VECTOR CONTROL OF INDUCTION MOTOR BASED SPACE VECTOR MODULATION

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Abstract: **It is well known that the vector control based on hysteresis regulators of induction machine presents less performance in term of current quality witch translated by strong ripples at steady state what increases the commutation losses in the inverter. For these reasons, we propose a new approach of FOC based on the SVM technique. Simulation results are shown to demonstrate the validity of the proposed methods.**

Key words: *Induction Motor, FOC, SVM, Hysteresis.*

I. INTRODUCTION

Nowadays as a consequence of the important progress realized in power electronics induction machines driven by static converters have become the most widely used machines in variable speed application, for this reasons of cost, size, reliability and efficiency. With the advances of industrial computers, control algorithms (FOC, DTC, robust and adaptative control) can now satisfactory be implemented. Among these techniques, field-oriented control has emerged for high performance control of induction machines [1] [2]. This control strategy can provide the same performances as achieved from a separately excited DC machines, and its main objective is, as in separately excited DC machines, to independently control the produce torque and the flux, this is done by choosing a d-q stationary reference frame with the stator flux space vector.

In the choice of the strategy of space vector modulation (SVM), a vector approach of the inverter which offers a direct bond with the transformations used in the modern controls.

Thus the methods known as of space vector modulation or SVM. The space vector modulation is a strategy of reference; its principle is the continuation of the vector tension. [3] [4].

In this paper, we present a simulation of an indirect field-oriented control for an induction motor based on SVM. The implemented system presented in this paper consists of an induction motor with its static inverter with technique SVM, and speed, and current controllers.

II. DESCRIPTION OF THE *SVM* ALGORITHM

Space vector modulation SVM is implemented using the direct method and is used in the induction motor. SVM is a preferred strategy for high performance as drives due to increased utilization of the dc link and the capability to reduce the switching losses as compared to the hysteresis current control.[8]

Based on the topology of the inverter power stage, shown in fig. 1 there are eight possible switching states for the output line voltage space vector, which is based on the constraint that the input lines can never be shorted and the phase currents must be continuous [6].The eight possible switching states are determined form the different possible values of the induction motor line to line voltages.

TABLE I

Switching States in a Tow-Level Inverter and the

state	Vab	Vbc	Vca	Vdqs
0 0 0	0	0	0	0
1 1 1	0	0	0	0
1 0 0	Vdc	0	-Vdc	$(2/3Vdc)e^{j30°}$
1 1 0	0	Vdc	-Vdc	$(2/3Vdc)e^{j90°}$
0 1 0	-Vdc	Vdc	0	$(2/3Vdc)e^{j150°}$
0 1 1	-Vdc	0	Vdc	$(2/3Vdc)e^{-j150°}$
0 0 1	0	- Vdc	Vdc	$(2/3Vdc)e^{-j90°}$
1 0 1	Vdc	- Vdc	0	$(2/3Vdc)e^{-j30°}$

Corresponding Output Line to Line Voltage and Stator dq Complex Voltage Space Vector

In addition, the inverter output line to line voltage space vector is designated as $[V_{ab}\ V_{bc}\ V_{ca}]^T$ .To help determine the possible inverter output line to line voltages, a

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simplified representation of the inverter is shown in Fig 2, each phase leg of the induction motor must be either connected to the positive side of the dc link, or to the negative side dc link. The equation relating the stator abc line to line voltages to the stator dq complex space vector is expressed by

$$V_{dqsl.l}=\frac{2}{3}\left(V_{ab}+V_{bc}.e^{j120°}+V_{ca}.e^{j240°}\right) \tag{1}$$

The possible switching states, resulting line to line voltages, and complex voltage space vectors are given in table I. The stator line to midpoint induction motor dq complex space vectors are related to the stator line to line dq complex space vectors by the expression given in (2), which relates the line to line voltages of a three phase Y connected load to the line to midpoint voltages

$$V_{dqsl.m}=\frac{V_{dqsl.l}\cdot e^{-j30°}}{\sqrt{3}} \tag{2}$$

The space vector diagram will all of the available inverter output voltage vectors is shown in fig.3, where the six non-zero voltage vectors have been identified. To additional switching vectors, which are not shown in Fig.2, are the zero vectors $V_0(000)$ and $V_7(111)$. The reference vector, r, shown in Fig.2, has a length of $(\frac{2}{3}d).V_{dc}$ and an angle of θ. The quantities d and θ are defined in (3) and (4), respectively, where $d\alpha$ and $d\beta$ are input as shown in Fig .3

$$d=\sqrt{d_\alpha^2+d_\beta^2} \tag{3}$$

$$\theta=\tan^{-1}\left(\frac{d^\beta}{d_\alpha}\right) \tag{4}$$

$$\vec{r}=\frac{2}{3}V_{dc}.d\angle\theta \tag{5}$$

Once the reference vector, r, is known, it is synthesized during each switching period by finding its projection onto the nearest tow adjacent switching vectors, using adjacent switching losses [5], [7]. In the case of this system, the switching period, T is 100µs, which corresponds to an inverter switching frequency, F of 10kHz. The synthesis of r in voltage sector 1 is shown in Fig.3. Since the duty cycle timing information is normalized to one, the zero vector must be used to account for the difference between (d_1+d_2) and unity, as shown in (6)

$$\begin{aligned} &d_1\vec{v}_1+d_2\vec{v}_2=\vec{V}_{ref}=mV_c.e^{jy}\\ &d_1+d_2+d_0=1 \end{aligned} \tag{6}$$

In a tow dimensional, the d_1 and d_2 duty cycles can be determined from a change of basis of ***r*** from the orthogonal $\alpha\beta$ basis to the basis defined by to adjacent switching vectors which for sector 1 are V_1 and V_2, as shown in Fig .3.

The basis matrix is determined by expanding the new basis vectors, [x,y], in terms of the standard basis vectors, which is show in (7).

A similar change of basis procedure can be used in the remaining five sectors. The change of basis matrices for each sector is summarized in table II. Once d1,d2, and d0 have been determined, the next step is to compute the da, db, and dc duty cycles. The normalized da,db, and dc duty cycles correspond to the time the top switch of the corresponding phase a,b or c leg is turned the switching period, when a phase leg is on, the state is “1” and the top switch of fig.3 is closed and the bottom switch is open. The phase leg duty cycles are determined based on the sector the reference vector is in and the switching state of the adjacent switching vector. Therefore, for the reference vector in sector 1, the da, db, and dc duty cycles are given as shown in (8) when the zero vector v0(000) is used. The da, db, and dc duty cycles are given in (9) when the zero vector v7(111) is used. Once the duty cycle times da, db, and dc are determined, as shown in Fig.4 for sector 1 for the case when the zero vector is v7(111).

$$\begin{bmatrix} d_1\\ d_2 \end{bmatrix}=\begin{bmatrix} 1 & -1/\sqrt{3}\\ 0 & 2/\sqrt{3} \end{bmatrix}\begin{bmatrix} d_\alpha\\ d_\beta \end{bmatrix} \tag{7}$$

$$\begin{aligned} &d_a=d_1+d_2\\ &d_b=d_2\\ &d_c=0 \end{aligned} \tag{8}$$

$$\begin{aligned} &d_a=1\\ &d_b=d_2+d_0\\ &d_c=d_0 \end{aligned} \tag{9}$$

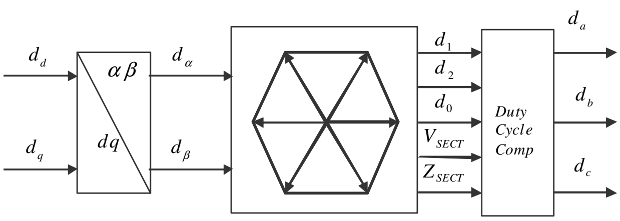

Figure.1 Space vector modulation controller.

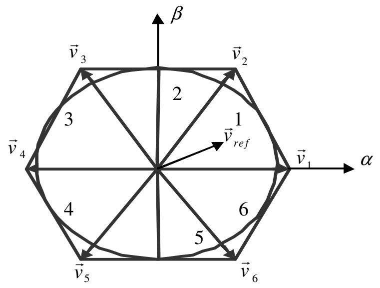

Figure. 2. Inverter output voltage vectors in the α-β stationary frame

TABLE II:

Change of basis matrix for each of the six sectors.

Sector : 1	2	3	4	5	6
$\begin{bmatrix} 1 & -1/\sqrt{3} \\ 0 & 2/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} 1 & 1/\sqrt{3} \\ -1 & 1/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} 0 & 2/\sqrt{3} \\ -1 & -1/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} -1 & 1/\sqrt{3} \\ 0 & -2/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} -1 & -1/\sqrt{3} \\ 1 & -1/\sqrt{3} \end{bmatrix}$	$\begin{bmatrix} 0 & -2/\sqrt{3} \\ 1 & 1/\sqrt{3} \end{bmatrix}$

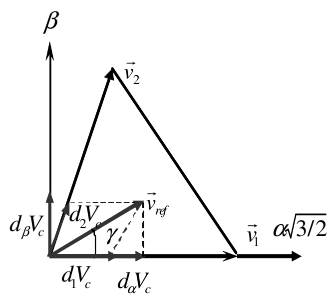

Figure. 3 Synthesis of the reference vector in sector 1

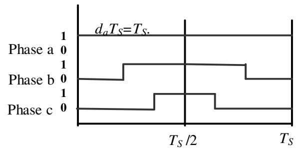

Figure. 4. Center based phase gating signals in sector 1

III. FOC WITH SVM

The out puts of the current regulators from the inputs to the space vector modulator, shown in Fig. 5. The outputs of the current regulators, the dd and dq duty cycles, are given in the rotating reference frame. The dd and dq duty cycles are returned to the stationary reference frame by using a rotating to stationary reference frame transformation, as shown in (7). The outputs of the reference frame transformation, and d and d are used as the inputs to the space vector.

IV. SIMULATION RESULTS

The system simulation arrangement shown in Fig.7 is used to obtain the switching wave forms for SVM.A similar arrangement is used to test hysteresis current control. The field-oriented controller in the stator flux reference frame shown in Fig.6, is used. A speed regulator has been added to regulate the rotor speed at the commanded value, and the load torque is applied to the induction motor modelled in the stationary frame, which is a common choice when the switching waveforms are simulated. From the results obtained, it is shown in Fig.8 and 9.that the harmonic components, when using hysteresis control, are broadly spaced around an average switching frequency of about 5kHz. When using SVM control, harmonic components are closely spaced around the switching frequency used, which was $f_s = 10$kHz .

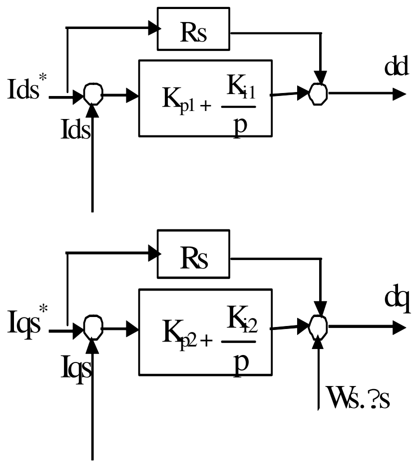

Figure. 5. dq current regulators in the synchronous reference frame

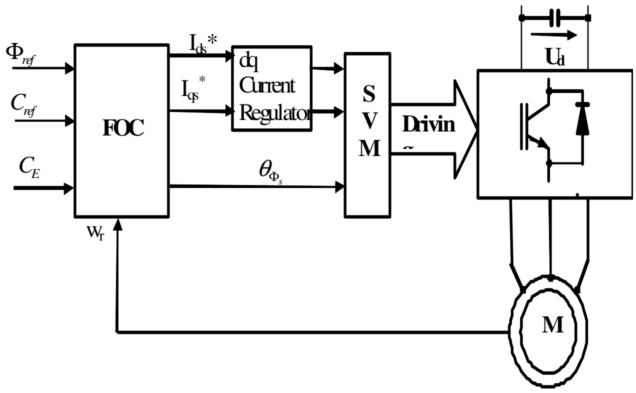

Figure.7. Schematic of basic control software for induction motor drive control

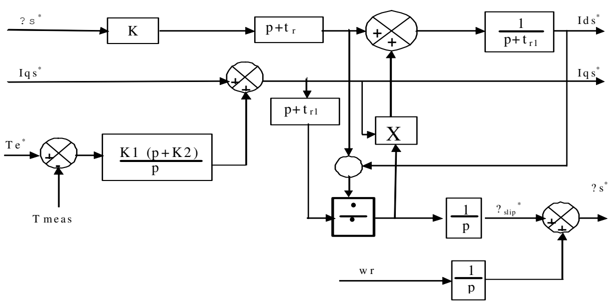

Figure 8. Field-oriented controller in the stator flux reference frame

V. CONCLUSION

In this paper, we have presented a simulation of an indirect field-oriented control for an induction motor using

MATLAB/SIMULINK. A simplified space vector modulation control scheme is present for reduced switching losses in converter-fed drives. The proposed scheme reduces the switching power losses significantly more than the conventional PWM based an hysteresis regulators and gives the same performances, more over, as those obtained with the SVM technique. The main advantages of the proposed scheme are:

1. Only two inverter legs are controlled in each operation interval.
2. The switching losses are reduced.
3. Switching frequency is controllable

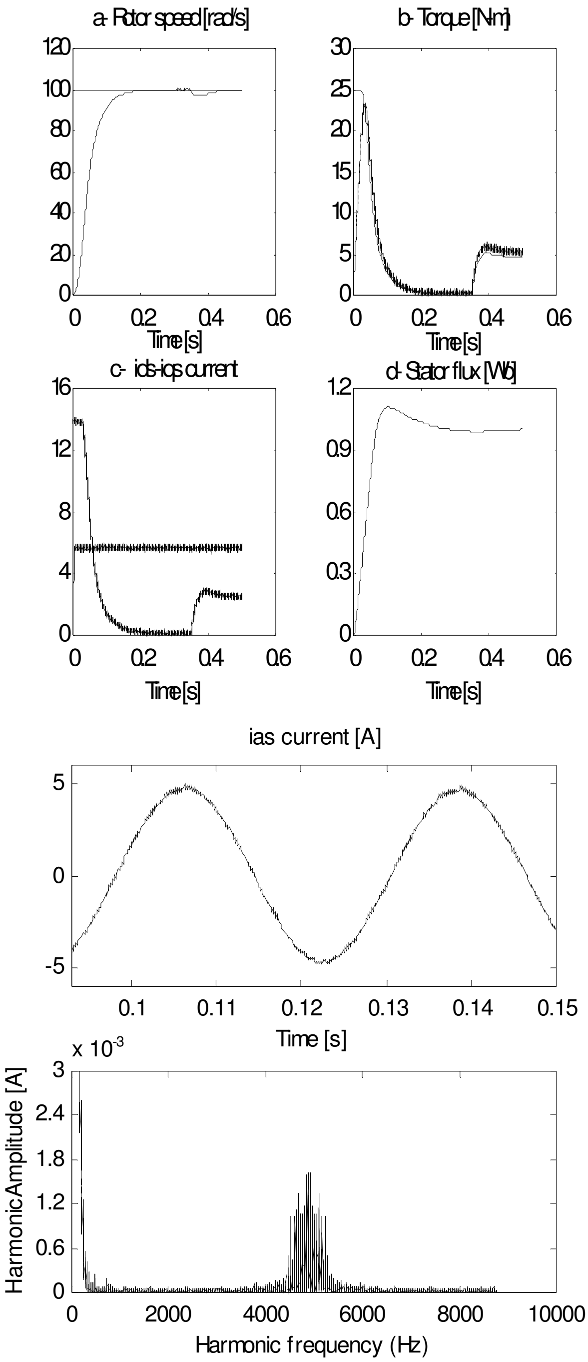

Figure.9 Simulation results FOC with hyst at 100rad/s and 5N-m

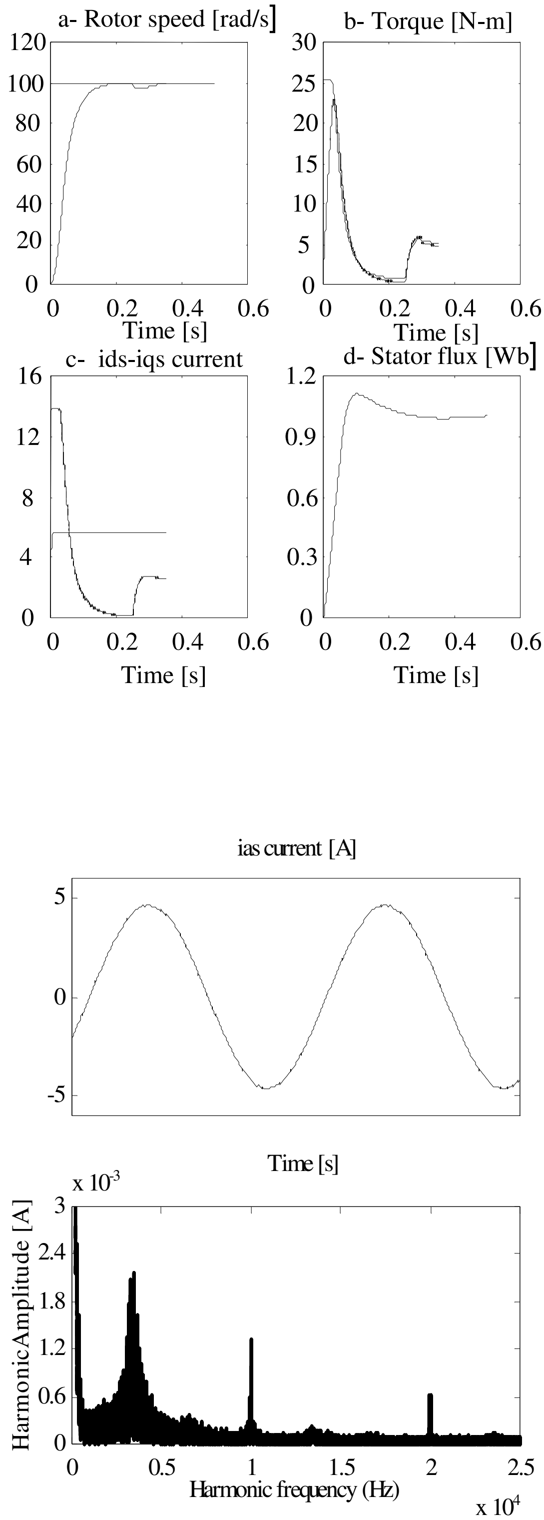

Figure 10. Simulation results FOC with SVM at 100rad/s and 5n-m

APPENDIX

Motor parameters
1.5 kW, 220/380, 50Hz, 1420r.p.m, 3.64/6.31A
p=2;
Rs=4.85Ω,
rr=3.805Ω,
Ls=0.274H,
Lr=0.274H,
lm=0.258H
J=0.031Kg.m^2,
fr=0.0002Nm/rd/s;
Φn=1Wb.

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