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Optimal Tuning of PID Controller by Firefly Algorithm in AVR System

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Abstract: In this Paper, a novel meta-heuristics algorithm, namely the Firefly Algorithm (FA) is applied to the Proportional Integral Derivative (PID) Controller parameter tuning for Automatic Voltage Regulator System (AVR). The main goal is to increase the time domain characteristics and reduce the transient response of AVR systems. This paper described in details how to employ Firefly Algorithm to determine the optimal PID controller parameters of an AVR system. The proposed algorithm can improve the dynamic performance of AVR system. Compared with Ziegler Nichols (Z-N), Particle Swarm Optimization (PSO) methods, it has better control system performance in terms of time domain specification.
Key words: Proportional Integral Controller (PID), Firefly Algorithm (FA), Particle Swarm Optimization (PSO) Automatic Voltage Regulator (AVR), Ziegler-Nichols (Z-N).

I. INTRODUCTION

Most commonly electric utilities operate their power systems at full power and very nearer to stability limits. The drawback of such operation is that it can render the entire power system into damage very easily. They will be easily subjected to overvoltage or under voltage conditions. In order to avoid such disgusting phenomenon AVR is used. The function of automatic voltage regulator is it allows the alternator to make enough power to maintain proper voltage level, but not allow the system voltage to rise to a harmful level and to control the reactive power flow. Although the possible of modern control techniques, the Proportional Integral Derivative (PID) type controller is still commonly used for AVR system. PID controllers are used to improve the dynamic response as well as eliminates the steady state error.

In this paper an efficient meta-heuristics algorithm is proposed for the practical higher order AVR system with PID controller to investigate the performance of the proposed method. Firefly Algorithm (FA) is one of the nature inspired computing algorithm. It has been found to robust in solving continuous non-linear optimization problems. In the PID controller design, the FFA algorithm is applied to search an optimal PID control parameters.

II. MODEL OF AVR SYSTEM

The role of Automatic voltage regulator (AVR) of the synchronous generator is to provide stable electrical power service with high efficiency and good dynamic response. A simple AVR consist of amplifier, exciter, generator and sensor [5]. The block diagram of AVR with PID controller is shown in Figure 1. Previously, the analog PID controller is generally used for the AVR, because, of its simplicity and economic. However, the tuning of PID parameter is not easy. This paper proposed a method to search these parameter by using a Firefly algorithm. The AVR system model is controlled by PID controller can be expressed in Fig.1. Where V_t is the output voltage of the system, V_e is the error voltage between the V_s and reference input voltage $V_{ref(s)}$, V_r is an amplify voltage by amplifier model, V_F is the output voltage by exciter model, and Vt is the output voltage of synchronous generator. The block diagram of AVR system with PID controller is shown in Fig.1.

The range of parameters limit and used parameter in this paper is shown in Table I.

TABLE I: RANGE OF AVR PARAMETERS

Block	Parameters Range	Used Parameter
Amplifier	$10 \le K_a \le 40$	$K_a = 10$
Exciter	$1 \le K_e \le 10$ $0.4 \le \tau_e \le 1$	$K_e = 1, \tau_e = 0.4$
Generator	K_g depend on load,(0.7-1), $1 \le \tau_g \le 2$	$K_g = 1, \tau_g = 1$
Sensor	$0.001 \le \tau_s \le 0.01$	$K_s = 1, \tau_s = 0.05$

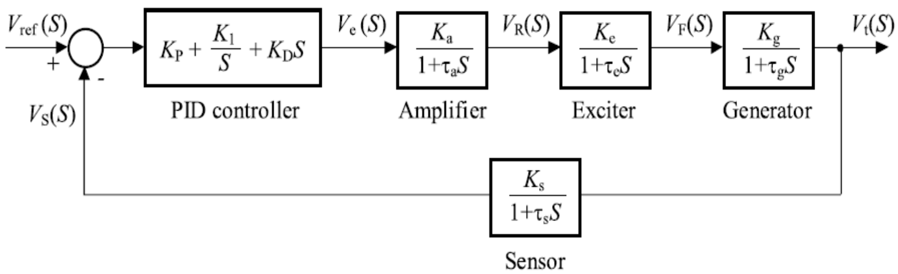

Fig.1: Block Diagram of AVR System with PID Controller.

In this paper, FA is applied to search a optimal PID parameters so that the controlled system has good dynamic control performance. Fig.2 Shows the FA based PID controller with AVR system.

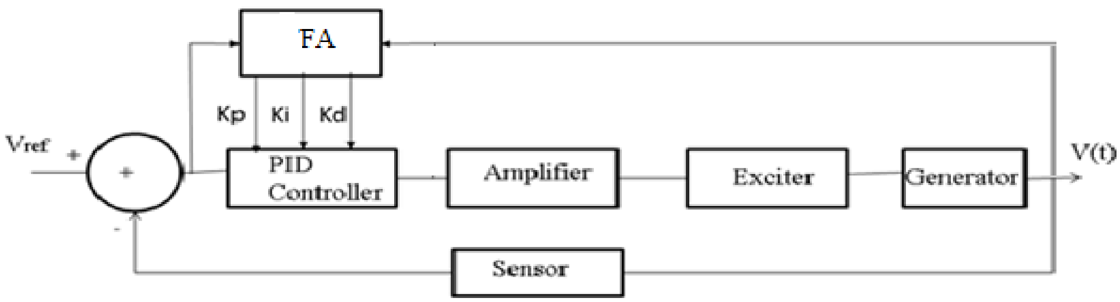

Fig.2: The Block Diagram of Firefly algorithm based PID controller.

III. BASICS OF FIREFLY ALGORITHM

Firefly algorithm (FA) is population –based algorithm to find the global optima of objective inspired by the flashing behaviour of fireflies. It has three idealized rules which are based in real on some major flashing characteristics of real fireflies. 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. When searching for solutions the fireflies use two main procedures: attractiveness and movement.

A. Attractiveness

The form of the attractiveness function of a firefly is the following monotonically decreasing function

$$\beta(r) = \beta_0 \exp(-\gamma r^m) \, with \, m \geq 1 \quad (1)$$

where r is the distance between any two fireflies, β_0 is the initial attractiveness at r = 0, and γ 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 as follows

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

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.

B. Movement

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

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2} (x_j - x_i) + \alpha(rand - 0.5) \quad (3)$$

where the first term is the current position of a firefly, the second term is used for considering a firefly's attractiveness to light

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

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 α is a randomization parameter determined by the problem of interest, while rand is a random number generator uniformly distributed in the space [0, 1].

C. Pseudo Code for FA

Initialize algorithm parameters;
Define the objective function of f(x), where $x = (x_1, \ldots\ldots\ldots, x_d)^T$
Generate the initial population of fireflies
Formulate the light intensity
Define the absorption coefficient γ
While (t< Max Generation)
For i = 1 to n (all n fireflies)
For j =1 to n (all n fireflies)
If (I_j>I_i), move firefly i towards j;
End if
Evaluate the new solutions and update light intensity
End for j;
End for I;
Rank the fireflies and find the current best:
End while;
Post process results and visualisation;
End procedure;

IV. FIREFLY ALGORITHM BASED TUNING OF THE CONTROLLER

To improve the step transient response of an AVR system, the main aim of the proposed FA-PID controller to adjust optimally as fast as possible the PID controller parameters by minimization of pre-determined fitness function. In time domain, the fitness can be formed by different performance specifications such as rise time, settling time, overshoot and steady state error. In this paper and for the purpose of comparison, the following performance function is used [6].

$$F(K) = (1 - e^{-\rho})(M_p + e_{ss}) + e^{-\rho}(t_s - t_r) \quad (4)$$

Where K = [K_P, K_I, K_D] is a parameter set of PID controller, ρ is a weighting factor, M_P, e_{ss}, t_s and t_r are respectively the maximum overshoot, the steady state error, the settling time and the rising time of the performance criteria in the time domain.

V. RESULT AND DISCUSSION

The closed loop transfer function of AVR system without PID controller is given in Equation (5) and step response of system is shown in Figure 3.

$$G(s) = \frac{0.5s+10}{0.002s^4+0.067s^3+.615s^2+1.55s+11} \quad (5)$$

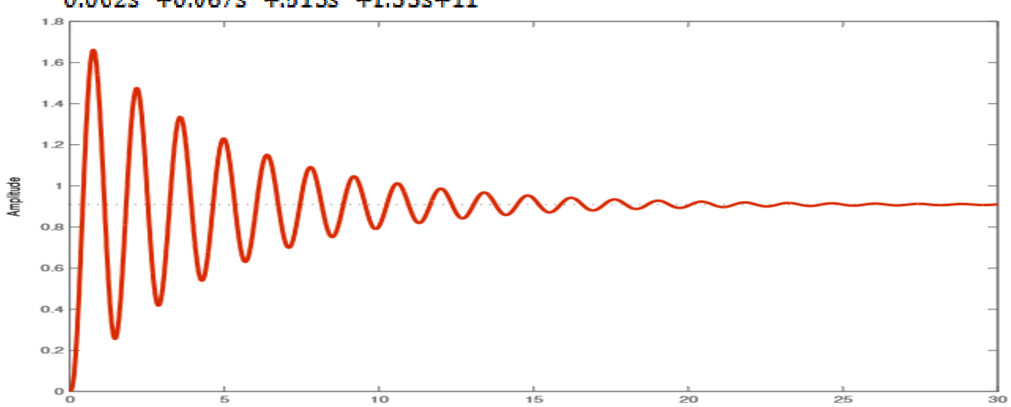

Fig.3: Step Response of AVR System without PID Controller

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The transfer function of AVR system with PID - FA method is shown in Equation (6) and step response of AVR system using PID-FA method is shown in Figure.4

$$G(s) = \frac{1.728s^2+4.846s+3.623}{0.002s^5+0.067s^4+0.615s^3+3.278s^2+5.846s+3.623} \quad (6)$$

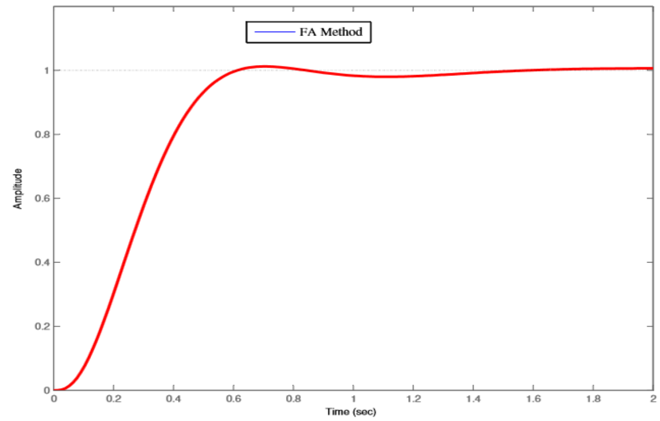

Fig.4 Step response of AVR system with PID controller using FA method

A. Comparisons with ZN, PSO-PID and FA-PID Controllers

For the purpose of comparison, the PSO-PID controller parameters are the same as in [6]. The terminal voltage step response of the AVR system controlled by PSO-PID, ZN-PID and FA-PID are shown in Fig.5. The controller's parameters and performance indices are given in Table II.

TABLE II: PID PARAMETERS AND RESULTS OBTAINED FROM DIFFERENT TUNING METHODS

Method/ Parameters	Z-N Tuning Based PID Controller	PSO Based PID Controller	FA Based PID Controller
Kp	0.80	0.5462	0.4846
Kd	0.5	0.2072	0.1728
Ki	0.866	0.6061	0.3623
Peak Overshoot Mp(%)	23.70% @0.358 sec	7.85% @0.969 sec	1.25% @0.705 Sec
Settling time t_s(sec)	2.73	1.72	0.564
Rise time t_r(sec)	0.153	0.436	0.354

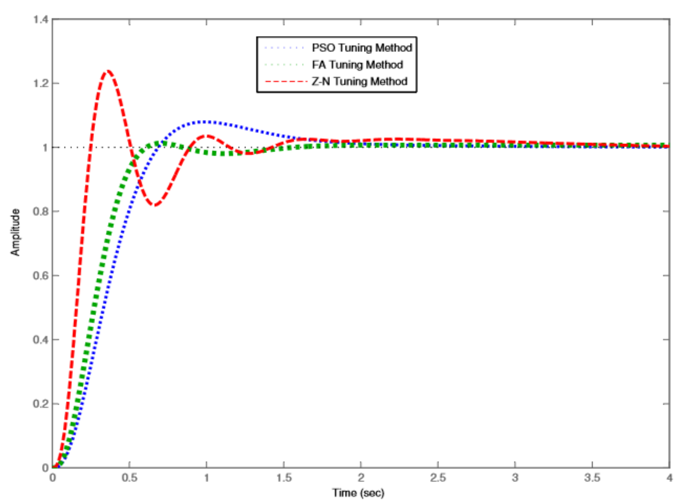

Fig.5: Comparative Analysis of ZN, PSO and FA tuning methods

VI. CONCLUSION

This paper presented a novel tuning method for the PID controller parameters using Firefly algorithm (FA) based voltage regulation of AVR. The fitness function of the proposed FF algorithm is designed according to the required control characteristics of AVR system. The proposed FA tuning method has better dynamic performance compared with the conventional ZN tuning method and PSO method. The results of the simulating AVR system is proved to be better than the tuning the controller after approximation or by any traditional existing methods.

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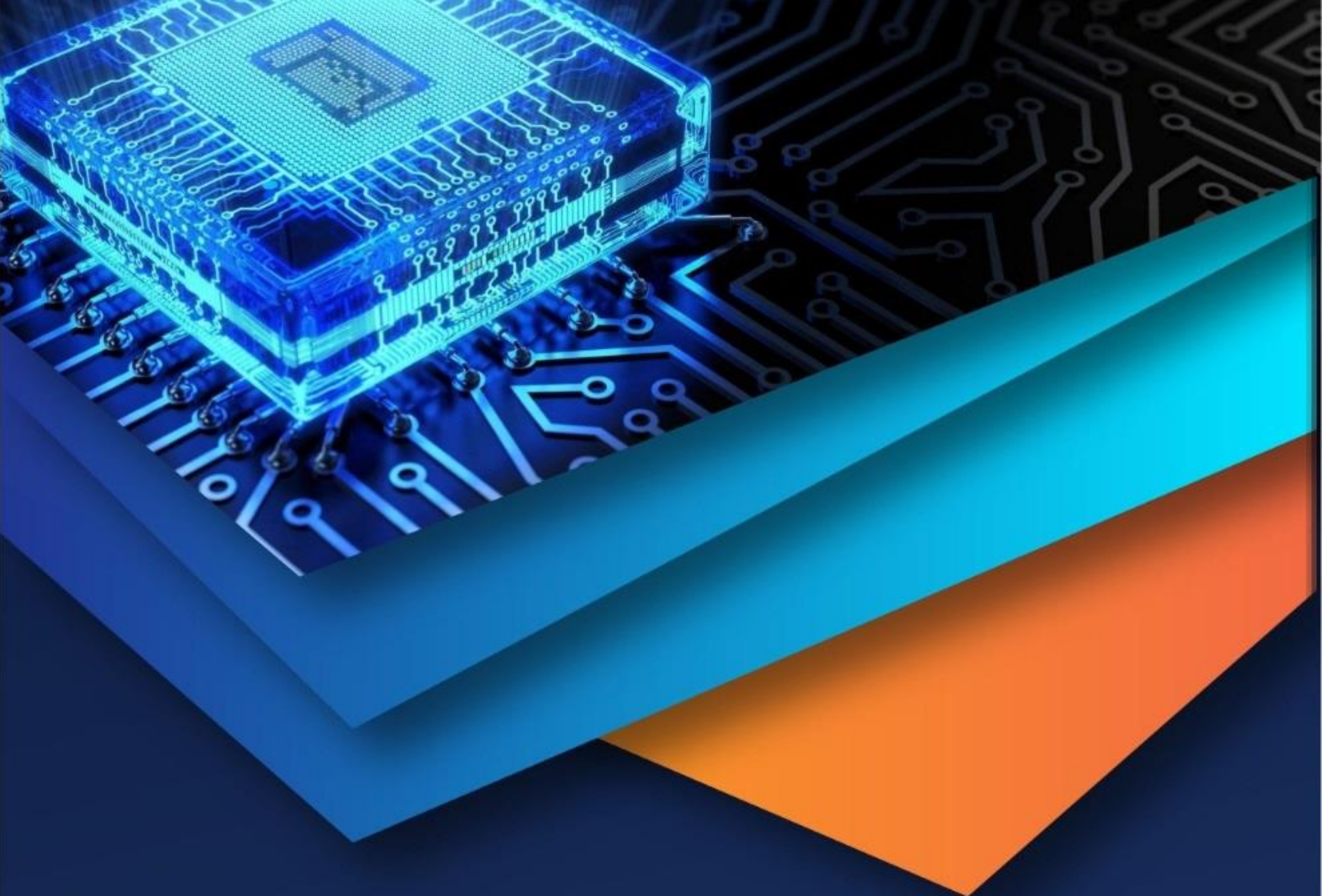

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