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Indirect Rotor Field Oriented Control (IRFOC) for Three Phase Induction Motor Drive Using MOSFET

Govind R Shivbhakt
PG Student,
Department of Electrical Engineering,
Government College of Engineering,
Aurangabad.

Bhole A.A
Associate Professor,
Department of Electrical Engineering,
Government College of Engineering,
Aurangabad.

Abstract:

Three phase induction motor are one of the widely used motors in the world .The interest accorded by research on the improvement of the quality and performance of these motors the availability of low cost static converter make possible the economic use of energy and improvement of the quality of electromagnetic torque. Nowadays Indirect Rotor Field Oriented control (IRFOC) technique on renaissance in modern high performance control of PWM Inverter fed three phase induction motor.

This paper presents a methodology for computational modeling of the Indirect Rotor Field Oriented Control (IRFOC) induction motor drive system. The numerical model of the squirrel-cage, three-phase induction motor is represented as a system of differential equations. In order to study the performance of the system a simulation program was implemented using Matlab. Implement the hardware set up for Indirect Rotor Field Oriented control (IRFOC) for three phase induction motor using MOSFET.

Keywords:
Three phase induction Motor, Indirect Rotor Field Oriented Control (IRFOC), MOSFET,

I Introduction:

In this paper Indirect Rotor Field Oriented Control (IRFOC) for three phase induction motor Pulse Width Modulation techniques are used.Using PWM techniques generating six pulse width modulation output .The frequency of PWM output can be varied from 10Hz to 100Hz.and 120 Degree and 180 Degree mode Due to the variable frequency control the speed of motor three phase induction motor system.

Indirect Rotor Field Oriented Control (IRFOC) technique for three phase induction motor system is experimentally implemented using MOSFET. Different static converter topologies to supply the three phase induction motor have been used. These papers also consider the six MOSFET proposed. There is no need to separate three phase supply. In field orientation, the motor input currents are adjusted to set a specific angle between fluxes produced in the rotor and stator windings in a manner that follows from the operation of a dc machine.

When the dynamic equations for an induction motor is transformed by means of well known rotating transformation methods into a reference frame that concedes with rotor flux, the results become similar to the dynamic behavior of a dc machine. This allows the ac motor stator current to be separated into a flux-producing component and an orthogonal torque-producing component, analogous to a dc machine field current and armature current [1].

The key to field-oriented control is knowledge of the rotor flux position angle with respect to the stator. Whatever the field-orientation approach, once the flux angle is known, an algorithm performs the transformation from three-phase stator currents into the orthogonal torque and flux producing components. Control is then performed in these components, and an inverse transformation is used to determine the necessary three-phase currents or voltages [3].

II-Mathematical Description of Three-Phase Induction Motor :

The space vector forms of the voltage equation give the induction motor model. The system model defined in the stationary α, β-coordinate system attached to the stator is expressed by the following equations [4].

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The motor model is supposed to be ideally symmetrical with a linear magnetic circuit characteristic.

a-The stator voltage differential equations:

$$Vs\alpha = Rsis\alpha + \frac{d}{dt}\lambda s\alpha \quad ....1$$

$$Vs\beta = Rsis\beta + \frac{d}{dt}\lambda s\alpha \quad ...2$$

b-The rotor voltage differential equations:

$$Vr\alpha = 0 = Rrir\alpha + \frac{d}{dt}\lambda r + w\lambda r\beta \quad ...3$$

$$Vr\beta = 0 = Rrir\beta + \frac{d}{dt}\lambda r - w\lambda r\alpha \quad ...4$$

c-The stator and rotor flux linkages expressed in terms of the stator and rotor current space vectors:

$$\lambda s\alpha = Lsis\alpha + Lmir\alpha \quad ...5$$

$$\lambda s\beta = Lsis\beta + Lmir\beta \quad ...6$$

$$\lambda s\alpha = Lrir\alpha + Lmis\alpha \quad ...7$$

$$\lambda s\beta = Lrir\beta + Lmis\beta \quad ...8$$

d- Electromagnetic torque expressed by utilizing space vector quantities:

$$T_e = \frac{3}{2}p(\lambda s\alpha is\beta - \lambda s\beta is\alpha) \quad ...9$$

Besides the stationary reference frame attached to the stator, motor model voltage space vector equations can be formulated in a general reference frame, which rotates at a general speed (wa). If a general reference frame, with direct and quadrature axes x,y rotating at a general instantaneous speed wa=dθa/dt is used, as shown in Fig.(1), where θa is the angle between the direct axis of the stationary reference frame (α) attached to the stator and the real axis (x) of the general reference frame, then the following equation defines the stator current space vector in general reference frame[5].

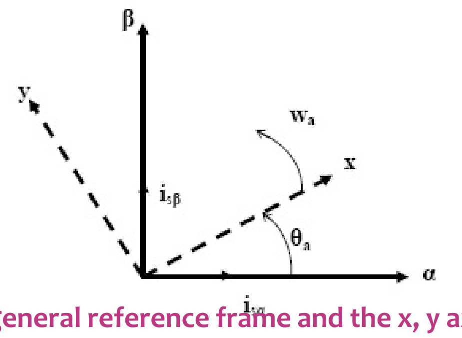

Fig.1 The general reference frame and the x, y axes rotating at general speed

$$is\alpha = ire^{-j\theta a} = isx + jisy \quad ....10$$

The stator voltage and flux-linkage space vector can be similarbtained in the general reference frame. Similar considerations hold for the space vectors of the rotor voltages, currents and flux linkages. The real axis (rα) of the reference frame attached to the rotor is displaced from the direct axis of the stator reference frame by the rotor angle θr. It can be seen that the angle between the real axis (x) of the general reference frame and the real axis of the reference frame rotating with the rotor (rα) is (θa-θr). In the general reference frame, the space vector of the rotor currents can be expressed as:

$$is\alpha = ire^{-j(\theta a - \theta r)} = irx + jiry \quad ...11$$

Where ir is the space vector of the rotor current in the rotor reference frame. Similarly the space vectors of the rotor voltages and rotor flux linkages in the general reference frame can be expressed. The reference frames may be aligned with the stator flux-linkage space vector, the rotor flux-linkage space vector or the magnetizing space vector. The most popular reference frame is the reference frame attached to the rotor flux linkage space vector with direct axis (d) and quadrature axis (q). After transformation into d-q coordinates the motor model is the following [6]:

$$vsd = Rsisd + p\lambda sd - ws\lambda sq \quad ...12$$

$$vsq = Rsisq + p\lambda sq - ws\lambda sd \quad ...13$$

$$Vrd = 0 = Rrird + p\,\lambda rd - (ws - w)\lambda rq \quad ...14$$

$$Vrq = 0 = Rrirq + p\,\lambda rq + (ws - w)\lambda rd \quad ...15$$

$$\lambda sd = Lsisd + Lmird \quad ...16$$

$$\lambda sq = Lsisq + Lmirq \quad ...17$$

$$\lambda rd = Lrird + Lmisd \quad ...18$$

$$\lambda rq = Lrirq + Lmisq \quad ...19$$

$$T_e = \frac{3}{2}p(\lambda sdisq - \lambda sqisd) \quad ...20$$

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III-Field-Oriented Control of Three Phase Induction Motor:

This control is usually performed in the reference frame (d-q) attached to the rotor flux space vector. That's why the implementation of vector control requires information on the modulus and the space angle (position) of the rotor flux space vector.

The stator currents of the induction machine are separated into flux-and torque producing components by utilizing transformation to the d-q coordinate system, whose direct axis (d) is aligned with the rotor flux space vector. It means that the q-axis component of the rotor flux space vector is always zero.

$\lambda rq=0$ and also $p\ \lambda rq = 0$ ...21

Fig. (2) Shows the basic structure of the indirect field-oriented control of the three-phase induction motor.

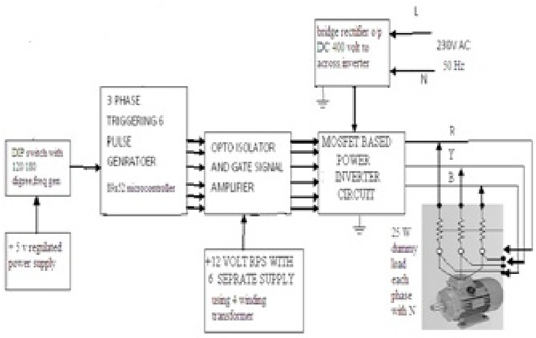

Fig.2Basic structure of the indirect field-oriented control of the three-phase induction motor

IV-Rotor Flux Model:

Knowledge of the rotor flux space vector magnitude and position is key information for the three phase induction motor vector control. With the rotor magnetic flux space vector, the rotational coordinate system (d-q) can be established. There are several methods for obtaining the rotor magnetic flux space vector.

The implemented flux model utilizes monitored rotor speed and stator voltages and currents. It is calculated in the stationary reference frame (α-β) attached to the stator. The rotor flux space vector is obtained by solving the following two differential equations, which are resolved into the α and β components [7]

$$[(1-\sigma)\tau s+\tau r]p\lambda r\alpha = \frac{Lm}{Rs}vs\alpha - \lambda r\alpha - w\tau r\lambda r\beta - \sigma Lm\ \tau spis\alpha \quad ...22$$

$$[(1\text{-}\sigma)\ \tau s+\tau r]p\lambda r\beta = \frac{Lm}{Rs}vs\beta - \lambda r\beta + w\tau r\lambda r\alpha - \sigma Lm\tau spis\beta \quad ...23$$

V-Proposed Indirect Rotor Field Oriented Control Scheme.

Fig .(3) shows the implemented block diagram of an induction motor indirect field-oriented control, incorporating a decoupling circuit. The details of Fig.(1) The starred variables represent the reference values of the variables, and are obtained under constant flux condition.

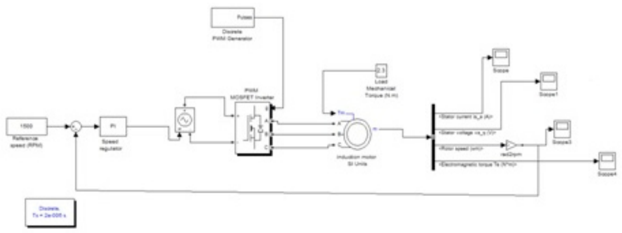

Fig. 3 Matlab /simulink model of the IRFOC of three phase induction motor.

$$Vsd = Vsd^{lin} + Vsd^{decouple} = [K_R isd + K_L pisd] - \left[wsK'_L isq + \frac{\lambda rdLm}{Lr}\right] \quad ...24$$

$$Vsq = Vsq^{lin} + Vsq^{decouple} = [K_R isq + K_L pisq] - \left[wsK'_L isd + \frac{\lambda rdLm}{Lr}w\right] \quad ...25$$

Where

$$K_R = Rs + \frac{Lm}{L^2r}Rr \quad ...26$$

$$K_L = Ls\text{-}\frac{Lm}{L^2r} \quad ...27$$

$$Vsd^{decouple} = \left[wsK'_L isq + \frac{Lm}{Lr\tau r}\lambda rd\right] \quad ...28$$

$$Vsq^{decouple} = \left[wsK'_L isd + \frac{Lm}{Lr}w\lambda rd\right] \quad ...29$$

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$$i_{sq}^{*} = \frac{\lambda^{*}_{rd}}{L_m} \quad ...30$$

$$i_{sq}^{*} = \frac{2L_r}{PL_m}\frac{T_e^{*}}{\lambda^{*}_{rd}} \quad ...31$$

$$w_{sl}^{*} = \frac{2L_r}{PT_r}\frac{T_e^{*}}{\lambda^{*2}_{rd}} \quad ...32$$

$$w_{sl}^{*} = w_s - w \quad ...33$$

VI-Performance Test and Analytical Result :

To implement the hardware setup of IRFOC for three phase induction motor as shown in fig.4. The output of PWM pulses are used to trigger the power MOSFET switches. Figure 5 shows the square wave as a result of PWM.

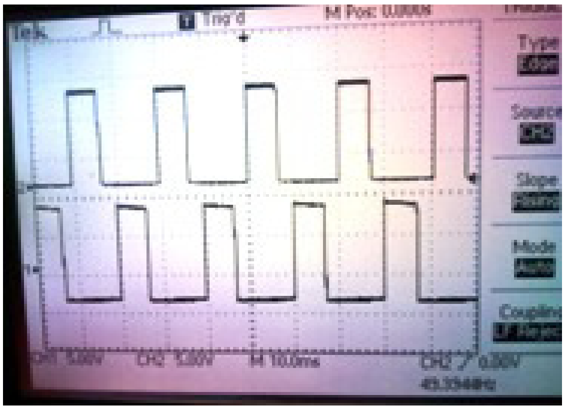


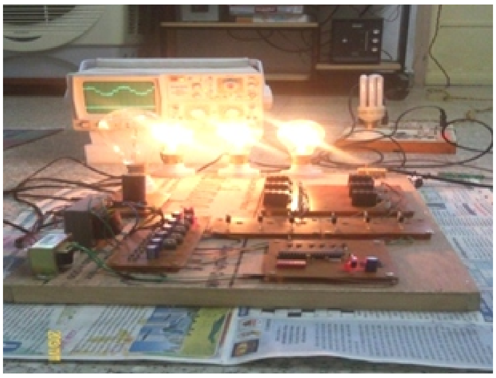
Fig.5a 49.99 Hz waveform

A Three phase induction machine whose parameters are listed below in Table A.1.

Table A.1.
Three phase induction machine parameters.

Sr.No	Specification	Rating	Parameters
1.	Rated Power	0.18 kw	Rsd
2.	Rated voltage	430 V	Rsq
3.	Rated current	2 amp	Rr
4.	Rated frequency	50 Hz	Lsd
5.	Number of poles	4 poles	Lr
6.	Power factor	0.82	Msrd

A static power electronics converter a diode rectifier and a three leg voltage source MOSFET inverter.



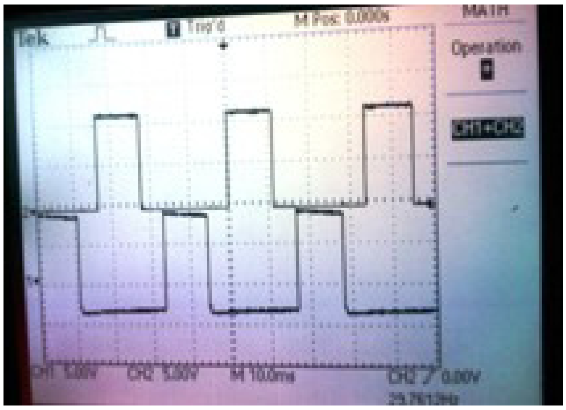


Fig.5b 29.99 Hz waveform

Fig.4 Experimental setup of IRFOC for three phase induction motor.

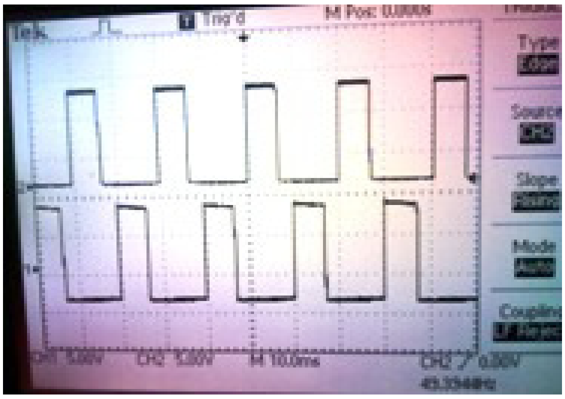


Fig.5a 49.99 Hz waveform

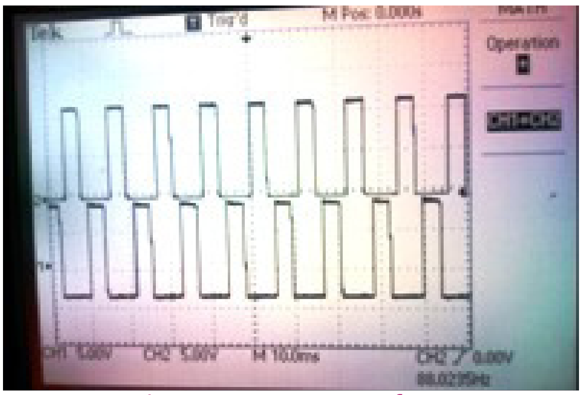


Fig.5c.88.99 Hz waveform

Fig 5.Experimental w/f at various frequency

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Table A.2Practical result of at variable voltage:

Sr.No	Without Loading		
	Input Voltage (Volt)	Current (Amp)	Speed (RPM)
1	110 V	0.1Amp	955 RPM
2	150 V	0.16 Amp	960 RPM
3	200 V	0.25 Amp	972 RPM
4	250 V	0.32 Amp	980 RPM
5	300V	0.39Amp	985 RPM
6	400V	0.56 Amp	995 RPM

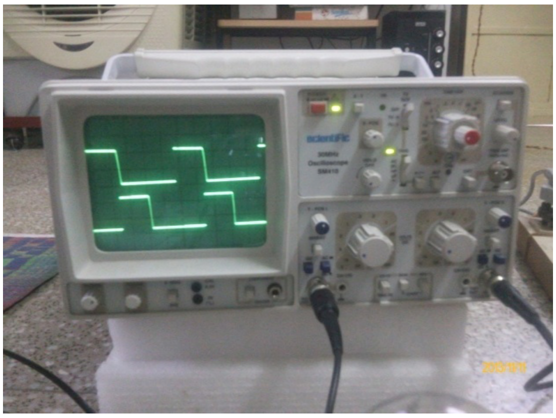

Fig.6.a.Waveforms Vr- Vy-
Fig.6.Output waveform of PWM

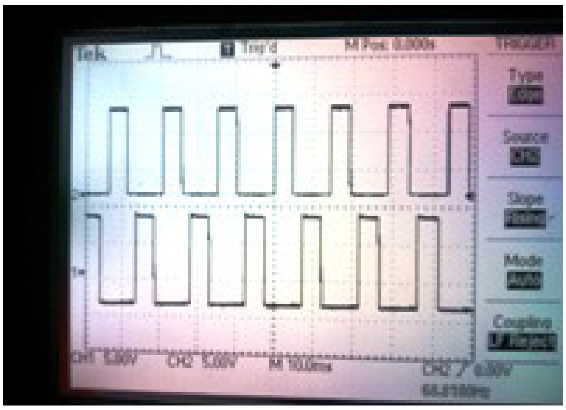

Fig.5e 68.88 Hz waveform

Table A.3.Practical result of I.M. variable voltage and variable load.

Sr.No	With Loading		
	Input Voltage (Volt)	Current (Amp)	Speed (RPM)
1	110 V	0.2 Amp	800RPM
2	150 V	0.39Amp	750RPM
3	200 V	0.78Amp	600RPM
4	250 V	1.5Amp	450RPM

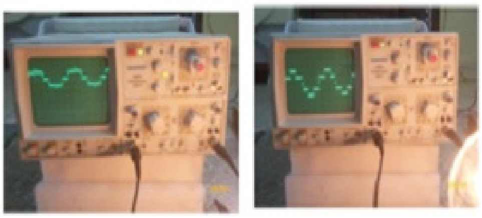

Fig.6.b.Waveforms Vr- Vy-

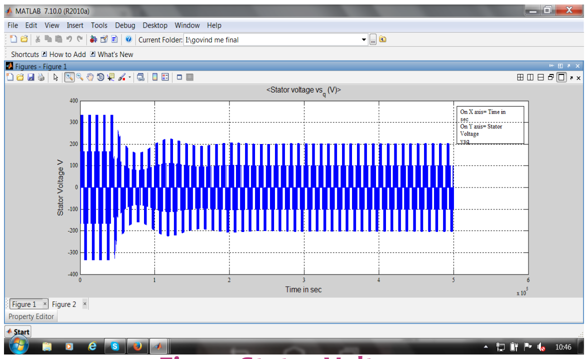

Fig.7a.Stator Voltage.

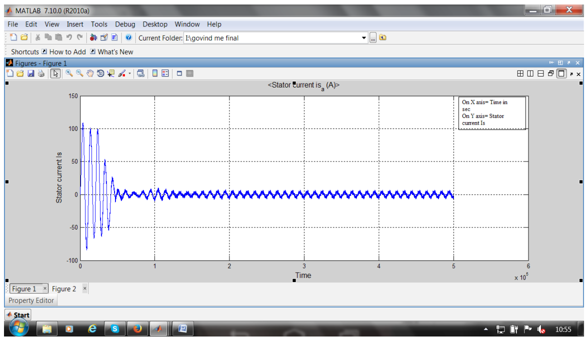

Fig.7c.Stator Current.

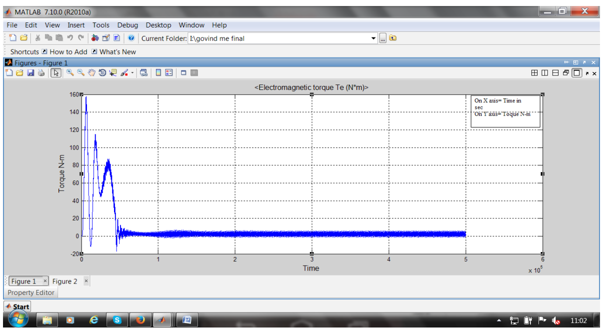

Fig.7b. Electromagnetic torque.

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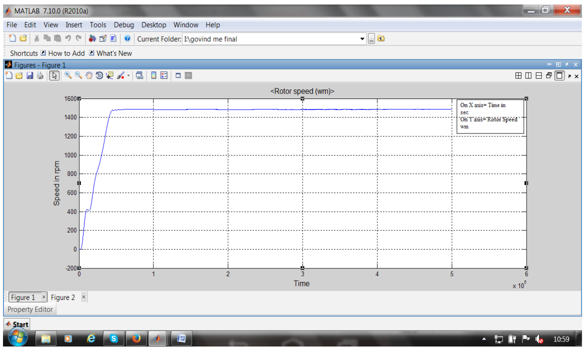

VII-CONCLUSIONS:

In this paper, implementation of simulink model for indirect field-oriented induction motor drive system has been introduced using Matlab/Simulink software unlike most other drive models implementations, with this model , the user has access to all the internal variables for getting an insight into the machine operation. The ease of implementing controls with this model is also demonstrated with several run results.

The results show a good agreement to the theoretical background of the drive system. High dynamic performance of PWM inverter fed Three Phase Induction Motor is achieved using method of Indirect Rotor Flux Oriented Control (IRFOC) method.

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