The Analysis and the Simulation of the SVM used for the Control of PMSM Machine with Fuzzy Logic Controller

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Abstract— The Permanent Magnet Synchronous Motor (PMSM) has been widely used in the low to medium power system due to its characteristics of high efficiency, high torque to inertia ratio, high reliability and fast dynamic performance. With the advent of the vector control methods, permanent magnet synchronous motor can be operated like separately excited dc motor high performance application. The complexity of PI controller tuning and high response time is overcome by Fuzzy controller. Which has less response time and high accuracy without any mathematical calculation .This paper presents a simulation of speed control system on fuzzy logic approach for an indirect vector controlled permanent magnet synchronous machine drive by applying space vector modulation. The design, analysis and simulation of the proposed system is done using MATLAB\ SIMULINK

Index Terms— ***Permanent magnet synchronous motor (PMSM), Fuzzy Logic Controller (FLC), Space Vector Modulation SVM.***

I. INTRODUCTION

Permanent magnets Synchronous machines are used as actuators in automated industries where they replace the DC motors because they have many advantages. In fact, they have better performance than DC motors in terms of torque mass and it don't have mechanical commutates (collector) which causes problems of maintenance and can't conduct in severe environments

However, the DC motor is more used because it is powered by a simple converter (rectifier or inverter) and the regulation of the current's armature can control the torque. For the PMSM, the functioning of the collector is ensured by an electronic circuit composed by a power inverter, a position sensor and a current regulatory control the torque.

The progress of power electronics as well as the development of control techniques have made possible now to implement a control structure much more advanced.

The PWM modern inverters in the electric drives with synchronous motors often use microprocessors, digital signal processors or ASIC (Application Specific Integrated Circuits) to generate the waveforms in real time. The wave shapes can be obtained now with an accuracy which couldn't be generation. The advantages brought by these solutions are bound both for getting of waveforms lacked for undesirable harmonics and also for the possibility of controlling the level of the amplitude of harmonics using different generation techniques. The control in real time offers the possibility of changing the amplitude of voltage and the frequency of this, very quickly, and it's a fact which allows the using of a complex strategy to control the PMSM motor [2].

the methods used for controlling the speed of the synchronous machine is the method of vector control, using the SVM (Space Vector Modulation) strategy, a method which was described in [1].

A solution of control which is proposed in the literature is a fuzzy logic control to provide a better performance for the PMSM in spite of the parametric variations [1].

This paper presents

The analysis and the simulation of SVM generator, an essential subsystem in the technique of space vector modulation.

The results of simulation of the vector control based on two types of a speed controller: the PI controller for the tow currents (id,iq) and the fuzzy logic controller for the speed.

II. THE MODELING OF THE PERMANENT MAGNET SYNCHRONOUS MACHINE

To obtain a simpler formulation and reduce the complexity of the machine model, the establishment of its mathematical model will be developed based on simplistic to say that the machine is symmetric assumptions, is operating in the saturated regime and the various losses and the effect of damping is negligible.

The Park model of the synchronous machine with permanent magnet pole pairs P is defined by the following system of equations:

$$\begin{cases} V_{sd} = R_s i_{sd} + \dfrac{d\phi_d}{dt} - \omega_r \phi_q \\ V_{sq} = R_s i_{sq} + \dfrac{d\phi_q}{dt} + \omega_r \phi_d \end{cases} \tag{1}$$

$$\begin{cases} \phi_q = L_q i_{sq} \\ \phi_d = L_d i_{sd} + \phi_r \end{cases} \tag{2}$$

The mechanical equation is:

$$J\frac{d^2\theta}{dt^2} + f\frac{d\theta}{dt} = C_{em} - C_r \tag{3}$$

The electromagnetic torque is given by:

$$C_{em} = \frac{3}{2} p(\phi_r i_{sq} + (L_d - L_q) i_{sd} i_{sq}) \tag{4}$$

III. STATE MODEL OF PMSM:

From the equations last's, the system can be written in the following form:

$$\begin{cases} \dot{X}=[A].X+[B].U \\ Y=[C].X+[D].U \end{cases} \tag{5}$$

The model in matrix form is:

$$\frac{d[X]}{dt}=[A].X+[B].U \tag{6}$$

with:

$$[X]=\begin{bmatrix} i_{sd} & i_{sq} \end{bmatrix}^T$$
$$[U]=\begin{bmatrix} V_{sd} & V_{sq} & \phi_r \end{bmatrix}^T \tag{7}$$

$$\begin{bmatrix} \dot{i}_{sd} \\ \dot{i}_{sq} \end{bmatrix}=\begin{bmatrix} -\frac{R_s}{L_d} & \omega_r\frac{L_d}{L_q} \\ -\omega_r\frac{L_d}{L_q} & -\frac{R_s}{L_d} \end{bmatrix}.\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix}+\begin{bmatrix} \frac{1}{L_d} & 0 & 0 \\ 0 & \frac{1}{L_d} & \frac{-\omega_r}{L_q} \end{bmatrix}.\begin{bmatrix} V_{sd} \\ V_{sq} \\ \Phi_r \end{bmatrix} \tag{8}$$

IV. VECTOR CONTROL OF PMSM

The technique applied to the PMSM is to maintain I_d zero to produce maximum torque and use I_q component for achieving the cascade control to ensure the performance of the chase speed. The block structure of this control scheme is shown in (Fig. 1)

the control theory by field oriented can assimilate the behavior of the synchronous machine with permanent magnets a continuous-current machine with separate excitation, in which the magneto motive force of the armature made an angle of 90° with the axis of field flow, and this, whatever the speed of rotation.

To achieve control, it is necessary to direct the flow in quadrature with the torque generating current. Thus, we obtain a model of the machine where the flux and electromagnetic torque are decoupled so that we can act on the torque without affecting the flow, since the torque depends only on the current (i_q). This will allow obtaining significant performance, for the system response under dynamic similar to that of DC machines.

The control flow is directed to guide the current along the axis(q). Thus, the electromagnetic torque can be controlled by a single quadrature component(i_q). This amounts to maintain the stator current in quadrature with the inductor's flow, which gives a maximum torque, and to regulate the speed by the current (i_q) via the voltage(v_q). This verifies the principle of the DC machine.

Vector Control returns to control both components (i_q) and (i_q) of the stator current tensions by imposing (v_d) and (v_q) appropriate. To impose voltages (v_d) and(v_q), it suffices to impose the reference voltages (v_{qref}) and (v_{dref}) at the input of the inverter [2]. Using the regulators, we get the reference currents(i_{dref}) and(i_{qref}).

Vector control laws feeder machines voltages pose couplings between actions on the axes (d) and(q). In a reference (d) and (q) with the axis (d) aligned with the rotor flow

To decouple the evolution of currents, (i_d) compared to controls, we will define the terms of compensation e_{sd} and e_{sq} as:

$$\begin{cases} e_{sq}=\omega_r.L_q.i_{sq} \\ e_{sd}=\omega_r.L_d.i_{sd}+\omega_r.\phi_r \end{cases} \tag{9}$$

$$\begin{cases} v_{sd}=v_{sd1}-e_{sd} \\ v_{sq}=v_{sq1}-e_{sq} \qquad (5) \end{cases} \tag{10}$$

With

$$\begin{cases} v_{sd1}=L_{sd}\frac{di_{sd}}{dt}+r_s i_q \\ v_{sq1}=L_{sq}\frac{di_{sq}}{dt}+r_s i_{sd} \end{cases} \tag{11}$$

The currents i_d and i_q are decoupled. The current i_d only depends v_d and the current i_q depends only v_q The (fig. 4) represents the different stages of the vector control's structure with a rotor's flux orientation.

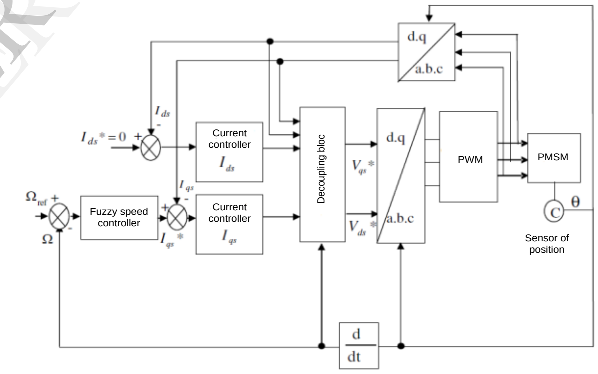


Fig. 1. System Configuration of Field-Oriented Synchronous Motor

A. PI Controller

The proportional integral (PI) controller is one of the famous controllers used in a wide range in the industrial applications. The PI controller is defined by the following function:

$$C(p)=k_p+\frac{K_i}{p} \tag{12}$$

B. Fuzzy logic controller

The general structure of a complete PI fuzzy control system is given in Fig.2. The control voltage u is inferred from the two variables state, error e and variant of Δe. The actual crisp input are approximates to the closer values of the respective universes of discourse. Hence, the Fuzzy fiend inputs are described by singleton fuzzy sets. The elaboration of this controller is based on the phase plant. the fuzzy logic controller executes the 49 control rules shown in Table 1 taking the fuzzy variables e and ce as inputs and the output quantity Δi_{q^*} is processed in the defuzzification unit. The rules are formulated using the knowledge of the permanent magnets synchronous motor behavior and the experience of control engineers.

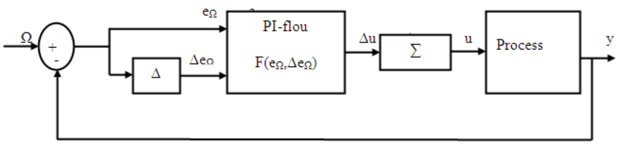


Fig. 2. structure of PI fuzzy controller

The continuity of input membership functions, reasoning method, and defuzzification method for the continuity of the mapping fuzzy $(e, \Delta e)$ is necessary. In this work, the triangular membership function, the max-min reasoning method, and the center of gravity defuzzification method are used, as those methods are most frequently used in many literatures [1]

TABLE I. FUZZY CONTROL RULES FOR SPEED CONTROLLER

		Error ‘e’						
		NB	NS	NS	Z	PS	PM	PB
Change of error 'Δe'	NB	NB	NB	NB	NB	NM	NS	Z
	NM	NB	NB	NB	NM	NS	Z	PS
	NS	NB	NB	NM	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PM	PB	PB
	PM	NS	Z	PS	PM	PB	PB	PB
	PB	Z	PS	PM	PB	PB	PB	PB

V. SIMULATION OF THE SVM

This modulation is represented by the vector only three sinusoidal output voltages as desired. We approximate the best vector for each modulation interval by influencing the control of three sets of complementary switch. This vector PWM does not rely on separate calculations for each arm of the inverter, but the determination of a global vector control approximated on a modulation period T

Determination of reference voltages Vα, Vβ.

Identification of sector.

Calculation of switching time for each sector.

Generate of control signals.

The Simulink scheme of the SVM generator (Fig. 1) is formed by subsystems disposed on the structure of the operating principle scheme, presented in [1], each of this having its own Simulink model.

We'll show the main blocks from the scheme, their role and the equations on which they were built

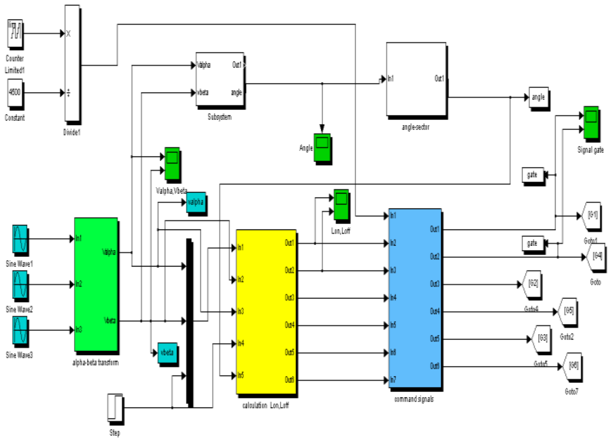


Fig. 3. The Simulink scheme of SVM generator

A. Determination of Vα, Vβ:

This block is used to project the three-phase voltages in the repository (α, β) by performing the processing in Simulink Clarke, one obtains:

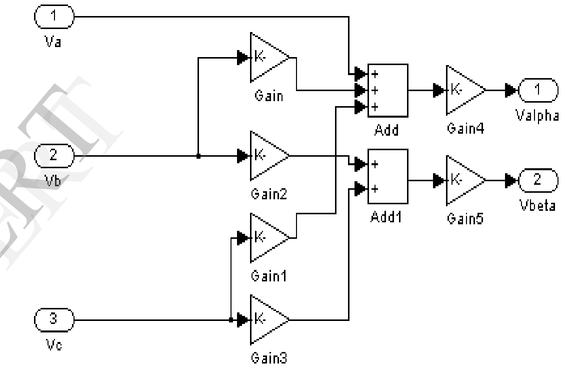


Fig. 4. The Simulink scheme for transform. abc-αβ

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE and SI do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

B. The vector sector in αβ coordinates

The subsystem determines the sector (1 to 6) in which the voltage vector lies, comparing the signal Angle with the limits of every sector. the output signal is periodical, in six stages of amplitude. we present In (Fig. 3) the Simulink partial scheme of the subsystem for 1 and 2 sector and it is completed in the same way for the other sectors.

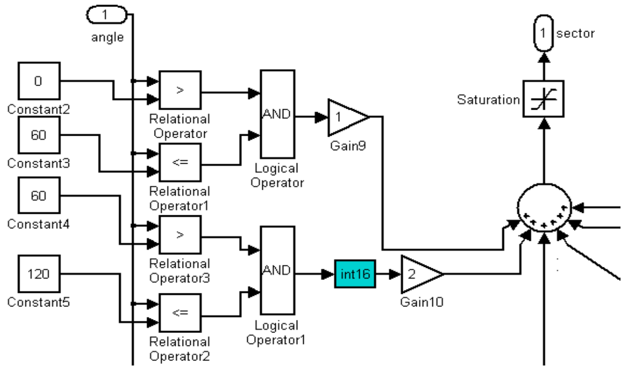


Fig. 5. generation of sectors in the reference αβ

C. The switching time calculator

In (Fig. 4) we present the block which corresponds to the A branch where a multiport switch chose one of the f1, f2, f3, f4, f5, f6 functions (from the Table I).

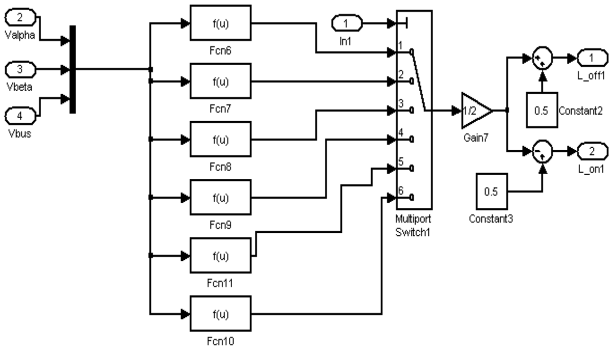


Fig. 6. switching time calculator

TABLE II. THE FUNCTIONS EXPRESSIONS

Function	*Mathematical expression*
$f1, f4$	$\sqrt{2}(\sqrt{2}V_{bus} + \sqrt{3}V_{\alpha} + V_{\beta}) / 4V_{bus}$
$f2, f5$	$(V_{bus} + \sqrt{6}V_{\alpha}) / 2V_{bus}$
$f3, f6$	$\sqrt{2}(\sqrt{2}V_{bus} + \sqrt{3}V_{\alpha} - V_{\beta}) / 4V_{bus}$
$f7, f10$	$\sqrt{2}(\sqrt{2}V_{bus} - \sqrt{3}V_{\alpha} + 3V_{\beta}) / 4V_{bus}$
$f8, f11$	$(V_{bus} + \sqrt{2}V_{\alpha}) / 2V_{bus}$
$f9, f12$	$\sqrt{2}(\sqrt{2}V_{bus} - \sqrt{3}V_{\alpha} + V_{\beta}) / 4V_{bus}$
$f13, f16$	$\sqrt{2}(\sqrt{2}V_{bus} - \sqrt{3}V_{\alpha} - V_{\beta}) / 4V_{bus}$
$f14, f17$	$(V_{bus} - \sqrt{2}V_{\beta}) / 2V_{bus}$
$f15, f18$	$\sqrt{2}(\sqrt{2}V_{bus} - \sqrt{3}V_{\alpha} - 3V_{\beta}) / 4V_{bus}$

D. The gates logic

The subsystem receives the six Loff, Lon signals through the input gate timing. the ramp signal obtained through the integration in discrete time of a constant (here 4500 Hz), with reset controlled by the true value of the comparison ramp 1.

The subsystem, whose Simulink scheme is presented in (Fig. 5), compares on every phase, the ramp signal with Loff (ramp Loff), respectively with Lon (ramp Lon) and it units with an AND operator the two results. The resultant signal and also the same denied signal are taken off at the output, and they represent the control signals on gate for activate the inverter switches.

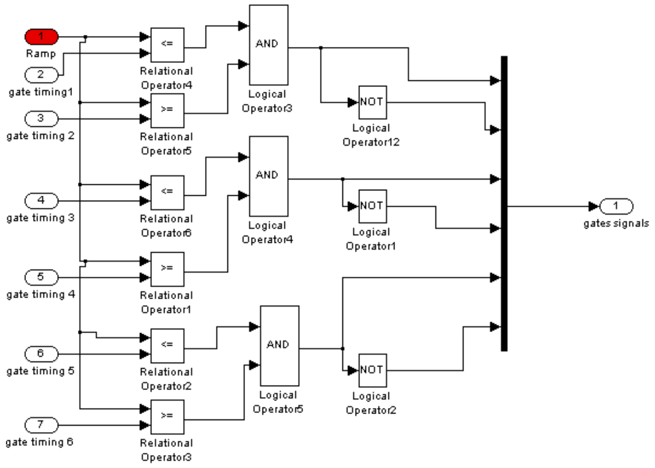


Fig. 7. generation of control signals

VI. THE RESULTS OF SIMULATIONS

We make simulations on the complete scheme of electric drive with synchronous motor presented in [1], which contains the SVM generator. We consider its following parameters:

- ✓ switching frequency 5000 Hz.
- ✓ SVM sampling time 0.5s.

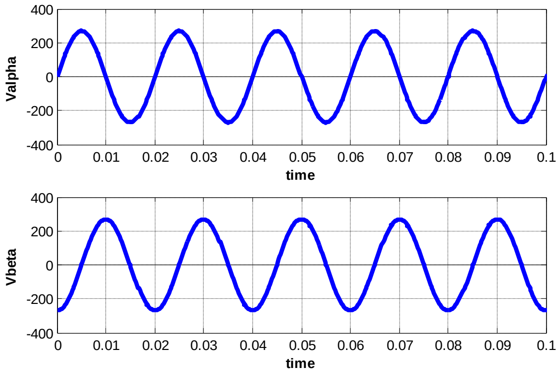


Fig. 8. Voltage (Valpha, Vbeta)

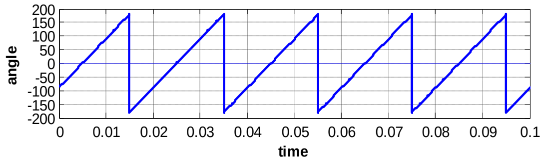


Fig. 9. angle(rad)

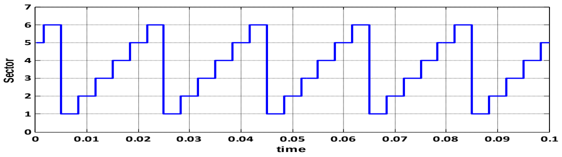


Fig. 10. Sector

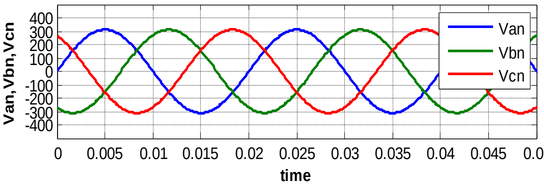


Fig. 11. Voltages Va Vb Vc

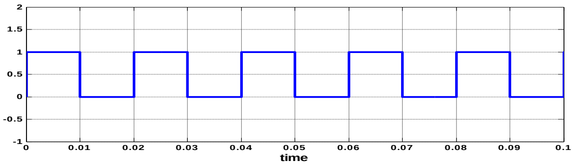


Fig. 12. Signal for gate 1

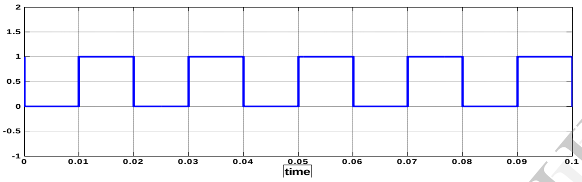


Fig. 13. Signal for gate 2

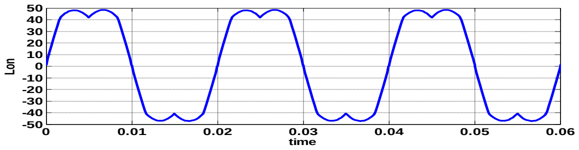


Fig. 14. L_on branch A

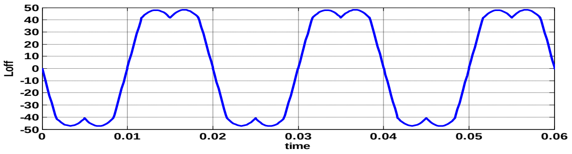


Fig. 15. L_off branch A

VII. SIMULATION RESULTS OF VECTOR CONTROL FOR PMSM

In order to validate the control strategies discussed above, digital simulation studies were made the system described in Figure 4. The speed and currents loops of the drive were also designed and simulated with PI current (Id,Iq) control and with fuzzy speed control.

The transient response was tested on closed loop with two PI current controls and a fuzzy for the speed control. The simulation of the starting mode without load is done. The load $\left(Cr = 4\,Nm\right)$ is applied at t = 1 s.

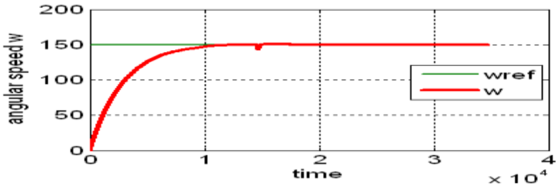


Fig. 16. speed

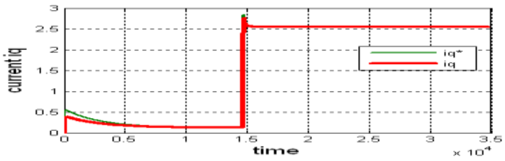


Fig. 17. Current *iq*

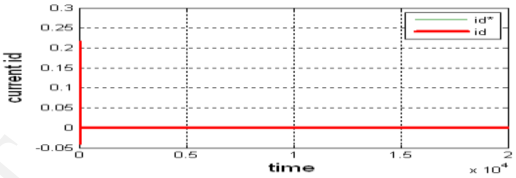


Fig. 18. *Current id*

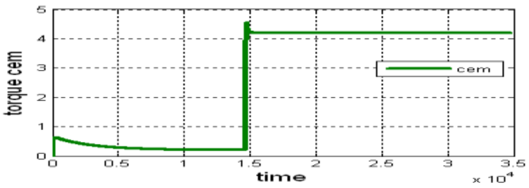


Fig. 19. Torque *cem*

The speed response of the permanent magnet synchronous machine is similar to a first order system.

The application of load torque as using the fuzzy logic controller stay the speed invariable.

The fuzzy controller rejects the load disturbance rapidly with no overshoot and with a negligible static error.

The right choice of adjustment coefficients of the current regulator maintains the component i_d always equal to zero and the component i_q with the same look and the same dynamics as the electromagnetic torque and that to meet the load torque.

VIII. CONCLUSION

WE simulate a SVM generator is used to control, through the technique of space vector modulation, of the electric drives with PMSM machine.

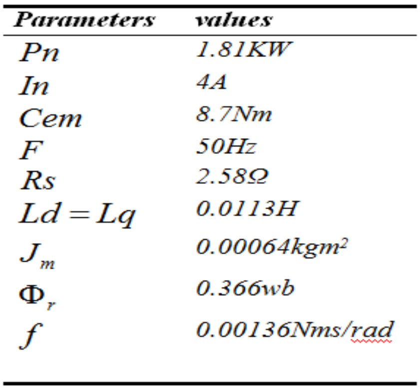
We present the Simulink schemes of the main subsystems of SVM generator, built on the corresponding equations.

We analyzed how the model works, observing the waveforms of various signals.

we noticed that the vector control and the proper choice of the coefficients of the controller can achieve decoupling of the machine and the production of a similar machine DC linear model and the other for good performance such as stability, precision and speed.

The fuzzy controller rejects the over current and the oscillations at starting. It decreases the influence of the load torque on the speed of the PMSM.

TABLE III. PARAMETER OF PMSM



Parameters	*values*
Pn	$1.81KW$
In	$4A$
Cem	$8.7Nm$
F	$50Hz$
Rs	2.58Ω
$Ld = Lq$	$0.0113H$
J_m	$0.00064kgm^2$
Φ_r	$0.366wb$
f	$0.00136Nms/rad$

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