CONTINUOUS FIREFLY ALGORITHM FOR OPTIMAL TUNING OF PID CONTROLLER IN AVR SYSTEM

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This paper presents a tuning approach based on Continuous firefly algorithm (CFA) to obtain the proportional-integral-derivative (PID) controller parameters in Automatic Voltage Regulator system (AVR). In the tuning processes the CFA is iterated to reach the optimal or the near optimal of PID controller parameters when the main goal is to improve the AVR step response characteristics. Conducted simulations show the effectiveness and the efficiency of the proposed approach. Furthermore the proposed approach can improve the dynamic of the AVR system. Compared with particle swarm optimization (PSO), the new CFA tuning method has better control system performance in terms of time domain specifications and set-point tracking.

Key words: automatic voltage regulator (AVR), continuous firefly algorithm (CFA), PID controller, power system security

1 INTRODUCTION

In modern secure power system, damping of generator terminal voltage oscillation following disturbances is of great concern because it can seriously affect the security of the entire power system. In practice, this role is devoted to the generator excitation system in order to maintain generator voltage and to control the reactive power flow using an automatic voltage regulator (AVR) [1]. Hence, with the advancement in the design of fast acting AVRs as well as the increasing complexity of large interconnected power systems, oscillations may continue for an extended period and even instability may occur following some system disturbances.

Despite the potential of the modern control techniques with different structure, Proportional Integral Derivative (PID) type controller is still widely used for AVR system [2]. Industrial implementations of PID controllers in AVR systems show that the appropriate selection of PID controller parameters results in satisfactory performance during system upsets. Thus, the optimal tuning of a PID gains is required to get the desired level of robust performance. Since optimal setting of PID controller gains is a multimodal optimization problem and more complex due to nonlinearity and time-variability of real world power system operation. Therefore, the traditional techniques are not completely systemic and most of them occasionally yield poor performance in practice, so they are not suitable for such a problem.

Recently, metaheuristic approaches, have received increased attention from researchers dealing with AVR’s control problems. In 2004, a PSO based PID type controller for AVR system was presented By Giang [3] to find the optimal parameters of the PID controller so that the desired system specifications are satisfied. Kim and Cho developed an optimal tuning method using hybrid Genetic Algorithm (GA) and Bacterial Foraging (BF) technique to improve the performance of PID control of AVR system [4]. In order to obtain an optimal PID controller for an AVR, Mukherjee and Ghoshal presented a craziness based particle swarm optimization (CRPSO) and binary coded genetic algorithm (GA) [5]. Ching-Chang suggested a real-valued genetic algorithm (RGA) and a particle swarm optimization (PSO) to design PID controller for AVR system [6].

More recently, Shayeghi and Dadashpour presented an anarchic society optimization based PID control of an Automatic voltage regulator system [7]. In this paper, an efficient tuning approach is proposed to find the optimal PID parameters, and a practical high order AVR system with a PID controller is adopted to investigate the performance of the proposed CFA-PID controller.

The approach is based on one of the recent metaheuristic optimization methods inspired by the real fireflies’ behaviour, namely the firefly algorithm. The idea of employing the cooperating fireflies agents to solve optimization problems was introduced by Xin-She Yang at Cambridge University and presented in [8] then extended in his further work [9]. It has been, recently, adapted for solving various design problems [10–12]. The FA has been successfully applied to the Permutation Flow Shop Scheduling Problems in [10], to the Clustering problem in [11], and to Mixed variable structural optimization in [12]. Firefly algorithm achieves very good results in many applied areas. The FA has also been adapted with success to other combinatorial optimization problems [13, 14].

2 LINEARIZED MODEL OF AN AVR SYSTEM WITH PID CONTROLLER

2.1 Pid controller

The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-
The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at the origin and increases the system order by one and reduces the steady-state error due to a step function to zero. The PID controller transfer function is done by

\[ G_{PID}(s) = k_P + \frac{k_I}{s} + K_D s. \]  

### 2.2 Linearized model of an AVR

The AVR system contains four main components which are: amplifier, exciter, generator, sensor. Thus, the real model of such system is depicted in Fig. 1 [1].

In order to model the four aforementioned components and determine their transfer functions. Each component must be linearized taking into account the major time constant and ignores the saturation or other nonlinearities. The approximate transfer functions of these components may be represented, respectively, as follows [3].

- **Amplifier model**

  The amplifier is represented by a gain \( K_a \) and a time constant \( \tau_a \), and the transfer function is

  \[ \frac{V_F(s)}{V_e(s)} = \frac{K_a}{1 + \tau_a s}. \]  

- **Exciter model**

  In the simplest form, the transfer function of a modern exciter may be represented by a single time constant \( \tau_e \) and a gain \( K_e \):

  \[ \frac{V_F(s)}{V_R(s)} = \frac{K_e}{1 + \tau_e s}. \]  

  The time constant of modern exciters are very small.

- **Generator model**

  In the linearized model, the transfer function relating the generator terminal voltage to its field voltage can be represented by a gain \( K_g \) and a time constant \( \tau_g \) and the transfer function is

  \[ \frac{V_t(s)}{V_F(s)} = \frac{K_g}{1 + \tau_g s}. \]  

- **Sensor model**

  The sensor is modeled by a simple first order transfer function, given by

  \[ \frac{V_s(s)}{V_t(s)} = \frac{K_s}{1 + \tau_s s}. \]  

Utilizing the above models, the AVR block diagram compensated with PID is shown in Fig 2.

### 3 BASICS OF FIREFLY ALGORITHM

Continuous Firefly Algorithm (CFA) is a nature inspired algorithm, which is based on the flashing light of fireflies. In fact, the algorithm has three particular idealized rules which are based in real on some major flashing characteristics of real fireflies [8]. These are the following:

1. all fireflies are unisex, and they will move towards more attractive and brighter ones regardless their sex.
2. the degree of attractiveness of a firefly is proportional to its brightness which decreases as the distances from the other fireflies increases.
3. If there is no brighter or more attractive firefly then a particular one, then it will move randomly. For an optimization problem, the flashing light is associated with the fitness function in order to obtain efficient optimal solutions. The main steps of standard
The form of the attractiveness function of a firefly is the following monotonically decreasing function

$$\beta(r) = \beta_0 \exp(-\gamma r^m) \quad \text{with} \quad m \geq 1 \quad (6)$$

where $r$ is the distance between any two fireflies, $\beta_0$ is the initial attractiveness at $r = 0$, and $\gamma$ is the absorption parameter which controls the decrease of the light intensity.

The distance $r$ between any two fireflies $i$ and $j$ at position $x_i$ and $x_j$, respectively, can be defined as a Cartesian or Euclidean as follows

$$r_{ij} = \sqrt{\sum_{k=1}^{d} (x_{i,k} - x_{j,k})^2} \quad (7)$$

where $x_{i,k}$ is the $k^{th}$ component of the spatial coordinate $x_i$ of the $i^{th}$ firefly and $d$ is the dimensions number.

**Movement**

The movement of a firefly $i$ which is attracted by a brighter firefly $j$ is given by

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2} (x_j - x_i) + \alpha (\text{rand} - \frac{1}{2}) \quad (8)$$

where the first term is the current position of a firefly, the second term is used for considering a firefly’s attractiveness to light intensity seen by adjacent fireflies, and the third term is used for the random movement of a firefly in case there are not any brighter ones. The coefficient $\alpha$ is a randomization parameter determined by the problem of interest, while $\text{rand}$ is a random number generator uniformly distributed in the space $[0,1]$.

### 4 IMPLEMENTATION OF CFA–PID CONTROLLER

In this paper, a PID controller using CFA was proposed to improve the dynamic of an AVR system. The block diagram of a practical AVR system using CFA-PID is shown in Fig. 3.
4.2 CFA-PID mechanism in AVR system

Similarly to other metaheuristics optimization methods, firefly algorithm generates initial random population of feasible candidate solutions. All fireflies of the population are handled in the solution search space with the aim to guide the search to the best location in the search space using their flashing light (Fitness) and randomness. Each firefly in the population moves in the three-dimensional (PID parameters) search space with an attractiveness which is dynamically updated based on the knowledge of the firefly and its neighbours. In this paper, conversely to the standard CFA, we note that the randomness factor is iteratively reduced in order to accelerate the algorithm convergence according to this equation

\[ \alpha_{t+1} = \alpha_t \delta e^{-\beta_t^t} \]  

(10)

where \( t \) is the iteration counter, \( \delta \) is a positive weighting factor.

Applying this search mechanism over the iterations, the CFA finds looks for the optimal set of PID parameters, while minimizing the fitness function. The flow chart of the proposed CFA for PID tuning is shown in Fig. 4.

5 SIMULATION RESULTS

The proposed approach is implemented in MATLAB language on the Pentium-4 dual core 1.66 GHz PC. The determination of the approach control parameters is a significant problem for the CFA implementation. However, there is no formal methodology to solve the problem because different value-combinations of the parameters result in different performance of the approach. Regarding this, we have performed our parameters in such a way that we have not to update their values whenever we change the test system. In fact, preliminary numerical tests were used to set the values of the parameters and the best obtained ones are presented in Tab. 2.

To investigate the efficiency and the performance of the proposed approach, a practical high-order AVR system, as shown in Fig. 4, was tested. The parameters of the block diagram are chosen as \( K_a = 10, K_e = K_g = K_s = 1.0, \tau_a = 0.1 \text{s}, \tau_e = 0.4 \text{s}, \tau_s = 0.01 \text{s}, \tau_g = 1.0 \text{s}. \) Only \( K_a \) is load dependent, where the lower and upper bounds of the PID controller parameters are: \( 0 \leq K_P \leq 1.5, 0 \leq K_I, K_D \leq 1.0 \).

In this section, we represent the terminal voltage of the AVR system with and without CFA-PID controller at first. In second, to emphasize the advantage of the proposed CFA-PID method in terms of performance, we have compared the results with the PSO-PID and the RGA-PID literature existing approach’s [6] for two different values of the fitness weighting factor.

5.1 AVR terminal voltage step response

The terminal voltage step response of the AVR system without CFA-PID is shown in Fig. 5. In this case the system presents an undesirable oscillatory behavior. For two fitness weighting factor, the best solutions of the AVR system with CFA-PID are summarized in Tab. 3, and the corresponding step responses are shown in Fig. 6. The curves indicate clearly that the system response is greatly improved by introducing the CFA-PID.

For the considered weighting factors, the CFA-PID parameters searching process and the convergence characteristics graphs are given in Figs. 7 and 8, respectively. As we can see from these characteristics, the approach reaches a satisfactory value without much fluctuation after 50 iterations.

5.2 Comparison with PSO-PID controller

For the purpose of comparison, the PSO-PID controller parameters are the same as in [6]. The terminal voltage step responses of the AVR system controlled by
Fig. 5. Terminal Voltage step response of AVR system without PID controller

Fig. 6. Terminal Voltage step response of AVR system with CFA-PID controller

Fig. 7. CFA-PID parameters searching process over iterations: (a) — $\rho = 1$, (b) — $\rho = 1.5$

Fig. 8. Convergence characteristics of CFA-PID controller

Fig. 9. Terminal Voltage step response of AVR system with CFA-PID and PSO-PID controllers

PSO-PID controller and CFA-PID controller are shown in Fig. 9. The controller parameters and performance indices in the time domain are listed in Tab. 4.

It is observed in Fig. 9 that the CFA-PID controller has better setpoint tracking compared to PSO-PID controller. From Tab. 4, it can be stated, that the terminal voltage step response of the AVR system controlled by CFA-PID controller has smaller rising time and settling time for both weighting factor.

6 CONCLUSION

This paper introduced a novel approach based on continuous firefly algorithm (CFA) for tuning the PID controller parameter in an AVR system. The obtained results through simulation experiments on a practical high order AVR system shows that the proposed method can perform an efficient search for the optimal PID controller parameters. Furthermore, the simulation results demon-
straté that the new tuning method using continuous firefly algorithm can improve the control system performance in terms of time domain specifications and setpoint tracking when compared with particle swarm optimization.

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