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Optimal Tuning of PID controller by Bat Algorithm in an Automatic Voltage Regulator System

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ABSTRACT

This Paper presents a tuning method based on biologically inspired computing approach to determine the Proportional-Integral-Derivative (PID) controller parameters in Automatic Voltage Regulator (AVR) system. The main objective is to increase the step response characteristics and reduce the transient response of AVR systems. This paper described in details how to employ Bat Algorithm Optimization (BAO) Technique 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.

***Key words**: Proportional Integral controller (PID), Bat Algorithm Optimization (BAO), 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 bio-inspired approach is proposed for the practical higher order AVR system with PID controller to investigate the performance of the proposed method. Bat Algorithm Optimization (BAO) is one of the biologically inspired computing algorithm. It has been found to robust in solving continuous non-linear optimization problems. In the PID controller design, the BAO algorithm is applied to search a best 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 Bacteria Foraging (BF) 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. There are five components: (a) PID controller model, (b) Amplifier model, (c) Exciter model, (d) Generator model, and (e) Sensor model.

The range of parameters limit and used parameter in this paper is shown in Table 1.

Table 1: Range of AVR Parameters

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

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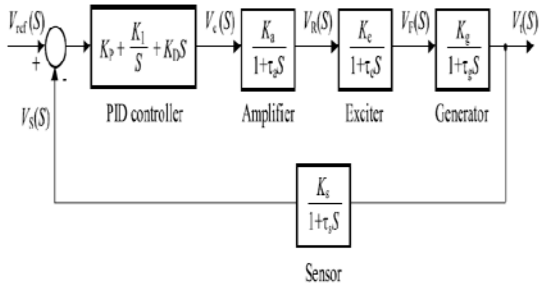

Fig.1: Block Diagram of AVR System with PID Controller.

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

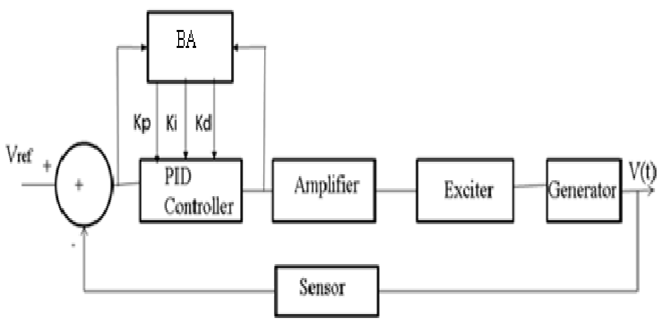

Fig.2: The Block Diagram of Bat algorithm Optimization based PID controller.

III. Basic Theory of Bat Algorithm

The Bat algorithm (BA) is a bio- inspired algorithm developed by Xin-She Yang in 2010. The bat algorithm is based on the echolocation behaviour of micro bats with varying pulse emission and loudness. The invention of echolocation can be summarized as follows: Each virtual bat flies randomly with a velocity v_i at position x_i with a varying frequency at i^{th} step. Search is strengthened by a local random walk. Selection of the best continues until certain stop criteria are met. Firstly, the initial position of x_i, velocity v_i and frequency f_i are initialized for each bat. For each step t, the movement of the virtual bat is given by updating their velocity and position using (1), (2) and (3) as follows.

$$f_i = f_{min} + (f_{min} - f_{max})\beta \quad (1)$$

$$v_i^j(t) = v_i^j(t-1) + [x_{cgbest}^j - x_i^j(t-1)]f_i \quad (2)$$

$$x_i^j(t) = x_i^j(t-1) + v_i^j(t) \quad (3)$$

Where β indicates a randomly generated number within the interval [0, 1]. The result of equation (1) is used to control the space and the range of bats movement. The variable x_{cgbest}^j represents the current global solution for decision variable j, which is achieved comparing all the solution provided by the n bats. For the local search part, once a solution is selected among the current best solution, a new solution for each bat is generated locally using random walk:

$$x_i^{new} = x_i^{old} + \sigma A_{mean}^{old} \quad (4)$$

Where, σ is a random number and A_{mean}^{old} is the average loudness of all the bats at this time step.

Pseudo Code of the Bat Algorithm

Define the objective function f(x)
Initialize the bat population x_i and v_i $(i = 1,2, \dots \dots . . n)$
Initialize frequencies f_i, pulse rates r_i and the loudness A_i
while (t< Max number of iterations)
Generate new solutions by adjusting frequency.
Update velocities and locations using equation [(1) to (3)]
If (rand > r_i)
Select a solution among the best solutions.
Generate a local solution around the selected best solution
end if
Generate a new solution by flying randomly
if $(rand < A_i \,\&\, f(x_i) < f(x_{cgbest}))$
Accept the new solutions
Increase r_i and reduce A_i
end if
Rank the bats and find the current best
End while

IV. Bat Algorithm Based Tuning of the Controller

The optimal value of the PID parameters Kp, Ki, Kd are to be found Using Bat Algorithm. All possible set of controller parameters values are adjusted to minimise the objective function. The objective function used in this paper is [6],

$$F(k) = (1 - e^{-\beta})(M_p + e_{ss}) + e^{-\beta}(t_s - t_r) \quad (5)$$

V.RESULT AND DISCUSSION

The closed loop transfer function of AVR system without PID controller is given in Equation (6) and step response of system is shown in Figure 3.

$$G(s) = \frac{0.5s+10}{0.002s^4 + 0.067s^3 + .615s^2 + 1.55s + 11} \quad (6)$$

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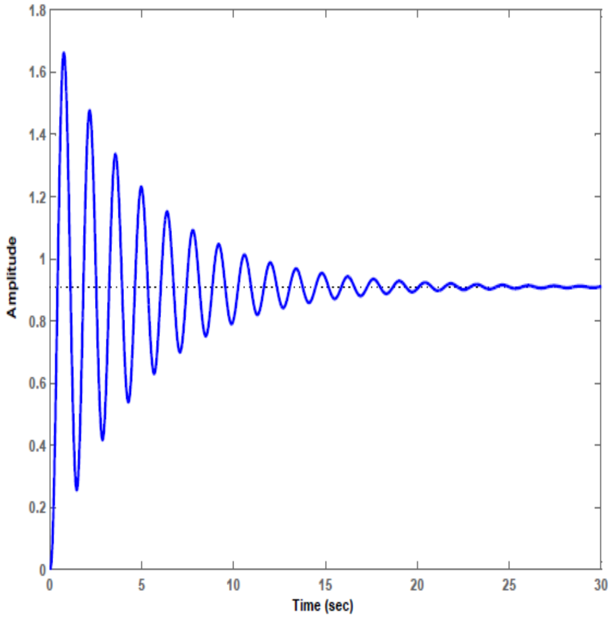

Fig.3: Step Response of AVR System without PID Controller

The transfer function of AVR system with PID - BA method is shown in Equation (7) and step response of AVR system using PID-BA method is shown in Figure.5

$$G(s) = \frac{1.54s^2 + 4.52s + 3.325}{0.002s^5 + 0.067s^4 + 0.615s^3 + 3.09s^2 + 5.52s + 3.325} \quad (7)$$

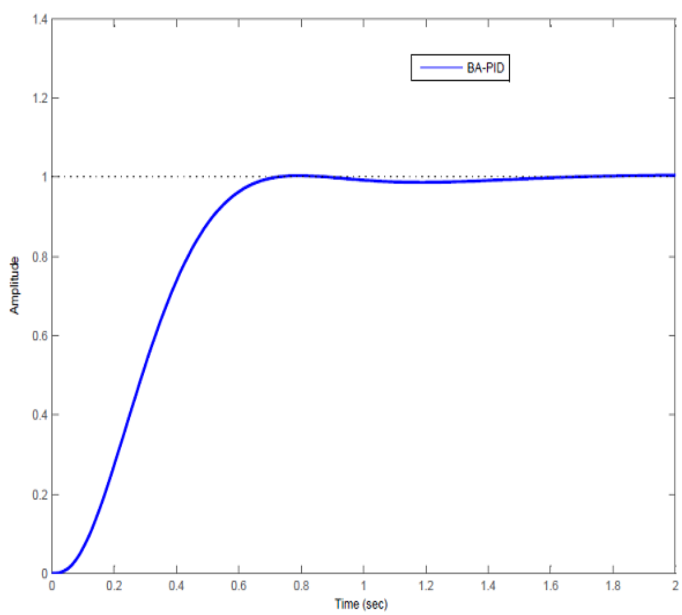

Fig.4 Step response of AVR system with PID controller using BA method

V.Comparisons with ZN, PSO-PID and BA-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 BA-PID are shown in Fig.5. The controller's parameters and performance indices are given in Table2.

Table 2 : PID Parameters and results obtained from different tuning methods

Method/ Parameters	Z-N Tuning Based PID Controller	PSO Based PID Controller	BA Based PID Controller
Kp	0.80	0.5462	0.4520
Kd	0.5	0.2072	0.1540
Ki	0.866	0.6061	0.3325
Peak Overshoot Mp(%)	23.70% @0.358 sec	7.85% @0.969 sec	0.536% @2.29 Sec
Settling time t_s(sec)	2.73	1.72	0.636
Rise time t_r(sec)	0.153	0.436	0.394

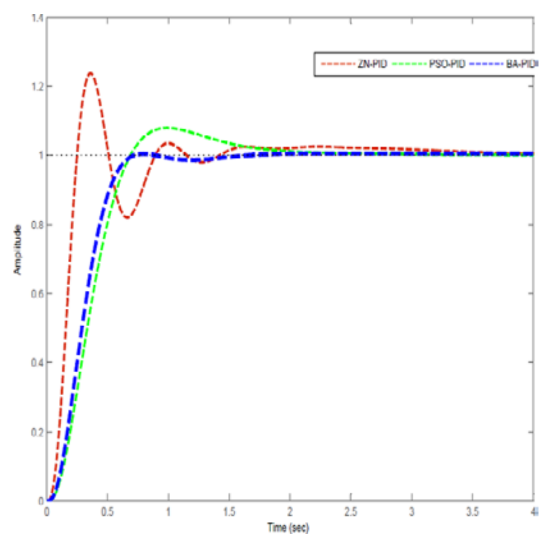

Fig.5: Comparative Analysis of ZN, PSO and BA tuning methods

VII. CONCLUSION

This paper introduced a novel tuning method for the PID controller parameters using Bat algorithm Optimization (BAO) based voltage regulation of AVR. The objective function of the proposed BAO algorithm is designed according to the required control characteristics of AVR system. The proposed BAO tuning method has better 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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