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Design and Implementation of PID Controller Based BFOA for Buck Converter Fed DC Motor Speed Control

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***Abstract*— This paper presents the speed control DC motor is designed and implementation by supply the output of buck converter as input to armature of dc motor. The mathematical model of the buck converter circuit operating in the continuous conduction mode (CCM) and the mathematical model of DC motor separately excited in state-space equations form are presented. PID controller and hybrid PID controller based bacterial foraging algorithm are used to designed an optimal controller of the dc motor speed control. Analysis and comparison between Simulation and practical of open loop system, close loop system with PID controller and hybrid PID based bacterial foraging controller results are performed for different, writing conditioning such as sudden changing in the load torque. The results show that the best testing cases when used PID based bacterial foraging algorithm method.**

***Index Terms*— Proportional, integral and derivative controller (PID), Direct Current machine (DC), Bacterial Foraging Optimization Algorithm (BFOA).**

I. INTRODUCTION

At the moment of the world the development of the direct current machines depending on their uses and DC machines became more useful in many applications such as electrical cars and electronic circuits. The speed of DC motor can be adjusted to a great extent so as to provide easy control and high performance [1]. The speed control and improving performance of DC motor separately excited using fuzzy logic based Particle Swarm Optimization "PSO" Algorithm [2].The speed control of DC motor separately excited using fuzzy logic based Particle Swarm Optimization "PSO" Algorithm [3]. There are several conventional and numeric controller types intended for controlling the DC motor speed at its executing various tasks: PID Controller, Fuzzy Logic Controller; or the combination between them: Fuzzy-Swarm, Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-Particle Swarm Optimization**.**

The tuning of PID controller is performed mostly using the conventional techniques trial and error method, Ziegler-Nichols method, GA, PSO etc., Tuning a controller means adjusting the controller gains to satisfy the performance specifications like margin of stability, transient response, bandwidth and stead-state error. Most of the articles have concentrated on design of PI and PID controllers [4].

In 2002 Kevin M Passino, proposed bacterial foraging as a tool for distributed optimization and control. This bacterial foraging optimization algorithm (BFOA) mimics the foraging strategy of *E. coli* bacteria (those living in our intestines) which try to maximize the energy intake per unit time. From the very early days it has drawn attention of researchers due to its effectiveness in the optimization domain. So as to improve its performance a large number of modifications have already been undertaken [5].

In 2007 Kim *et al.* came up with BFOA Genetic algorithm (GA) hybridization for better performance [6].

BF algorithms are applied to search globally optimal gains of PID controller. Furthermore, the performances of PID trial and error tuning, PID–BF tuning controllers are compared. Simulation and practical results are given to show the effectiveness of controller.

Mathematical Model

The system mathematical model consist two parts are**:**

Model Buck Converter

Considering the wide use of electronics equipment's and utilization of renewable energy sources, DC-DC converters have found significant attention in the recent decades. The main purpose of a DC-DC converter is to supply a regulated DC output voltage to a variable-load resistance from an unstable DC input voltage. The converters are widely used for the control of motor voltage in electric cars, ceiling elevators, mine excavation etc., [7]. Buck converter that produce reliable output voltage and the same polarity of the input voltage, Fig (1) presents buck converter circuit diagram [8].

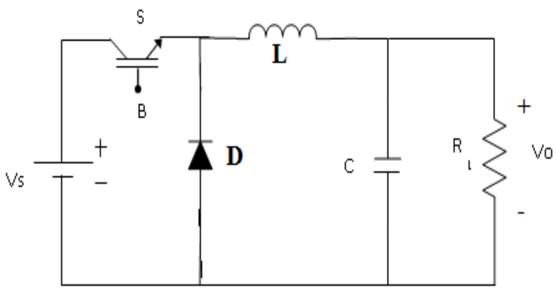

Fig. (1) Buck converter circuit diagram.

The buck converter matrices after connecting two modes of converter operation are given:

$$\begin{bmatrix} \dot{i}_L \\ \dot{v}_C \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{(R_L \cdot C)} \end{bmatrix} \begin{bmatrix} i_L \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{d}{L} \\ 0 \end{bmatrix} \cdot V_S$$

Model of DC Motor

DC machines are characterized by their versatility. By

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means of various combinations of shunt-, series-, and separately-excited field windings they can be designed to display a wide variety of volt-ampere or speed-torque characteristics for both dynamic and steady-state operation. Because of the ease with which they can be controlled systems of DC machines have been frequently used in many applications requiring a wide range of motor speeds and a precise output motor control [1].

In this paper, the separated excitation DC motor model is chosen according to his good electrical and mechanical performances more than other DC motor models. The DC motor is driven by applied voltage shown in Fig. (2). Show the equivalent circuit of DC motor with separate excitation wound type when armature control. The Symbols, Descriptions and Units of buck converter and DC motor are given in Table 1.

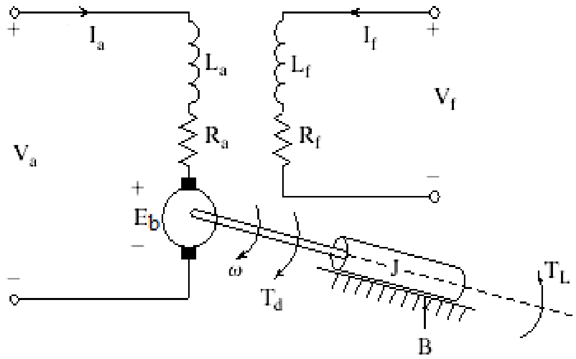

Fig. (2). DC motor equivalent circuit.

Using Kirchhoff's voltage law of DC motor when constant field voltage that produce constant field current, the motor equations are:

$$v_a = R_a i_a + L_a \frac{di_a}{dt} + e_a \qquad (1)$$

$$e_a = \text{kw} \qquad (2)$$

$$T_e = \text{J}\frac{dw}{dt} + \text{Bw} + T_L \qquad (3)$$

$$\frac{di_a}{dt} = -\frac{R_a}{L_a} i_a + \frac{v_a}{L_a} - \frac{K_b}{L_a}\text{w} \qquad (4)$$

$$\frac{dw}{dt} = \frac{k_b}{J} i_a - \frac{B}{J}\text{w} - \frac{1}{J} T_L \qquad (5)$$

The DC motor matrices are

$$\begin{bmatrix} \dot{i}_a \\ \dot{\omega} \end{bmatrix} = \begin{bmatrix} \frac{-R_a}{L_a} & \frac{-k_b}{L_a} \\ \frac{k_b}{J} & \frac{-B}{J} \end{bmatrix} \begin{bmatrix} i_a \\ w_m \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} & 0 \\ 0 & \frac{-1}{J} \end{bmatrix} \begin{bmatrix} V_a \\ T_L \end{bmatrix}$$

The matrices of the buck converter fed to DC motor are given:

Let:

$$i_L = x_1 \;;\quad v_c = x_2 \;;\quad i_a = x_3 \;;\quad w = x_4 \;;$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} & 0 & 0 \\ \frac{1}{C} & \frac{-1}{(R_L \cdot C)} & 0 & 0 \\ 0 & \frac{1}{L_a} & \frac{-R_a}{L_a} & \frac{-k_b}{L_a} \\ 0 & 0 & \frac{k_b}{J} & \frac{-B}{J} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} + \begin{bmatrix} \frac{d}{L} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{-1}{J} \end{bmatrix} \begin{bmatrix} V_s \\ T_L \end{bmatrix}$$

Table (1)

Symbols	Designations	Units
V_s	Converter supply voltage	V
i_L	Converter inductor current	A
v_c	Converter output voltage	V
i_a	Induced current	A
v_a	Induced voltage	V
J	Moment of Inertia.	[Kg.m2]
B	Viscous fraction coefficient	[N.m.Sec/Rad]
k_b	Motor coefficient	[V/A-rad/sec]
L_a	Armature Inductance	H
$R_a = R_L$	Armature Resistance	[Ω]
L	Converter inductance	H
C	Converter capacitance	F
W	speed of the DC Motor	[Rad/Sec]

From the state matrices of buck converter and DC motor, can construct the model with the environment MATLAB. The model of the system in Simulink is shown in Fig. 3. The various parameters of the buck converter and DC motor are shown in Table 2.

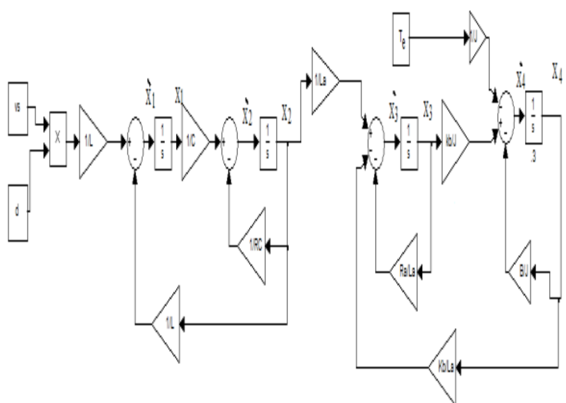

Fig. (3). The system model in Matlab.

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Table 2: Parameters of the buck converter and DC Motor

$v_a = v_c$	La=20.4[H]	Vs=220[v]
Vex=220[v]	Lm=1.8[H]	C=1 [mF]
Rex=550[Ω]	J=0.041 [Kg.m2]	L=30 [mH]
Ra=2.8[Ω]	B=0.0012[N.m.Sec/ Rad]	F=4KH
Lex=8.2[H]	Kb=1.4 [V/A-rad/sec]	

The PID controller

The PID controller is used to improve the dynamic response of the system as well as to reduce or eliminate the steady-state error. 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, thus increasing system type by one and reducing the steady-state error due to a step function to zero. The transfer function of PID controller is:

$$Gc = Kp + \frac{Ki}{s} + Kd\, s \qquad \ldots (6)$$

Where Kp, Ki and Kd are the proportional, integral and derivative gains respectively of PID controller. The block diagram of PID controller in MATLAB shown in Fig. (4).

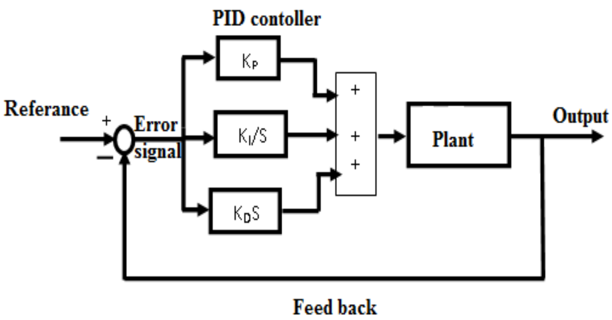

Fig. (4). The block diagram of PID controller.

Bacterial Foraging Algorithm

In BFOA the coordinates of a bacterium represent an individual solution to the optimization problem. Such a set of trial solution converges towards global optimal following a foraging group dynamics of the bacteria population. Each bacterium first undergoes a chemotactic movement as long as it goes in the direction of positive nutrient gradient (i.e., decreasing fitness). After a certain number of complete swims the best half of the population undergoes reproduction eliminating the rest of the population. In order to escape local optima an elimination-dispersal event is carried out where some bacteria are liquidated at random with a very small probability while the new replacements are randomly initialized over the search space [9].

The bacterial foraging system consists of four principal mechanisms, namely chemotaxis, swarming, reproduction, and elimination dispersal [5,10,11]. Below we briefly describe each of these processes.

Chemotaxis

This process simulates the movement of an E. coli cell through swimming and tumbling via flagella. Biologically, an E. coli bacterium can move in two different ways. It can swim for a period of time in the same direction, or it may tumble, and alternate between these two modes of operation for the entire lifetime. Suppose θi (j, k, l) represents ith bacterium at jth chemotactic, kth reproductive and lth elimination dispersal step. C (i) is the size of the step taken in the random direction specified by the tumble (run length unit).

Swarming

An interesting group behavior has been observed for several motile species of bacteria including E. coli and S. typhimurium, where intricate and stable spatiotemporal patterns (swarms) are formed in a semisolid nutrient medium. A group of E. coli cells arrange themselves in a traveling ring by moving up the nutrient gradient when placed amidst a semisolid matrix with a single nutrient chemo effecter. The cells, when stimulated by a high level of succinate, release an attractant aspertate, which helps them to aggregate into groups and thus move as concentric patterns of swarms with high bacterial density.

Initialized over the search Reproduction

The least healthy bacteria eventually die while each of the healthier bacteria (those yielding lower value of the objective function) asexually split into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

Elimination and Dispersal

Gradual or sudden changes in the local environment where a bacterium population lives may occur due to various reasons: e.g., a significant local rise of temperature may kill a group of bacteria that are currently in a region with a high concentration of nutrient gradients. Events can take place in such a fashion that all the bacteria in a region are killed or a group is dispersed into a new location. To simulate this phenomenon in BFOA, some bacteria are liquidated at random with a very small probability while the new replacements are randomly space.

PID tuned Bacterial Foraging Optimization Algorithm Controller Design

To design an optimal PID controller, the BFO algorithms are applied to search its globally optimal gains. The implementation of BFOA in this work is complex task, because the performance of the system must be examined in each particles and iteration position during the optimization process. Therefore, the optimization algorithm is implemented by using MATLAB m-file program and linked with the system simulation program in MATLAB /SIMULINK, to check the system performance in each particle. The BFOA produces the PID controller gains which give the minimum fitness function shown in Fig. (5) using

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Integral Squared Error (ISE) method which give optimal performance of the system.

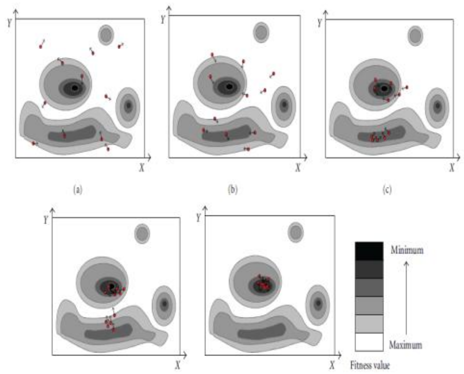

Fig (5) Trajectory of particles in the search space at various iterations in order to move towards the global minimum values of fitness function in the search space [12].

The following Bacterial Foraging Optimization Algorithm parameters have been chosen properly [13] where:

p: dimension of the search space = 3.

S: total number of bacteria in the population = 6.

Nc: the number of chemotactic steps = 10.

N: the swimming length = 6.

The total number of bacteria in the population S = 6. Each bacterium in the population has a position .The position of the bacterium is represented by three variables: the PID controller gains so the dimension of the search space which is represented by the three variables are equal to three (p=3). In the beginning the initial bacterium position must be chosen. The important thing here is the performance (tr, ts, ess, p.o.s) during the average difference between the reference speed and the running speed. The Bacterial Foraging technique simulates the error as the objective function (fitness function) to be as small as possible for the given search space.

The BFOA has been programed using MATLAB M-file to calculate the optimal gains of PID controller then connect with system simulink. The hybrid PID controller with BFOA flowchart is shown in Fig. (6).

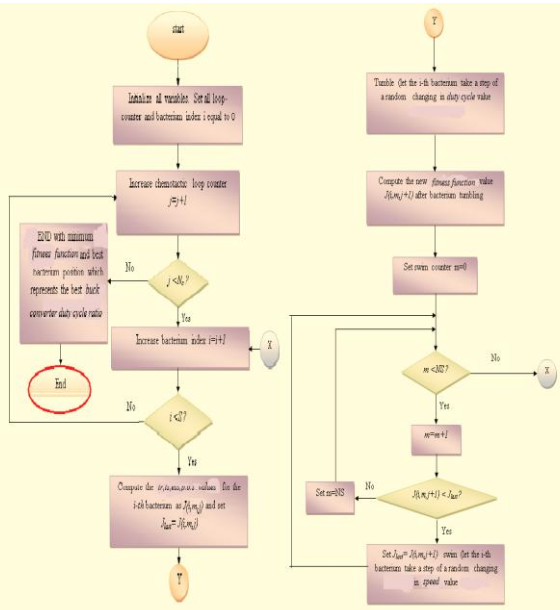

Fig. (6). Flowchart of Bactarial Foraging Optimization Algorithm.

System Realization

The system is implemented practically as open loop, close loop with PID controller tunning using trial and error method and hybrid PID controller with BFOA. The block diagram of the practical system realization is shown in Fig. (7).

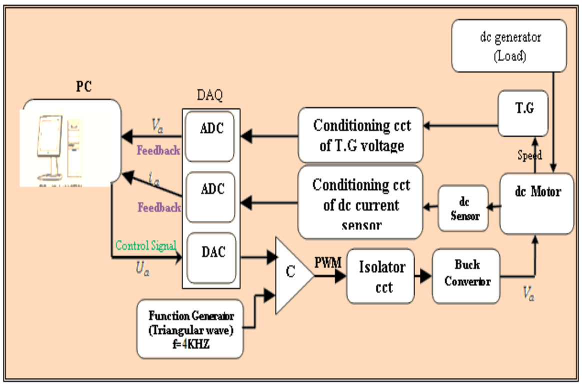

Fig. (7). The block diagram of the practical system

II. RESULTS AND DISCUSSION

The open loop DC motor speed responses when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) theortically and practically responses respewctivaly shown in Fig. (8, 9). The close loop speed response with FLC when referance speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) theortically and practically responses respectively shown in Fig. (10, 11). The close loop speed response with hybrid PID controller based BFOA when referance speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) theortically and practically responses respectively shown in Fig. (12,13).

The PID controller gains are chosen by trail and error method to get the best output performance of DC motor but this process needed long time.The hybrid PID controller based BFOA is proposed because of the PID controller disadvantages such as (trail and error method, long time of search time and PID controller gains one operation reverse to other one). Hybrid PID controller based BFOA produce best performance with less computing time compared with PID (trail and error method).

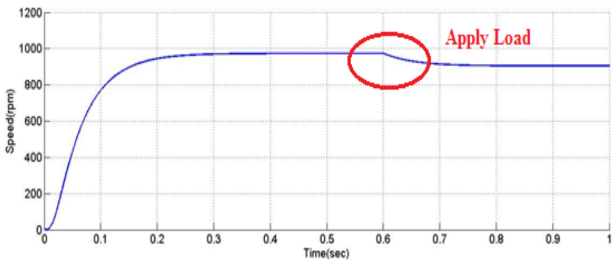

Fig. (8). The open loop DC motor speed response when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) theortically.

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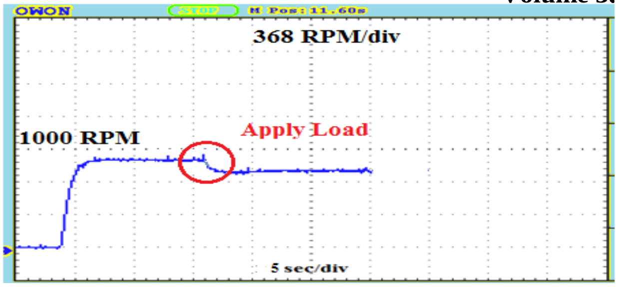

Fig. (9).The open loop DC motor speed response when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) practically.

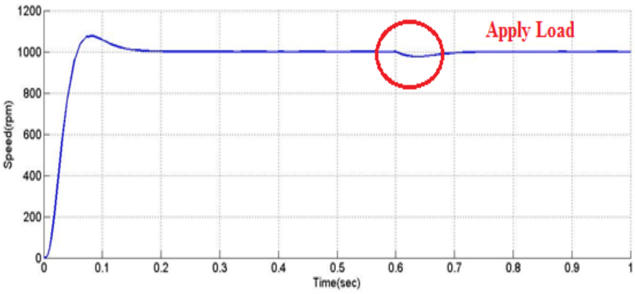

Fig. (10). The close loop DC motor speed response when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) with PID controller theortically.

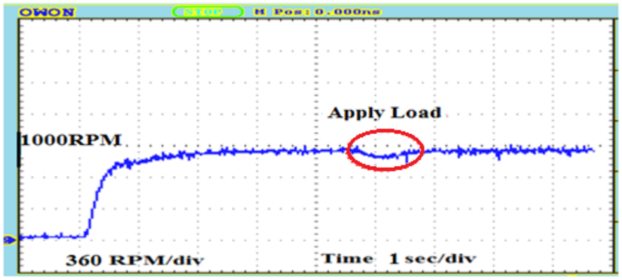

Fig. (11). The close loop DC motor speed response when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) with PID controller practically.

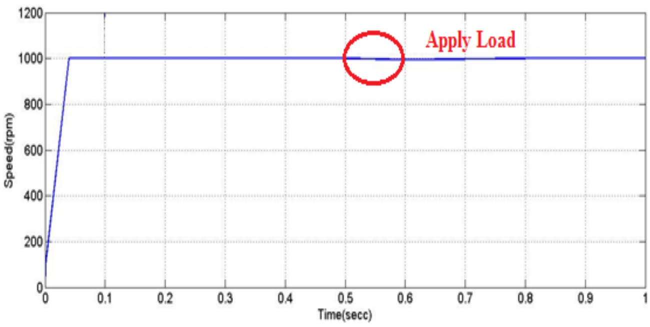

Fig. (12). The close loop DC motor speed response when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) with Hybrid PID controller based BFOA theortically.

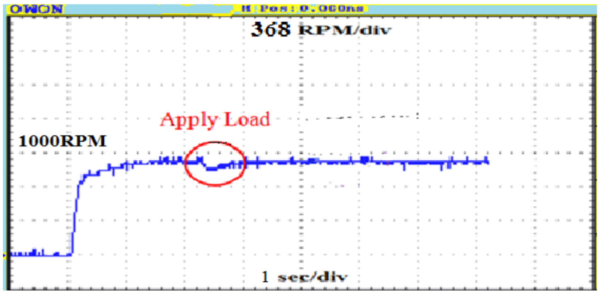

Fig. (13). The close loop DC motor speed response when desired speed (N=1000 rpm) at no load then apply external rated load torque (T_L=8 N.m) with Hybrid PID controller based BFOA practically.

The comparison between theoretical and practical results for open loop close loop PID and hybrid PID controller based BFOA when reference speed (N=1000 rpm) are shown in the table (3).

Table (3): Comparision of the system performance for the different techniques when referance Speed (N=1000 rpm).

Design system	Steady state error (e_{ss}) [%] at no load	Steady state error (e_{ss}) [%] at rated load	Peak Over shoot (p.o.) [%]	Setllin g time (t_{ss}) [s]	Risin g time (t_r) [s]
Open loop system theoretically	4	11	0	2.8	0.17
Close loop system with PID theoretically	0	0	9	0.16	0.06
Close loop system with Hybrid PID/BFOA theoretically	0	0	0	0.04	0.035
Open loop system practically	6	14	0	3.6	2
Close loop system with PID practically	0.5	1	0.5	1.4	0.7
Close loop system with Hybrid PID/BFOA practically	0.25	0.3	0	0.9	0.55

From the table (3) above, it is show that the performance of the DC motor for open loop system for peak overshoot, the settling time, rising time state steady error are high. Manual optimization of PID controller gains (Kp=0.16, Ki=0.31 and Kd=0.0023) have been used and given that (p.o.s, tr, tss and

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ess) are improvement. Hybrid PID based BFOA with (Kp=0.18, Ki=0.29 and Kd=0.0015), that given (p.o.s, tr, tss and ess) are improved. The realized system performance appears to be near that of the theoretical ones except. The comparison of the results show that the proposed (PID based BFOA) method is the best.

III. CONCLUSION

The system (Buck converter and DC motor) has been design. Its mathematical model in state space form has been developed. The DC motor output speed response as an open-loop system has been analyzed. Two techniques have been used to improve the output speed response of the DC motor. PID controller tuning using trial and error method has been used. Hybrid PID controller based Bacterial Foraging Optimization Algorithm has been proposed also. The DC motor output speed response with the feedback controller and two technique has been studied. It has been seen that the response of the DC motor with PID based BFOA were better than PID controller. The computation time for the PID gains are very short using BFOA. The designed system with the controllers was implemented. The practical results are the near as the simulated results. Therefore one can conclude that PID based BFOA method is the best form.

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