DESIGN OF STATE FEEDBACK CONTROLLER BASED BACTERIAL FORAGING OPTIMIZATION TECHNIQUE FOR SPEED CONTROL OF DC MOTOR

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ABSTRACT: - The aim of this work is to design state feedback controller based on bacterial foraging optimization (BFO) technique for speed control of separately excited dc motor (SEDM). The social foraging behavior of Escherichia (E. Coli) bacteria has been used to optimize the controller performance by tuning it's parameters (state feedback controller gains K_1 & K_2).The SEDM state space model is simulated using MATLAB simulink toolbox. The SEDM is loading for different loads ranging from no-load to full-load to test the controller behavior and it's robustness for wide range of loadings variations. First the SEDM is simulated with feeding back the angular speed only (output feedback system), second is simulated with feeding back the armature current and angular speed (state feedback system). For both systems the controller's gains are tuned using BFO. The proposed controller results are compared with output feedback system results. The results show the superiority of state feedback controller based BFO versus output feedback system based BFO for SEDM speed control which leads to improve the transient and steady state performance of speed responses for SEDM with different loads.

Keywords: Bacterial Foraging Optimization (BFO), Escherichia (E. Coli) Bacteria, Separately Excited DC Motor (SEDM), State Space, Output Feedback, State Feedback.

1- INTRODUCTION

DC motor drives are widely used in applications requiring adjustable speed, good speed regulations and frequent starting, braking and reversing. Some important applications are rolling mills, paper mills, mine winders, hoists, machine tools, traction, printing presses, textile mills, excavators and cranes. Fractional horsepower DC motors are widely used as servo motors for positioning and tracking. Although, it is being predicted that AC drives will replace DC drives, however, even today the variable speed applications are dominated by DC drives because of lower cost, reliability and simple control. As per the control of DC motor,

there are lot of methods to control the speed and position of the motor [1]. Years ago, the majority of the small servomotors used for control purposes were ac. In reality, ac motors are more difficult to control, especially for position control, and their characteristics are quite nonlinear, which makes the analytical task more difficult. DC motors, on the other hand, are more expensive, because of their brushes and commutators, and variable-flux dc motors are suitable only for certain types of control applications [2]. DC machines are characterized by their versatility. By 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 [3, 4].

In convention control theory analysis of control systems is based on transfer functions and graphical approaches such as root locus, Bode and Nyquist plot. The input and output relationships are in the form of transfer function. In this approach of analysis initial conditions are considered zero (i.e., the system is initially at rest) and the time solution obtained is in a general form due to input only. For analyzing systems which are initially not at rest, multiple-input, multiple output transfer function approach is not adequate and not convenient. On the other hand, state variable analysis i.e., modern control theory, takes care of initial conditions and it is also possible to analyze time varying or time-invariant linear or non-linear, single or multiple input output systems [5]. The time-domain method, expressed in terms of state variables, can also be used to design a suitable compensation scheme for a control system. Typically, we are interested in controlling the system with a control signal u(t) that is a function of several measurable state variables. Then we develop a state variable controller that operates on the information available in measured form. This type of system compensation is quite useful for system optimization and will be considered [6].

During the last four decades, state feedback notion has attracted the attention of numerous researchers and has been very widely used in many control strategies. Due to the easiness of the control principle and its implementation, several methods were proposed to put some control strategies under a state feedback, as for example, predictive control, adaptive control, sliding mode control and high gain control. As high gain controller is computationally efficient, many works were proposed to put such control strategy under state feedback form [7].

In recent years, chemotaxis (i.e. the bacterial foraging behavior) as a rich source of potential engineering applications and computational model has attracted more and more attention. A few models have been developed to mimic bacterial foraging behavior and have

been applied for solving some practical problems. Among them, bacterial foraging optimization is a population-based numerical optimization algorithm presented by Passino [8]. Due to its unique dispersal and elimination technique can find favorable regions when the population involved is small. These unique features of the algorithms overcome the premature convergence problem and enhance the search capability. Hence, it is suitable optimization tool for power system controllers [9]. BFO is a simple but powerful optimization tool that mimics the foraging behavior of E. coli bacteria. Until now, BFO has been applied successfully to some engineering problems, such as optimal control, harmonic estimation, transmission loss reduction, and machine learning [8].

2- MATHEMATICAL MODEL OF SEPARATELY EXCITED D.C. MOTOR

The most commonly used DC machines are separately excited DC machines and permanent magnet DC machines. The main advantage of separately excited DC machines is that the armature and field windings are fed from different sources. This property allows obtaining the desired speed-torque characteristics. It is very common application to control the speed of DC motor by changing its terminal voltage. The armature current and field current, consequently the torque and flux, in these motors are controlled separately from each other. It allows motors to have high performance. In the system analysis, it is a desired property to use a linear model. Therefore, in the control of motor, the field current is taken as a constant value and the torque is directly proportional to the armature current. The motor drive system is controlled by only one variable, armature current [10]. In a separately excited dc motor, the field coil is supplied from a different voltage source than that of the armature coil. The field circuit normally incorporates a rheostat through which the field current, and thus the motors characteristics, can be externally controlled. This motor is mainly suitable for two types of loads; those that require constant torque for speed variations up to full-load speed, and those whose power requirements are constant for speed variations above nominal speed. The field current is constant, and then the flux must be constant [3].

The continuous-time electromechanical equations related to a separately excited DC motor circuit in Figure (1) are given in Eqs. (1a) and (1b). Eq. (1a) is the electrical circuit equation of armature. Eq. (1b) is the mechanical equation of DC motor with load.

$$E_b + R_a i_a(t) + L_a \frac{di_a}{dt} = V_a \qquad \qquad \dots(1a)$$

$$B\omega_m + J\frac{d\omega_m}{dt} = T_e - T_L = T_a \qquad \qquad \dots (1b)$$

where L_a is the armature inductance; R_a the armature resistance; i_a the armature current, V_a the terminal voltage of DC motor, E_b the back emf; T_L the load torque, T_e the

electromechanical (air gap) torque, T_a the acceleration torque, J the torque of inertia, B the viscous friction coefficient and ω_m is the speed of motor.

The electrical variable of DC motor is armature current, the mechanical variable is speed. In Eqs. (1a) and (1b), the back emf (E_b) is proportional to speed, the produced torque (T_e) is proportional to armature current as shown in Eqs.(2a) and (2b). Where, K_b is equal for both torque constant and back emf constant in a separately excited DC motor.

$$E_b = K_b \, \omega_m \qquad \qquad \dots (2a)$$

$$T_e = K_b \, i_a \qquad \qquad \dots (2b)$$

By substituting the back emf, E_b, in Eq. (2a) into Eq. (1a) and the produced torque, T_e, in Eq. (2b) into Eq. (1b), the electrical circuit equation of armature and the mechanical equation of DC motor are rearranged as;

$$K_b \, \omega_m + R_a i_a(t) + L_a \frac{di_a}{dt} = V_a \qquad \qquad \dots (3a)$$

$$B\omega_m + J\frac{d\omega_m}{dt} = K_b \, i_a - T_L \qquad \qquad \dots (3b)$$

Eqs. (3a) and (3b) constitute the dynamic model of DC motor with load. By taking account these equations together, the state space model of electromechanical system is obtained as follows [10].

$$\frac{d}{dt}\begin{bmatrix} i_a \\ \omega \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{K_b}{L_a} \\ \frac{K_b}{J} & -\frac{B}{J} \end{bmatrix}\begin{bmatrix} i_a \\ \omega \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} & 0 \\ 0 & -\frac{1}{J} \end{bmatrix}\begin{bmatrix} V_a \\ T_L \end{bmatrix} \qquad \dots (4)$$

3- DESCRIPTION OF E COLI BACTERIUM MOTILITY BEHAVIOR

E. coli bacterium can move in two different ways: it can "run" (swim for a period of time) or it can "tumble," and it alternates between these two modes of operation its entire lifetime (i.e., it is rare that the flagella will stop rotating). If the flagella rotate clockwise, each flagellum pulls on the cell and the net effect is that each flagellum operates relatively independent of the others and so the bacterium "tumbles" about (i.e., the bacterium does not have a set direction of movement and there is little displacement) as shown in Figure (2-a). To tumble after a run, the cell slows down or stops first. Since bacteria are so small they experience almost no inertia, only viscosity, so that when a bacterium stops swimming, it stops within the diameter of a proton. Call the time interval during which a tumble occurs a "tumble interval." If the flagella move counterclockwise, their effects accumulate by forming a "bundle" (it is thought that the bundle is formed due to the viscous drag of the medium) and hence, they essentially make a "composite propeller" and push the bacterium so that it runs (swims) in one direction (Figure (2-a)).

4- CHEMOTAXIS AND CLIMBING NUTRIENT GRADIENTS

The motion patterns (called "taxes") that the bacteria will generate in the presence of chemical attractants and repellents are called "chemotaxes" if an *E. coli* is in some substance that is neutral, in the sense that it does not have food or noxious substances, and if it is in this medium for a long period of time (e.g., more than one minute), then the flagella will simultaneously alternate between moving clockwise and counterclockwise so that the bacterium will alternately tumble and run. This alternation between the two modes will move the bacterium, but in random directions, and this enables it to "search" for nutrients (Figure (2-b)). Next, suppose that the bacterium happens to encounter a nutrient gradient (e.g., serine) as shown in Figure (2-c). The *change* in the concentration of the nutrient triggers a reaction such that the bacterium will spend more time swimming and less time tumbling. As long as it travels on a positive concentration gradient (i.e., so that it moves towards increasing nutrient concentrations) it will tend to lengthen the time it spends swimming (i.e., it runs farther). Finally, suppose that the concentration of the nutrient is constant for the region it is in, after it has been on a positive gradient for some time. In this case, after a period of time (not immediately), the bacterium will return to the same proportion of swimming and tumbling as when it was in the neutral substance so that it returns to its standard searching behavior [11].

5- BACTERIAL FORAGING OPTIMIZATION

The Bacterial Foraging Optimization (Passino 2002) is based on foraging strategy of *E. coli* bacteria. The foraging theory is based on the assumption that animals obtain maximum energy nutrients 'E' in a supposed to be a small time 'T'. The basic Bacterial Foraging Optimization consists of three principal mechanisms; namely chemotaxis, reproduction and elimination-dispersal. The brief descriptions of these steps involved in Bacterial Foraging are presented below [12]. To define our optimization model of E. coli bacterial foraging, we need to define a population (set) of bacteria, and then model how they execute chemotaxis, swarming, reproduction, and elimination/dispersal. After doing this, we will highlight the limitations (inaccuracies) in our model [11].

6- CHEMOTAXIS

In the classical BFO, a unit walk with random direction represents a "tumble" and a unit walk with the same direction in the last step indicates a "run". Suppose $\theta^i(j, k, \ell)$ represents the bacterium at j^{th} chemotactic, k^{th} reproductive, and ℓ^{th} elimination-dispersal step. C(i), namely, the run-length unit parameter, is the chemotactic step size during each run

or tumble. Then, in each computational chemotactic step, the movement of the ith bacterium can be represented as: $\theta^i(j+1,k,\ell) = \theta^i(j,k,\ell) + C(i) \dfrac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}}$ …(5)

where $\Delta(i)$ is the direction vector of the jth chemotactic step. When the bacterial movement is run, $\Delta(i)$ is the same with the last chemotactic step; otherwise, $\Delta(i)$ is a random vector whose elements lie in $[-1, 1]$. With the activity of run or tumble taken at each step of the chemotaxis process, a step fitness, denoted as $J(i,j,k,\ell)$, will be evaluated [8].

7- SWARMING

During the movements, cells release attractants and repellents to signal other cells so that they should swarm together, provided that they get nutrient-rich environment or avoided the noxious environment. The cell-to cell attraction and repelling effects are denoted as:

$$J_{cc}(\theta,P(j,k,\ell)) = \sum_{i=1}^{S} J_{cc}^i(\theta, \theta^i(j, k, \ell)) = \sum_{i=1}^{S}\left[-d_{attract}\, exp\left(-w_{attract} \sum_{m=1}^{p}(\theta_m - \theta_m^i)^2\right)\right]$$
$$+ \sum_{i=1}^{S}\left[-h_{repellant}\, exp\left(-w_{repellant} \sum_{m=1}^{p}(\theta_m - \theta_m^i)^2\right)\right] \qquad …(6)$$

where $J_{cc}(\theta,P(j,k,\ell))$ is the objective function value to be added to the actual objective function to present time varying objective function, S is the total number of bacteria, P is the number of variables involved in the search space, $\theta = [\theta_1, \theta_2, … , \theta_P]^T$ is a point on the optimization domain, and θ_m^i is the mth components of the ith bacterium position θ^i. $d_{attract}$, $w_{attract}$, $h_{repellant}$, and $w_{repellant}$ are different coefficients used for signaling [13].

8- REPRODUCTION AND ELIMINATION/DISPERSAL

After N_c chemotactic steps, a reproduction step is taken. Let N_{re} be the number of reproduction steps to be taken. For convenience, we assume that S is a positive even integer. Let, Sr= S / 2 be the number of population members who have had sufficient nutrients so that they will reproduce (split in two) with no mutations. For reproduction, the population is sorted in order of ascending accumulated cost (higher accumulated cost represents that it did not get as many nutrients during its lifetime of foraging and hence, is not as "healthy" and thus unlikely to reproduce); then the S_r least healthy bacteria die and the other S_r healthiest bacteria each split into two bacteria, which are placed at the same location. Other fractions or approaches could be used in place of Equation (7) this method rewards bacteria that have encountered a lot of nutrients, and allows us to keep a constant population size, which is convenient in coding the algorithm. Let N_{ed} be the number of elimination-dispersal events, and for each such event event, each bacterium in the population is subjected to elimination-dispersal with probability p_{ed}. We assume that the frequency of chemotactic steps is greater than the frequency of reproduction steps, which is in turn greater in frequency than

elimination-dispersal events (e.g., a bacterium will take many chemotactic steps before reproduction, and several generations may take place before an elimination dispersal event) [11]. Figure (3) shows the Flowcharts of foraging process.

9- OUTPUT FEEDBACK AND STATE FEEDBACK CONTROLLERS

Output feedback control is a state feedback control where the only measurable state introduced in the control law is the output of the system and other states are estimated on line [7]. The concept of feed-backing all the state variables back to the input of the system through a suitable feedback matrix in the control strategy is known as the full-state variable feedback control technique [15].

Although output feedback is sufficient for many systems, state feedback is very useful for multi input multi-output systems and for control systems with optimal constraints such as those requiring minimal control effort or minimum time to final value [16]. The main difference between the state and output feedback methods are the following. The state feedback method has the advantage over the output feedback method in that it has greater degrees of freedom in the controller parameters [17].

10- SIMULATION AND RESULTS

A state space representation of SEDM is simulated using MATLAB toolbox based on it's dynamic electrical and mechanical equations. A state model is derived by defining two states: the armature current (i_a) and the motor speed (ω). The speed control of SEDM is done by varying armature voltage (armature voltage control method). The output feedback and state feedback controllers are designed using BFO technique by tuning it's gains. The results are compared between the motor response when feeding back only the motor speed (output feedback) and the motor response when both armature current and motor speed are feeding back (state feedback). The SEDM are loaded at different loads ranging from no-load to full-load for checking the controller's performance and robustness for load variations.

11- DESIGN REQUIREMENTS

Since the most basic requirements of a motor are that it should rotate at the desired speed, the steady-state error e_{ss} of the motor speed should be less than 2%, the settling time T_s for 2% criterion should be less than 0.2sec, percent overshoot less than 50%. The performance index used in this work is ITAE.

12- SIMULATION OF SEDM USING MATLAB/SIMULINK

The proposed state space model is developed from the mechanical and electrical dynamic equations of the SEDM, equations (3a) & (3b). The simulink of the SEDM state space model is shown in Figure (4).

13- SEDM RATING & PARAMETERS

The parameters values of SEDM used in the simulation is taken from MATLAB/Toolbox and shown in Table (1).

14- SEDM LOADS

The SEDM are loaded for four different loads (assumed). These loads are :(no-load, light load (0.3 of full-load), half full load (0.5 of full-load), and full-load). Figure (5) and Figure (6) show the complete closed loop simulink model of SEDM with output feedback and state feedback controllers respectively.

15- TUNING OF OUTPUT FEEDBACK AND STATE FEEDBACK CONTROLLERS BASED BFO

The parameters of BFO algorithm are listed in Table (2) for both controllers, while the obtained controller's parameters are listed in Table (3).

Figures (7) and Figures (8) shows the bacteria (S=10) motility behavior (bacteria trajectories) and the average cost plots for each generation for two elimination/dispersal events (Ned =2) for tuning the two controller's parameters respectively. The bacteria's motility behavior depends on bacteria average cost achieved during each iteration (chemotactic step N_c). The generation number represent reproduction step (N_{re}) while iteration j represent chemotactic steps (N_c). These bacteria motility behavior achieved for two elimination/dispersal events (Ned =2). For every generation at the end of all chemotactic steps, the controller's parameters are obtained with best cost (or fitness) value which represents the best value of compensator parameters.

Figures (9), Figures (10) and Figures (11) show the speed step responses (state two (x_2)of state space model), armature current (state one (x_1) of state space model) and electromagnetic torque of SEDM for different loads with output feedback and state feedback controllers based on BFO technique respectively.

The time response specifications of SEDM speed response are listed in Table (4) for output feedback and state feedback controllers with different loading conditions.

From Table (4) it is clearly that, the transient and steady state specifications are improved of SEDM with tuned state feedback controller versus tuned output feedback controller for different loads. Due to the search ability and fast convergence for BFO behavior, both controllers performance are slightly change although loading SEDM from no-load to full-load which make both controllers robust for any loading conditions.

16- CONCLUSIONS

In this work, BFO technique has been used to design output feedback and state feedback controllers for speed control of SEDM. BFO is used to find optimal controller parameters (K, K_1 and K_2). The results are compared for both controllers. The SEDM is simulated using state space model and loading for different loads ranging from no-load to full-load to test the controller robustness for load variation conditions. From simulation results the following tips can be concluded:

1) The BFO technique is robust and efficient for controllers tuning.

2) BFO required less execution time, due to the small numbers of bacterial foraging parameters and fast convergence ability.

3) BFO has fast convergence due to the bacteria social behavior for finding nutrient and it is efficient tool for optimization problems.

4) The proposed controller (state feedback) superior than output feedback controller due to improvement in transient and steady state specifications.

5) The proposed controllers are robust for wide range of loading conditions.

6) The proposed controller improved the time response specifications for speed control purpose of SEDM for different loads.

7) BFO technique has potential to be useful for other practical optimization problems (e.g., engineering design, online distributed optimization in distributed computing, and cooperative control) as social foraging models work very well in such environments.

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Table (1): SEDM parameters.

Motor ratings and parameters	values
Power	10 hp
Armature voltage	500V
Speed	1750 R.P.M.
Field voltage (V_f)	300 V
Armature resistance (R_a)	4.712Ω
Armature inductance (L_a)	0.05277 H
K_b	2.242
Inertia of the rotor (J)	0.04251 Kg.m^2
damping coefficient (B)	0.003406 N.m.s

Table (2): BFO parameters used in tuning PID controller.

BFO parameters	Output feedback Parameters values	State feedback Parameters values
Number of bacteria in the population (s)	10	10
The length of swim (N_s)	2	2
Number of reproduction steps (N_{re})	4	4
Number of chemotactic step (N_c)	10	10
Number of elimination/dispersal events (N_{ed})	2	2
Number of bacteria splits per generation (S_r)	s/2	s/2
Probability of dispersal occurrence (P_{ed})	0.25	0.13
Height of repellent effect (h_{rep})	0.1	0.1
Width of repellent effect ($w_{rep.}$)	10	10
Width of attractant effect ($w_{attr.}$)	0.2	0.2
Width of attractant effect ($d_{attr.}$)	0.1	0.1

Table (3): Controller's parameters

Controller parameters	Output feedback	State feedback
K	250.8	0
K_1	0	593.782
K_2	0	0.0248

Table (4): Time response specifications.

	Rise time (m sec.)	Peak time (m sec.)	% Overshoot	Settling time (m sec.)
SEDM at no-load				
Output feedback	3.3501	5.8993	72.67	89.7
State feedback	2.457	3.9105	44.51	18.5
SEDM at light-load				
Output feedback	3.3829	5.876	71.85	101.5
State feedback	2.4745	3.8963	43.66	18.7
SEDM at half full-load				
Output feedback	3.4044	5.8507	71.2	102.1
State feedback	2.4861	3.8801	43.02	25.5
SEDM at full-load				
Output feedback	3.458	5.7929	69.5	124.3
State feedback	2.5145	3.8365	41.33	34.1
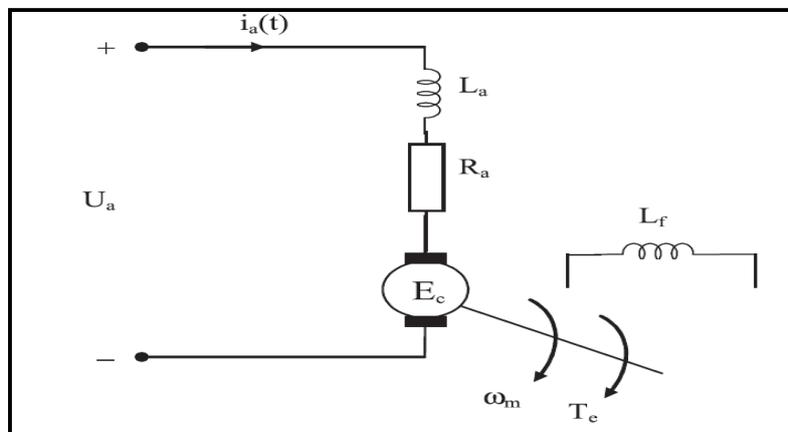
Figure (1): Armature equivalent circuit of DC motor.
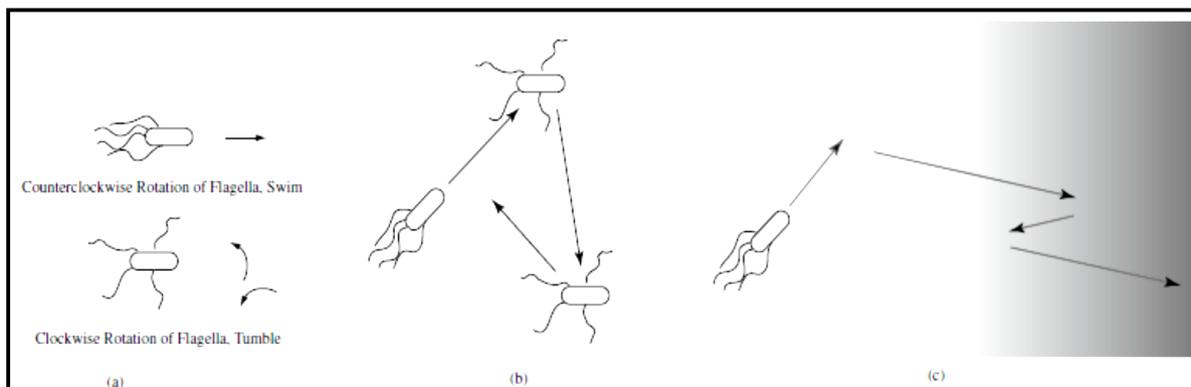
Figure (2): Bundling phenomenon of flagella shown in (a), swimming and tumbling behavior of the *E. coli* bacterium is shown in (b) in a neutral medium and in (c) where there is a nutrient concentration gradient, with darker shades indicating higher concentrations of the nutrient.

(a) Flow chart of foraging process

(c) Flow chart of reproduction steps

(b) Flow chart of chemotactic steps
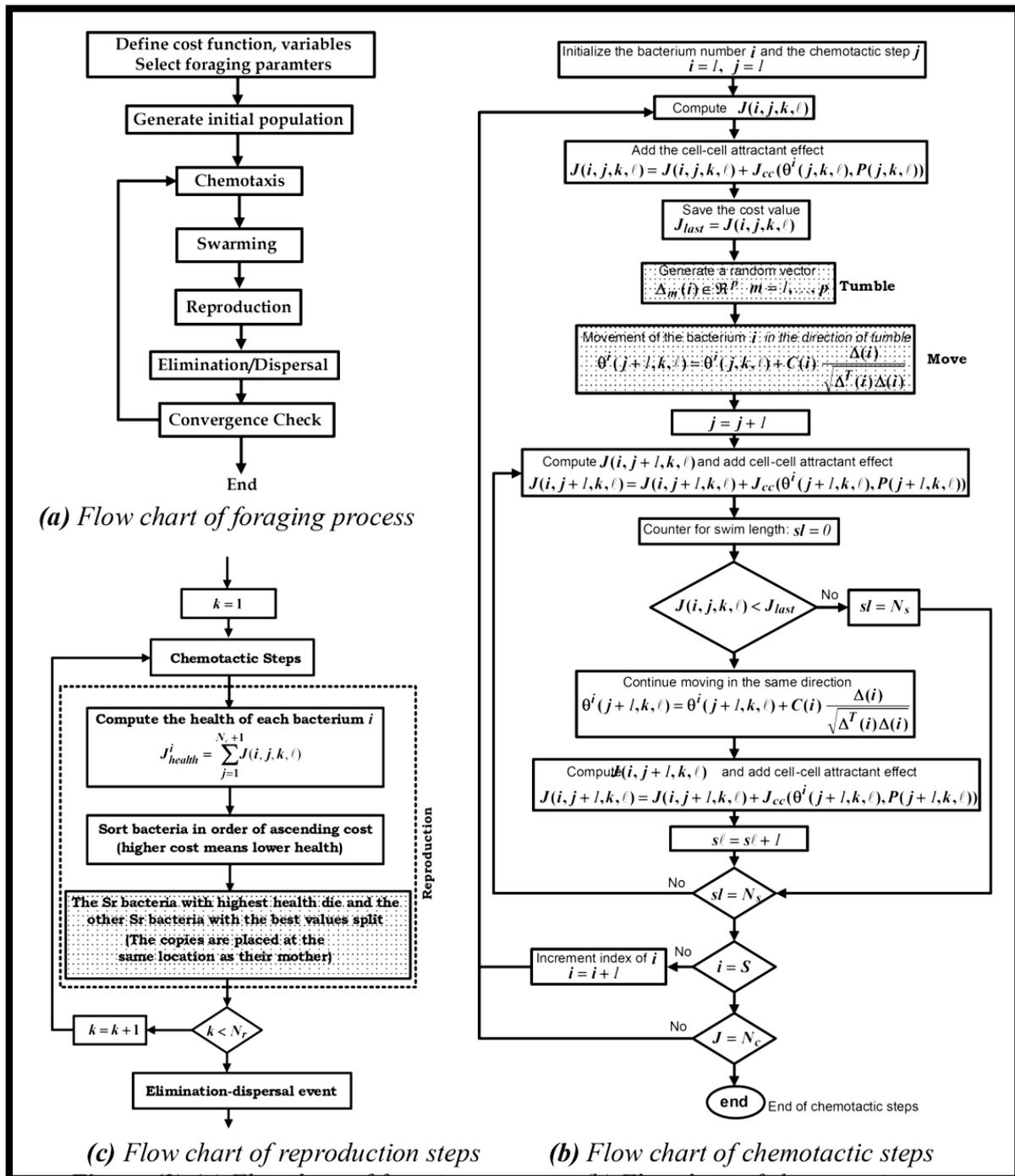
Figure (3): (a) Flowchart of foraging process (b) Flow chart of chemotactic steps (c) Flowchart of reproduction steps [14]
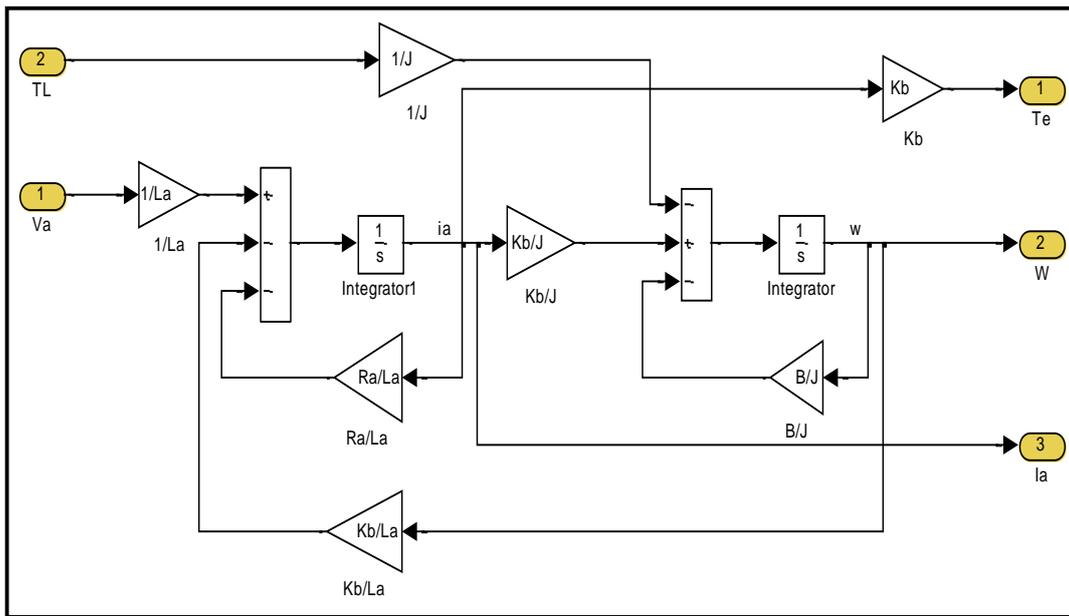
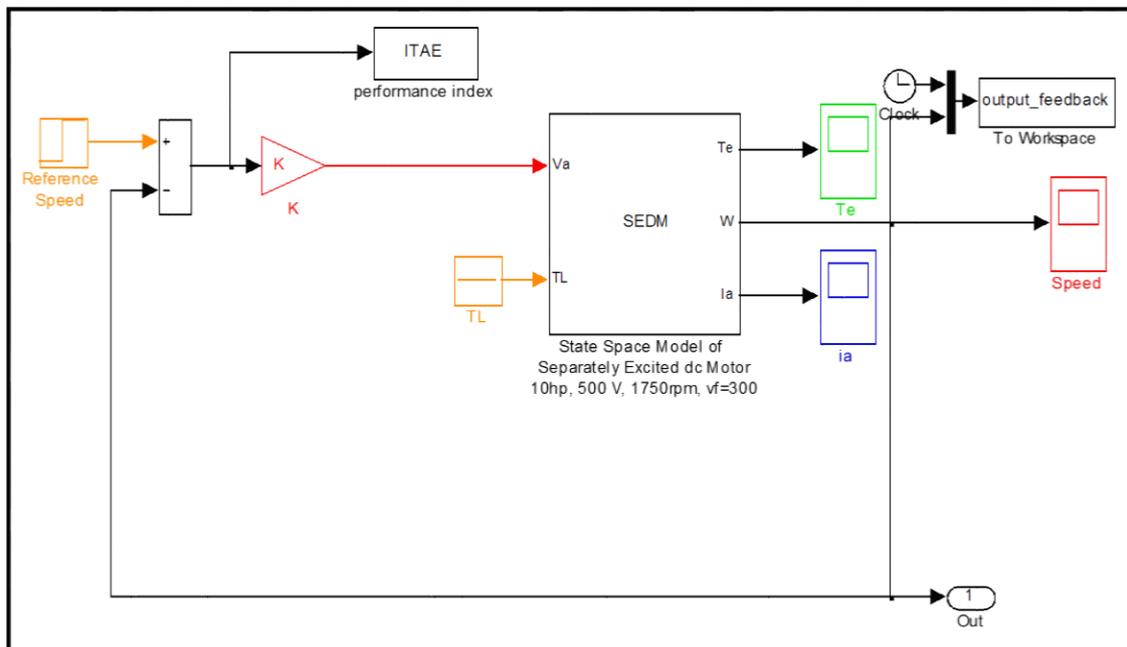**Figure (4):** Simulink of SEDM state space model

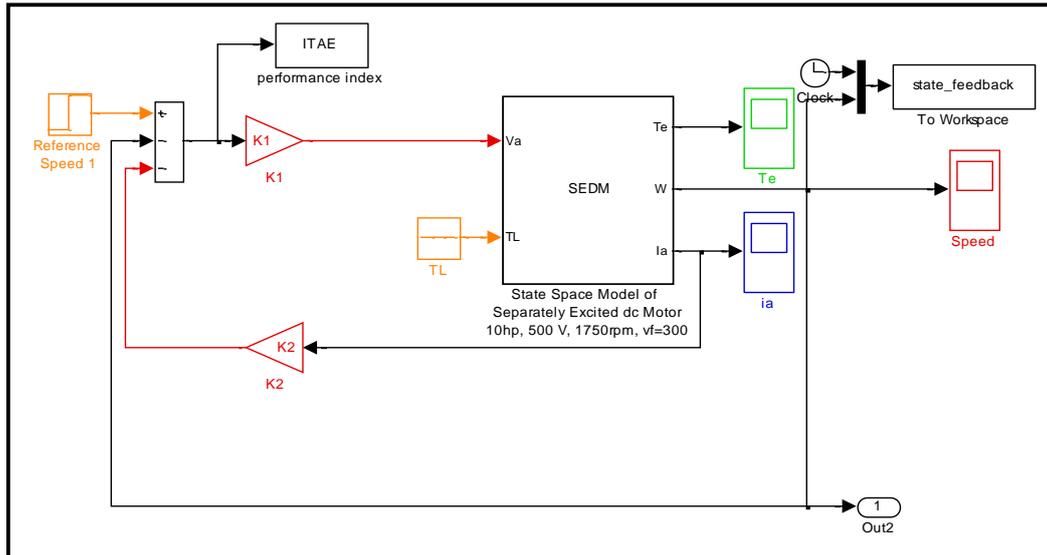**Figure (5):** Closed loop speed control system of SEDM with output feedback controller

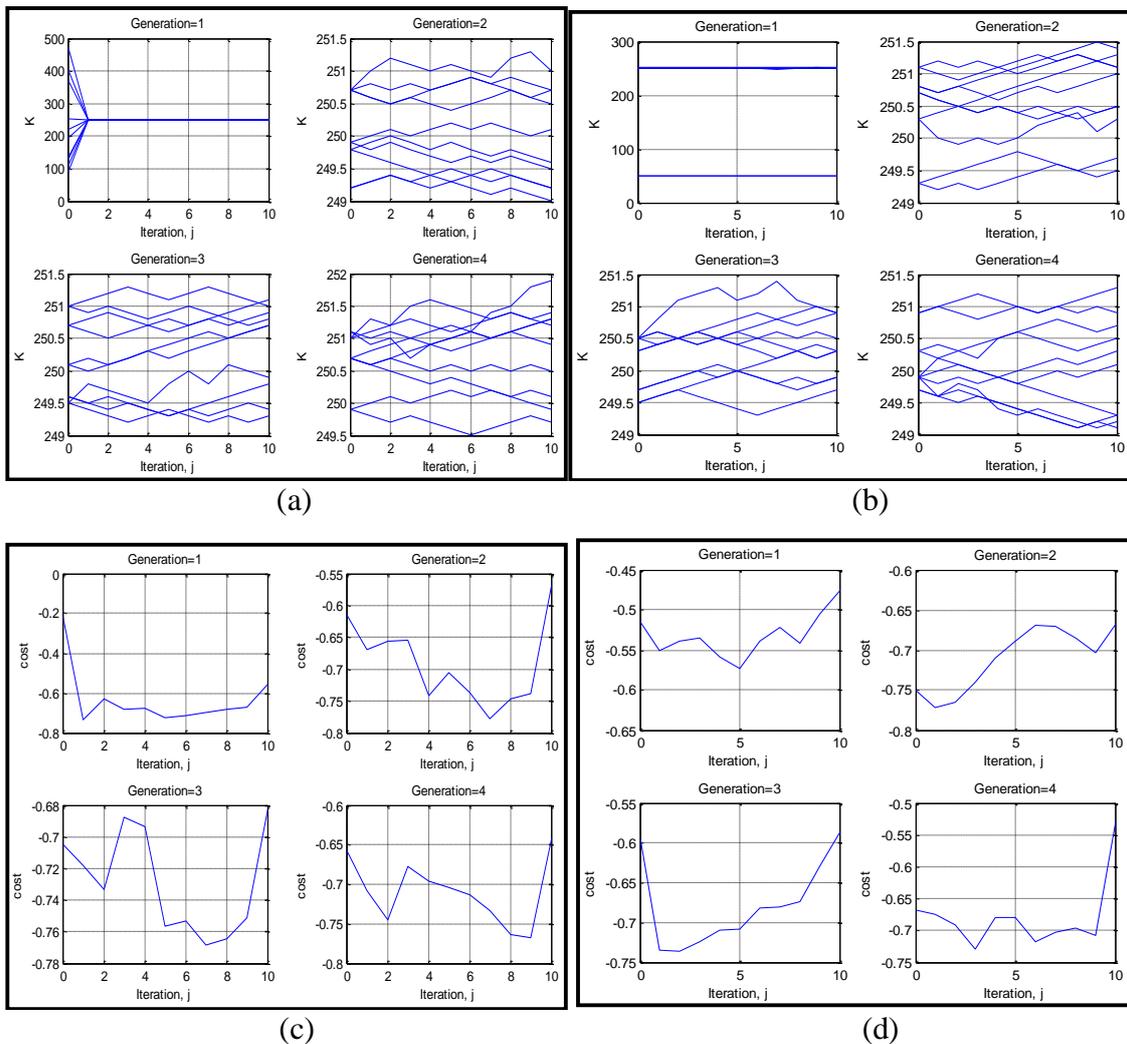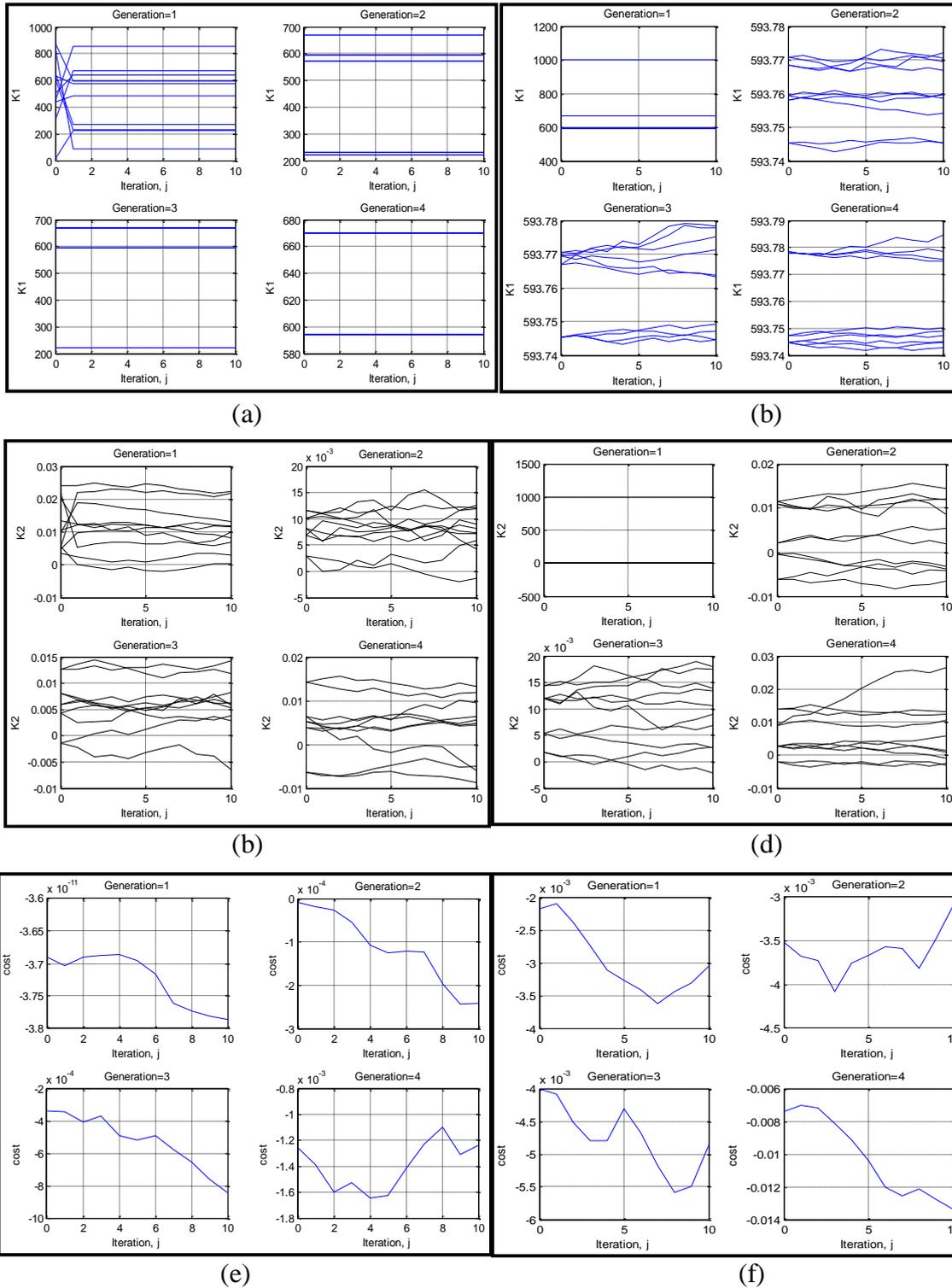**Figure (6):** Closed loop speed control system of SEDM with state feedback controller


(a)

(b)

(c)

(d)

Figures (7): Bacteria trajectories and average cost plot for bacteria trajectories for tuning
output feedback controller
(a) Bacteria trajectories for first elimination/dispersal event (for gain K)
(b) Bacteria trajectories for second elimination/dispersal event (for gain K)
(c) Average cost for first elimination/dispersal event
(d) Average cost for second elimination/dispersal event

(a)

(b)

(b)

(d)

(e)

(f)

Figures (8): Bacteria trajectories and average cost plot for bacteria trajectories for tuning
state feedback controller

(a) Bacteria trajectories for first elimination/dispersal event (for gain K1)

(b) Bacteria trajectories for second elimination/dispersal event (for gain K1)

(c) Bacteria trajectories for first elimination/dispersal event (for gain K2)

(d) Bacteria trajectories for second elimination/dispersal event (for gain K2)

(e) Average cost for first elimination/dispersal event

(f) Average cost for second elimination/dispersal event
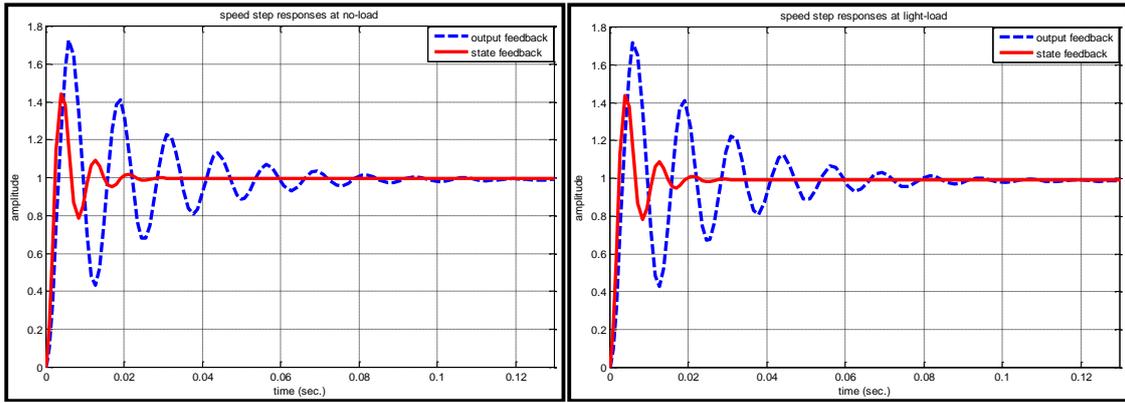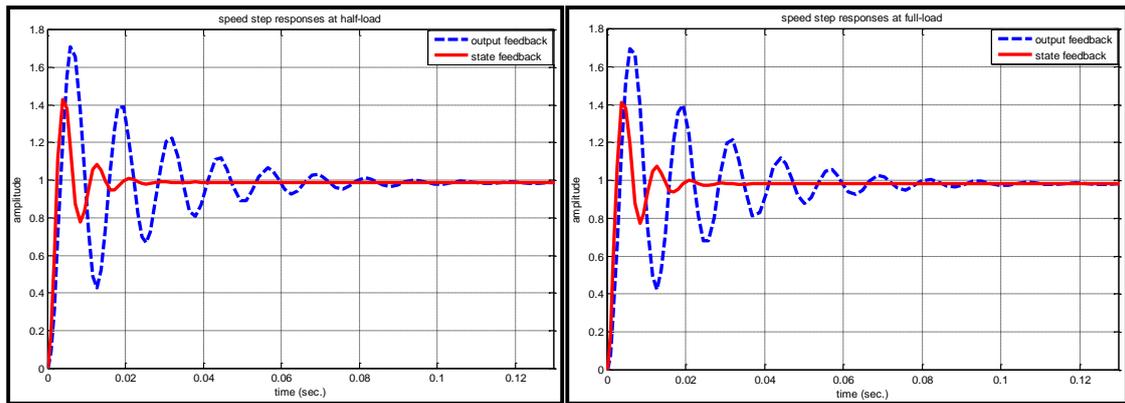
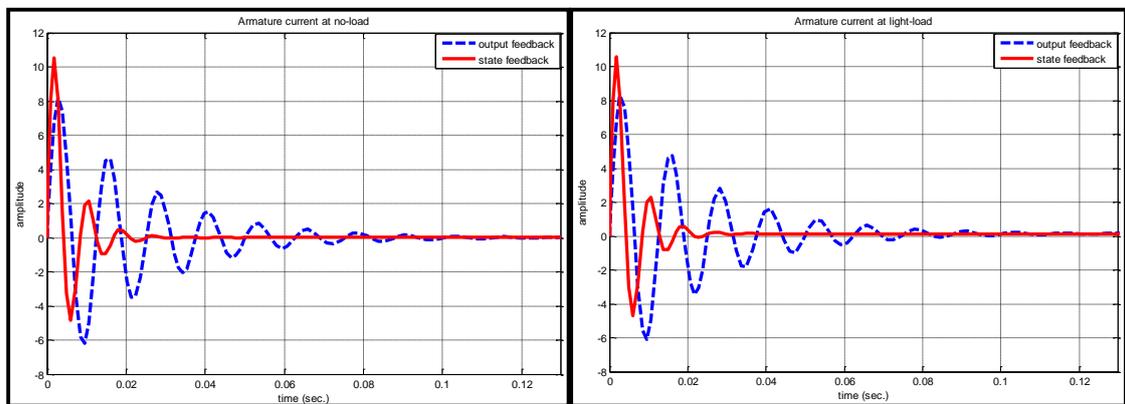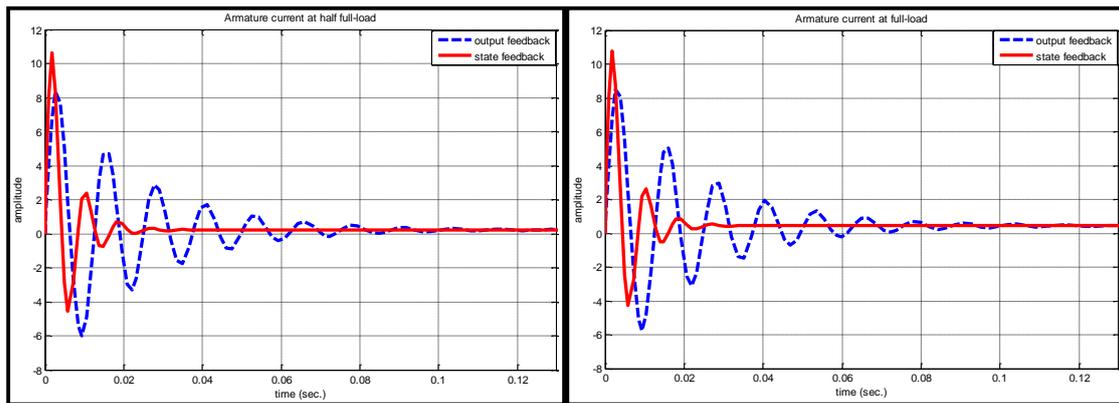**Figures (9):** Speed responses of SEDM with output feedback and state feedback controllers
    (a) SEDM at no-load
    (b) SEDM at light load
    (c) SEDM at half full-load
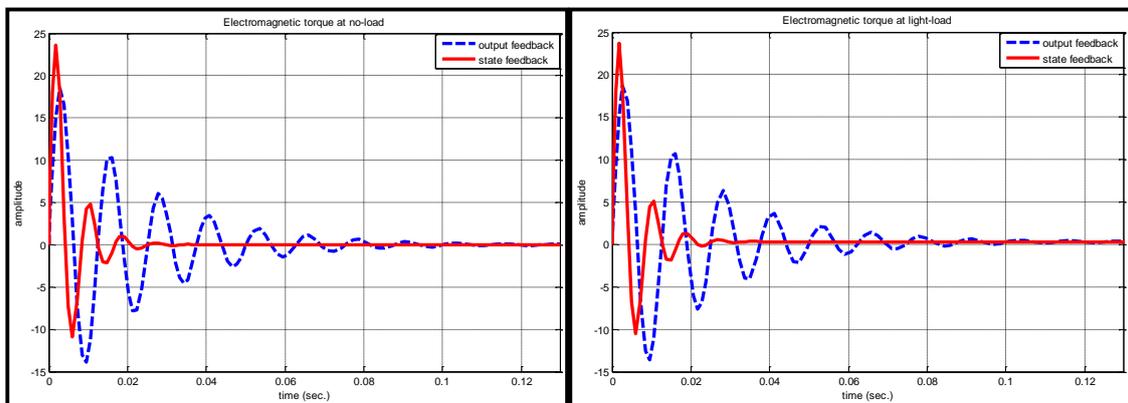   (d) SEDM at full-load

(c)   (d)

Figures (10): Armature current of SEDM with output feedback and state feedback controllers
        (a) SEDM at no-load
        (b) SEDM at light load
        (c) SEDM at half full-load
        (d) SEDM at full-load
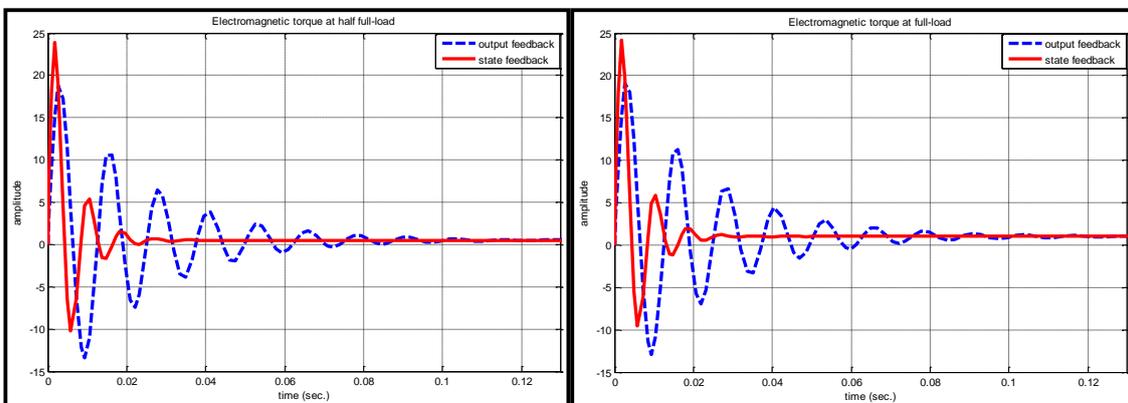

(a)   (b)

(c)   (d)

Figures (11): Torque of SEDM with output feedback and state feedback controllers
        (a) SEDM at no-load
        (b) SEDM at light load
        (c) SEDM at half full-load
        (d) SEDM at full-load

تصميم مسيطر التغذية المرتدة للحالة المعتمد على تقنية أمثلية تغذية البكتيريا للسيطرة على سرعة محرك تيار مستمر

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الخلاصة

الهدف من هذا العمل تصميم مسيطر التغذية المرتدة للحالة المعتمد على تقنية أمثلية تغذية البكتيريا (BFO) للسيطرة على سرعة محرك تيار مستمر منفصل التغذية (SEDM). تم الاعتماد على السلوك الاجتماعي لبكتريا من نوع القولونية (اي كولي) لتحسين أداء المسيطر عن طريق ضبط معاملاته (معاملات مسيطر التغذية المرتدة للحالة K_1 & K_2). تمت محاكاة نموذج فضاء الحالة (state space model) باستخدام صندوق الادوات لبرنامج الماتلاب.تم تحميل المحرك بعدة احمال مختلفة تتراوح من حالة اللاحمل الى حالة الحمل الكامل و ذلك لاختبار اداء المسيطر و متانته لمدى واسع من تغيير الاحمال. اولا تمت محاكاة محرك التيار المستمر منفصل التغذية بتغذية مرتدة للسرعة الزاوية فقط (نظام التغذية الراجعة للخرج)، ثانيا تمت محاكاته بتغذية مرتدة لتيار الجزء المنتج و السرعة الزاوية (نظام التغذية المرتدة للحالة). تم ضبط معاملات المسيطرات للنظامين باستخدام تقنية أمثلية تغذية البكتيريا. نتائج المسيطر المقترح تمت مقارنتها مع نتائج نظام التغذية الراجعة للخرج. اظهرت النتائج افضلية مسيطر التغذية الراجعة للحالة و المعتمد على تقنية أمثلية تغذية البكتيريا ازاء نتائج نظام التغذية الراجعة للخرج و المعتمد ايضا على تقنية أمثلية تغذية البكتيريا للسيطرة على سرعة محرك تيار مستمر منفصل التغذية و التي ادت الى تحسين الحالة العابرة و المستقرة لاستجابة السرع للمحرك لمختلف الاحمال.

الكلمات المفتاحية: أمثلية تغذية البكتريا (BFO) ، البكتريا القولونية، محرك تيار مستمر منفصل التغذية، فضاء الحالة، نظام التغذية الراجعة للخرج، التغذية المرتدة الحالة.