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GA SPEED AND DQ CURRNETS CONTROL OF PMSM WITH VECTOR CONTROL BASED SPACE VECTOR MODULATION USING MATLAB/SIMULINK®

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ABSTRACT

In recent years, permanent magnet synchronous motors (PMSM) have gained variety industrial applications, because of simple structures, high efficiency and ease of maintenance. But these motors have a nonlinear mathematical model. To resolve this problem several studies have suggested the application of soft-computing technique. This paper presents vector control of PMSM fed by space vector modulation inverter using genetic algorithm (GA) controllers to improve speed, currents and the electric torque by significantly reducing their ripples, which offer an extra advantage of this study. The proposed method effectiveness has been verified by computer simulations using Matlab/Simulink®. These results are compared with the ones obtained with a vector control using PI controllers for speed and current [1] and the second obtained with adaptive controller based speed estimation technique [2].

Keywords: *Permanent Magnet Synchronous Motor (PMSM), Vector Control, Space Vector Modulation (SVM), Genetic Algorithm (GA).*

1. INTRODUCTION

In the past, DC motors were used extensively in areas where variable-speed operation was required, since their flux and torque could be controlled easily by the field and armature current [3]. In particular, the separately excited DC motor has been used mainly for applications where there was a requirement of fast response and four-quadrant operation with high performance near zero speed [3]. However, DC motors have certain disadvantages, which are due to the existence of the commutator and the brushes, that is, they require periodic maintenance, and they have limited commutator capability under high-speed, high-voltage operational conditions [3]. These problems can be overcome by the combination of rapid development of semiconductors, microprocessors and control technology of AC motor. Now PMSM motor has become a leading in the industrials applications because it has simple and rugged structure, high maintainability and economy, it is also robust and immune to heavy overloading, etc [3]. Its small dimension compared with DC motors allows PMSM motor to be used widely in industrials applications.

The vector control technique, which is developed upon the field orientation principle proposed by Haase, in 1968, and Blaschke, in 1970 for IM, and is well-proven in permanent magnet synchronous machine (PMSM) by Novotny and Lipo in 1996, decouples the flux and torque control in a PMSM. Thus, it makes the control task of PMSM drives similar to a separately excited DC motor while maintaining the general advantages of AC over DC motors and hence suitable for high performance variable speed drive applications.

Numerous important contributions have been made in this field by contributors from many countries, including Canada, Germany, Italy, Japan, the UK, and the USA. Many industrial companies have marketed various forms of induction motor and synchronous-motor drives using vector control [3].

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Recently, intelligent control, act better than conventional adaptive controls. Artificial intelligent (AI) which is generally regarded as the aggregation of fuzzy logic control, neural network control, genetic algorithm and expert system, has exhibited particular superiorities and used widely in electrical drives[4][5]. In reference [6] a neural-network based space-vector PWM controller for three-level voltage fed inerter induction motor drive is implemented, where reference [7] presents excitation control of synchronous machine using polynominial neural networks, also the neural network controller for synchronous machine is presented in [8] and a fuzzy logic controller for synchronous machine and induction motor are presented in reference [9][10],while reference[11] presents a neuro-fuzzy controller for speed control of a permanent magnet synchronous motor drive. Others studies have suggested the application of the techniques of AI to control speed loop of AC motors as one of them PMSM.

This paper proposes GA controllers for the speed and both (dq) stator currents which have also advantages to minimise their ripples that allow us to minimise them for electrical torque, which give an extra advantage for this study. The inverter used in this paper is based on space vector modulation PWM. The performance of the proposed GA controllers based PMSM with SVM drive is investigated with different PMSM parameters in simulation. In order to prove the superiority of the proposed GA controllers, the performances of it also are compared to those obtained by a conventional PI and with adaptive controller based speed estimation technique [1][2]. The proposed GA controllers based PMSM drive is found to be more robust as compared to the conventional PI and adaptive controllers based drive and hence found suitable for high performance industrial applications.

The contents of this paper are organized as follows. In section 2, the analytic model of PMSM is developed, the principal of SVM and GA controllers are treated in sections 3 and 4, vector control with proposed GA controllers and the space vector modulation inverter is implemented on PMSM in section 5, motor parameters and comparisons between simulation results are given and show the validity and the limits of the proposed method in sections 6 and 7. Finely section 8 concludes the paper.

2. ANALYTIC MODEL OF PMSM

By developing the coupled three-phase mathematical model of PMSM, the (dq) axis current, voltage and flux will be obtained from two transformations. The first part transfers the three phases (abc) to two phases $(\alpha\beta)$ .The second part is the quantities at stationary to rotational frame (dq) figure 1. Where θ represents the rotor position, X_i represent the stator currents, voltage vector and flux at several reference frame and i is $(a,b,c,\alpha,\beta,d \text{ and } q)$.

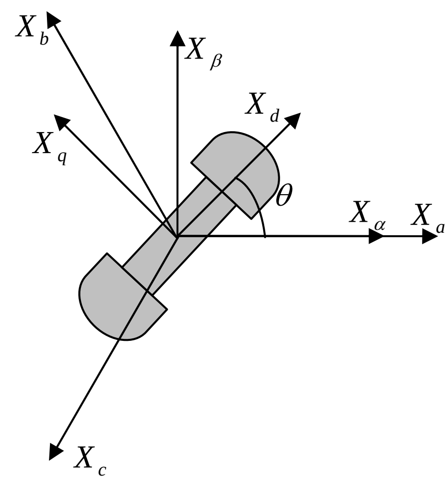

Figure 1. Vector diagram of PMSM.

Electromechanical behaviour of the PMSM in the (dqo) frame is as follows:

$$V_d = Ri_d - \omega_r \lambda_q + \frac{d\lambda_d}{dt} \tag{1}$$

$$V_q = Ri_q + \omega_r \lambda_d + \frac{d\lambda_q}{dt} \tag{2}$$

$$V_o = Ri_o + \frac{d\lambda_o}{dt} \tag{3}$$

$$\lambda_d = L_d i_d + \lambda_m \tag{4}$$

$$\lambda_q = L_q i_q \tag{5}$$

$$\lambda_o = L_o i_o \tag{6}$$

$$T_e = \frac{3}{2} p\left(\lambda_m i_q + \left(L_d - L_q\right) i_d i_q\right) \tag{7}$$

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$$\frac{d\omega_r}{dt} = \frac{p}{J}\left(T_e - B\omega_r - T_m\right) \tag{8}$$

$$\omega_r = p\omega_m \tag{9}$$

Where R represents resistance, V_d and V_q represent stator voltage at rotational reference frame, ω_r, ω_m represent electrical and mechanical rotor speed, i_o represent zero-sequence components of stator current, λ_d and λ_q represent stator flux at rotational reference frame, λ_m represents stator flux linkages due two the permanent magnet, T_e represent electrical torque, p represents the number of pole pairs, J represents rotor inertia, B represents friction T_m represents mechanical load torque, and L_d, L_q represent stator inductance. If the angle between stator and rotor field flux is kept at 90°, then, $i_d^* = 0$. Where i_d^* represents stator reference currents at rotational reference frame. By this assumption and considering that $i_o = 0$, we can determine i_q which lends to controlling the electrical torque:

$$T_e = \frac{3}{2} p\lambda_m i_q \tag{10}$$

3. SPACE VECTOR MODULATION

SVM for three phase voltage source inverters is based on the representation of the three phase quantities as vector in two-dimensional $(\alpha\beta)$ plane. The reference voltages are given by space voltage vector, and the output voltages of the inverter are considered as space vectors. There are 2^3 possible output voltage with two zero vectors V_0, V_7 Figure 2.

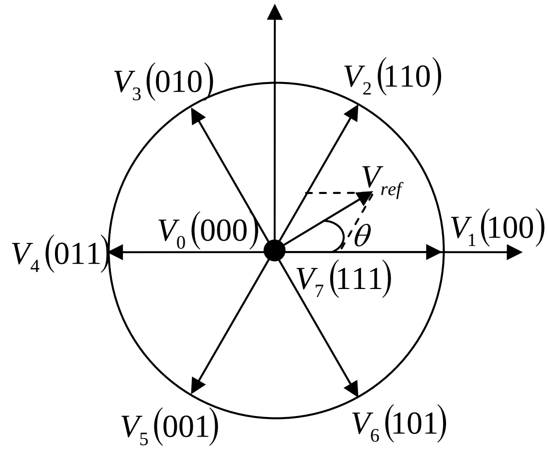

Figure 2. Output voltage represented as space vector

According to SVM method, the inverter will switch from vector V_0 to V_7 with consideration of times switching depends on angle (θ) Figure 3.

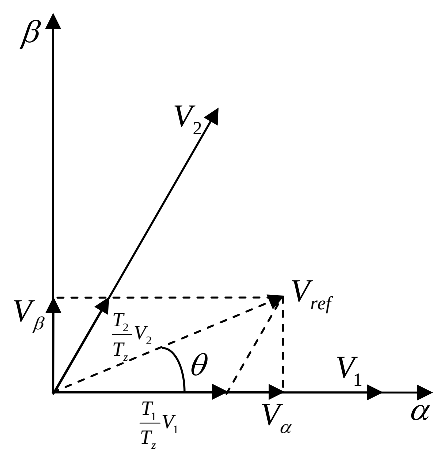

Figure 3. Specification of the voltage vector V_{ref}

Therefore, space vector PWM can be implemented by the following steps:

Step 1: Determine V_{ref} and angle θ:

From figure 3, the V_{ref}, and angle θ can be determined as follows:

$$\left|\overline{V_{ref}}\right| = \sqrt{V_\alpha^2 + V_\beta^2} \tag{11}$$

$$\theta = \arctan\left(\frac{V_\beta}{V_\alpha}\right) \tag{12}$$

Step 2: Determine time duration T_1, T_2, T_0 and T_7.

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From Figures 2 and 3 we conclude the following equations.

$$T_1 = \frac{\sqrt{3}.T_z.\left|V_{ref}\right|}{v_{dc}} \sin\left(\frac{n}{3}\pi - \alpha\right)$$

$$T_2 = \frac{\sqrt{3}.T_z.\left|V_{ref}\right|}{v_{dc}} \sin\left(\alpha - \frac{n-1}{3}\pi\right) \tag{13}$$

$$T_0 = \frac{(T_z - T_1 - T_2)}{2}$$

$$T_7 = \left(\frac{T_z - T_1 - T_2}{2}\right)$$

Where, n =1 through 6, that is, sector1 to 6.

Step 3: Determine the switching time of each transistor $\left(S_1\ to\ S_6\right)$.

In each sector the sequence of switching time is established as follow in figure 4:

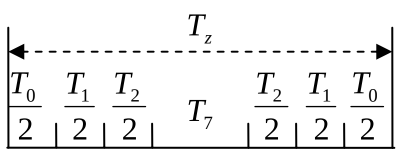

Figure 4. Switching times of each transistor

4. PROPOSED GA CONTROLLERS

GA are based on an analogy to the genetic code in our own DNA (deoxyribonucleic acid) structure, where its coded chromosome is composed of many genes [13][14][12]. GA approach involves a population of individuals represented by strings of characters or digits. Each string is, however, coded with a search point in the hyper search-space. From the evolutionary theory, only the most suited individuals in the population are likely to survive and generate offspring that passes their genetic material to the next generation.

GA is a search mechanism based on the principle of natural selection and population genetics that are transformed by three genetic operators: selection, crossover and mutation. Each string (chromosome) is a possible solution to the problem being optimised and each bit (or group of bits) represents a value or some variable of the problem (gene).

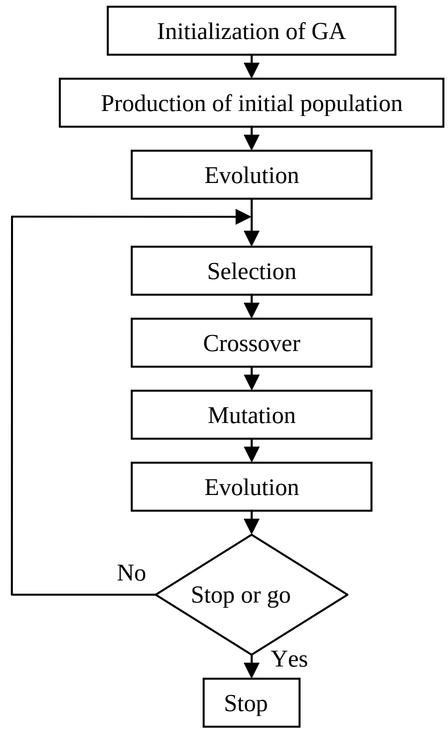

Figure 5. The flow chart of GA

These solutions are classified by an evaluation function, giving better values, or fitness, to better solutions. Each solution must be evaluated by the fitness function to produce a value [15]. The flow chart of the GA is shown in Figure 5. A PI controller with the transfer function $\frac{K_P s + K_I}{s}$ is employed to control the process. The configuration of genetic algorithm parameters is given as follow:

Population size: The first stage of writing a Genetic Algorithm is to create a population. This command defines the population size of the GA.

Variable Bounds: Since this project is using genetic algorithms to optimize the gains of PI controllers. Six strings are going to be assigned to each member of the population, these members will be comprised of K_P and K_I string that will be evaluated throughout the course of the GA processes. The six terms are entered into the genetic algorithm via the declaration of a six-row variable bounds matrix. The number of rows in the variable bounds matrix represents the number of terms in each member of the population. Table 1 illustrates a population of eighty members being initialized with values randomly selected between -100 and 100.

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Table 1. Initialising the genetic algorithm

```
populationSize=80;
variableBounds=[-100 100;-100 100;100 100;-100 100; 100 100;-100 100];
evalFN='GA_PI;
evalOps=[];
options=[1e-6 1 0 0];
initPop=initializega(populationSize,variableBounds,evalFN,evalOps,options)
```

EvalFN: The evaluation function is the Matlab function used to declare the objective and execute the codes and return the values back to the main codes.

Selection function: Tournament selection operator is used to select the fittest individuals, which minimise the performance function to form the next generation.

Crossover operator: Arithmetic crossover operator was chosen as the crossover procedure, single point is to simplistic to work effectively on a chromosome with two alleles, a more uniform crossover procedure thought the chromosome is required. The arithmetic crossover procedure is specifically used.

Mutation operator: The uniform mutation function is used as the mutation operator.

5. PRINCIPLE OF VECTOR CONTROL WITH PROPOSED GA CONTROLLERS

Based on the theoretical statements [16] and GA controllers, the intelligent control structure of a PMSM drive system with field orientated control shall now be looked at in some more detail in figure 6.

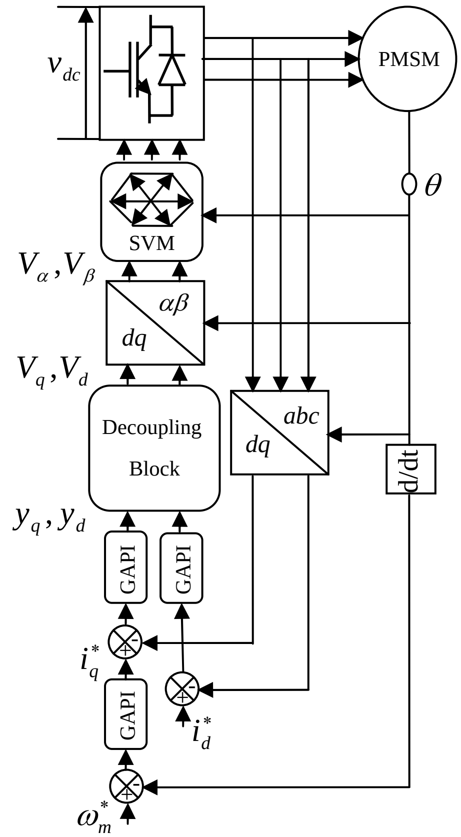

Figure 6. Modern structure vector control for PMSM based on speed and dq currents GA controllers with SVM

Using the current i_d and the speed ω_m, the decoupling block calculates the stator voltage components V_d and V_q from the output quantities y_d and y_q of the $GAPI$ currents controllers. If the field angle θ reference axis is known, the components V_d, V_q can be transformed, from the field coordinates dq into the stator-fixed coordinates $\alpha\beta$. After transformation and processing the well known SVM, the stator voltage is finally applied on the motor terminals with respect to amplitude and phase. When, direct component i_d has the value zero, the current vector i_s located vertically to the vector of the pole flux.

6. MOTOR PARAMETERS AND SIMULATION

The following table represents the PMSM parameters:

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Table 2. PMSM Parameters

Parameters	***Values***
Stator resistance. R	1.4 Ω
d -axis inductance. L_d	6.6 mH
q -axis inductance. L_q	5.8 mH
Magnetic flux constant. λ_m	0.15 wb
Friction coefficient. f	0.00038 $Nmrad^{-1}s^{-1}$
Motor inertia. J	0.00176 kgm^2

The GA speed and dq currents control of PMSM with vector control based SVM inverter using genetic algorithm controller is done using Matlab/Simulink®. And results are discussed in the next section.

In the first time, the evaluation function GA_PI.m was written. This function firstly extracts the relevant parameters from the chromosome passed in, after performing some checking the parameter are used to create GAPI controllers for speed and dq currents. In the second case the Simulink model is then called as the following Matlab algorithm in table 3.

Table 3. Matlab algorithm

```
Ga_control.m      %main function
Initialisega.m    %Initialisation of genetic
%algorithm
GA_PI .m          % Evaluation function
   Make_GAPI.m
   sim('PMSM') %Simulink Model
   Run_ga.m       % the run of genetic algorithm
   GA_PI .m       % Evaluation function
Make_GAPI.m
   Sim('PMSM') %Sim Simulink Model
End               %end of main function
```

Figure 7 presents the system's response to speed reference equals to +100,-100 and stator current i_d reference to 0A without mechanical load.

Figure 8 shows the results of speed control according to a profile +50,-100 with a fixed charge of 4N.m at (0.5s). Speed, torque, and stator currents are visualised in each simulation.

7. RESULTS

In order to demonstrate the high performance of the proposed GA controllers, numerous simulation tests were performed under different operating conditions. Sample significant simulation results are presented below. Figure 7 shows the speed, torque and stator currents control. The speed and stator current references are applied as order respectively with +100, -100 rad/s and 0A. It is clear that the system follows these references faster than the results shown in [1]. The torque and the currents ripples due to the harmonic of SVM are reduced in comparison with conventional PI [1]. It is found that the GA controllers based PMSM drive has small settling time (0,012s) for both positive and negative speed without any overshoot/undershoot. In contrast to [17] has multiple overshoot/undershoot with the settling time (0,025s). A comparison between the PI controller presented in [1] and the proposed GA controllers proves the superiority of the proposed GA controllers.

In Figure 8, the motor starts under no load. The starting electromagnetic torque is 25Nm, which drops rapidly to zero when speed is reached quickly and tightly without overshoot/undershoot at t=0.012s. A 4Nm load is applied at 0.5s, the controller rejects the disturbance rapidly and follows the reference with minimum ripples whereas the classical PI in [1] shows large ripples. At 0.7s the reference speed inversed to -100 and we show also that the proposed controllers track the references speed and current rapidly at 0.712s. Figure (8-c) shows clearly that the stator current i_d is not influenced by the application of such load.

Figure (8-e) presents also the stator current i_a with little harmonic in comparison to the same in [17] when the controller is classical PI. The stator current is sinusoidal with fluctuations order of 0.5% around the average value, due to the SVM.

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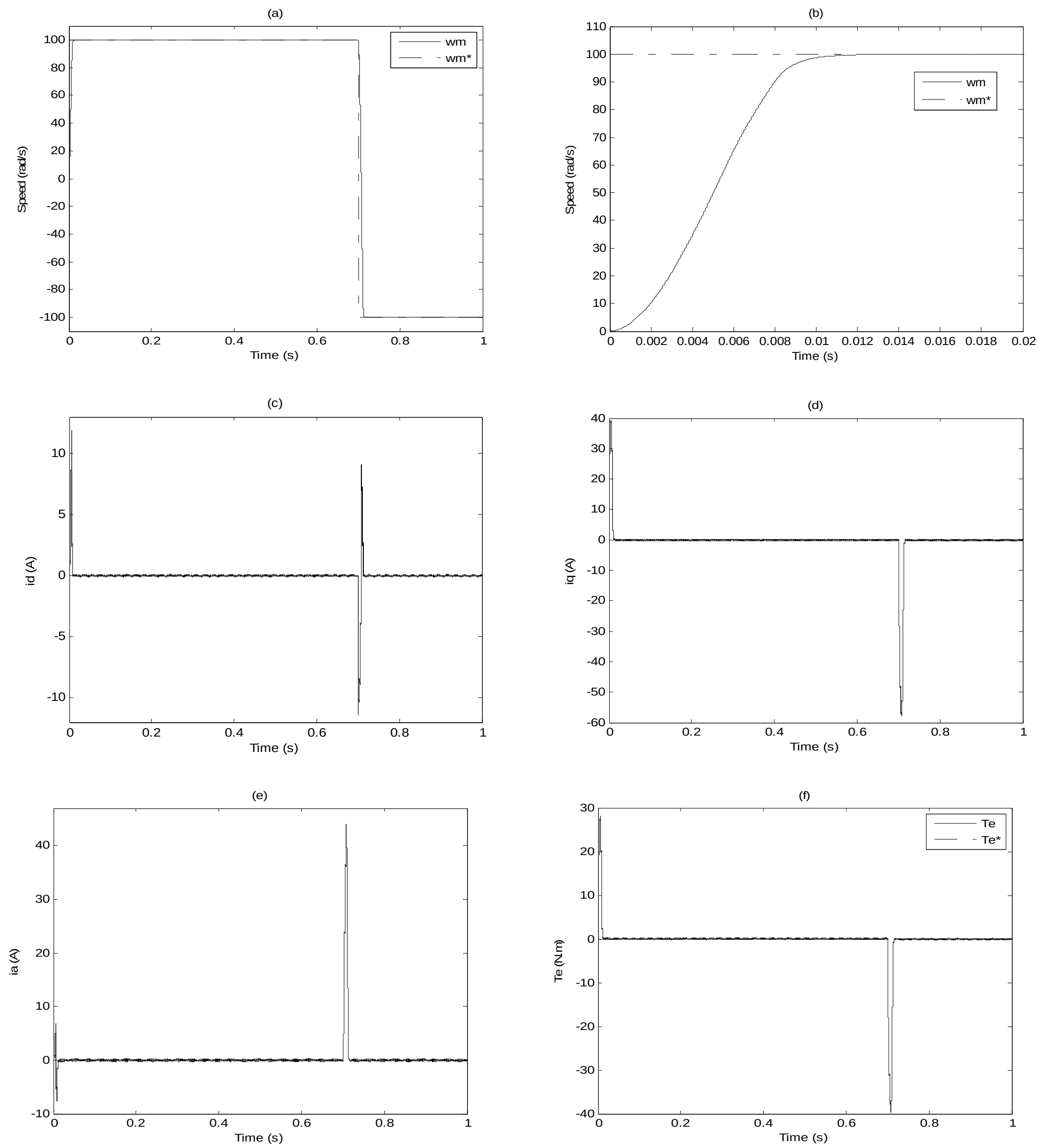
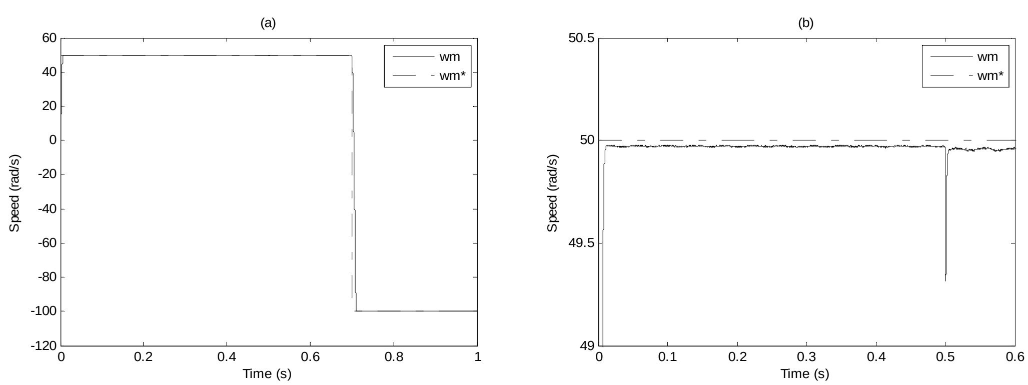


Figure 7. Simulated speed, torque and dq currents responses of the PMSM drive with GAPI for a +100,-100 speed reference without fixed charge: (a) ω_m, (b) zoom of ω_m, (c) i_d, (d) i_q, (e) i_a, (f) T_e.



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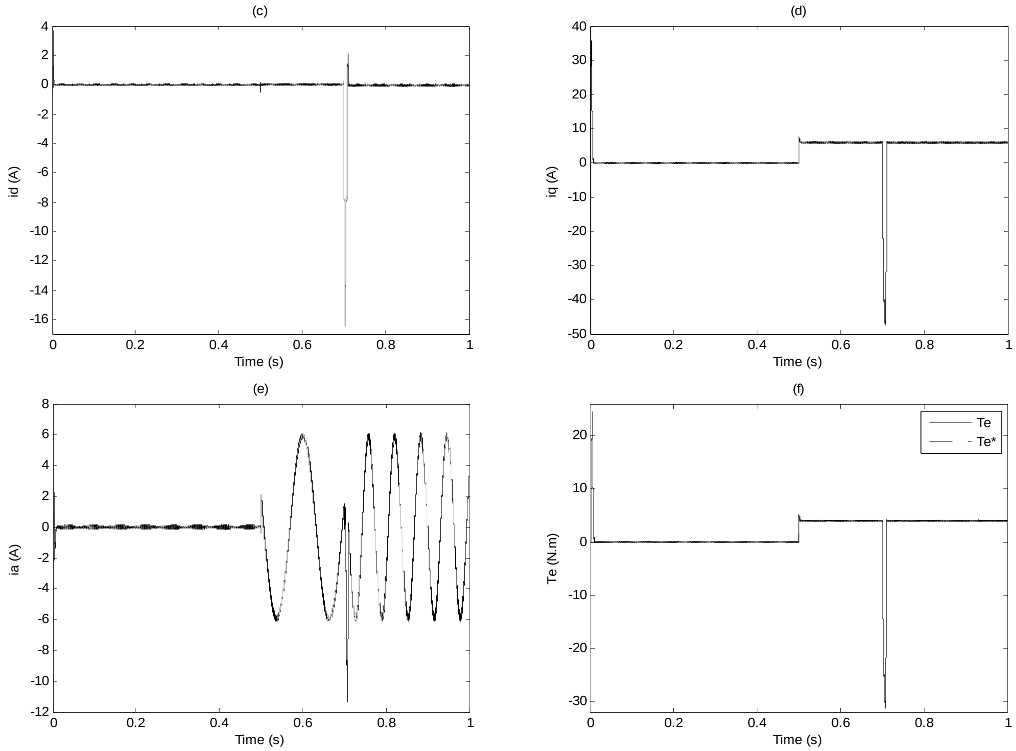

Figure 8. Simulated speed, torque and dq currents responses of the PMSM drive with GAPI for a +50,-100 speed reference with a fixed charge of 4N.m: (a) ω_m, (b) zoom of ω_m,(c) i_d, (d) i_q, (e) i_a,(f) T_e.

8. CONCLUSIONS

In this article a GA speed and (dq)current controllers of PMSM motor with space vector modulation SVM has been proposed and simulated with Matlab/Simulink®. The speed controller proposed is a GAPI controllers designed without the mathematical model of the PMSM motor. The excellent simulation results obtained show the effectiveness of this technique in the speed, torque and (dq)current regulation of the PMSM.

Our future research work is to develop and improve other intelligent techniques such as the neural network by using the genetic algorithms to reduce more the torque ripple of the PMSM.

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