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Speed Control of DTC_SVM for Induction Motor By Using Genetic Algorithm-based PI Controller

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Abstract

This work presents analysis of three-phase Induction Motor (IM) performance with Direct Torque Control based Space Vector Modulation (DTC-SVM). DTC-SVM scheme is a kind of high-performance control of IM drives to improve the ripples of torque and flux in steady state, this drawback of conventional DTC. (DTC-SVM) has three Proportional-Integral (PI) controllers, one utilized as the PI speed controller and other PI flux controller and PI torque controller which are utilized to produce the stator voltage reference V_ds and V_qs respectively. This paper offers a comparison among two methods utilized for tuning the PI speed controller in DTC_SVM of IM drive. One is trial and error method, while the second is Genetic Algorithms (GA). GA helps to get the optimal PI speed controller parameters. The results of a simulation carried out utilizing MATLAB/Simulink program (R2014a) show that the response of speed motor with GA is better and reaches to the reference value faster than another method.

Keywords: DTC_SVM, Genetic Algorithm (GA), Induction Motor (IM), PI Controller and Space Vector Modulation (SVM).

Introduction

The Squirrel Cage Induction Motor (SCIM) is basically a simple manufacture, reliability, robustness, low maintenance needs and low cost due to these advantages of the motor; it is broadly utilized in industrial applications such as robotics and wind generation systems, , paper and textile mills, and hybrid vehicles. However, this motor with high-performance control considered a difficult problem due to the coupling impacts among the current of rotor and stator field, the properties of the nonlinear and several of the parameters differ with the operating conditions such as reference speed set point, load torque, temperature of motor and resistance of rotor [1]. The controlling method of this motor is a variable frequency control divided into two methods vector control and scalar control, as shown in Fig.1.The scalar based control works well in steady state condition but in case of transient state condition, a problem happens in space vector position. While, vector-based control operates on both transient state condition and steady state condition. The most commonly utilized method in a transient state is Field Oriented Control (FOC). In FOC, the equation of motor is transformed into a coordinate system which spins in synchronization with the rotor flex vector control. This is the main drawback for FOC which is eliminated by Direct Torque Control (DTC) which is based on maintaining the magnitude of stator flux constant and avoiding electromagnetic transient [2].

In DTC, the flux and torque of the machine are directly controlled by utilizing hysteresis comparators. The main benefits of DTC are the rapid response for torque and robust, no requisites for coordinate transformation no requisites for current regulators and PWM pulse generation. The main drawback of the DTC drive is the flux and torque ripples in steady state. The flux and torque pulses impact the precision of the speed estimation. This also results in higher acoustic noise and harmonic losses. There are two approaches to reducing the ripples of flux and torque of the DTC drives. The first approach is multi-level inverter; the second approach is Space Vector Modulation (SVM). In the first approach, the complication and the cost will be a rise, in the second approach, the ripples of flux and torque can be decreased [3] and maintaining the switching frequency is fixed. In DTC-SVM approach, the PI controllers are utilized instead of the hysteresis comparators for torque and flux in conventional DTC [4].

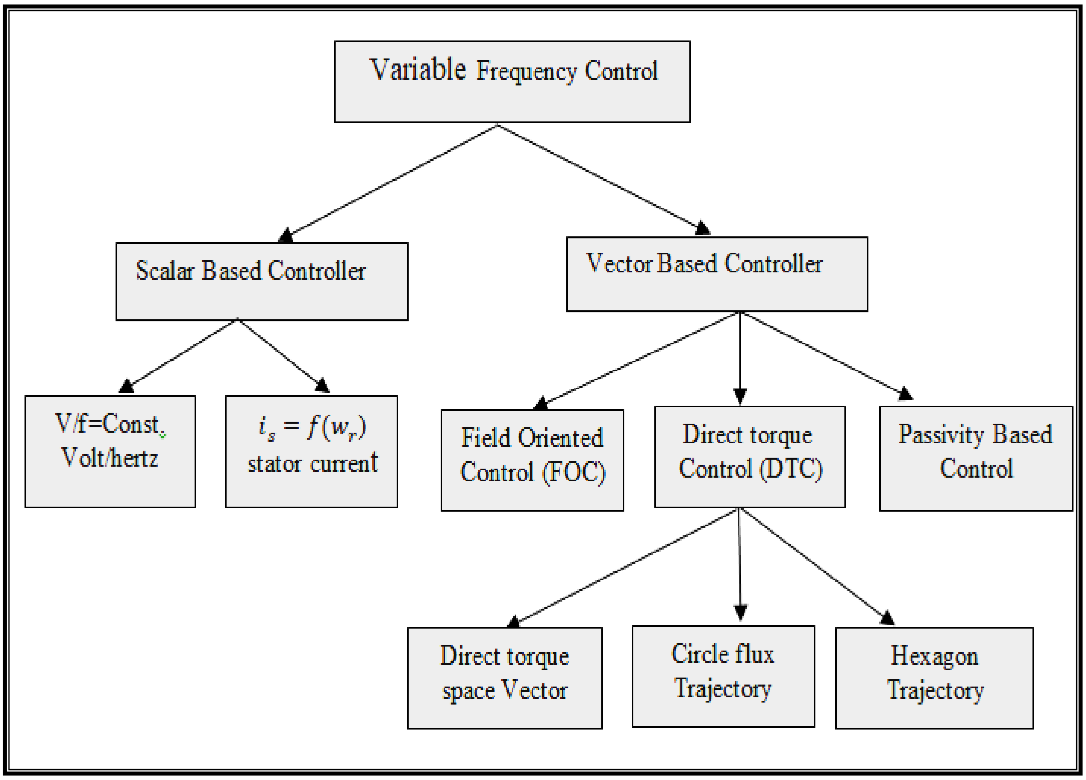

Fig.1.Classification of IM control

The PI controller parameters are specified by the reduction of an objective function. The aim of this paper is show that optimization the parameters of PI controller can be achieved by utilizing GA and compares the results of GA with the trial and error method. GA methods have been broadly utilized in control applications. GA is randomness optimization method depend on the principles of natural biological evolution. The GA approach was swimmingly utilized to resolve difficult optimization problems. The GA approach, which is utilized to determination the various controller parameters are practical due to their reasonable accuracy and rapid convergence [5]. There are several studies related to DTC_SVM and GA such as: In 2011, Mohamed Chebre et al. designed a PI controller with GA for controlling the speed of an IM utilizing the Indirect Field-oriented Control (IFOC) approach. GA helps to perfectly calculate the PI controller parameters and compares the results with the conventional PI controller. The results of simulation shown that the GA led to an enhancement in the speed regulation of IM and on another hand a good dynamic, static performance and a better robustness over the conventional PI controller [5]. In 2013, M. M. Eissa et al. suggested the tuning the parameters of PI controller utilizing GA strategy for speed control of IM. The results of simulation presented show the effectiveness of the suggested method and decrease the settling time of the responses and designed an effective controller utilizing GA -PI control strategy [6].

In 2015, Naveen Gael et al. Modified DTC or (DTC_SVM) scheme for IM drive is suggested where three PI controllers are utilized instead of the hysteresis controllers to decrease the ripples of torque. The outer loop having PI speed controller is tuned utilizing GA for improving the responses of speed and torque [7].

1. Induction Motor Modeling

The equivalent circuit of the SCIM in $(d-q)$ axis is shown in Fig.2, the three phase voltage stator of an IM can be given by the following equations [8].

$$V_a = V_m \sin(\omega t) \tag{1}$$

$$V_b = V_m \sin\left(\omega t - \frac{2\pi}{3}\right) \tag{2}$$

$$V_c = V_m \sin\left(\omega t + \frac{2\pi}{3}\right) \tag{3}$$

These three phase balance voltages are transformed into the two-phase stationary reference frame of $(d-q)$ axis. This can be given by Eq. (4) and Eq. (5).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{3}{2}\begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (4)$$

Then, the voltage in the $(d-q)$ axis

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \qquad (5)$$

The mathematical model of Three- phase (SCIM) in the stationary reference frame $(d-q)$ can be given by the following equations [9].

$$V_{ds} = (R_s + pL_s)i_{ds} + pL_m i_{dr} - \omega\psi_{ds} \qquad (6)$$

$$V_{qs} = (R_s + pL_s)i_{qs} + \omega\psi_{qs} + pL_m i_{qr} \qquad (7)$$

$$V_{dr} = 0 = (R_r + pL_r)i_{dr} + pL_m i_{ds} - (\omega - \omega_r)\psi_{dr} \qquad (8)$$

$$V_{qr} = 0 = (R_r + pL_r)i_{qr} + (\omega - \omega_r)\psi_{qr} + pL_m i_{qs} \qquad (9)$$

$$L_s = L_{ls} + L_m \quad \& \quad L_r = L_{lr} + L_m \qquad (10)$$

Where ψ_{ds} , ψ_{qs} are the stator flux linkages in the $(d-q)$ frame in Eq.(11) and ψ_{dr} , ψ_{dr} are rotor flux linkages in the $(d-q)$ frame in Eq.(12), while $p = d/dt$.

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \quad \& \quad \psi_{ds} = L_s i_{ds} + L_m i_{dr} \qquad (11)$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad \& \quad \psi_{dr} = L_r i_{dr} + L_m i_{ds} \qquad (12)$$

The rotor and stator current can be determined from the voltage equations:

$$i_{ds} = \int \frac{1}{L_s}(V_{ds} - R_s i_{ds} + \omega L_s i_{qs} - pL_m i_{dr} + \omega L_m i_{qr})\, dt \qquad (13)$$

$$i_{qs} = \int \frac{1}{L_s}(V_{qs} - R_s i_{qs} - \omega L_s i_{ds} - pL_m i_{qr} - \omega L_m i_{dr})dt \qquad (14)$$

$$i_{dr} = \int -\frac{1}{L_r}(pL_m i_{ds} - L_m(\omega - \omega_r)i_{qs} + R_r i_{dr} - L_r(\omega - \omega_r)i_{qr})dt \qquad (15)$$

$$i_{qr} = \int -\frac{1}{L_r}(L_m(\omega - \omega_r)i_{ds} + pL_m i_{qs} + R_r i_{qr} + L_r(\omega - \omega_r)i_{dr}) \qquad (16)$$

The torque and speed can be determined by following equations.

$$T_{em} = \frac{3}{2}\frac{P}{2}L_m(i_{qs}i_{dr} - i_{ds}i_{qr}) \qquad (17)$$

$$T_{em} = \frac{2}{P}Jp\omega_r + B\omega_r + T_l \qquad (18)$$

$$\frac{d\omega_r}{dt} = \frac{P}{2J}(T_{em} - B\omega_r - T_l) \qquad (19)$$

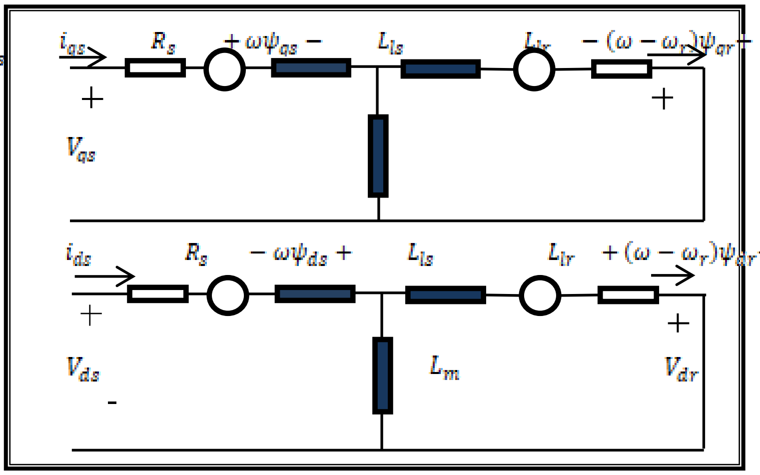

Fig.2 Equivalent Circuit of IM in $(d-q)$

2. *Direct Torque Control with Space Vector Modulation (DTC_SVM):*

The suggested DTC_SVM system as shown in the Fig.(3) have been usage three PI controllers for processing errors of speed, flux, and torque. The torque reference $(T_e{}^*)$ is generated by speed error, that it is processed during the PI speed controller ,while the PI flux controller and PI torque controller are generating the command voltages V_{ds} and V_{qs} respectively. The equations of voltage in the stationary reference frame can be given in Eq.(20) and Eq.(21).The output of the PI torque controller and PI flux controller can be taken as the voltage stator reference components V_{qs}, V_{ds} are the stator flux oriented coordinates $(d-q)$, converted these

$(d-q)$ coordinate component to $(\alpha-\beta)$ components from Eq. (22)[10].

$$V_{ds} = (K_{p\psi} + \frac{K_{i\psi}}{s})({\psi_s}^* - \psi_s) \qquad (20)$$

.

$$V_{qs} = (K_{pT} + \frac{K_{iT}}{s})({T_e}^* - T_e) \qquad (21)$$

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} \qquad (22)$$

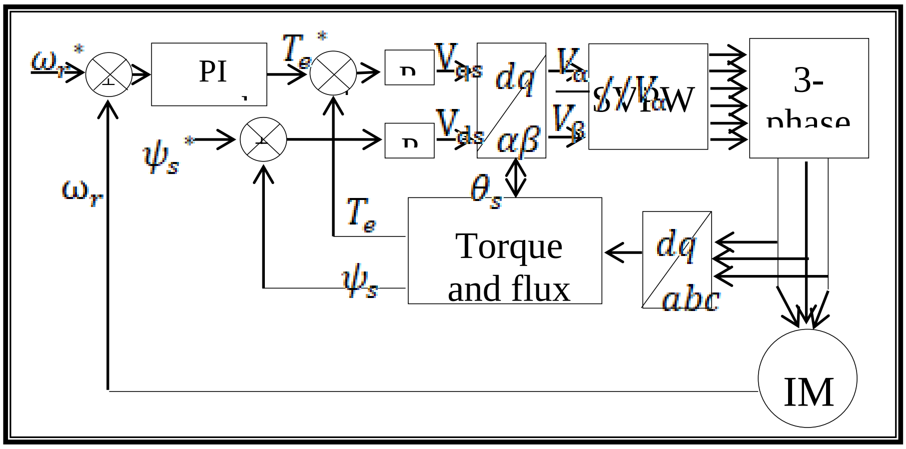

Fig.3The PI controller with proposed DTC_SVM

Where V_{ds} , V_{qs}, and V_{dr} , V_{qr} are the voltages for stator and rotor in the $(d-q)$ frame respectively , while R_s, R_r, ω_r, ω are stator resistance, rotor resistance, rotor angular speed, and the electrical angular speed respectively. The stator, rotor and mutual inductance are L_s, L_r and L_m, respectively.

The flux estimator model is dependent only on the resistance of stator (R_s), the stator flux linkages ψ_{ds} & ψ_{qs} in $(d-q)$ frame can be obtained from equations (23) and (24) respectively ,while the magnitude of the stator flux linkage ψ_s and the phase angle of the stator flux linkage θ_s are given in equations (25) and (26) respectively [7].

$$\psi_{ds} = \int (V_{ds} - i_{ds}R_s)dt \qquad (23)$$

$$\psi_{qs} = \int (V_{qs} - i_{qs}R_s)dt \qquad (24)$$

$$\psi_s = \sqrt{{\psi_{ds}}^2 + {\psi_{qs}}^2} \qquad (25)$$

$$\theta_s = \tan^{-1} \frac{\psi_{qs}}{\psi_{ds}} \qquad (26)$$

3. *Space Vector Modulation Technique*

Space Vector Pulse Width Modulation (SVPWM) is one of the best and advanced techniques utilized in variable frequency drive. The main objective of this technique is to have variable output with maximum fundamental component and minimum harmonics. It offers minimum THD and higher voltage which is further fed to the motor. The transformation of the three phases to their equivalent two-phase quantities has been done utilizing this modulation technique in the stationary or synchronously rotating frame. The reference vector magnitude is derived from these two components which modulate the inverter output [11]. As shown in Fig.4, the vectors (V_1-V_6) division the plane into 6 sectors, each sector is60°. One null voltage (V_0,V_7) vectors and two adjacent voltage (V_1-V_6) are using to generate the reference voltage V_{ref}. The V_1, V_2, V_{ref} and angle (α) must be specified to realize SVPWM [12]. Table (1) shows the different sector determination [13].

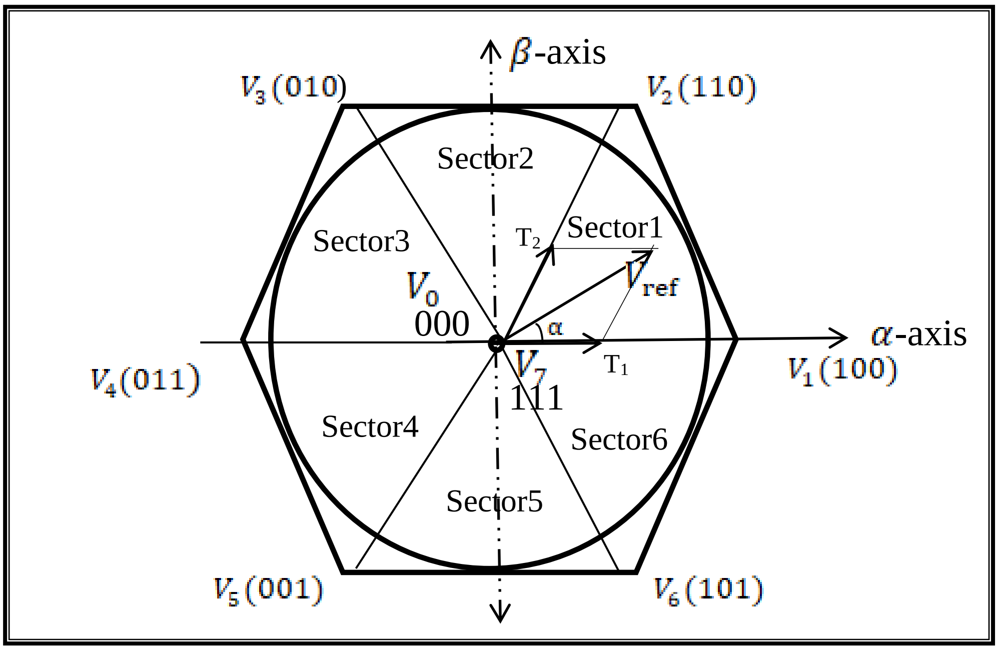

Fig. 4 Principle of space vector modulation

Tabel.1 Sector determination

Angle (α).	Sector (Where Vref is placed)
$0^\circ \leq \alpha \leq 60^\circ$	Sector1
$60^\circ \leq \alpha \leq 120^\circ$	Sector2
$120^\circ \leq \alpha \leq 180^\circ$	Sector3
$180^\circ \leq \alpha \leq 240^\circ$	Sector4
$240^\circ \leq \alpha \leq 300^\circ$	Sector5
$300^\circ \leq \alpha \leq 360^\circ$	Sector6

4. *PI controller*:

Proportional-Integral (PI) controller is easy to design, simple structure and low cost, it is most broadly utilized in industrial application because of these benefits for PI controller. The output signal of PI controller consists of a sum of error and the integral of that error. E is the error which represents the difference among the desired and the actual of motor speed and it is specified by Eq.(27).

$$E = \omega_r^* - \omega_r \qquad (27)$$

The transfer function for PI controller is given by Eq.(28)

$$\frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} \qquad (28)$$

where: K_p is the proportional gain, while K_i is the integral gain.

U(s) is the output of PI speed control signal which denote torque reference (T_e^*) in DTC_SVM drive [14].

4.1- Trial and error Method for Tuning of PI Speed Controller:

Value of the PI speed controllers gains (K_p, K_i) are given in Table .2 by utilized the trial and error method.

Table .2 Parameters of PI speed controller utilized trial and error

PI controllers gains	K_p	K_i
Value	82	0.4

4.2- Genetic Algorithm Approach for Tuning of PI Speed Controller:

GA can be employed to the optimization the parameters of PI controllers (K_p, K_i) for speed to guarantee best control performance of the IM [5]. GA put forward by John Holland in 1970 and it is one of the most robust optimization algorithms. GA is a search method utilized in the calculation to find true or near solutions for optimization and problem solving. GA is a special class of evolutionary algorithm that utilizes evolution-based biology techniques such as mutation, selection and, crossover. GA is based on the natural phenomenon of evolution and survival of the fittest [15]. The flow chart of GA for tuning of PI controller parameters as show in Fig.5.

The steps of the GA can be described below [16].

Step 1: Producing a set of chromosomes (generated in a random method). The generated chromosomes are the present nominated solutions of the problem.

Step 2: Calculating the fitness values (Mean Square Error (MSE) in this chapter) for all chromosomes.

Step 3: Arranging chromosomes by starting from the better solution (i.e. least fitness value).

Step 4: Cloning the best chromosomes to get better attributes in the population

Step 5: Executing a crossover process for the parent chromosomes in order to get new population.

Step 6: Mutating chromosomes with a small predetermined value.

Step 7: Calculating the new fitness values for all chromosomes.

Step 8: Re-executing Step 3 through Step 7 while the minimum error criterion is not met.

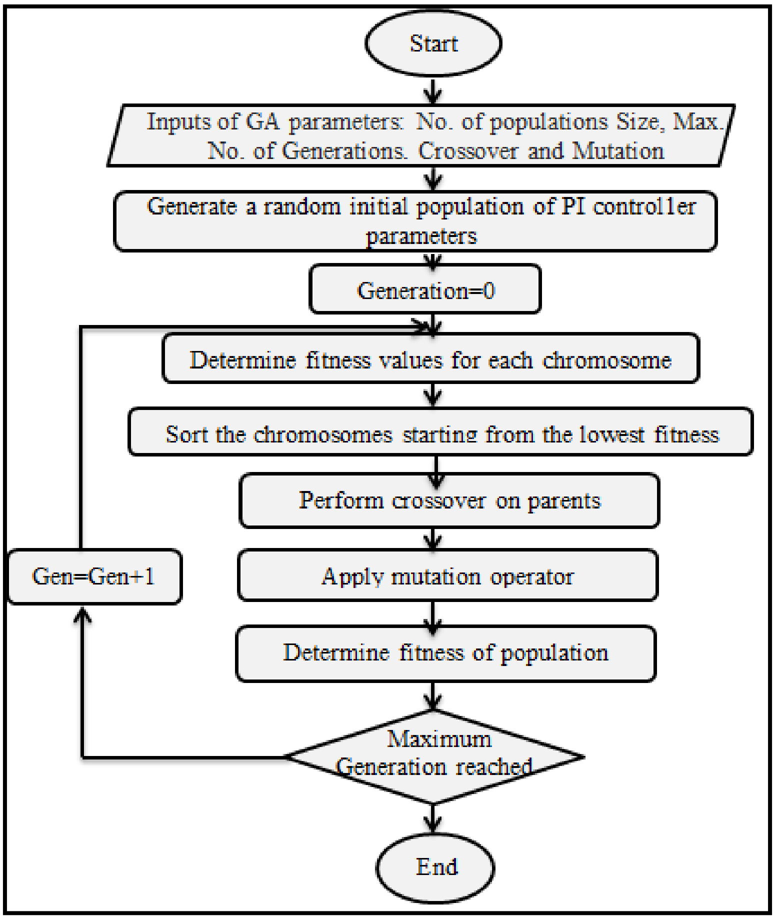

Fig.5.The flow chart of the GA

The parameters of a PI controller are required to be tuned for minimizing the objective function. In this paper, GA technique is utilized to the tuning of PI speed controller parameter to minimize the objective function i.e. MSE [2].

Where: ω_r^* is the speed reference.

ω_r is the rotor angular speed of the IM .

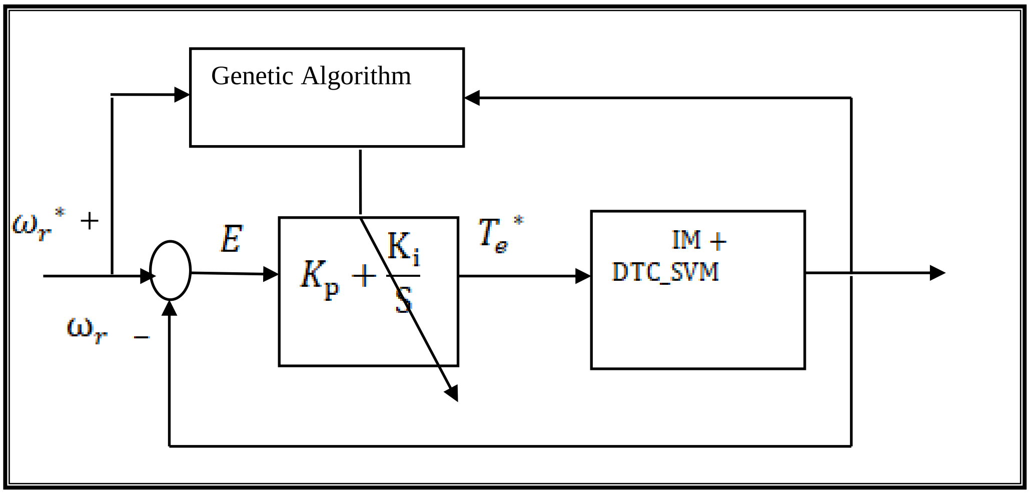

Fig.6 The suggested optimized PI speed controller

The parameters of GA utilized in this paper can be given in Table.3

Table .3 The parameters of GA.

Properties of GA	Value
Size of population	30
Maximum number of generations	20
Probability of crossover	0.5
Probability of mutation	0.2
Number of variables	2
Variables high[K_p K_i]	[150 1]
Variables low[K_p K_i]	[80 0.001]
Objective function	Mean square error (MSE)

The parameters of PI controller gotten according to steps of GA are given in Table.4

Table .4 Parameters of PI speed controller using GA

PI controllers gains	K_p	K_i
Value	103.1559	0.75702

The parameter of three-phase IM, PI flux controller, and PI Torque controller are given in the table. 5

Table 5. The parameter of three-phase IM and PI controllers for flux and torque

Parameter	Value
Power rating of IM	HP= 3
Voltage applied	220 V
Frequency	60 Hz
No of poles(P)	4
Stator Resistance (R_s)	0.435 Ω
Rotor Resistance(R_r)	0.816 Ω
Stator leakage inductance(Ll_s)	0.002 H
Rotor leakage inductance(Ll_r)	0.002 H
Mutual inductance (L_m)	0.0693 H
Inertia moment (J)	0.089kg.m^2
PI-Torque controller(K_p,K_i)	(226.46,1.25)
PI- Flux controller(K_p, K_i)	(6.56,16.21)

5. Simulation and Result:

Simulink implementation of the DTC_SVM for IM drive is shown in Fig.(7), it was carried out utilizing MATLAB/SIMULINK simulation program. The speed reference and stator flux reference value are 377rad/sec and 0.3 Web respectively. The motor is unloaded at startup and the torque load (T_l) 10 Nm is applied at t 1.5 sec, then the load is changed to 5 Nm at t = 3 sec . The switching frequency of SVM is 5 kHz. The simulation results show the comparison between the tuning PI speed controller using GA and trial and error methods based on DTC_SVM for IM drive. Fig.(8) show the response of speed in trial and error method without load , while Fig(.9) which show that the response of speed in GA without load. The results in Fig.(9) shows that the speed response takes lesser time to reach settle value in a short time with respect to Fig.(8), for same parameter and same model. From results are obtained that the speed of the motor with GA is better and reaches the reference value faster than when the trial and error method is used. Here the settling time for trial and error method is 0.336sec .Whereas for GA, it is 0.1684sec. Fig.(10) which shows the response of speed in trial and error method for load torque equal to 10 Nm is applied at t 1.5 sec, then the load is changed to 5 Nm at t = 3 sec, while Fig.(11) shows the response of speed in GA method for load torque equal to10 Nm applied at t 1.5 sec, then the load is changed to 5 Nm at t=3sec.

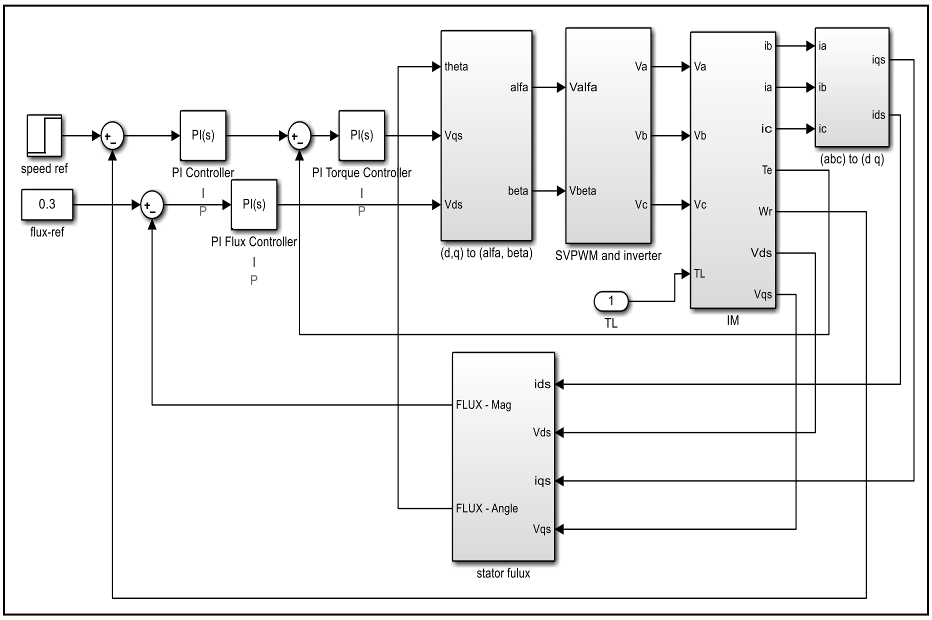

Fig.7. The Simulink model of the DTC_SVM for IM drive

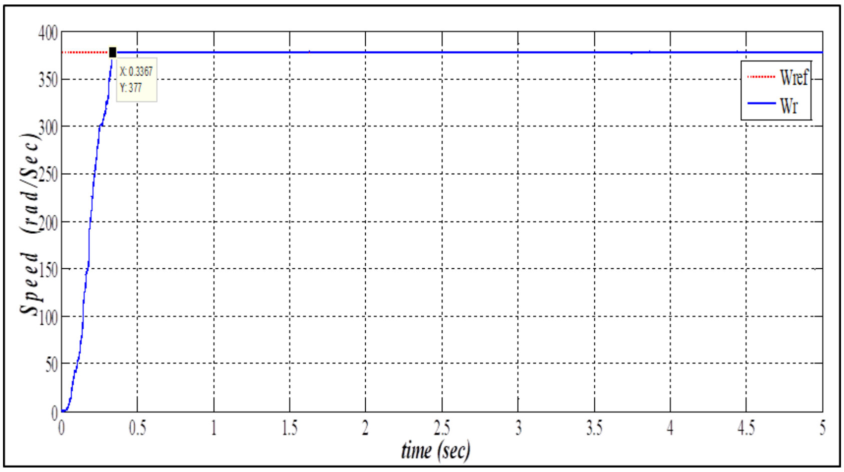

Fig.8.The response of controlled speed when using trial and error method

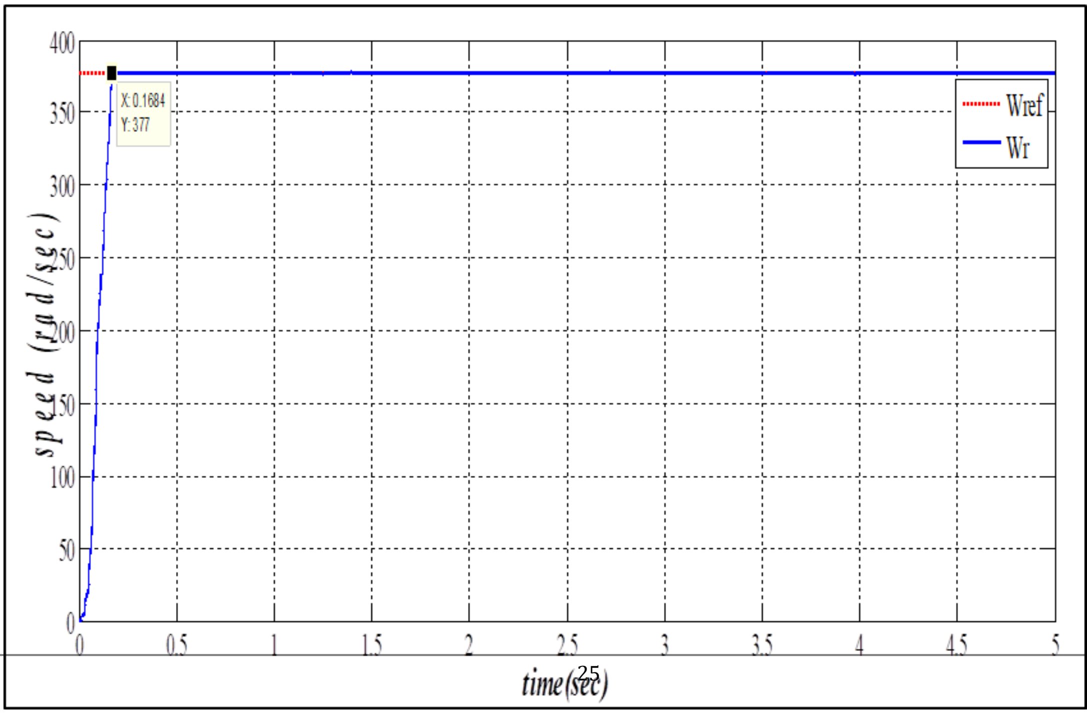

Fig.9 The response of controlled speed when utilized GA

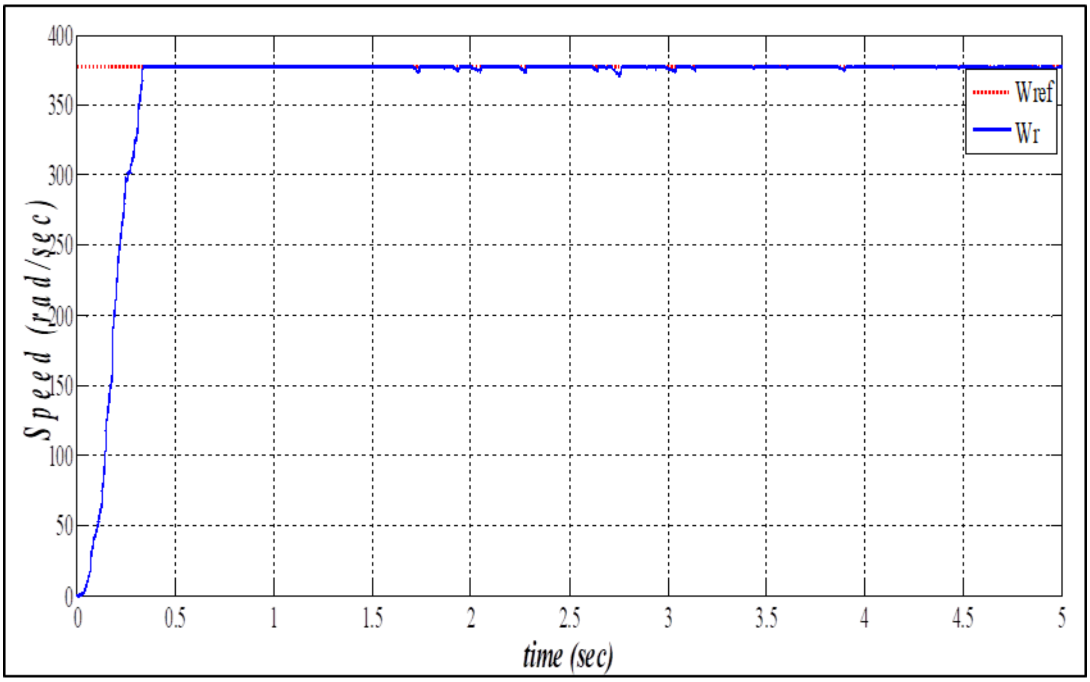

Fig.10. Controlled speed response when utilized Trial and error with T_l =10 Nm at t 1.5 sec and changed $T_l to$ 5 Nm at t =3sec

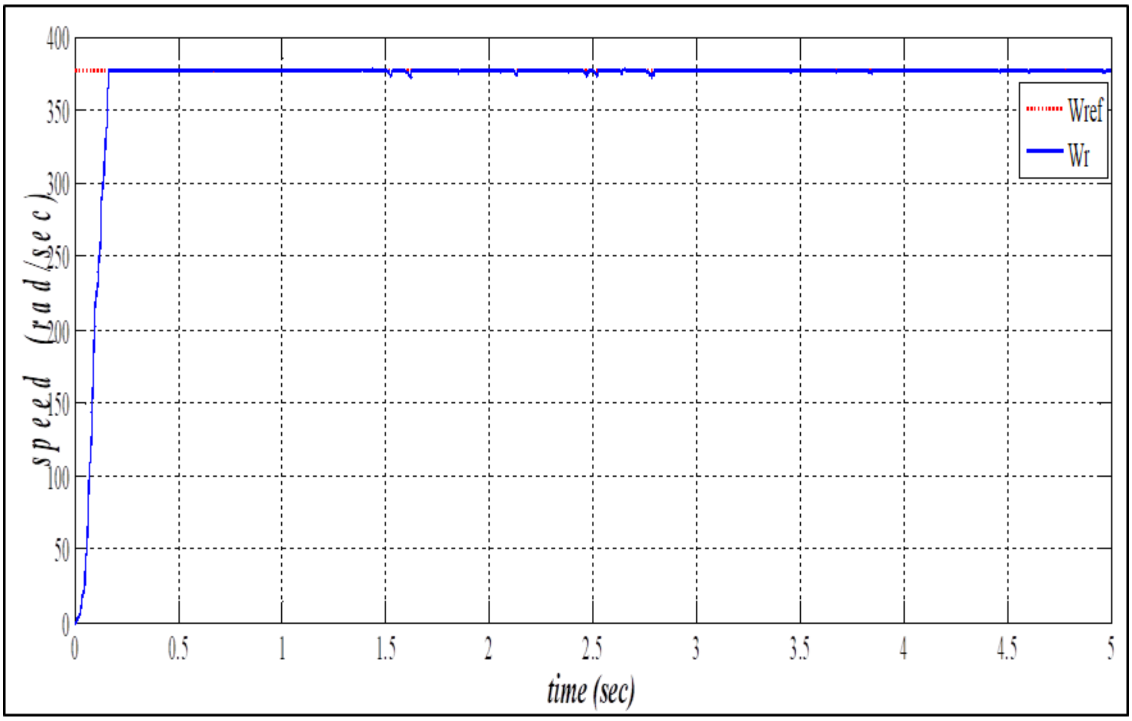

Fig.11.Controlled speed response when utilized GA with T_l =10 Nm at t 1.5 sec and changed $T_l to$ 5 Nm at t 3sec

6.Conclusion

In this work, a GA is applied to find the optimal gains for the PI speed controller of DTC_SVM IM drive and comparison with trial and error method. Optimization is achieved by the MSE fitness function. The results of the simulation are execute by utilized MATLAB/SIMULINK show that the response of motor speed with GA is improved the performance of the motor to sudden change with a fast settling time, less error of steady state, no overshoot, and has a beast performance than trial and error method is utilized.

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