectively, $\Delta Ptie_i$ shows the change in tie-line power when no bilateral transaction is considered. n represents the number of areas. The error in the tie-line power flow can be represented as,

$$\Delta Ptie_{i\_error} = \Delta Ptie_{i\_actual} - \Delta Ptie_{i\_schd} \quad (2)$$

Therefore, the modified ACE signal can be represented as,

$$ACE_i = B_i \Delta f_i + \Delta Ptie_{i\_error} \quad (3)$$

where, B_i is the frequency bias factor and Δf_i is the frequency deviation in area-i. Fig. 1 represents the block diagram of the k^{th} Genco in area-i. The pf is the Genco participation factor, R_i is the droop,

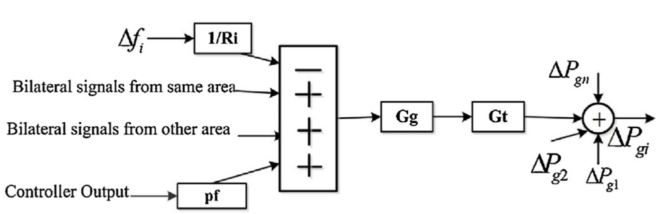

Fig. 1. Block diagram of Genco-k of area-i.

and G_g and G_t represents the transfer function model of governor and turbine respectively. $\Delta P_{g1}, \Delta P_{g2}, \ldots\ldots \Delta P_{gk}, \ldots\ldots \Delta P_{gn}$ represents the change in the output of Gencos in area-i. Fig. 2 shows the overall block diagram representation for the AGC scheme of area-i

3. PID controller design using ICA

3.1. PID controller

PID controllers are the most widely used industrial controllers because of simple and easy implementation. The structure of a PID controller can be expressed as the sum of three terms, proportional, integral, and derivative control. The transfer function of such a PID controller can be expressed as:

$$G_{PID}(s) = K_P + \frac{K_I}{s} + K_D s \quad (4)$$

where, K_P, K_I, K_D are the proportional, integral and derivative gains of the controller. For the good performance of the system, these gains should be determined optimally. In this study, ICA is utilized to determine the optimal parameters of PID controller for each area. It is necessary to use a proper objective function for optimal tuning of controller parameters using evolutionary algorithms. The optimal values of gains of controller are obtained by minimizing the considered objective function. In this paper mean square error of ACE is taken as the optimization function which can be formulated in the following manner,

Minimize mean square of area control error

$$f = \frac{1}{n}\sum_{i=1}^{n}\left[(\mathrm{ACE}_i)^2\right] = \frac{1}{n}\sum_{i=1}^{n}\left[(B_i \Delta F_i + \Delta \mathrm{Ptie}_{i\_error})^2\right] \quad (5)$$

Here, f is used to determine the optimum gains of the PID controller for step load disturbance in different areas with the consideration of the following constraints

$$\begin{aligned} &K_{P,i}{}^{\min} \le K_{P,i} \le K_{P,i}{}^{\max} \\ &K_{I,i}{}^{\min} \le K_{I,i} \le K_{I,i}{}^{\max} \\ &K_{D,i}{}^{\min} \le K_{D,i} \le K_{D,i}{}^{\max} \end{aligned} \quad (6)$$

where, $K_{P,i}{}^{\min}$, $K_{I,i}{}^{\min}$, $K_{D,i}{}^{\min}$ and $K_{P,i}{}^{\max}$, $K_{I,i}{}^{\max}$, $K_{D,i}{}^{\max}$ are the lower bounds and upper bounds of the PID controller for area-i. The ACE minimization problem has been solved using the ICA which is explained in the following section.

3.2. Imperialist competitive algorithm (ICA)

ICA was proposed by Esmail Atasphaz- Gargari for optimization [31]. It starts with an initial population known as country, which is further divided in colony and states to make empires. After forming empires, imperialistic competition takes place among all the empires. During this competition weak empires will lose their power and collapse and at the end of competition only one empire will exists. The details of ICA are well explained in the references [31–39].

The major steps involved to determine the optimal PID parameters using ICA are given below.

3.2.1. Initialize the empires

In this step, first an array of variables (country) which is to be optimized is determined as,

$$\mathrm{Country} = [p_1, p_2, p_3, \ldots.p_N] \quad (7)$$