International Journal of Electrical and Computer Engineering.
ISSN 0974-2190 Volume 3, Number 1 (2011), pp. 47-56

http://www.irphouse.com

Indirect Field Oriented Control for Induction Motor Drive using Space Vector Modulation Technique

Rutuja S. Hiware and J.G. Chaudhari

M.Tech. IV SEM (IPS), G.H.R.C.E., Nagpur, India
E-mail: rutujah1901@rediffmail.com,
jagdish_chaudhari123@rediffmail.com

Abstract

Indirect Field Oriented Control (IFOC) is known to produce high performance in induction Motor (IM) drives by decoupling rotor flux and torque producing current components of stator current. The decoupling control between the rotor flux and the torque is no longer achieved in terms of stator current components this paper introduces a decoupled rotor flux and torque control based on the magnetizing current components by incorporating PI control system and using space vector modulation (SVM) technique. It is able to perform high performance control in IM drives using SVM technique. In order to perform the control strategy, the rotor flux and magnetizing current estimator is proposed. A good performance is obtained By means of PI controller and SVM technique, and the rotor flux and the magnetizing current are obtained properly by the proposed observer.

Keywords: Induction machine, Vector control method, SVPWM, PI-Controller, Field Oriented Control, Indirect Field oriented control.

Introduction

Induction machines are largely used in industrial plants and are adequate for almost any kind of environment. Their popularity is due to their high efficiency, reliability, low maintenance. Since the development of the vector control techniques, induction machines based drives became able to deliver the same performance as the traditional direct current machine drives in applications that require torque or speed control. The vector control of ac drives has been widely used in high performance control system. Indirect field oriented control (IFOC) is one of the most effective vector control of induction motor due to the simplicity of designing and construction. In order to obtain the high performance of torque and speed of an IM drive, the rotor flux and torque generating current components of stator current must be decoupled suitably respective to the rotor flux vector like separately excited dc motor.

This paper develops a decoupled rotor flux and torque control based on the magnetizing current components. However, this developed control system is valid only for steady state condition. By incorporating PI control system and using space vector modulation technique, the decoupled control system is used to perform in both transient and steady state conditions.

The space-vector PWM method is an advanced method and is possibly the best among all the PWM technique. With a machine load, the load neutral is normally isolated, which causes interaction among the phases. The SVM method considers interaction of the phases and optimizes the harmonic content of three-phase isolated neutral load. The space-vector PWM (SVM) method is an advanced, computation-intensive PWM method. It is possibly the best among all the PWM techniques for the variable-frequency drive application. It has been finding widespread application because of its superior performance. This method is best explained by considering the three-phase inverter. It gives best PWM performance. It also considered the SVM theory (the concept of rotating space vector). SVM method optimizes the harmonic content. It is slightly differ than PWM as it treated inverter as a single unit but PWM treated it separately. Modulation is accomplished by switching the state of inverter. SVM is a digital modulating technique where the objective is to generate PWM load line voltages.

In order to perform IFOC of IM drives using SVM it is necessary to measure primary angular frequency, the stator voltages, the stator currents, the magnetizing currents, the rotor fluxes and the rotor speed. However, among those the rotor fluxes and magnetizing currents are difficult to measure. The design of the observer is based on the solution of simultaneous Lyapunov equations. The validity of IFOC using SVM and the proposed observer scheme are verified by simulation.

Mathematical Model of induction motor

During start-up and other severe transient operations induction motor draws large currents, produces voltage dips, oscillatory torques and can even generate harmonics in the power systems. In order to investigate such problems, the d, q axis model has been found to be reliable and accurate. The equivalent circuit of q and d axes in general reference frame as shown in fig (1). Considering balanced voltage supply and a balanced symmetric machine.

In the d-q axis equivalent circuit of field oriented control induction motor considering core loss due to eddy current, a resistance Rc is connected in parallel across the internal induced voltage branch. The d-q axis equivalent circuit of induction motor in a synchronously rotating reference frame is shown in Fig.1

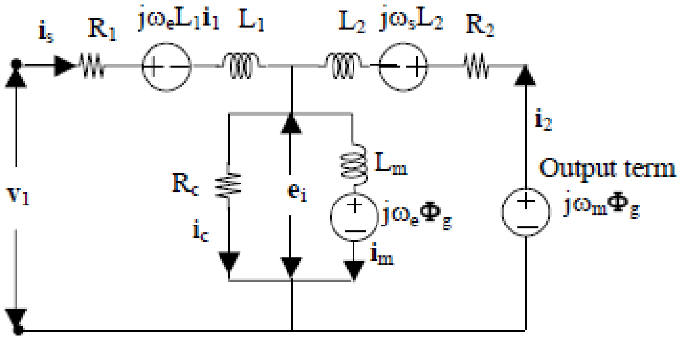


Figure 1: d-q axis equivalent circuit of induction motor in a synchronously rotating reference frame

The voltage equations used for the modeling purpose are as follows:

$$Vqs = Rs\ iqs + \omega\lambda ds + p\lambda qs$$

$$Vds = Rs\ ids - \omega\lambda qs + p\lambda ds$$

$$V'qr = R'r\ i'qr + (\omega\text{-}\omega r)\ \lambda'dr + p\lambda'qr$$

$$V'dr = R'r\ i'dr - (\omega\text{-}\omega r)\ \lambda'dr + p\lambda'dr$$

Where $p = (d/dt)$

& $\lambda qs = Lsiqs + Lmi'qr$

$\lambda ds = Lsids + Lmi'dr$

$\lambda'qr = L'ri'qr + Lmiqs$

$\lambda'dr = L'ri'dr + Lmids$

PI Controller Design-

The control of torque and flux can be established in steady state condition by using. PI controllers are dynamic controllers, very useful in practice and superior to static controllers, since they offer great simplicity and flexibility in satisfying the closed-loop system's specifications.

The torque control can be achieved from speed error, since the developed electromagnetic torque affects the speed dynamic. Applying PI controller into the error signal between

Reference and measured or calculated speed and flux, it is possible to find out the desired magnetizing component imd*and imq*. Therefore, the equations for PI controller can be written as follows:

$$i^*_{md}=\{K_{P\Phi}+(K_{1\Phi}/s)\}(\Phi_{2d}-\Phi_{2d}) \quad (1)$$

$$i^*_{mq}=\{K_{P\omega}+(K_{I\omega}/s)\}(\omega_m{}^*-\omega_m) \quad (2)$$

The required inputs, stator voltages and primary angular frequency can be calculated from the outputs imd*and imq* of PI controller by using equations,

$$i_{1d}^*=i_{md}^*-(L_m/R_c)\ \omega_e i_{mq}^* \qquad (3)$$

$$i_{1q}^*= (L_r/L_2)i_{mq}^*+(L_m/R_c)\ \omega_e i_{md}^* \qquad (4)$$

$$v^*_{1d}= (R_1+R_c)i_{1d}^*-Rci_{md}^*-\omega_e L_1 i_{1q}^* \qquad (5)$$

$$v^*_{1q}=(R_1+R_c)i_{1d}^*-(R_cL_r/L_2)i_{mq}^*+\omega_e L_1 i_{1d}^* \qquad (6)$$

For speed control, it is needed to modify KPω and KIω constants

Field Oriented Control

The Field Orientated Control (FOC) [1][3] consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. These projections lead to a structure similar to that of a DC machine control. Field orientated controlled machines need 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 simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model.

Indirect Field Oriented Control-

Field-Oriented control is the most popular method of obtaining improved or high performance in an induction motor drive. There are two basic categories of field-oriented control: the direct and the indirect method. The main difference between them is that the direct method accomplishes commutation with electrical or magnetic feedback from the motor while the indirect method accomplishes commutation with velocity feedback from the motor and a feed forward slip command. Both schemes typically utilize some type of stator current regulation. The indirect field-orientation method utilizes the motor velocity feedback and a feed forward slip command to provide the instantaneous commutation. The velocity signal is generally a cleaner control signal than the voltage from a PWM inverter; thus, control is inherently more robust with the indirect method. The significant difference between this method and others is that the developed motor model and outputs are based on the fundamental operating condition of the motor and not some unrelated signals. In other words, it is based on fundamental component terminal voltages and currents of the motor.

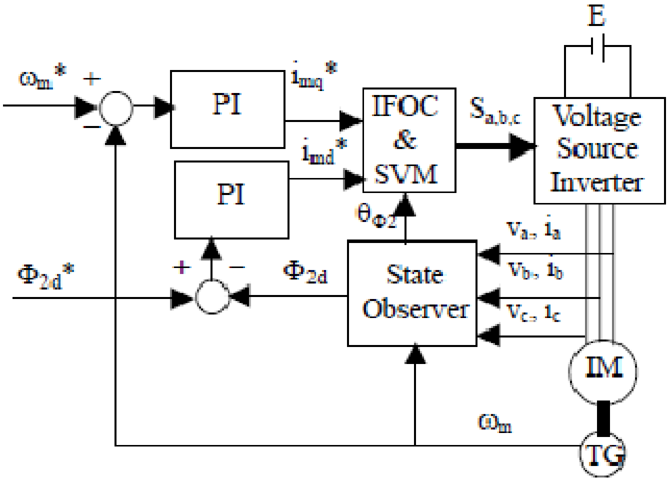


Figure 2: IFOC for different operating conditions.

Space Vector Modulation Technique in PWM inverter

SVM technique is more preferable scheme for PWM voltage source inverter since it gives a large linear control range, less harmonic distortion and fast transient response. The SVM units in Fig. 2 produces inverter control signal. It receives the reference voltages v^*1d and v^*1q in a synchronously rotating reference frame. These voltages are converted into a stator reference frame such as $v^*1\alpha$ and $v^*1\beta$.The SVM principle is based on the switching between two adjacent active vectors and a zero vectors during one switching period. The six active-states are forming a regular hexagon and dividing it into six equal sectors denoted as I, II,III, IV, V, VI shown in Fig3..

The inverter control is simple and switching loss is low because there are only six switching per cycle of fundamental frequency. Unfortunately, the lower order harmonics of the six-step voltage wave cause large distortions of current wave. So SVPWM technique is used. The SVPWM technique used to control the output voltage of inverter as well as optimize the harmonics. To understand SVM theory, the concept of rotating space vector is very important. For example, if three-phase sinusoidal and balanced voltages given by equations

$$Va=Vm\cos\omega t \tag{7}$$

$$Vb = Vm \cos (wt - 2\Pi/3) \tag{8}$$

$$Vc = Vm \cos (wt +2\Pi/3) \tag{9}$$

are applied to three-phase induction machine using equation $V = (2/3) [Vas + aVbs + a^2 Vcs]$ where $a = e^{j(2\Pi/3)}$ and $a^2 = e^{-j(2\Pi/3)}$ it can be shown that the space vector with V magnitude Vm rotates in circular orbit at angular velocity ω.

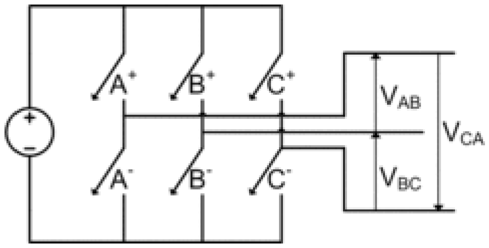


Figure 3: Three –phase inverter.

A three-phase bridge inverter, as shown in fig.3 has 8 permissible switching states. Table 2 gives summery of the switching states and corresponding voltages. Consider, for example, state 1 when switches T1, T6 and T2 are closed. In this state, phase a is connected to positive bus and phase b and c are connected to the negative bus. The inverter has six active states (1-6) when voltage is impressed across the load, and two zero states (0 and 7) when machine terminals are shorted through the lower or upper devices respectively.

Table 1: Summary of the switching state

Voltage vectors	Switching vectors			Line to neutral voltage			Line to line voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

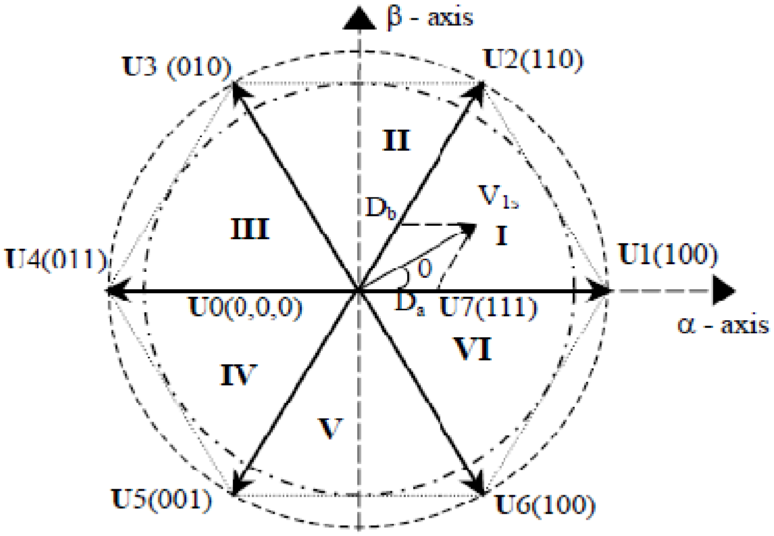
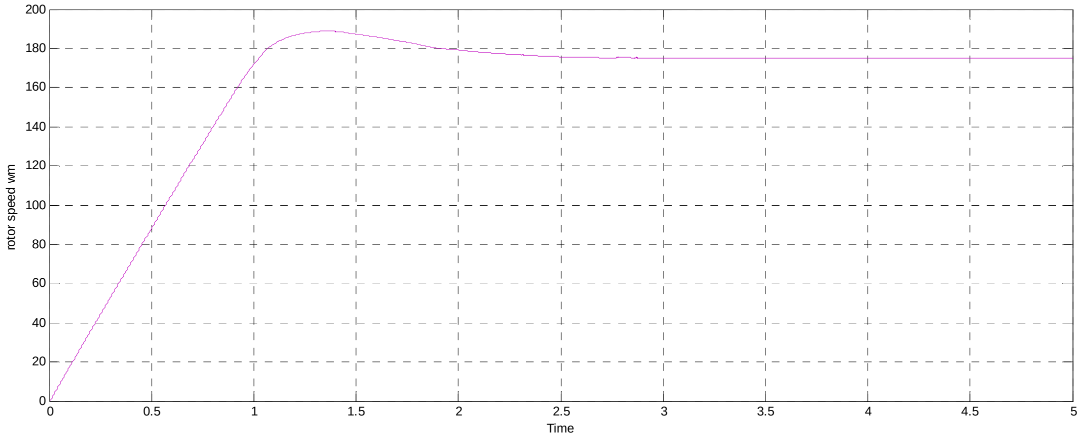


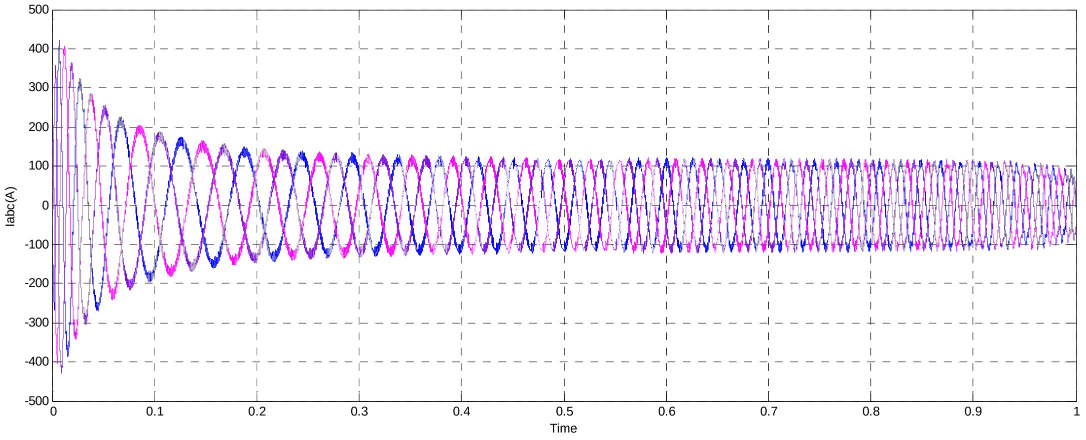
Figure 4: Representation of a inverter states in reference frame.

Simulation Results

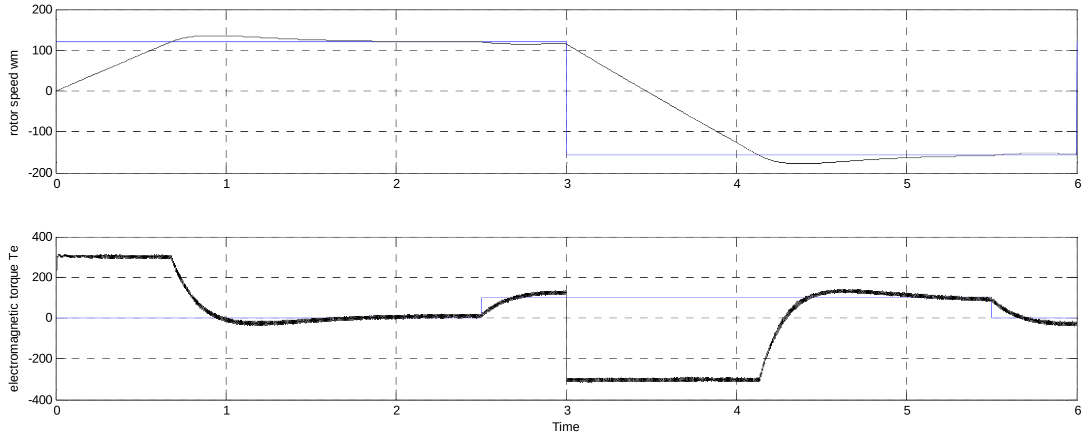
IFOC Results

1. For free running condition

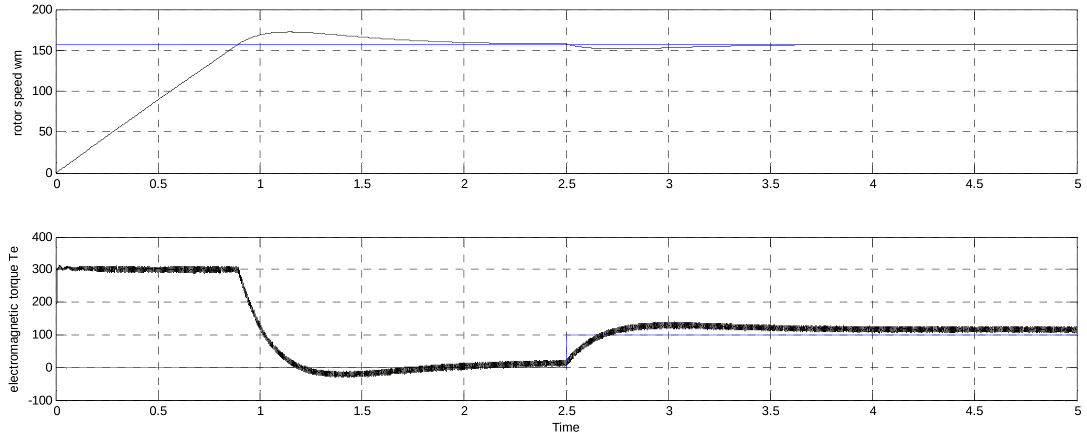




Reversal & Step rise in load



Constant speed and step rise in load



Conclusion

This paper has presented the IFOC of IM drives using SVM technique. An observer for estimating the rotor flux and the magnetizing current in a synchronously rotating reference frame The verification of the proposed control is performed by simulation results. The dynamical requirement of IFOC is achieved by applying PI controller in transient and steady state conditions. IFOC Scheme results are achieved in MATLAB simulink. And the simulation results of IFOC are shown as stator current, rotor speed, electromagnetic torque and dc voltage. There are four different types of simulation results showing different condition of load and speed operation. Firstly we obtained the no load condition and then in reversal of speed and step rise in load.

Finally we can conclude that the speed is improved by loading and torque is also improved in starting and running conditions.

References

[1] Mannan.M.A;Murata.T;Tamura.J;Tsuchiya.T."Indirect-Field Oriented Control For High Performance Induction Motor Drives Using Space Vector Modulation With Consideration Of CoreLoss", Power Electronics Specialist Conference 2003,IEEE Trans.Vol 3, pp 1449-1454.

[2] Dong-Choon Lee, Seung-Ki Sul and Min-Ho Park, "High Performance Current Regulator for a Field-Oriented Controlled Induction Motor Drive,"IEEE Trans on Industry Application, vol. 30, no.5, pp. 1247-1257, 1994.Toshiaki Murata, Takeshi Tsuchiya and Ikuo Takeda, "Vector Control for Induction Machine on the Application of Optimal Control Theory," IEEE Trans on Industrial Electronics, vol. 37, no. 4, p p. 283-290, 1990.

[3] C.B. Jacobina, J. Bione Fo, F.Salvadori,A.M.N.Lima & L.A.S.Riberio, "A Simple Indirect Field Oriented Control of Induction Machines witout Speed Measurement".IEEE Trans 2000 pp.1809-1813.

[4] Sergei Peresada,Andrea Tilli,Alberto Tonieri ,"Indirect Field Oriented Control of Induction Motor New Design Leads toImproved Performance & Effciency",1998 pp 1609-1614.

[5] Holtz J., Juntao Quan, " Sensorless vector control of induction motors at very low speed using a nonlinear inverter model and parameter identification", IEEE Trans. On Industry Applications, Volume: 38, Issue: 4, July-Aug 2002.

[6] H. W. Van Der Brock, H. C. Skudelny and G. V. Stanke,"Analysis and Realization of a Pulse Width Modulator Based on Voltage Space Vectors," IEEE Trans on Industry Application, vol. 24, no. 1, pp.142- 150,1988

[7] Emil Levi, "Impact of Iron Loss on Behavior of Vector Controlled Induction Machine," IEEE Transon Industry Application, vol. 31, no. 6,pp. 1287-1296, 1995.

[8] Kouki Matsuse, Tatsuya Yoshizumi, Seiji Katsuta, and Shotaro Taniguchi, "High-Response FluxControl of Direct-Field-Oriented Induction Motor with High Efficiency Taking Core Loss into Account," IEEE Trans on Industry Application, vol. 35, no. 1, pp. 62-69, 1999.

[9] Schauder, C.D. and Caddy, R., "Current control of voltage-source inverters for fast fourquadrant drive performance", IEEE Trans., IA-18,2, 1982, pp. 163-171.
[10] B.K. Bose, Modern Power Electronics and AC Drive , Prentice-Hall, 2002.
[11] P.C. Krause, Analysis of Electric Machinery, McGraw-Hill, 1986.
[12] Power Electronics by Muhammad H.Rashid.