

DEA-Based Variable Structure Position Control of DC Servo Motor

Ladan Maijama'a, Jibril D. Jiya, Ejike C. Anene

Abstract—This paper presents Differential Evolution Algorithm (DEA) based Variable Structure Position Control (VSPC) of Laboratory DC servomotor (LDSCM). DEA is employed for the optimal tuning of Variable Structure Control (VSC) parameters for position control of a DC servomotor. The VSC combines the techniques of Sliding Mode Control (SMC) that gives the advantages of small overshoot, improved step response characteristics, faster dynamic response and adaptability to plant parameter variations, suppressed influences of disturbances and uncertainties in system behavior. The results of the simulation responses of the VSC parameters adjustment by DEA were performed in Matlab Version 2010a platform and yield better dynamic performance compared with the untuned VSC designed.

Keywords—Differential evolution algorithm, laboratory DC servomotor, sliding mode control, variable structure control.

I. INTRODUCTION

POSITION control is a classical problem with wide industrial and Institutional applications. Practically, every aspect of human day-to-day activities is affected by some types of control system. They are seen in all sectors of industries such as quality control of manufactured goods, power system, robotics etc. Servo motors are used in a variety of applications in industrial electronics and robotics that includes precision positioning as well as speed control [1].

Electric motor servo systems are indispensable in modern industries. A D.C machine, in general is bulky and expensive compared to an A.C machine. Due to its excellent speed control characteristics, the DC motor has been widely used in industry even though its maintenance costs are higher than that of the induction motor. As a result, position control of DC motor has attracted considerable research and several methods have evolved. PID controllers have been widely used for speed and position control of DC motors [2]. In this study, the LDSCM used as a Plant for the analysis and design in this experiment is the Feedback DC Modular MS150 kits [3].

The variable structure control strategy using the sliding-mode has been focused on many studies and research for the control of the DC servo drive systems by [4]. The basic concept of the VSC is that of the Sliding Mode Control (SMC). Switching Control Function (SCF) is generally

designed to generate sliding surfaces, or sliding modes. When this is attained the switching functions keep the trajectory on sliding surfaces and the closed loop system becomes insensitive, to certain level of parameter variations and disturbances. So the control laws are designed such that the system trajectory always reaches the sliding mode. The system dynamics often employed is those of reduced order which are insensitive to parameter variations and external disturbances [5].

In recent years, differential evolution algorithm (DEA) procedures have been attracting significant attention from the researchers as they have been found to be extremely effective in solving control optimization problems. This is due to its simple structure, ease of use, immediate accessibility to practical applications, speed and robustness. This paper discusses the application of Differential Evolution (DE) to tune parameters of a VSC for position control of a DC servo motor.

II. PLANT SYSTEM DESCRIPTION OF LDSCM

A. Dynamic Model of the System

Motor to be controlled is a separately excited dc motor as shown in Fig. 1 with its various associated parameters.

1. Mathematical Model

The current in the field coil and the armature are independent of one another. As a result, these motors have excellent speed and position control [1]. Since one is interested in controlling the shaft position, θ_m , the transfer function of the DC servo motor as in [5] is,

$$\frac{\theta_m(s)}{E_a(s)} = G(s) = \frac{K}{s(ST+1)} \quad (1)$$

where, K , T , θ_m , E_a , are the gain, time constant, angle (output displacement), applied voltage respectively. S is d/dt . Fig. 2 gives the closed loop block diagram that gives the system's closed loop transfer function in (2). That is used for the designing of the controller, where U and ω are the motor control input and angular velocity respectively.

$$\frac{\theta_m(s)}{U(s)} = \frac{K}{(TS^2 + S + K)} \quad (2)$$

III. DE-BASED VSC

In this paper DE is used to find the optimal parameters of VSC position control system of a LDSCM. Fig. 3 shows the block diagram of optimal VSC for LDSCM, with error E .

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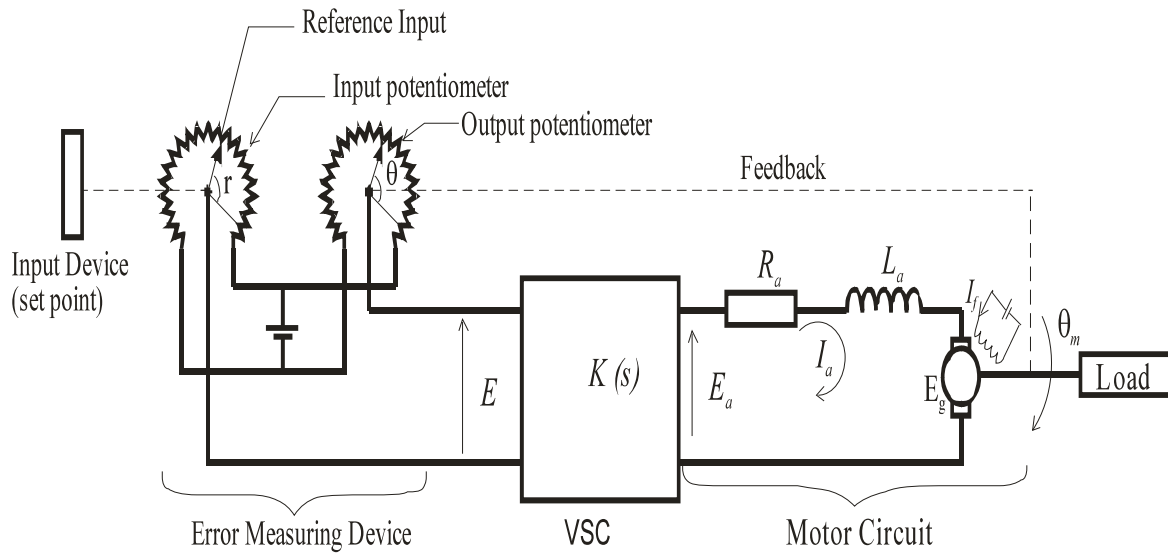


Fig.1 Schematic model of the system

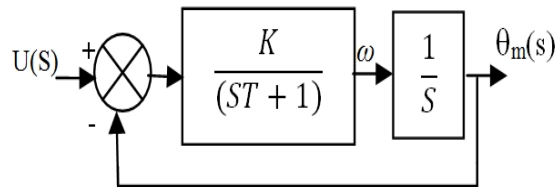


Fig. 2 Closed loop Motor block diagram

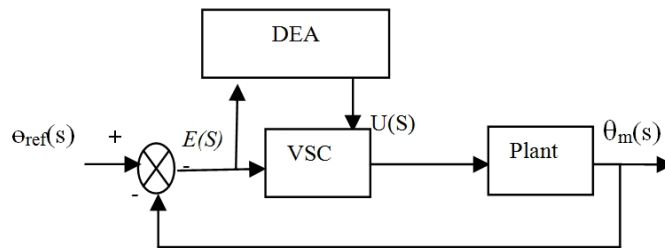


Fig. 3 Optimal DE-based VSC system block diagram

The gains of the VSC are usually determined by trial and error for untuned system and for tuned system the proposed DEA is used for optimal selection of VSC parameters.

A. Variable Structure Control

The fundamental theory of variable structure system (VSS) may be found in [6], [7]. However, VSC is a control method in which the structure of feedback is altered to get desired output for the position of DC motor [8].

SMC concept is a special class of the control mechanism characterized by a discontinuous control action, which changes the structure upon reaching a set of sliding surfaces [9]. That is to say in VSS the system is assumed to consist of subsystems known as structures. These structures are changed or switched depending on the state of the system as stated in [10].

Equation (2) shows that the plant is a second order plant with a feedback and a variable structure system takes the general system of Canonical Equations whose free motion is described by;

$$\dot{X}_i = X_{i+1}, \quad 1 \leq i \leq n-1 \quad (3)$$

$$\dot{X}_n = -\sum_{i=1}^n a_i X_i - bu \quad (4)$$

$$u = \sum_{i=1}^n \psi_i X_i \quad (5)$$

The feedback control law u depends on the state variables X_i where: ψ_i is a variable parameter that is given in (6), which takes values of the gains α and β as the structure changes. i.e.

$$\psi_i = \begin{cases} \alpha_i & \text{if } X_i \sigma > 0, \quad 1 \leq k \leq (n-1) \\ \beta_i & \text{if } X_i \sigma < 0, \end{cases} \quad (6)$$

These values switch on the hyper plane or manifold $\sigma \approx 0$ as illustrated in Fig. 4.

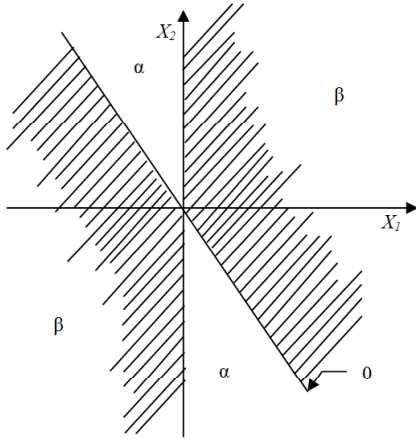


Fig. 4 Phase Plane of the plant [6]

The Switching function σ is given by;

$$\sigma = \sum_{i=1}^k C_i X_i \quad (7)$$

where: C_i is the coefficient in the switching function defines the characteristic equation of the sliding mode, (i.e. allowing the control to depend on the state X_i)

B. VSC Law

The block diagram of VSC for the position control of DC motor in sliding mode is shown in Fig. 5 using the Canonical Equations (3)-(7) and Fig. 2. From Fig. 5, (8) was deduced.

$$\dot{X}_1 = \frac{a}{b} X_2 \quad (8)$$

$$\dot{X}_2 = \frac{1}{T}(bku - X_2) \quad (9)$$

where $X_1 = a\theta_m$, $X_2 = b\omega$, and a and b are the gains of potentiometer angle and tachometer (speed transducers) respectively, and θ_m is the desired angle to be achieved, u is the input signal (control effort). The design problem considered is the determination of α , β , and C such that the system state will be brought from any initial position in the phase plane to the switching line $\sigma = 0$.

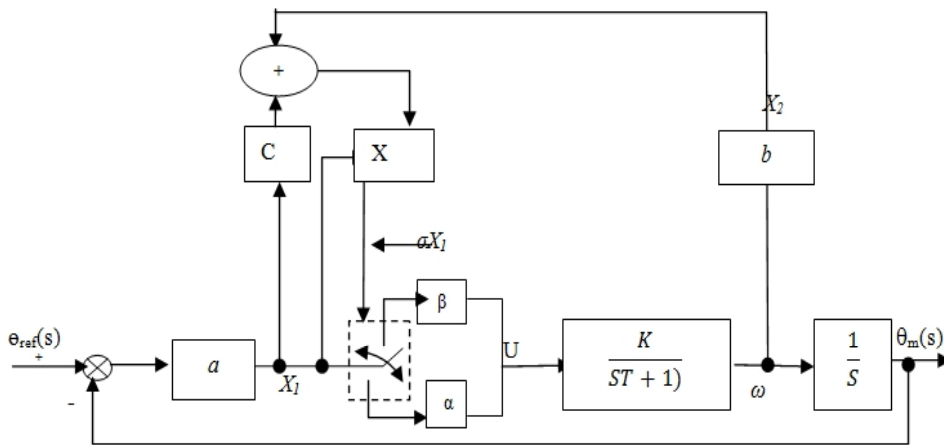


Fig. 5 Block diagram of VSC Control system [11]

The following VSC law for second order plant law derived below is used to enable fast hitting and minimal chattering in steady state:

From (5);

$$u = \psi_i X_i \quad (10)$$

From (6);

$$\psi_i = \begin{cases} \alpha_i & \text{if } X_i \sigma > 0 \\ \beta_i & \text{if } X_i \sigma < 0 \end{cases} \quad (11)$$

From (7);

$$\sigma = C X_1 + X_2 \quad (12)$$

Differentiating (12) yields

$$\dot{\sigma} = C\dot{x}_1 + \dot{x}_2 \quad (13)$$

Substituting (8) into (13) gives

$$\dot{\sigma} = x_2 \left(\frac{aC}{b} - \frac{1}{T} \right) + \frac{1}{T} b k \psi x_1$$

where: $u = \psi_1 x_1$

In the proximity of the switching line (sliding plane) $\sigma = 0$, $x_2 = -C x_1$, that is

$$\dot{\sigma} = x_1 \left[-\frac{aC^2}{b} + \frac{C}{T} + \frac{b k \psi}{T} \right] \quad (14)$$

Putting (12) into a Lyapunov function $\sigma \dot{\sigma} < 0$, gives;

$$\sigma \left[x_1 \left[-\frac{aC^2}{b} + \frac{C}{T} + \frac{b k \psi}{T} \right] \right] < 0 \quad (15)$$

therefore,

$$\psi = \begin{cases} \varepsilon & \text{if } X_1 \sigma > 0 \\ \varepsilon & \text{if } X_1 \sigma < 0 \end{cases} \quad (16)$$

where;

$$\varepsilon = \frac{T}{b k} \left[\frac{aC^2}{b} - \frac{C}{T} \right]$$

From the characteristic of the motor the values of k , T , a and b are found and the values of the parameters (α , β and C) were initiated and tuned by DE scheme.

C. Differential Evolution Algorithm

A DEA is an evolutionary computation method that was originally introduced by Stone and Price in 1995 [12]. They developed a DEA that was reliable and versatile function optimiser and readily applicable to a wide range of optimisation problems. DEA uses selection and less stochastic approach in solving optimisation problems than other classical Evolutionary algorithms (EAs). DEA has a number of significant advantages when used, which were summarised in [13]. Ability to find the true global minimum regardless of the initial parameter values, fast and simple with regard to application and modification, requires few control parameters, parallel processing nature and fast convergence, capable of providing multiple solutions in a single run, effective on integer, discrete and mixed parameter optimisation, and ability

to find the optimal solution for a nonlinear constrained optimisation problem with penalty functions. Most of the initial researches were conducted by the differential evolution algorithm inventors (Stone and Price) with several papers, which explained the basis of differential evolution algorithm and how the optimisation process is carried out [14].

DEA is a parallel direct search method that employs a population P of size NP , consisting of floating point encoded individuals or candidate solutions as shown in (17):

$$P^{(G)} = (X_1^{(G)}, \dots, X_i^{(G)}, \dots, X_{NP}^{(G)}) \quad (17)$$

At every generation G during the optimization process, DEA maintains a population $P^{(G)}$ of NP vectors of candidate solutions to the problem at hand. Each candidate solution X_i is a D -dimensional vector, containing as many integer-valued parameters (18) as the problem decision parameters D .

$$X_i^{(G)} = (X_{1,j}^{(G)}, \dots, X_{j,i}^{(G)}, \dots, X_{D,i}^{(G)}), i = 1, \dots, NP, j = 1, \dots, D. \quad (18)$$

DEA consists of the three basic genetics operations as arranged in Fig. 7, the application of these operations stopped after several repetitions across a number of generations to improve the fitness values when it reaches the stage that provides the best (optimal) solution of the problem.

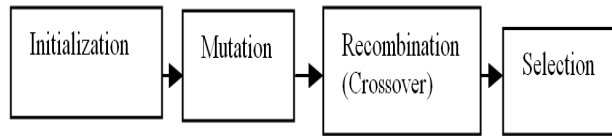


Fig. 6 General Block diagram of DEA procedure

The DE-based VSC architectural flowchart is shown in Fig. 7.

IV. SIMULATION RESULTS AND DISCUSSION

The results of the simulations performed that illustrate the application of DE-based VSPC of LDCSM. The fourth order Runge Kutta integration algorithm coded in matlab software is employed to simulate the system.

The fitness function against number of iterations (generations) is as shown in Fig. 8. This shows the convergence of the DEA method with the following DEA parameters: population size=15, Crossover =1, mutation rate =0.6 and number of generations = 50. They are used to verify the performance of DE-VSC.

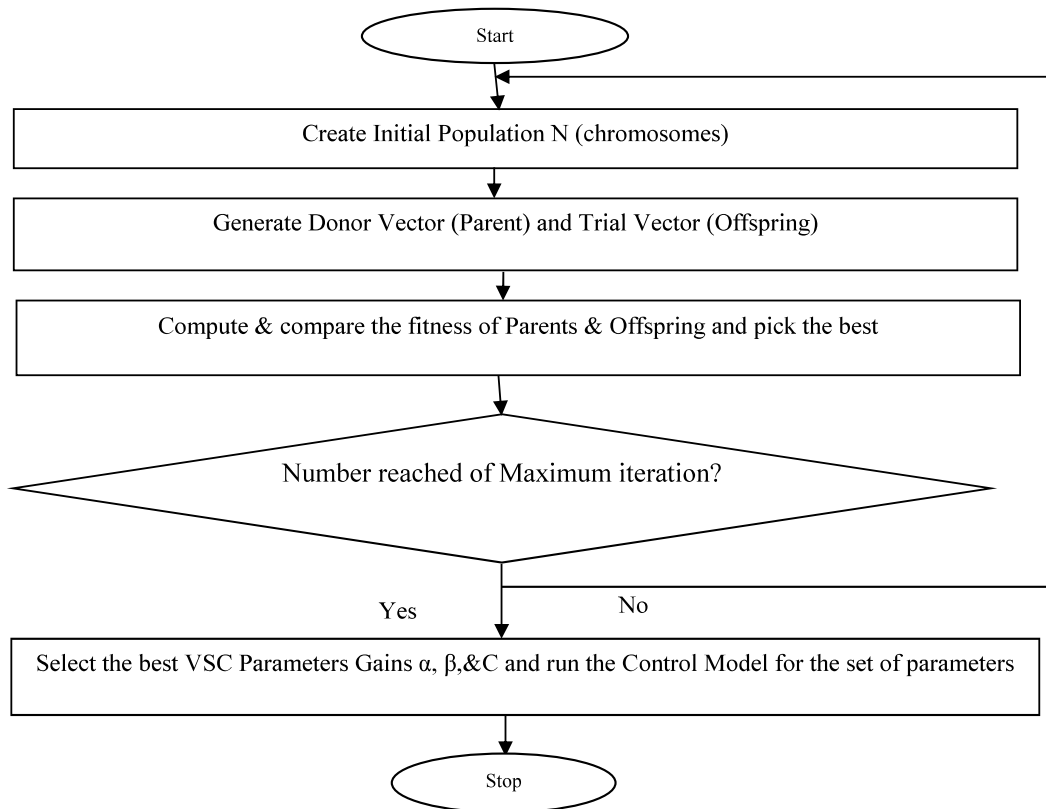


Fig. 7 DE-based VSC Flowchart

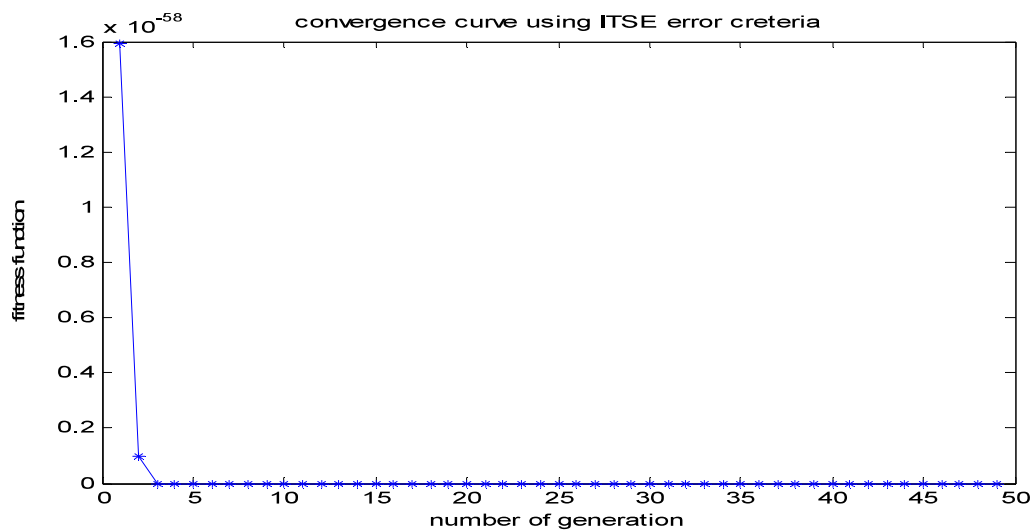


Fig. 8 Fitness function showing convergence of the DEA

A performance index must be selected among others which in this case is Integral time squared error ITSE that gives the optimal values of $\alpha = 0.551975$, $\beta = 0.333695$ and $C = 1.054048$.

The untune VSC and DE-tuned VSC with step response is as shown in Fig. 9. It shows the better performance of DE-tuned in terms of % overshoot, rise time, settling time and steady state error.

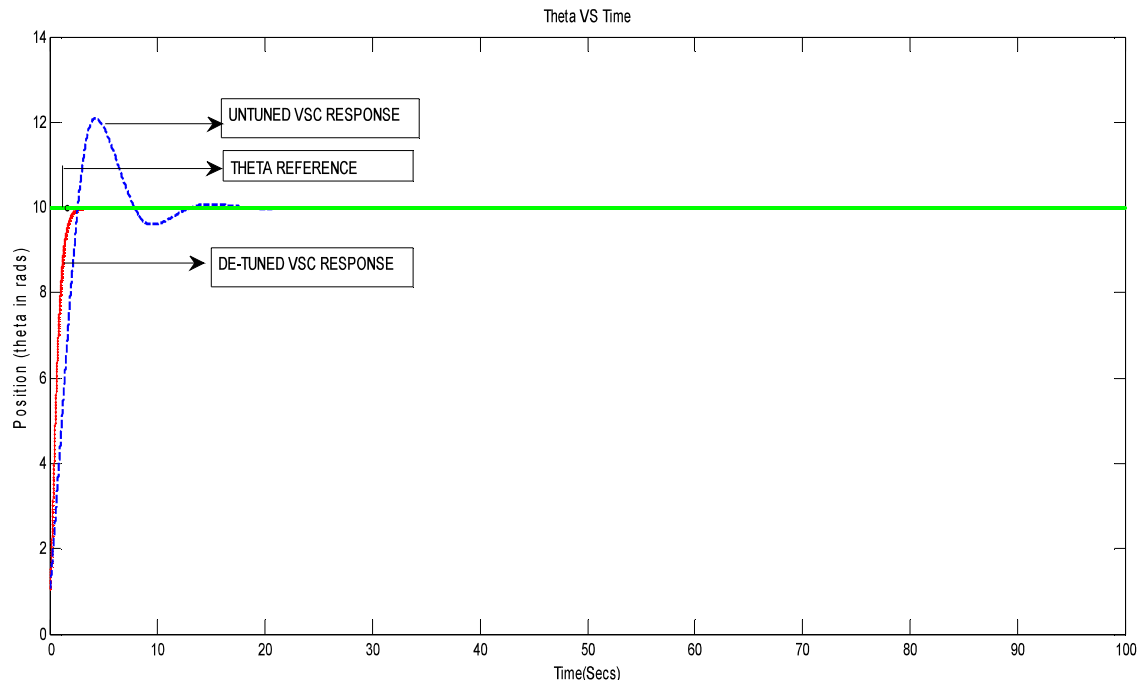


Fig. 9 Comparative step responses of tuned and untuned VSC

Best minimum values of rise time = 0.4336ms, settling time = 1.3885, percentage overshoot = 7.4674% and undershoot = 0%.

Fig. 10 shows the control effort that gives the simulation results of the control input to the plant when the system is

subjected to a reference step input, the feedback gains obtained through the DEA approach gives a dramatic decrease in the magnitude of control effort (u). This is considered as an advantage of DEA gains selection.

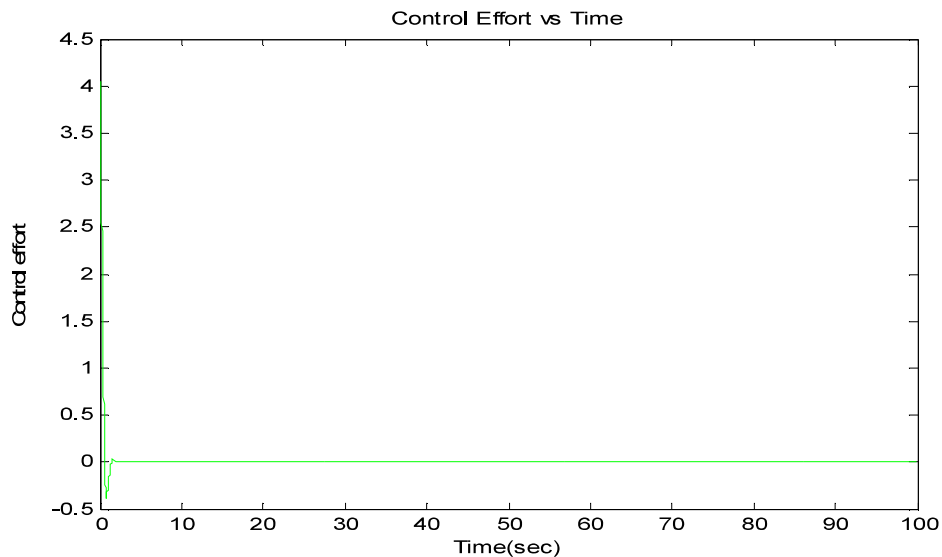


Fig. 10 Control Signal

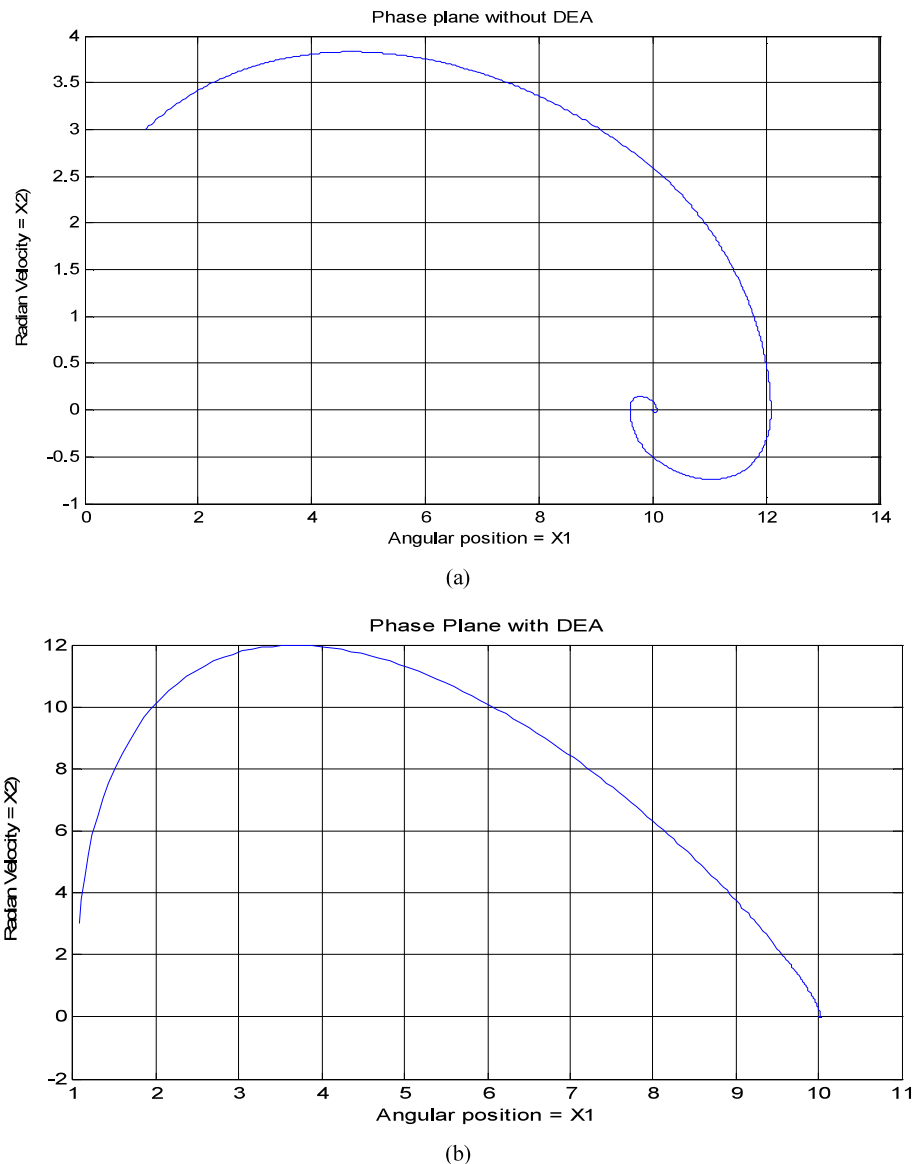


Fig. 11 VSC phase portrait in 2-D (a) without DEA (b) with DEA

Fig. 11 shows the comparison results of the phase trajectories when the sliding condition is without DEA tuning it enters unstable region and with DEA tuning it enters stable region.

V.CONCLUSION

This paper has presented the successful implementation of DE-based variable structure controller for position control of LDCSM using matlab. The results show that the proposed method can perform an efficient search for optimal VSC parameters and yielded better performance in terms of step response parameters. By comparison with tuned and untuned VSC methods.

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