# A New Variable Structure DC Motor Controller Using Genetic Algorithms

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***Abstract*: This paper presents a new application of the genetic algorithm for the selection of the variable structure controller (VSC) feedback gains and switching vector for a separately excited DC motor. Contrary to the VSC design methods reported in the literature, the present method provides an optimal and systematic design procedure for the selection of the feedback gains and switching vector. By the proposed VSC controller, the speed of a tested DC motor follows a pre-determined speed track to a high degree of accuracy. The proposed controller has been found robust against high variations in the motor parameters.**

## I. INTRODUCTION

DC drive systems are often used in many industrial applications such as robotics, actuation and manipulators. In the first two, a wide range of speed or position control is required. In manipulators, dc motors are used to follow a predetermined speed or position track under variable load. Many control strategies have been proposed to control and achieve good performance of DC motors [1-20]. The proportional integral control is successful in achieving zero steady state error in the speed, but it exhibits poor dynamic performance as evidenced by large overshoot and transient speed deviation. Moreover, the settling time is relatively large. In the application of optimal control techniques, the controller design is normally based on a fixed parameter model of the system derived by linearization process. Therefore, as the operating conditions change, system parameters with controllers designed for a specific operating point will no longer be optimal. In recent years, the application of the adaptive control theory to the DC motor performance problem has found acceptance because of its role in eliminating some of the problems associated with classical and optimal control. Self-tuning regulators (STR), model reference adaptive control (MRAC) as well as variable structure control (VSC) are used under the heading adaptive control. One of the main underlying problems associated with VSC controller design is the selection of the feedback gains and switching vector [17-20]. Generally, they are chosen by trial and error such that they will satisfy certain system performance requirements. Very recently, the problem of VSC feedback gains selection has been considered to solve the load frequency control problem by [21]. Their approach essentially was to try all allowable values of the feedback gains and evaluate a performance index for each possible set of feedback gains. The optimal feedback gains selected are those which minimize the performance index. This approach is numerically intensive especially for large numbers of feedback gains.

In the present paper, a new procedure for the variable structure controller design is proposed via genetic algorithms (GA). Both the VSC switching vector and feedback gains are selected in a novel and systematic manner. This is accomplished by formulating the VSC design as an optimization process. The proposed design method has been applied to the speed control of a separately excited field controlled DC motor.

## II. SYSTEM MODEL

The equations describing the dynamic behavior of the motor are [17]:

$$v_a = R_a i_a + L_a \frac{di_a}{dt} + K_f i_f \omega \tag{1}$$

$$v_f = R_f i_f + L_f \frac{di_f}{dt} \tag{2}$$

$$\frac{d\omega}{dt} = \frac{K_{fi}\, i_f i_a}{J} - \frac{f}{J}\omega \tag{3}$$

where $v_a$, $v_f$, $i_a$, $i_f$, $L_a$, $L_f$, $R_a$, and $R_f$ are the armature and field voltages, currents, inductance and resistance, respectively. The inertia constant is $J$ and $f$ is the friction constant. $\omega$ is the motor speed and $K_f$ is a constant.

## III. THEORY OF VSC

The fundamental theory of variable structure systems may be found in [22]. Different control goals such as stabilization, tracking, regulation can be achieved using VSC by the proper design of the sliding surface. A block diagram of the VSC for the regulation problem is shown in Fig. 1. The control law is a linear state feedback whose coefficients are piecewise constant functions. Consider the linear time-invariant controllable system given by

$$\dot{X} = AX + BU \tag{4}$$

Where

$X$ $n$-dimensional state vector
$U$ $m$-dimensional control force vector
$A$ $n\times n$ system matrix
$B$ $n\times m$ input matrix

The VSC control laws for the system of (4) are given by

$$u_i = -\psi_i^T X = -\sum_{j=1}^{n} \psi_{ij} x_j; \qquad i = 1,2,\ldots,m \tag{5}$$

Where the feedback gains are given as

$$\psi_{ij} = \begin{cases} \alpha_{ij}, & if \quad x_i\sigma_j \rangle 0; \; i = 1,....,m \\ -\alpha_{ij}, & if \quad x_j\sigma_i \langle 0; \; j = 1,....,n \end{cases}$$

and

$$\sigma_i(X) = C_i^T X = 0, \qquad i = 1,....,m \qquad (6)$$

Where $C_i$'s are the switching vectors which are selected by pole placement [23] or linear optimal control theory [17]. The feedback gains $\alpha_{ij}$ are usually determined by simulating the control system and trying different values until satisfactory performance is obtained. In Section IV, the proposed method of selecting the switching vectors and the feedback gains for the DC motor is presented.

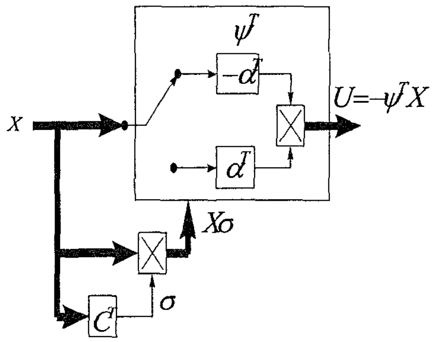


Fig. 1: Block diagram of variable structure controller

## IV. GENETIC ALGORITHMS

Genetic algorithms are directed random search techniques, which can find the global optimal solution in complex multidimensional search spaces. GA were first proposed by Holland [24] and have been applied successfully to many engineering and optimization problems [25]. GA employ different genetic operators to manipulate individuals in a population of solutions over several generations to improve their fitness gradually. Normally, the parameters to be optimized are represented in a binary string . To start the optimization, GA use randomly produced initial solutions created by random number generator. This method is preferred when a priori knowledge about the problem is not available.

The flow chart of a simple GA is shown in Fig. 2. There are basically three genetic operators used to generate and explore the neighborhood of a population and select a new generation. These operators are selection, crossover, and mutation. After randomly generating the initial population of say $N$ solutions, the GA use the three genetic operators to yield $N$ new solutions at each iteration. In the selection operation, each solution of the current population is evaluated by its fitness normally represented by the value of some objective function, and individuals with higher fitness value are selected. Different selection methods such as stochastic selection or ranking-based selection can be used.

The crossover operator works on pairs of selected solutions with certain crossover rate. The crossover rate is defined as the probability of applying crossover to a pair of selected solutions. There are many ways of defining this operator. The most common way is called the one-point crossover which can be described as follows. Given two binary coded solutions of certain bit length, a point is determined randomly in the two strings and corresponding bits are swapped to generate two new solutions.

Mutation is a random alteration with small probability of the binary value of a string position. This operation will prevent GA from being trapped in a local minimum. The fitness evaluation unit in the flow chart acts as an interface between the GA and the optimization problem. Information generated by this unit about the quality of different solutions is used by the selection operation in the GA. The algorithm is repeated until a predefined number of generations have been produced. More details about GA can be found in [24-26].

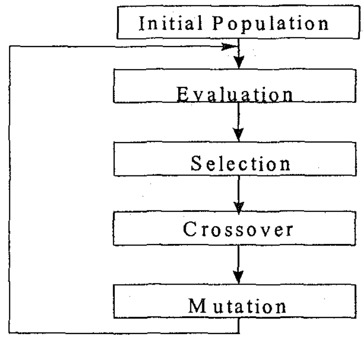


Fig. 2: Flow Chart for a Simple Genetic Algorithm

## V. GENETIC-BASED VSC DESIGN

The VSC for the separately excited field controlled dc motor is shown in Fig. 3. The objective of the control is to keep the dc motor speed as close as possible to some desired speed ( $\Delta\omega_{ref}$ ).

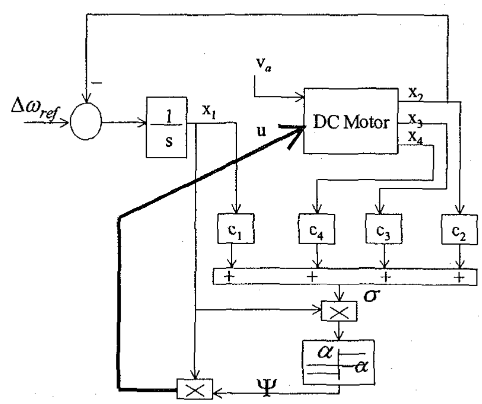


Fig. 3: VSC controller of the field controlled DC motor

Linearizing (1-3) about an operating point (denoted by the subscript 0) and defining a new state ( $x_1$ ) to transform the tracking problem into a regulation problem yields a state space representation of the form

$$\dot{x}(t) = Ax(t) + Bu(t) + Fd(t) \quad (7)$$

where $x$ is a 4-dimensional state vector, $u$ is a 1-dimensional control force vector, $d$ is a 1-dimensional disturbance vector, $A$ is a 4×4 system matrix, $B$ is a 4×1 input matrix, $F$ is 4×1 disturbance matrix. The state, input and disturbance vectors are given by $x = [x_1\ x_2\ x_3\ x_4]^T$, $u = v_f$, $d = v_a$ respectively. The states are defined as $x_1 = \int(\Delta\omega_{ref} - \Delta\omega)\,dt$ ($\Delta\omega_{ref}$ is the desired speed), $x_2 = \Delta\omega$, $x_3 = \Delta i_a$, and $x_4 = \Delta i_f$. The system matrices $A$, $B$ and $F$ are

$$A = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & -\frac{f}{J} & \frac{K_f I_{f0}}{J} & \frac{K_f I_{a0}}{J} \\ 0 & -\frac{K_f I_{f0}}{L_a} & -\frac{R_a}{L_a} & -\frac{K_f w_0}{L_a} \\ 0 & 0 & 0 & -\frac{R_f}{L_f} \end{bmatrix}$$

$$B^T = \begin{bmatrix} 0 & 0 & 0 & \frac{1}{L_f} \end{bmatrix}$$

$$F^T = \begin{bmatrix} 0 & 0 & \frac{1}{L_a} & 0 \end{bmatrix}$$

In the following, the proposed GA approach for the selection of the switching vector ($C = [c_1\ \ c_2\ \ c_3\ \ c_4]$) and the feedback gain ($\alpha$) of the VSC is explained. To start the proposed GA method, a performance index must be defined. The following performance index is use

$$J = \frac{1}{2}\int_0^\infty x_1^2\,dt \quad (8)$$

Minimizing $J$ forces the state ($x_1$) to go to zero and hence the speed of the DC motor ($\Delta\omega$) will follow the desired speed ($\Delta\omega_{ref}$). The following step by step procedure describes the proposed method:

1) Generate randomly a set of possible switching vectors and feedback gains depending on the size of the search space.
2) Evaluate the performance index given by 8 for all possible switching vectors and feedback gains generated in step 1.
3) Use genetic operators (selection, crossover, and mutation) to produce new generation of switching vectors and feedback gains.
4) Evaluate the performance index in step 2 for the new generation of switching vectors and feedback gains. Stop if certain predetermined number of generations has been used, otherwise go to step 3.

## VI. Simulation Results

The parameters of the DC motor are given below in Table I [17]

Table I: Parameters of the DC motor

| | |
|---|---|
| hp = 5 | $R_f$ = 60 Ω |
| rpm = 1750 | $L_a$ = 0.01 H |
| $v_a$ = 240 V | $L_f$ = 60 H |
| $J$ = 0.208 kgm$^2$ | $K_f i_{f0}$ = 1.2 Vs /rad |
| $f$ = 1.1099 Nm/rad/s | $K_f$ = 0.3 |
| $R_a$ = 1.2 Ω | |

The numerical values of the system matrices $A$, $B$ and $F$ are

$$A = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & -5.336 & 5.769 & 24.46 \\ 0 & -120 & -120 & -5497.8 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

$$B = [0\ \ 0\ \ 100\ \ 0]^T,\ F = [0\ \ 0\ \ 0\ \ 0.016]^T$$

Using the proposed method described in Section V, the parameters for the GA are selected as 30, 0.7, and 0.001 for the population size, crossover probability, and mutation probability respectively. The switching vector and the gain of the VSC are obtained as $C = [19.01\ \ -3.77\ \ -0.68\ \ 3.74]$, and $\alpha = 30.0$. The VSC is simulated for a changing reference input, and the results are shown in Figs. 4 and 5. It can be seen that the output of the controlled system is closely following the desired output which demonstrates the successful performance of the proposed VSC design method. The robustness of the proposed VSC is investigated by changing some of the parameters of the DC motor. The results shown in Figs. 6 and 7 demonstrate the performance of the proposed VSC when the inertia constant $J$ and the friction constant $f$ are changed respectively.

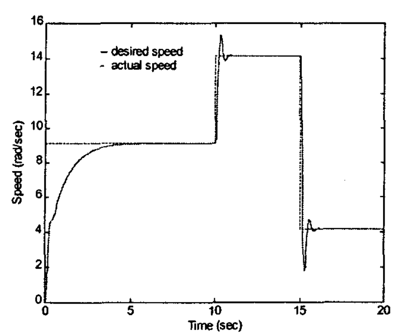


Fig. 4: Actual and desired speed of the DC motor for step changes

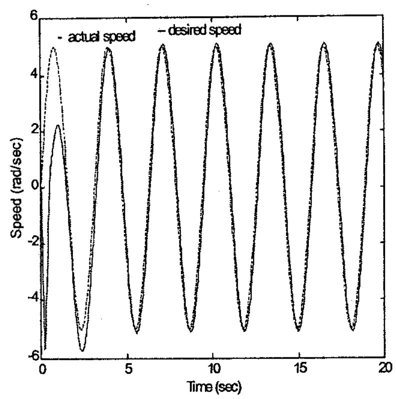


Fig. 5: Actual and desired speed of the DC motor for sinusoidal changes

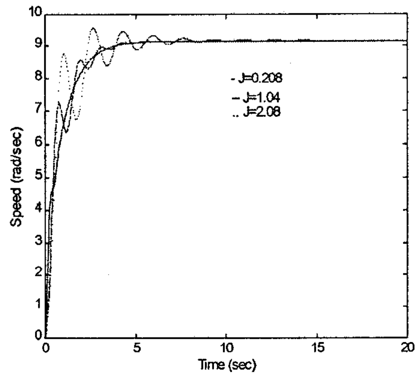


Fig. 6: Effect of inertia constant variations on the speed

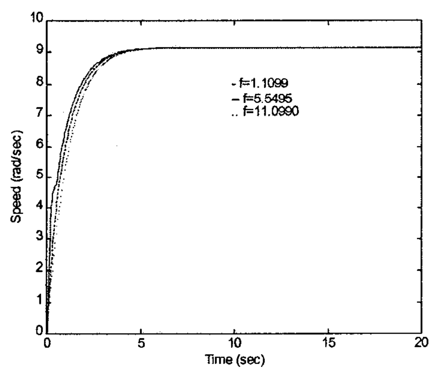


Fig. 7: Effect of friction constant variations on the speed

The complexity of the VSC can be reduced greatly by minimizing the number of states used as feedback to the controller. In this study, the proposed design method is used to find the switching vector and the gain of the VSC when only one state ($x_1$) is used as feedback signal. The switching vector and the gain of the VSC are given by

$C=[14.70]$, and $\alpha=30.0$. The tracking performance is shown in Fig. 8 which is very close to the results shown in Fig. 4 for the full state feedback case.

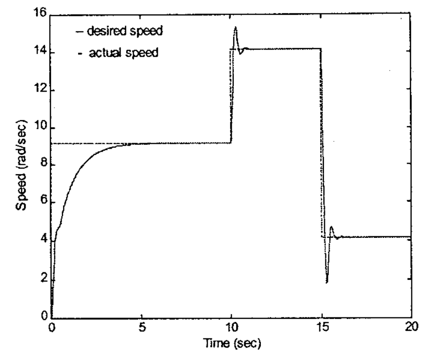


Fig. 8: Actual and desired speed of the DC motor with feedback from ($x_1$) only

## CONCLUSIONS

In this paper, genetic algorithms have been used in the selection of the feedback gains and switching vector of the VSC for a separately excited field controlled DC motor. The use of genetic algorithms provide an optimal and systematic procedure for the selection of feedback gains and switching vector of VSC compared to other approaches. Moreover, genetic algorithms can be used to reduce the number of states used in the feedback for the VSC. Simulation results have demonstrated the capabilities of the proposed controller in tracking predetermined desired speed trajectory. Also, robustness of the proposed controller has been investigated by varying the motor parameters.

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