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A RELIABLE VECTOR CONTROL METHOD: IFOC FOR THREE PHASE INDUCTION MOTOR DRIVES USING SVPWM

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ABSTRACT

The vector control of ac drives has been broadly used in high performance control system. Indirect field oriented control (IFOC) is one of the most efficient vector control of induction motor due to the simplicity of designing and construction. This paper presents the performances of three phase induction motors using space vector pulse width modulation (SVPWM) scheme. The SVPWM system is entrenched with the two control loops, the inner current control loop and the outer speed control loop using PID controller. Both systems were run and tested using MATLAB/SIMULINK software. The simulation results demonstrate that the SVPWM can improve the feature of the stator current and reduce the torque ripple while keeping the other performance characteristics of the system.

Keywords: CSI, induction motor, IFOC, SVPWM (space vector pulse width modulation).

1. INTRODUCTION

Almost 30 years ago, in 1971 F. Blaschke presented the first paper on field-oriented control (FOC) for induction motors. Since that time, the technique was wholly developed and today is grown-up from the industrial point of view. Today field oriented controlled drives are an industrial certainty and are obtainable on the market by several producers and with different solutions and performance. Variable speed AC motor drives have been incessantly developed during the last decades due to the advances in power electronics, control theory and microprocessors technology. In recent industrial development, induction motor is broadly used for variable speed control system, which needs a precise and quick torque response. An enhancement of the drive performance can be obtained using a new Indirect Field Oriented control algorithm based on the application of the space vector modulation. The performance of the output voltage of inverter that fed induction motor system is mostly determined by pulse width modulation (PWM) strategy. The plain implementation is use current control based on hysteresis current controller. With this method, fast response current loop will be attained and information of load parameter is not required. However this method can cause variable switching frequency of inverter and produce undesirable harmonic generation. Another method of PWM that have become popular and obtained big interest by researcher is SVPWM. This technique have better DC bus exploitation and easy for digital implementation. This paper is structured as follows. The Description of field oriented control presented section II, and then Space Vector PWM based indirect field orientated control is offered in section 3. The performance of the system is presented in simulation result in section 4 and finally some last remarks are stated in the end section.

2. DESCRIPTION OF VECTOR CONTROL

In this paper, we think about the basic arrangement of indirect FOC with two separate control inputs: flux and torque.

Field oriented control: The Field Orientated Control (FOC) consists of controlling the stator currents represented by a vector. This control is based on protrusions which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. These protrusions lead to a structure similar to that of a DC machine control. Field oriented controlled machines require two constants as input references: the torque component (aligned with the q co-ordinate) and the flux component (aligned with d co-ordinate). As Field Orientated Control is merely based on projections the control structure holds instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model. In order to estimate the rotor flux vector is possible to utilize two different strategies: **DFOC** (Direct Field Oriented Control): rotor flux vector is either measured by means of a flux sensor mounted in the air-gap. **IFOC** (Indirect Field Oriented Control): rotor flux vector is estimated using the field oriented control equations (current model) requiring a rotor speed measurement.

Indirect field oriented control: Figure-1 shows a block diagram of an indirect field-oriented control system for an induction motor. In this system, the d-q coordinates reference frame is sheltered to the rotor flux vector rotating at the stator frequency ω_e as shown in Figure-2**.** This results in a decoupling of the variables so that flux and torque can be separately controlled by stator direct-axis current i_d, and quadrature-axis current i_{qd} * respectively.

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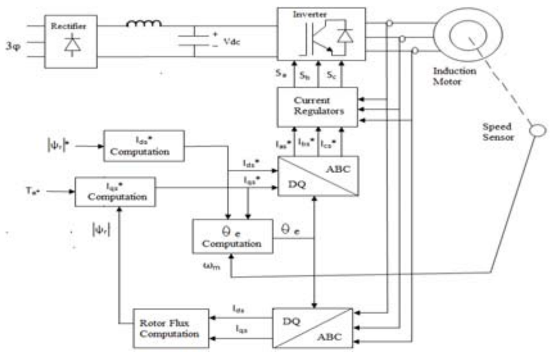

Figure-1. Indirect field-oriented control of an IM.

The stator quadrature-axis reference i_{qs}^* is calculated from torque reference input T_e^*,as:

$$i_{qs}^* = \frac{2}{3}\cdot\frac{2}{p}\cdot\frac{L_r}{L_m}\cdot\frac{T_e^*}{|\psi_r|_{est}} \quad (1)$$

Where $|\psi_r|_{est}$ is the estimated rotor flux linkage given by:

$$|\psi_r|_{est} = \frac{L_m i_{ds}}{1+\tau_r s} \quad (2)$$

The stator direct-axis current reference i_{ds}^* is acquired from rotor flux reference input $|\psi_r|^*$:

$$i_{ds}^* = \frac{|\psi_r|^*}{L_m} \quad (3)$$

The rotor flux position θ_e, required for coordinate's transformation is generated from the rotor speed ω_m and slip frequency ω_{s1}:

$$\theta_e = \int(\omega_m + \omega_{sl})dt \quad (4)$$

The latter is calculated from the stator reference current iqs*and the motor parameters:

$$\omega_{sl} = \frac{L_m}{|\psi_r|_{est}}\frac{R_r}{L_r} i_{qs}^* \quad (5)$$

The transformation of the three-phase (*abc*-axis) current components of an induction motor to the equivalent two-phase (*dq*-axis) current components can be achieved by

$$\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta-\frac{4\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{4\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \quad (6)$$

The three-phase current components i_{as}, i_{bs}, and i_{cs} are in stationary reference frame which does not rotate in space whereas the two phase current components i_{ds}, i_{qs} are in the synchronous reference frame whose direct and quadrature axes rotate in space at the synchronous speed

$$\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) \\ \cos\left(\theta-\frac{4\pi}{3}\right) & -\sin\left(\theta-\frac{4\pi}{3}\right) \end{bmatrix}\cdot\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} \quad (7)$$

The i_{qs}*and i_{ds}* current references are converted into phase current references i_a*, i_b*, i_c* for the current regulators. The regulators process the calculated and reference currents to produce the inverter gating signals S_a, S_b, S_c.

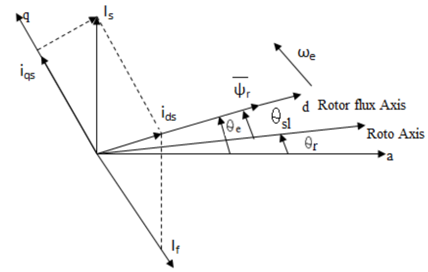

Figure-2. Field-oriented control principle.

3. SVPWM BASED INDIRECT FIELD ORIENDED CONTROL

SVPWM: The use of PWM drive is gainful in many ways, for example it achieves its DC input through uncontrolled rectification of commercial AC mains and has good power factor, good efficiency, relatively free from regulation problems, it has the ability to operate the motor with nearly sinusoidal current waveform. The conventional PWM techniques are appropriate for open loop control, for the implementation of a closed loop controlled AC drive Space vector PWM (SVPWM) technique is applied. In this technique, the switching patterns for the bridge inverter are generated from the knowledge of stator current space phasor. A reference voltage vector is created to generate a field synchronous with the rotating current vector by utilizing the different switching states of a three phase bridge inverter [5].When three phase supply is given to the stator of the induction machine, a three phase rotating magnetic field is created. Due to this field flux, a three phase rotating current vector is generated which lags the flux by 90º. This field can also be recognized by a logical combination of the inverter switching which is the basic concept of SVPWM. It can be pictured as a regular hexagon by dividing it into six equal sectors denotes by I, II, III, IV, V, VI in Figure-3 The reference current vector in any sector can be referred to as I_{qd}*.

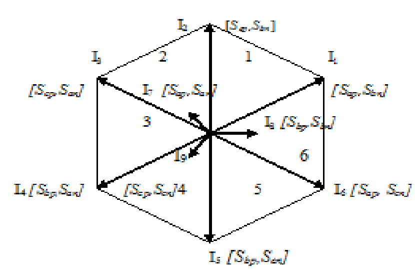

Figure-3. Space vector diagram of the CSI.

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The space vector modulation technique is based on the fact that every vector I_{qd}^{*} inside the hexagon can be stated as a weighted average combination of the two adjacent active space vectors and the null-state vector I_7, I_8, I_9. Therefore, in each cycle the desired reference vector may be achieved by switching between these five states. From Figure 4, assuming I_{qd}^{*} to be lying in sector k, the adjacent active vectors are I_k and I_{k+1}, where K+1 is set to 1 for K = 6. In order to attain an optimal harmonic performance and the minimum switching frequency for each of the power devices, the state sequence is assembled such that switching of only one inverter leg performs the transition from one state to the next. This condition is met if the sequence begins with one zero-state and the inverter switches are reversed, ending with the first zero –state. If for instance, the reference vector sits in sector I, the state sequence has to be $I_7\ I_1\ I_2\ I_8\ I_2\ I_1\ I_0$…. whereas in sector IV it is …$I_8\ I_5\ I_4\ I_9\ I_4\ I_5\ I_0$ … .The central part of the space vector modulation strategy is the computation of both the active and zero state switching times for each modulation cycle, which may be calculated by equating the average current to the desired value. Null times t_o have to be sequenced in every sector. The stator flux and Torque calculated from the machine terminal voltage and current. The torque is proportional to the product of the rotor flux linkage and the stator *q*-axis current. This condition looks like the air gap torque expression of the DC motor that is proportional to the product of the field flux linkages and the armature current. If the rotor flux linkage is retained as a constant, then the torque is proportional to the torque-producing component of the stator current. The time constant is also measured in the order of a few milliseconds. The digital implementation of integrators for estimating the rotor flux of an IM from the stator voltages and stator currents causes problems associated with the offset in sensor amplifiers. Conventional low-pass filters can replace the integrator. Thus, the rotor flux estimated by using a low-pass filter is explained in this work. The instantaneous flux linkage can be computed by using the measured *d*-axis stator current according to the following equation, which is referred to as the current model:

$$\lambda_{r} = \frac{L_m i_{ds}}{1+T_r s} \qquad (8)$$

The signal computation block also estimate the sector number S(k)(where k= 1,2,3…6) in which the flux vector λ_s lies. There are six vectors (each π/3 angle wide)as indicated in figure.2The current vector table block for the proposed DTC system receive the signals $\Delta\lambda_s$ and ΔT_e and S(k) and generates the approximate control voltage vector(switching states) for the inverter by a lookup table which is shown in Table-1. For the proposed IFOC strategy is shown in Figure-3. Table-1 applies the selected current vector which really affects both torque and flux simultaneously. For example an operation in sector 2 the $\Delta\lambda_s$ = -1and ΔT_e = +1 the flux is too high and torque is too low produce current I_4. In same sector 2 the $\Delta\lambda_s$ = +1 and ΔT_e= +1 and this will produce the I_3vector from the table.

Table-1: Optimum Current Switching-Vector Look-Up Table.

Δλs	ΔTe	S_1	S_2	S_3	S_4	S_5	S_6
1	1	I_2	I_3	I_4	I_5	I_6	I_1
	0	I_0	I_0	I_0	I_0	I_0	I_0
	-1	I_6	I_1	I_2	I_3	I_4	I_5
-1	1	I_3	I_4	I_5	I_6	I_1	I_2
	0	I_0	I_0	I_0	I_0	I_0	I_0
	-1	I_5	I_6	I_1	I_2	I_3	I_4

From (1), the equivalent eddy currents are directly obtained. Proposed IFOC: SVPWM based IFOC technique in Figure-4, both reference current in d-axis and q-axis is evaluated from the feedback from the motor current through Clark and Park Transformation. From the respective error the voltage command signal is generated through PID controller and converted to three phase voltage and fed to SVPWM block.
The SVPWM can be implemented by:

- Determine V_d, V_q, V_{ref} and angle α
- Determine time duration T_1, T_2 and T_0
- Determine the switching time of each transistor

4. SIMULATION AND RESULTS

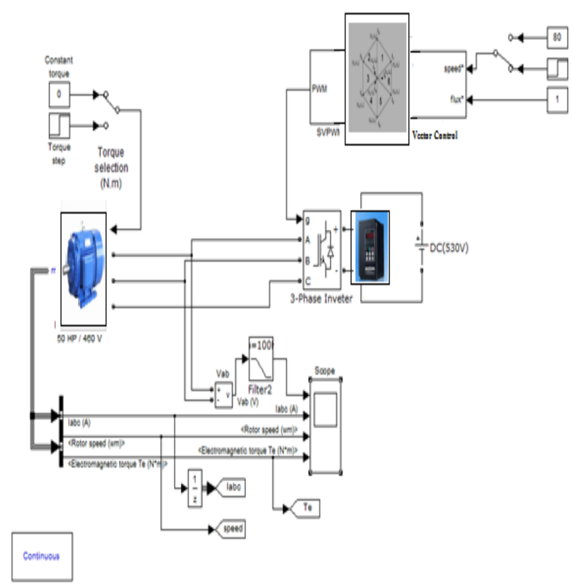

Figure-4. MATLAB block diagram of proposed model.

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Table-2. Induction motor parameters.

50HP, 460V, 4Pole, 60Hz, Squirrel-cage motor	
Values in SI Units	Nominal Parameters
Rs=0.087	Stator resistance (Ohm)
Rr=0.228	Rotor resistance (Ohm)
Lsl=0.8e-3	Stator leakage inductance (H)
Lrl=0.8e-3	Rotor leakage inductance (H)
Lm=34.7e-3	Magnetizing inductance (H)
P=4	Number of poles
J=1.662	Moment of inertia (kg.m2)
Bm=0.1	Torque speed coefficient

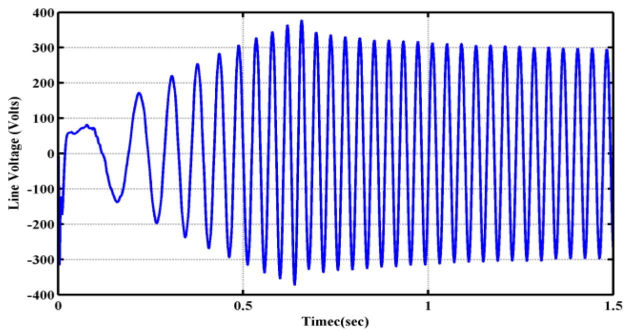

Figure-5. Stator voltage for proposed IFOC.

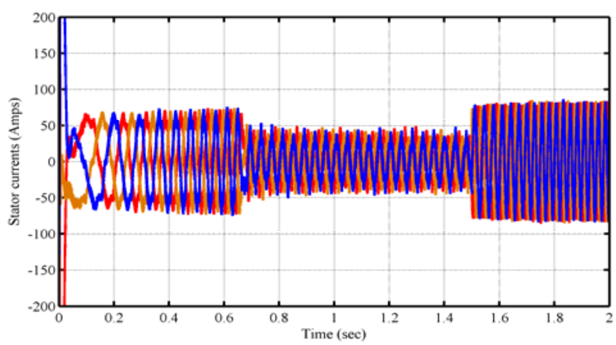

Figure-6. Stator currents for proposed IFOC.

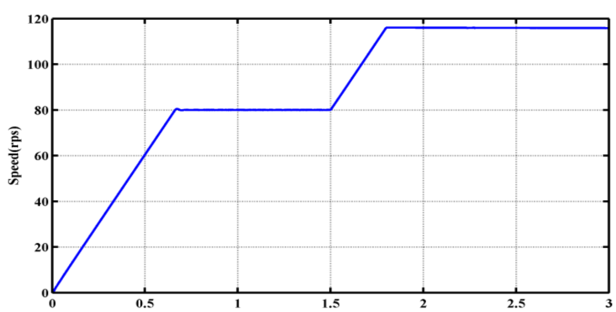

Figure-7. Speed for proposed IFOC.

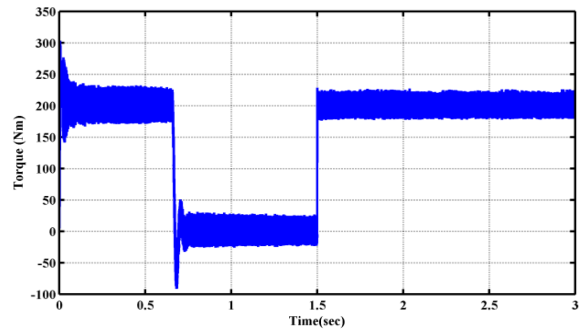

Figure-8. Torque for proposed IFOC.

From the simulation results, the stator voltage for the proposed IFOC scheme the line voltage was initially having some transients with a very minimum level up to 0.3secs most probably and after 0.5secs it a constant one. This is shown in the Figure-5.

From the Figure-6, the stator currents for the proposed IFOC scheme the initial value were the somewhat sluggish and after the 0.5^{th} sec it came to its reduced level because of increased voltage and then had got normalized.

From the Figure-7, the speed of the induction motor initiated from 0rps to 80rps at within nearly 0.6secs and got constant up to 1.5secs and then speeded up to nearly 120rps.

From the Figure-8, the torque for the proposed IFOC scheme the initial starting was high enough to make up the motor for its connected load and suddenly decreased when speed increased. Then it had a steep increase in torque and had got normalized till the end of the process.

5. CONCLUSIONS

This paper has presented a reliable vector control scheme IFOC for IM drives. The depiction of the control schemes and their principle of operation have been presented. The proposed CSI drive topology reveals the same high performance aspects as the corresponding VSI topology, both in terms of waveform quality and dynamic performance and also has been done using MATLAB/ Simulation. From the simulation results, proposed SVPWM scheme gives better performance in elimination of the stator current harmonics, reduction of the torque ripple and also increased the efficiency of the IM drives.

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