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PID Controller Tuning Optimization with BFO Algorithm in AVR System

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Abstract--This study presents the design and tuning of Proportional Integral Controller (PID) for Automatic Voltage Regulator (AVR) system to improve the dynamic performance and robustness of the system. The PID controller is the very commonly used compensating controller which is used in higher order system. This controller widely used in many different areas like Chemical process control, Aerospace, Automation and Electrical Drives etc. There are various soft computing techniques which are used for tuning of PID controller to control the voltage in AVR system. Tuning of PID parameters is important because, these parameters have a great effect on the stability and performance of the control system. Bacterial Foraging Optimization (BFO) techniques is one of the important techniques to tune the PID parameter in AVR system. Numerical solution based on the proposed PID control of an AVR system for nominal system parameters and step reference voltage input validates the good performance.

Keywords: *Proportional Integral Controller (PID), Bacteria Foraging Optimization (BFO), Automatic Voltage Regulator (AVR)*

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I. INTRODUCTION

The main function of an AVR system is to hold the magnitude of terminal voltage of a synchronous generator at a specified level. Thus, the stability of the AVR system would seriously affected the security of the power system. The step response of this system without control has oscillation which will reduce the performance of the regulation. Thus, a control technique must be applied to the AVR system. For this reason, the PID block is connected in series with amplifier. Several tuning methods have been proposed for the tuning of control loop. Bacteria foraging optimization technique is used to find out the optimum parameters for tuning the PID controllers. The most familiar conventional tuning methods are: Ziegler-Nichols, Cohen-Coon, and Astra-Hagglund [5-6].

BFO 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 BFO algorithm is applied to search a best PID control parameters. In this paper, BFO and Ziegler-Nichols based method of designing PID controller of AVR is presented.

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 Optimization (BFO) 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 an AVR model with PID controller is shown in Fig.1[5].

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

Table 1: 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	$0.001 \le \tau_s \le 0.01$	$K_s = 1, \tau_s = 0.05$

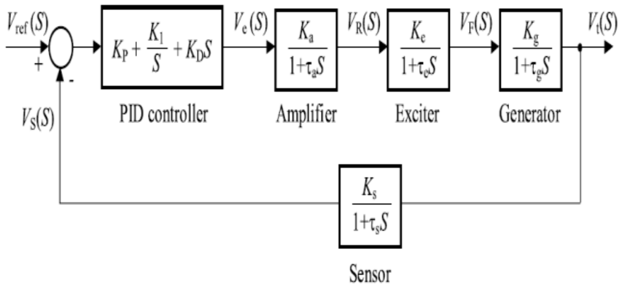

Fig.1: Block Diagram of AVR System with PID Controller.

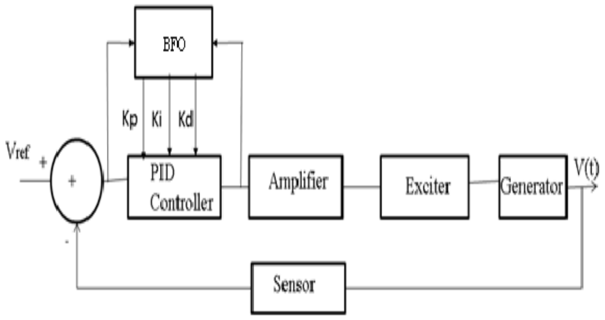

Fig.2: The Block Diagram of BFO algorithm based PID controller.

III. BACTERIA FORAGING OPTIMIZATION:

Bacterial Foraging Optimization (BFO) algorithm is a new method of biologically inspired computing technique invented by Kevin M.Passino, motivated by the natural selection which is tends to eliminate the animals with poor foraging strategies and favor those having successful foraging strategies [8-10]. The foraging strategy is governed basically by four process namely Chemotaxis, Swarming, Reproduction, Elimination and Dispersal.

(A) Chemotaxis:

The characteristics of movement of bacteria in search of food can be defined in two ways, i.e. swimming and tumbling together known as chemotaxis. A bacteria is said to be ‘swimming’ if it moves in a predefined direction, and ‘tumbling’ of moving in an altogether different direction.

Let j be the index of chemotaxis step, k be the reproduction step and ‘l’ be the elimination dispersal event. Let$\theta^i(j,k,l)$ is the position of the i^{th} bacteria at j^{th} chemotaxis step, k^{th} reproduction step and i^{th} elimination dispersal event. The position of the bacteria in the next chemotactic step after a tumble is given by

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i) \times \frac{\Delta(i)}{\sqrt{\Delta^T(i)\times\Delta(i)}} \text{ ------- (1)}$$

If the health of the bacteria improves after the tumble, the bacteria will continue to swim to the same direction for the specified steps or until the health degrades.

(B) Swarming:

Bacteria exhibits swarm behavior i.e. healthy bacteria try to attract other bacteria so that together they reach the desired location so that together they reach the desired location more rapidly. The effect of swarming is to make the bacteria gather into groups and moves as concentric pattern with high bacterial density. Mathematically swarming behavior can be modeled as:

$$J_c(\theta, P(j,k,l)) = \sum_{i=1}^{n} J_c(\theta, \theta^i(j,k,l)) = A + B \text{ --- (2)}$$

Where,

$$A = \sum_{i=1}^{s}[-d_{attract} exp(-W_{attract} \sum_{i=1}^{n}(\theta_m - \theta_m^i)^2)] \text{ --- (3)}$$

And

$$B = \sum_{i=1}^{s}[-h_{repellant} exp(-W_{repellant} \sum_{i=1}^{n}(\theta_m - \theta_m^i)^2)] \text{ --- (4)}$$

Where,

S = Total number of bacteria

N = Total parameters to be optimized

$d_{attract}$ = Depth of attractant signal released

$h_{repellant}$ = Height of repellent signal between bacterium

$W_{repellant}$ = Weight of repellent signals between bacterium and

$J_c(\theta,(i,j,k,l))$ is the objective function value θ is the point in the n dimensional search domain till the j^{th} chemotactic, k^{th} reproduction and i^{th} elimination. Also θ_m is the m^{th} parameter of global optimum bacteria.

(C) Reproduction:

. The original set of bacteria after getting through several characteristics stages reach the reproduction stage. The best set of bacteria get divided into two groups. The healthier half replaces with the other half of bacteria, which gets eliminated owing to their poorer foraging abilities. This makes the population of bacteria constant in the evolution process.

(D) Elimination and Dispersal:

This is the closing phase in the bacterial search. The bacterium population may decrease either gradually or suddenly depend on the environmental criteria such as change in temperature and availability of food etc. Significant local rise of temperature may kill a group of bacteria that are currently in a region with high concentration of nutrient gradients. Action may take place in such a way that are all the bacteria in a location are killed and eliminated or a group is relocated into a new food source. The dispersal possibly compresses the chemotaxis advancement. After dispersal, some bacteria may be located near the superior nutrient and this process is called ‘Migration’. The above events are continued until the entire dimensional search converges to optimal solutions or total number of iteration is reached.

IV. ALGORITHM FOR BFOA:

Parameters:

[Step 1] Initialize the following parameters

p as dimension of the search space

s as the number of bacteria in the population

N_c as the number of chemotactic steps per bacterium lifetime between reproduction steps

N_s as maximum number of swim of bacteria in the same direction

N_{re} as the number of reproduction steps

N_{ed} as the number of elimination and dispersal events

P_{ed} as the probability that each bacteria will be eliminated /dispersed

i=1,2,….,S as the index for the bacterium

J=1,2,…..,N_c as the index for chemotactic step

K=1,2,…..,N_{re} as the index for reproduction step

l=1,2,….,N_{ed} as the index of elimination and dispersal event

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m_s=1,2,……,N_s as the index for number of swim

[Step 2] Elimination –dispersal loop: for l=1, 2,…., Ned, do l=l+1

[Step 3] Reproduction loop: for k=1,2,….,N_{re}, do k=k+1

[Step 4] Chemotaxis loop: for j=1,2,….,N_c, do j=j+1

a .For i=1,2,…,s, take a chemotactic step for bacterium i:

b. Compute the nutrient media (cost function) value J(i,j,l). Calculate $J(i,j,l) = (J(i,j,l) + J_c(\theta^i(j,k,l), P(j,k,l))$.If there is no swarming effect then $J_c(\theta^i(j,k,l)),P((j,k,l)) = 0$

c. Put J_{last} = J(i, j ,k,l) to save this value since a better cost via run may be found.

d. Tumble: generate a random vector $\Delta(i) \in \Re^p$ with each element Δ_{mp} (i), m_p =1,2,….p, a random number on the range [-1,1]

e. Move: compute

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i) \times \frac{\Delta(i)}{\sqrt{\Delta^T(i) \times \Delta(i)}}$$

.This result in a step of size C (i) in the direction of the

tumble for bacterium i.

f. compute the nutrient media (cost function) value J(i,j+1,k,l) , and calculate J(i,j+1,k,l)= J(i,j+1,k,l)+$J_c(\theta^i(j+1,k,l)$,P(j+1,k,l)).If there is no swarming effect then $J_c(\theta^i(j+1,k,l)$,P(j+1,k,l))=0.

g.swim i. Put m_s=0 (counter for swim length)

ii. While m_s< (if have not climbed down too long)

count m_s= m_s+1

if J(i,j+1,k,l) < J_{last} then J_{last} = J(i,j+1,k,l) and calculate

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i) \times \frac{\Delta(i)}{\sqrt{\Delta^T(i) \times \Delta(i)}}$$

This result in a step of size C (i) in the direction of the tumble for bacterium i. Use this θ^i (j+1,k,l) as in sub step f above.

Else, m= N_s

h. Go to next bacterium (i+1) if i≠S to process the next bacterium.

[Step 5] If j<N_c ,go to step 4.

[Step 6] Reproduction:

a. For the given k and I, and for each i=1,2,3,….S, let

$$J^i_{health} = \sum_{j=1}^{N_c+1} J(i,j,l)$$

Be the health of bacterium i.Sort bacteria and chemotactic parameter C (i) in order of ascending cost J_{health}..

b. the Sr bacteria with the highest J_{health} values die and the other Sr bacteria with the best values split

[Step 7] if k< Nre , go to step 3.

[Step 8] Elimination –dispersal: for i=1, 2, 3,…..,S., eliminate and disperse each bacterium which has probability value less than P_{ed}. If one bacterium eliminated then it is dispersed to random location of nutrient media. This mechanism makes computation simple and keeps the number of bacteria in the population constant.

For m=1: S

If p_{ed}>rand (Generate random number for each bacterium and if the generated number is smaller than p_{ed} then eliminate positions for bacterium)

Generate new random position bacteria

else

Bacteria keep their current position (bacteria are not dispersed)

end

end

[Step 9] if l<N_{ed} , then go to step 2;otherwise end

V. BFO BASED TUNING OF THE CONTROLLER

The optimal value of the PID parameters Kp, Ki, Kd are to be found Using BFO. All possible set of controller parameters values are adjusted to minimise the objective function. The objective function used in this paper is[5-6],

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

VI. 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.

$$G(s) = \frac{0.5s + 10}{0.0002s^4 + 0.067s^3 + .615s^2 + 1.55s + 11} \qquad (6)$$

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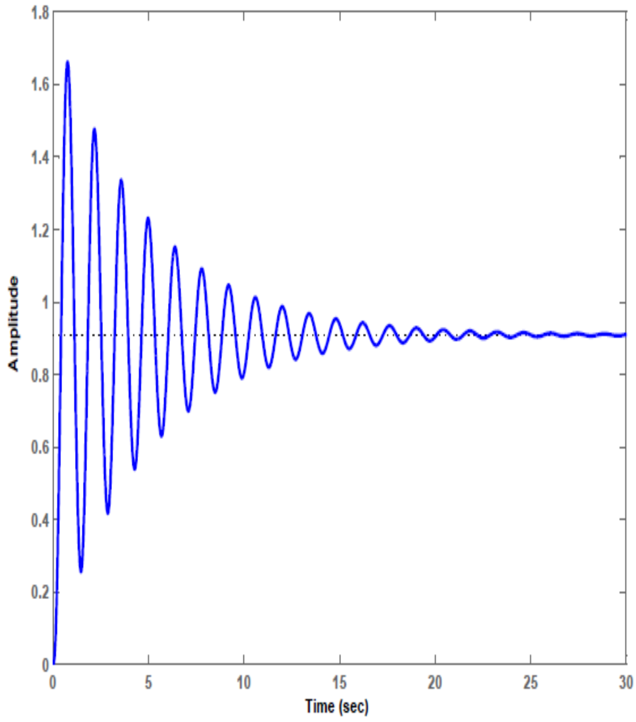

Fig.3: Step Response of AVR System without PID Controller

The transfer function of AVR system with PID using Ziegler-Nichols (Z-N) tuning method is shown in Equation (7) and step response of AVR system using Ziegler-Nichols tuning is shown in Figure.4.

$$G(s) = \frac{5s^2+8s+8.66}{0.002s^5+0.067s^4+0.615s^3+6.55s^2+9s+8.66} \quad (7)$$

The transfer function of AVR system with PID - BFO method is shown in Equation (8) and step response of AVR system using PID-BFO method is shown in Figure.5

$$G(s) = \frac{2.072s^2+5.462s+6.061}{0.002s^5+0.067s^4+0.615s^3+3.622s^2+6.462s+6.061} \quad (8)$$

Simulation results and PID parameters obtained using Z-N and BFO methods are shown in Table 2.

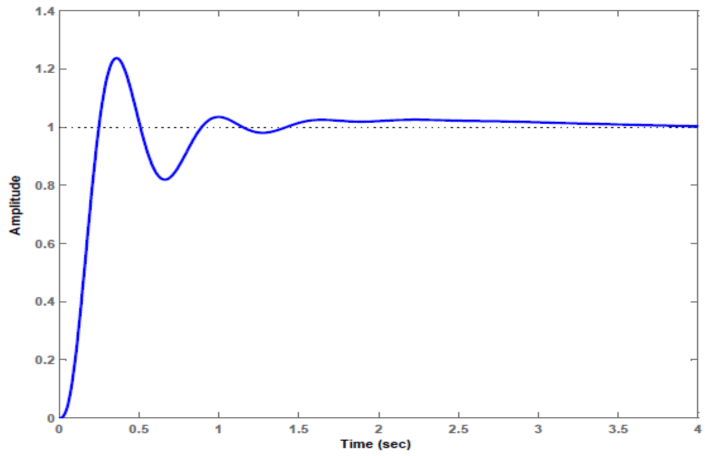

Fig.4: Step response of AVR system with PID controller using Ziegler-Nichols tuning method

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

Method/ Parameters	Z-N Tuning Based PID Controller	BFO Based PID Controller
Kp	0.80	0.5462
Kd	0.5	0.2072
Ki	0.866	0.6061
Peak Overshoot Mp(%)	23.70% @0.358 sec	7.26% @0.63 sec
Settling time t_s(sec)	2.73	2.47
Rise time t_r(sec)	0.153	0.292

From the above results, it shows that the tuning PID parameter using BFO technique gives good results.

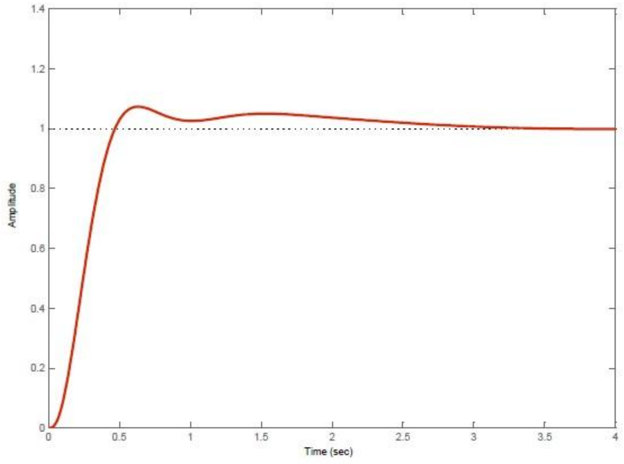

Fig.5 Step response of AVR system with PID controller using BFO tuning method

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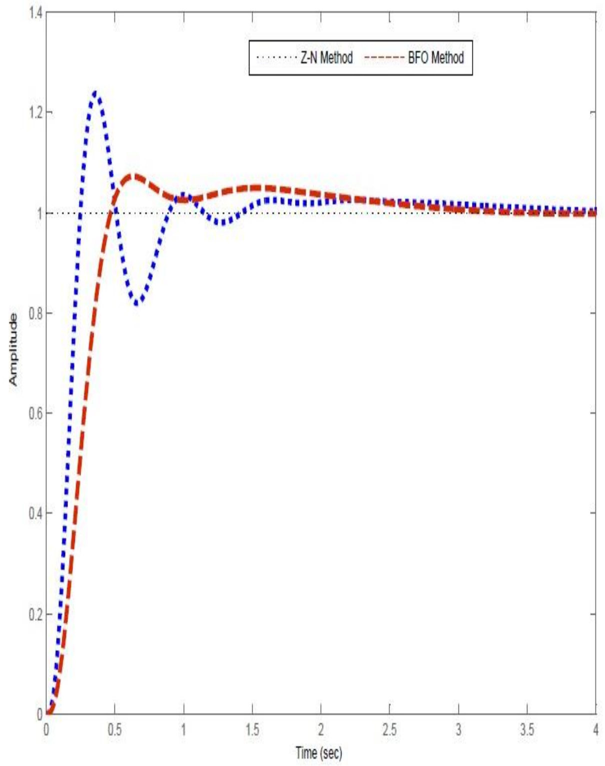

Fig.6: Comparative Analysis of ZN and BFO tuning method

VII. CONCLUSION

This paper presents a novel tuning method for the PID controller parameters using Bacterial Foraging Optimization algorithm (BFO) based voltage regulation of AVR. The objective function of the proposed BFO algorithm is designed according to the required control characteristics of AVR system. The proposed BFO tuning method has better performance compared with the conventional ZN tuning 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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