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Comparative performance analysis of Artificial Bee Colony algorithm in automatic generation control for interconnected reheat thermal power system

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A B S T R A C T

This study extensively presents the Automatic Generation Control (AGC) application of Artificial Bee Colony (ABC) algorithm. This algorithm is one of the new population based optimization algorithms which have been developed since 2005. In this study, the algorithm is applied to the interconnected reheat thermal power system in order to tune the parameters of PI and PID controllers which are used for AGC. The tuning performance of the algorithm is compared with that of Particle Swarm Optimization (PSO) algorithm through transient response analysis method. In addition to these, the robustness analysis is applied to the power system which is optimized by ABC algorithm so as to determine its response towards changing in the load and the system parameters, varied in the range of ±50%. The behavior of the system is also investigated with this analysis towards the different cost functions such as integral of absolute error (IAE), integral of squared error (ISE), integral of time weighted squared error (ITSE) and integral of time multiplied absolute error (ITAE). At the end of the study, it is seen that the ABC algorithm is successfully applied to the AGC in the application of interconnected reheat thermal power system, and it shows better tuning capability than the other similar population based optimization algorithm. Furthermore, it is also seen that the proposed system is robust and is not affected by changing in the load, the power system parameters and the cost functions.

1. Introduction

The aim of an interconnected electric power system is to generate transport and distribute electric energy with nominal system frequency and terminal voltage, values and tolerances of those are defined by some power quality standards. According to power system control theory, a nominal system frequency depends on the balance between generated and consumed real powers [1]. The difference between generated power and instant load demand causes changing of nominal system frequency at the normal state. If the amount of generated power is less than the demanded amount, speed and frequency of the generator units begin to decrease, and vice versa. Hence, the amount of production of the synchronous generators is made sense for frequency deviations occurred in the power system in order to maintain that balance. For this purpose, an automatic generation control concept is used. The aim of automatic generation control is that the steady state error of the system frequency deviations following a step load demand is made zero error.

It can be seen from the literature that early works on AGC was initiated by Cohn [2]. However, a modern optimal control concept for AGC designs of interconnected systems is put forward by Elgerd and Fosha for the first time [3]. They suggested a proportional controller and different feedback form to develop optimal controller. Until the present day, lots of different control strategies such as conventional, adaptive, variable structure, robust and some based on artificial intelligence have been reported [4]. However, gain scheduling adaptive control can be distinguished from the other control techniques because it makes the process which is under control less sensitive to changes in process parameters and in particular, it is also simpler to implement than the other modern control techniques. For these reasons, it is carried out to AGC system, frequently. The first gain scheduling control method for AGC of interconnected power system was proposed by Lee et al. in 1991 [5]. Their controller provided better control performance for a wide range of operating conditions than the performances obtained so far. Later on, Rubaai and Udo presented a multi-variable gain scheduling controller by defining a cost function with a term representing the constraints on the control effort and then minimizing that with respect to the control vector [6]. Since the conventional gain scheduling methods may be unsuitable in some operating

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Nomenclature

K_p	proportional gain constant	K_r	reheat gain constant
T_i	integral time constant	T_{12}	synchronization coefficient
T_d	derivative time constant	T_P	control area time constant
R_i	regulation constant	K_P	control area gain constant
B	frequency bias constant	ΔP_{tie}	tie-line power change
T_h	hydraulic time constant	Δf	frequency deviation
T_t	turbine time constant	ΔP_L	incremental load demand
T_r	reheat time constant		

conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points, a usage of artificial intelligence based methods were preferred by researchers from the beginning of these dates. In 1997, Chang reported the usage of fuzzy logic based gain scheduling method for power system AGC [7]. As different from the usage of two fuzzy rules for integral and proportional gains in PI controller by Chang, Çam and Kocaarslan who improved the performance of this approach in 2005 by which the rules for the gains are chosen to be identical [8]. Talaq suggested an adaptive fuzzy gain scheduling method for conventional PI controller in 1999 [9]. Then, Pingkang optimized the gains of PI and PID controllers through real coded genetic algorithm in a two area power system in 2002 [10]. After 1 year from Pinkang's study, Abdel-Magid and Abido proposed a usage of PSO for the same purpose [11]. In 2004, Yeşil suggested the self tuning fuzzy PID type controller for AGC [12]. One year after, Juang put forward the genetic algorithm based fuzzy gain scheduling method for PI controller [13]. In this study, to reduce both the fuzzy system design effort and the number of fuzzy rules, the fuzzy system used for gain scheduling is automatically designed by genetic algorithms. In 2006, Massiala used two layered fuzzy gain scheduling controller in order to improve the dynamic performance of AGC in a two area reheat thermal power system with generation rate constraints [14]. Taher composed a hybrid PSO algorithm for the gain scheduling of PI controller in a two area thermal power system in 2008 [15]. The hybrid PSO algorithm contained evolutionary operators like selection, crossover and mutation as in genetic algorithms or DE algorithm. In the year 2009, Nanda suggested a maiden application of bacterial foraging optimization based gain scheduling PI controller in a multi area AGC [16]. Rao et al. studied an automatic generation control on TCPS based hydrothermal system [17]. In 2010, Gozde et al. designed the PSO based PI-controller with the new cost function and compared their results with the results of Abdel-Magid and Abido's study [18]. In 2011, Gozde and Taplamacioglu proposed the usage of craziness based PSO algorithm for AGC system for an interconnected thermal power plants [19]. Except for those studies, it can be evaluated that ABC algorithm may be used as an alternative tuning method due to its superior local and global search capability provided by separate artificial bee colonies like as employers, onlookers and scouts [20,21]. So far, this algorithm successfully applied to the different optimization or control processes. Some of them are the neural networks training [22], the quadratic knapsack problem [23], and the parameter extraction of MESFETs [24], the economic dispatch problem [25], the clustering [26], the prediction of protein tertiary structure [27], the power system stabilizer [28], the load–frequency control for interconnected power system [29,30] and the PID controller tuning [31,32].

The aim of this study which is different from the above literature is that the ABC algorithm is applied to the AGC system for tuning the PI and PID controller parameters and its tuning performance and robustness are investigated comparatively by using PSO algorithm. For this purpose, a self-tuning PI and PID controllers are designed and their control parameters are tuned by the mentioned optimization algorithms separately and then the transient response analysis method is extensively used to determine the superiority of these algorithms according to each other.

2. Materials and methods

2.1. Power system model

Two area interconnected reheat thermal power system is deal with for the application of optimal AGC, because it is one of the simplest model of an interconnected electric power system. The linear model of such a system and the model parameters are given in Fig. 1 and Table 1 respectively. It is assumed that there is a step load change in the control area-1. The state space model of this power system is considered at the simulation study. For this purpose, the state equations are given in Appendix. In Fig. 1, u_1 and u_2 are the control inputs obtained from the outputs of the controllers. If it is thought that a PID controller is taken up as a control element in this study, these control inputs may be written as below. The parameters K_p, T_i and T_d are named the proportion gain, the integral time constant and the derivative time constant respectively.

$$u_1 = K_{p1}\left(ACE_1 + \frac{1}{sT_{i1}}ACE_1 + sT_{d1}ACE_1\right) \tag{1}$$

$$u_2 = K_{p2}\left(ACE_2 + \frac{1}{sT_{i2}}ACE_2 + sT_{d2}ACE_2\right) \tag{2}$$

The ACE signal is the area control error which includes the data about the frequency error and the tie-line power error of the related control area. They are depicted in (3) and (4) for area-1 and area-2 respectively.

$$ACE_1 = B_1\Delta f_1 + \Delta P_{tie1} \tag{3}$$

$$ACE_2 = B_2\Delta f_2 - \Delta P_{tie2} \tag{4}$$

The controllers' gains are tuned by the self-tuning algorithm according to sum of the ACE signals reached to the control center through SCADA system. ΔP_{L1} is 1% of step load perturbations of the nominal loading in the control area-1. Δf_1 and Δf_2 are frequency deviations of the control areas, and ΔP_{tie} is the change of tie-line power between them.

2.2. Gain scheduling control

A gain scheduling control is an adaptive control technique that changes some controller parameters according to tuning variables related to different operating regions which the plant works. This control technique deals with particularly nonlinear processes, processes with time variations or situations where the requirements on the control that change with the operating conditions [33].