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APPLICATION OF ARTIFICIAL BEES COLONY ALGORITHM IN AN AUTOMATIC VOLTAGE REGULATOR (AVR) SYSTEM

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Abstract- In this study, a new artificial intelligence based optimization method is applied to optimize the gains of PID controller for Automatic Voltage Regulator (AVR) system. A dynamic performance of the controller which is optimized with ABC algorithm is compared with the results which are obtained with Particle Swarm Optimization (PSO). The transient response analysis is used in order to determine the performances of the methods. At the end of the study, ABC algorithm showed better performance than the other population based optimization algorithm.

Keywords: Automatic Voltage Regulator, Artificial Bee Colony, Particle Swarm Optimization.

I. INTRODUCTION

Stability and constancy of nominal voltage level in an electric power grid is one of the main problems for an electric power system control since all equipments which are connected with this power grid has been designed for a certain voltage level called rated or nameplate voltage. If the nominal voltage level should be deviate from that value, the performance of these equipments will be effected and their life expectancy drop. In addition to this, the other important reason in order to control the nominal voltage level is the real line losses. These losses depend on real and reactive power flow, and reactive power flow depends greatly on terminal voltages of the power system. It is possible to minimize the real line losses by controlling the nominal voltage level. Nowadays, an Automatic Voltage Regulator (AVR) system is generally applied to the power generation units in order to solve this control problem [1].

When it is investigated the relevant literature, it can be seen that the lots of different control strategies such as optimal, adaptive and robust control etc. have been reported by researchers until the present day, in order to realize the AVR system which has the best dynamic response. However, a self-tuning adaptive control strategy may be distinguished from those control techniques, because it provides effective control almost independent to the changes in process parameters and in addition, its implementation is also simpler than the other modern control techniques.

Previous works on AVR system with self tuning control was initiated in the years of 1990s. Swidenbank and coworkers carried out the classical self-tuning control techniques to the AVR system in 1999 [2]. After this study, Finch used a generalized predictive control technique as a self-tuning control algorithm in the same year [3]. Since the conventional self-tuning control methods contains more mathematical calculation and may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. The usage of artificial intelligence based self-tuning controllers was preferred by researchers from the beginning of 2000. In particular, self-tuning PID type controllers which were tuned with the optimization methods based on artificial intelligence have been initiated to carry out to the AVR system since then. Gaing suggested a PSO based self-tuning PID controller for AVR system, and compared the results with that of genetic algorithm based methods in 2004 [4]. In 2006, Kim and colleagues developed the hybrid method which contains genetic algorithm and bacterial foraging optimization technique in order to improve the performance of self-tuning PID controller in AVR system [5]. In 2007, Mukherjee and Ghoshall reported the Sugeno fuzzy logic self-tuning algorithm based on crazy-PSO for PID controller and also proposed a novel cost function in this optimization method. They also compared their results with genetic algorithm based controller solutions [6]. Zhu suggested a chaotic ant swarm algorithm in order to optimize the gains of PID controller in AVR system in 2009 [7].

The aim of this study which is different from the above literature is that a usage of more recent artificial intelligence based optimization method called Artificial Bee Colony algorithm is exposed in order to tune the gains of PID controller. This algorithm is applied to the AVR system and is computed its dynamic performance with transient response analysis in accordance with the results which are obtained through the PSO algorithm.

II. MATERIALS AND METHODS

A. A Model of AVR System

The AVR loop provides the constancy and stability of the terminal voltage in the power system. A terminal voltage is continuously sensed by a voltage level sensor. It is rectified and smoothed in order to compare with a DC reference signal in the comparator. Following, the error voltage obtained from the output of the comparator is amplified in an amplifier. Finally, this signal is used in order to control the generator field winding by exciter. The real model of such a system is depicted in Figure 1 [1].

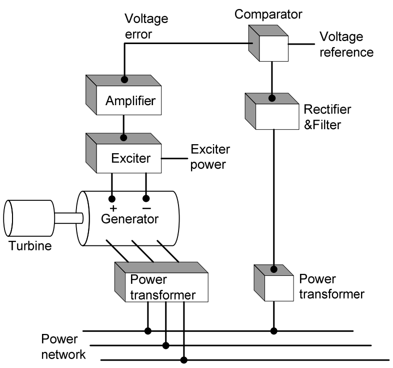

Figure 1. A real model of AVR system

It can be seen from the figure that a simpler AVR system contains five basic components such as amplifier, exciter, generator, sensor and comparator. A unit step response of this system without control has some oscillations which reduce the performance of the regulation. Hence, a control technique must be applied to the AVR system. A small signal model of this system which is constituted through the transfer functions of these components is presented in Figure 2, and the limits of the parameters used in these transfer functions are depicted in Table 1 [4].

In this system, PID controller has been used in order to achieve the control signal $u(s)$ which is given by Equation (1). The PID control is still a simpler control method used by industries owing to their easy implementation of hardware and software. In particular, when PID control is applied with self-tuning methods, it gains robustness to changing of the operating conditions. For that reason, a self-tuning PID controller is also preferred in this study.

$$u(s) = \Delta V_e(s).\left(K_p + \frac{K_i}{s} + K_d s \right) \quad (1)$$

In addition to these advantages of PID controller, a reduction of steady state error as well as an improvement of the dynamic response is also provided by applying this control technique.

Table 1. Transfer function and parameter limits of AVR system

	Transfer function	Parameter limits	Used parameter values
PID controller	$K_p + \frac{K_i}{s} + K_d s$	$0.2 \le K_p, K_i, K_d \le 2.0$	$K_p, K_i, K_d = optimum\_values$
Amplifier	$\frac{K_a}{1+sT_a}$	$10 \le K_a \le 40$ $0.02 \le T_a \le 0.1$	$K_a = 10$ $T_a = 0.1$
Exciter	$\frac{K_e}{1+sT_e}$	$1 \le K_e \le 10$ $0.4 \le T_e \le 1.0$	$K_e = 1$ $T_e = 0.4$
Generator	$\frac{K_g}{1+sT_g}$	K_g depends on load (0.7-1.0) $1.0 \le T_g \le 2.0$	$K_g = 1$ $T_g = 1$
Sensor	$\frac{K_s}{1+sT_s}$	$0.001 \le T_s \le 0.06$	$K_s = 1$ $T_s = 0.01$

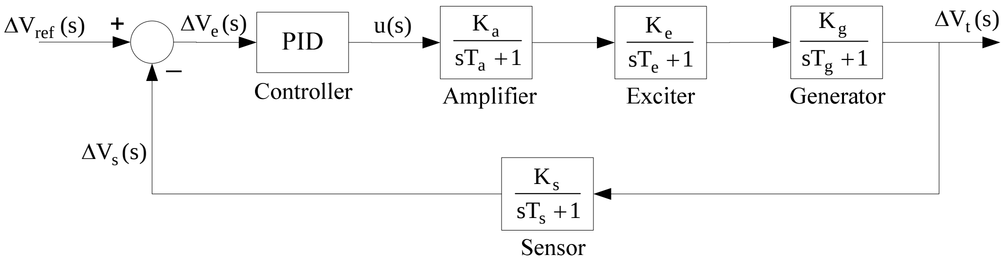

Figure 2. A transfer function model of AVR system

While a reduction of steady state error is achieved by adding a pole at the origin with the help of integral controller, thereby increasing the system type by one; transient response improvement may be achieved from the action of derivative controller which adds a finite zero to the open loop transfer function [6].

B. Particle Swarm Optimization (PSO)

Particle Swarm Optimization is swarm intelligence based optimization method which was first introduced by Kennedy and Eberhart in 1995.

High quality solutions within shorter calculation time and stable convergence characteristics can be obtained by the algorithm. It uses particles which represent potential solutions of the problem. Each particles fly in search space at a certain velocity which can be adjusted in light of proceeding flight experiences. The projected position of i^{th} particle of the swarm x_i, and the velocity of this particle v_i at $(t+1)^{th}$ iteration are defined from the following two equations:

$$v_i^{t+1} = w.v_i^t + c_1 r_1 \left(p_i^t - x_i^t \right) + c_2 r_2 \left(g_i^t - x_i^t \right) \quad (2)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (3)$$

where, i = 1, ..., n and n is the size of the swarm, w is inertia weight decreased linearly, c_1 and c_2 are positive constants, r_1 and r_2 are random numbers which are uniformly distributed in [0, 1], t determines the iteration number, p_i represents the best previous position of the ith particle and g represents the best particle among all the particles in the swarm. At the end of the iterations, the best position, "g", of the swarm will be the solution of the problem [9]. Basic algorithm of PSO can be summarized as follows:

Initialization
Repeat
Evaluate the fitness values of particles
Compare the fitness values to determine the p_i and g
Change velocity and position of the particles as to (3) and (4)
Until (requirements are met)

C. Artificial Bee Colony Algorithm (ABC)

Artificial Bee Colony Algorithm is one of the more recent swarm intelligence based optimization algorithms for solving multidimensional optimization problems. It has been reported by Karaboga in 2005 [12].

An intelligent behavior of honey bee colony which search new food sources around their hive was considered to compose the algorithm. In the algorithm, the colony of artificial bees consists of three groups of bees called employed bees, onlookers and scouts. While a half of the colony consists of the employed artificial bees, the other half includes the onlookers. There is only one employed bee for every food source. That is, the number of employed bees is equal to the number of food sources around the hive. The main steps of the algorithm are given below;

Send the scouts onto the initial food sources
Repeat
Send the employed bees onto the food sources and determine their nectar amounts
Calculate the probability value of the sources with which they are preferred by the onlooker bees
Stop the exploitation process of the sources abandoned by the bees
Send the scouts into the search area for discovering new food sources, randomly
Memorize the best food source found so far
Until (requirements are met)

Each cycle of the search consists of three steps: i) moving the employed and onlooker bees onto the food sources, ii) calculating their nectar amounts and iii) determining the scout bees and directing them onto possible food sources. A food source position represents a possible solution of the problem to be optimized. The amount of nectar of a food source corresponds to the quality of the solution represented by that food source. Onlookers are placed on the food sources by using a probability based selection process. As the nectar amount of a food source increases, the probability value with which the food source is preferred by onlookers increases, too. Every bee colony has scouts that are the colony's explorers. The explorers do not have any guidance while looking for food. They are primarily concerned with finding any kind of food source [12].

In this study, one of the employed bee is selected and classified as the scout bee. The selection is controlled by a control parameter called "limit". If a solution represents a food source is not improved by a predetermined number of trials, then that food source is abandoned by its employed bee and the employed bee is converted to a scout. The number of trials for releasing a food source is equal to the value of "limit" which is an important control parameter of ABC. In a robust search process exploration and exploitation processes must be carried out together. In the ABC algorithm, while onlookers and employed bees carry out the exploitation process in the search space, the scouts control the exploration process. In the case of real honey bees, the recruitment rate represents a "measure" of how quickly the bee swarm locates and exploits the newly discovered food source. Artificial recruiting process could similarly represent the "measurement" of the speed with the feasible solutions or the optimal solutions of the difficult optimization problems can be discovered [12].

III. SIMULATION RESULTS

In this study, three parameters of the PID controller are optimized. Their upper and lower limits are chosen as [0.2, 2]. In the PSO algorithm, the parameters are settled as which the population size is 30 and number of iterations are 50. In the ABC algorithm, the colony size is 20, control parameter in order to abandon the food source is 100 and number of runs is 3. The results are obtained by MATLAB software environment run on Core2 of 2

GHz, and RAM of 1 GB. The tuned parameters of the self-tuning PID controller through each algorithm are represented in Table 2 and the voltage variation curves which are obtained from the output of these controllers are shown in Figure 2.

Table 2. Optimum parameters of the PID controller

	ABC	PSO
K_p	1.6524	1.7774
K_i	0.4083	0.3827
K_d	0.3654	0.3184

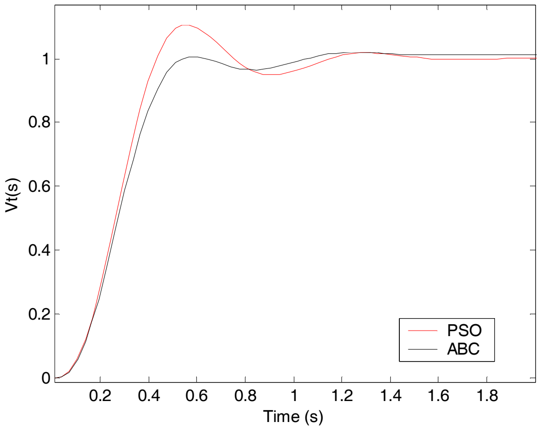

Figure 2. Voltage changing curves of the AVR system

The settling times and the maximum overshoots of the voltage variation curves are measured with transient response analysis as represented as Figure 3, in order to determine the performances of the proposed AVR system. 5% band of unit step change is for determining the settling times. The results of the transient response analysis are represented in Table 3.

Table 3. Result of the transient response analysis of AVR system

	Maximum overshoot of voltage changing (V)	Percent ratio (other/ABC) *100	Settling times (s) (5% band of step voltage change)	Percent ratio (other/ABC) *100
PSO	1.105	108.3	0.98	208.5
ABC	1.020	100	0.47	100

It is seen that the maximum overshoot obtained through the ABC algorithm is smaller than the results obtained through PSO algorithm. In addition to this, the settling time obtained through the ABC algorithm is approximately half of the times obtained through PSO algorithm. It is seen that, ABC algorithm gets better performance than the other optimization method according to the transient response analysis.

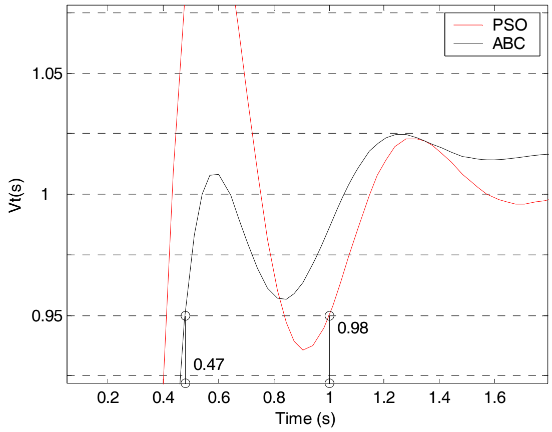

Figure 3. Zoom of voltage changing curves of the AVR system

VI. CONCLUSIONS

The usage of ABC algorithm in order to optimize the gains of PID controller which is used for AVR system is presented in this article as a maiden/first application of this algorithm. The optimizing performance of the ABC algorithm in this application is compared with those of the PSO algorithm. The transient response analysis is used for these comparisons. At the end of the analysis, the maximum overshoots and the settling times of the control system which is optimized with ABC algorithm are as small as about 50% of PSO algorithm. Finally, it may be said that the ABC algorithm gets better performance than the other population based optimization algorithms.

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BIOGRAPHIES

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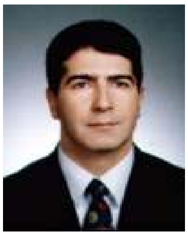

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