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Simulation And Implementation Of Ifoc Based 3-Phase Induction Motor Drive

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Abstract : This project presents the need of Speed Control in Induction Motors. Out of the various methods of controlling Induction motors, FOC has proven to be the most versatile. One of the basic requirements of this scheme is the VSI Inverter. A MATLAB simulation along with real time implementation has developed. This project presents closed loop indirect field-oriented control (Vector control) of 3-phase Induction Motor. Based on the popular constant volts per hertz principle, two improvement techniques are presented: keeping maximum torque constant or keeping magnetic flux constant. A squirrel-cage induction motor drive system that provides constant maximum torque is simulated and tested.

Keywords *- Induction motor drive,simulation of Indirect Field oriented control,imopleentation of Indirect field oriented control*

I. Introduction

The number of industry applications in which induction motors are fed by static frequency inverters is growing fast and, although much has already been done within this field, there is still a lot to be studied or understood regarding such applications. The advance of variable speed drives systems engineering increasingly leads to the need of specific technical guidance provision by electrical machines and drives manufacturers, so that such applications can be suitably designed in order to present actual advantages in terms of both energy efficiency and costs

Over the years induction motor (IM) has been utilized in the industry due to its easy construction and generally satisfactory efficiency. A.C. machines are preferred over D.C. machines due to their simple and most robust construction without any mechanical commutators. Induction motors are the most widely used motors for appliances like industrial control, and automation; hence, they are often called the workhorse of the motion industry [1]. However many applications need variable speed operation. The scalar V/f method is able to provide speed variation but does not handle transient condition control and is valid only during a steady state. The most efficient scheme of vector control: is the Indirect Field Oriented Control (IFOC), which is preferred in this work. Induction machine, with a speed/position sensor coupled to the shaft, acquires every advantage of a D.C. machine control structure, by achieving a very accurate steady state and transient control, but with higher dynamic performance. The well-developed vector control theory provides independent control between torque and flux where torque is controlled by the q-axis component of current if the flux is constant and oriented along the d-axis of the referred synchronous frame. The referred synchronous frame can be rotor flux, stator flux, or air-gap flux frame [2].

It is proved that rotor flux lies on d –axis when synchronous reference frame has been chosen. Compared to the D.C. motor, dynamic equations of the induction motor have been simplified. In a squirrel cage induction motor the stator phase current is a vector sum of the flux and torque producing current components. So, in order to achieve a dynamic performance similar to D.C. drive, a decoupling of the stator phase current into direct axis component (flux producing component) and quadrature axis component(torque producing component) is necessary.

II. Theory of Vector Control

FOC involves controlling the components of the motor stator currents, represented by a vector, in a rotating reference frame (with a d-q coordinate system). In a special reference frame, the expression for the electromagnetic torque of the smooth-air-gap machine is similar to the expression for the torque of the separately excited DC machine. In the case of induction machines, the control is normally performed in a reference frame aligned to the rotor flux space vector. To perform the alignment on a reference frame revolving with the rotor flux requires information on the modulus and the space angle (position) of the rotor flux space vector. In order to estimate the rotor flux vector is possible to use 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 or measured using the voltage equations starting from the electrical machine parameters.
- **IFOC** (Indirect Field Oriented Control): rotor flux vector is estimated using the field oriented control equations (current model) requiring a rotor speed measurement.

The usual terminology “Sensor less” specifies that no position/speed feedback devices are used with these algorithms, the stator currents of the induction machine are separated into flux and torque producing components by utilizing transformation to the d-q coordinate system. On this reference frame the torque component is on the q axis and the flux component is on the d axis. The vector control system requires the dynamic model equations of the induction motor and returns to the instantaneous currents and voltages in order to calculate and control the variables.

The technique described in this project is IFOC. Indirect vector control of the rotor currents can be implemented using the following data:

- Instantaneous stator phase currents, i_a, i_b, and i_c
- Rotor mechanical position
- Rotor electrical time constant.

The motor must be equipped with sensors to monitor the three-phase stator currents and a rotor position feedback device. An encoder is normally mounted on the shaft rotor for this purpose but in order to have a cheaper solution is possible to use a speed feedback device such as a tachometer.

The key for understanding how vector control works is to explain the coordinate reference transformation process. From the perspective of the stator, a sinusoidal input current is forced to the stator. This time variant signal causes the generation of a rotating magnetic flux. The speed of the rotor is a function of the rotating flux vector. From a stationary perspective, the stator currents and motor and the rotating flux vector look like AC quantities. Keep in mind that the rotor flux speed is not equal to the revolving magnetic field, produced by the stator phase windings, during the transient conditions. Looking at the motor from this perspective during steady state conditions, the stator currents become constant

III. Simulation Model Of Ifoc

Modeling of 3-phase induction motor drive

The dynamic model of the induction motor is derived by using a two phase motor in direct and quadrature axes as shown in Fig.3.1. This approach is desirable because of conceptual simplicity obtained with two sets of windings one on the stator and other on the rotor. The equivalence between the three phase and two phase models is derived from simple observation, and this approach is suitable for extending it to model an n – phase machine means of two phase machine. The concept of power invariance is introduced: the power must be equal in the three phase machine and its equivalent two phase model.

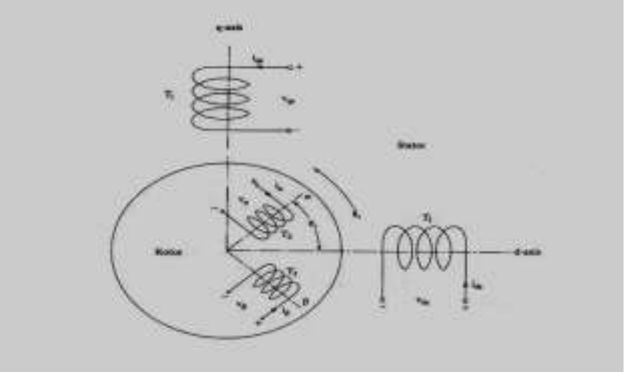

Fig-3.1 Two Phase Model of 3 Phase Induction Motor

The following assumptions are made to derive the dynamic model:

1. Uniform air gap
2. Balanced stator and rotor windings, with sinusoidally distributed mmf
3. Inductance versus rotor position is sinusoidal
4. Saturation and parameter changes are neglected.

A two phase induction machine with stator and rotor windings is as shown in the figure, the winding are displaced in space by 90 electrical degrees, and the rotor winding, α, is at an angle from the stator d axis winding. The number of turns per phase in the stator and rotor respectively are

The terminal voltages of the stator and the rotor windings can be expressed as the sum of voltage drops in resistances and rate of change flux linkages which are the products of the currents and the inductances, given by equations (1) to (4).

Stator Equations

$$V_{sa} = R_s i_{sa} + L_s \frac{di_{sa}}{dt} + L_m \frac{di_{ra}}{dt} \quad ....(1)$$

$$V_{sb} = R_s i_{sb} + L_s \frac{di_{sb}}{dt} + L_m \frac{di_{rb}}{dt} \quad ....(2)$$

Rotor Equations

$$0 = R_r i_{ra} + L_r \frac{di_{ra}}{dt} + \omega L_r i_{rb} + L_m \frac{di_{sa}}{dt} + \omega L_m i_{sa} .... (3)$$

$$0 = R_r i_{rb} + L_r \frac{di_{rb}}{dt} - \omega L_r i_{ra} + L_m \frac{di_{sb}}{dt} - \omega L_m i_{sa} .... (4)$$

The dynamic model for the three phase induction machine can be derived from the two phase machine if the equivalence between three and two phases is established. The equivalence is based on the equality of the mmf produced in the two –phase windings and equal current magnitudes. Assuming that each of the three phase windings has T1 turns per phase and equal current magnitudes, the two phase windings will have (3/2)*T1 turns per phase for mmf equality. The d and q axes mmfs are formed by resolving the mmfs of the three phases along the d and q axes. It may be seen that the synchronous reference frames transform the sinusoidal inputs into dc signals. This model is useful where the variables in steady state need to be dc quantities, as in the development of small – signal equations. Some high – performance control schemes use this model to estimate the control input; this led to a major breakthrough in induction – motor control by decoupling the torque and flux channels for control in a manner similar to that for separately excited dc motor drives.

The State Space model of 3 phase squirrel cage induction motor with stator and rotor current components as state variables are given by the equations (5) to (8). Equations (5) to (10) are used for the modelling of the 3 phase squirrel cage induction motor.

$$\frac{di_{sa}}{dt} = \frac{1}{\sigma L_s}\left[V_{sa} - R_s i_{sa} + \frac{L_m R_r i_{ra}}{L_r} + \omega L_m i_{rb} + \frac{\omega L_m^2 i_{sb}}{L_r}\right] \quad ....(5)$$

$$\frac{di_{sb}}{dt} = \frac{1}{\sigma L_s}\left[V_{sb} - R_s i_{sb} + \frac{L_m R_r i_{rb}}{L_r} - \omega L_m i_{ra} - \frac{\omega L_m^2 i_{sa}}{L_r}\right] \quad ....(6)$$

$$\frac{di_{ra}}{dt} = \frac{1}{\sigma L_r}\left[-R_r i_{ra} - \frac{L_m V_{sa}}{L_s} - \omega L_m i_{sb} - \omega L_r i_{rb} + \frac{L_m R_s i_{sa}}{L_s}\right] \quad ....(7)$$

$$\frac{di_{rb}}{dt} = \frac{1}{\sigma L_r}\left[-R_r i_{rb} - \frac{L_m V_{sb}}{L_s} + \omega L_m i_{sa} + \omega L_r i_{ra} + \frac{L_m R_s i_{sb}}{L_s}\right] \quad ....(8)$$

Electromagnetic Torque developed by the motor is given by:

$$T_e = \frac{2}{3}\frac{P}{2} L_m [i_{sb} i_{ra} - i_{rb} i_{sa}] \quad ....(9)$$

Load Dynamics is given by:

$$T_e = J\frac{d\omega_m}{dt} + B\omega_m + T_l \quad ....(10)$$

Torque control can be achieved by controlling its armature current. Since the torque results from the interaction of two perpendicular magnetic fields, which are the stator field generated by the PM excitation and armature field, created by the armature current. Once the flux level of stator field is kept constant, the torque can be controlled by armature current. To apply this two-axis theory for dc motor control to induction motor control, it is required to transform the alternating current quantities to dc components, which can be achieved using a synchronous frame as the reference frame. The synchronous frame, which rotates with synchronous speed, can be fixed to the axis of rotor flux, stator flux, or air gap. In this project synchronous frame is fixed to the axis of rotor flux.

3 Phase to 2 Phase Transformation.

Let i_{SA}, i_{SB}, and i_{SC} are 3 Phase currents and i_{sa}, i_{sb} are 2 Phase currents in stationary(stator) reference frame. Voltage transformations are same as that of current. The transformation is given by equations (11) and (12).

$$i_{sa} = \frac{3}{2} i_{SA} \quad \text{...(11)}$$

$$i_{sb} = \frac{\sqrt{3}}{2} [i_{SB} - i_{SC}] \quad \text{...(12)}$$

2 Phase to 3 Phase Transformation

$$i_{SA} = \frac{2}{3} [i_{sa}] \text{ ....(13)}$$

$$i_{SB} = -\frac{1}{3} i_{sa} + \frac{1}{\sqrt{3}} i_{sb} \text{ ....(14)}$$

$$i_{SC} = -\frac{1}{3} i_{sa} - \frac{1}{\sqrt{3}} i_{sb} \text{ ....(15)}$$

For an isolated neutral Balanced System,

$$i_{SA} + i_{SB} + i_{SC} = 0 \text{ ....(16)}$$

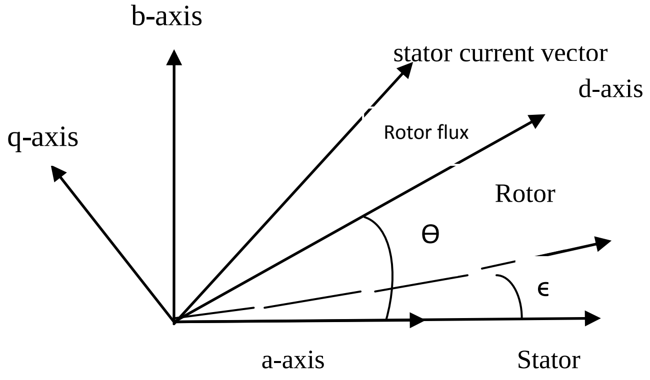

Fig-3.2 Orientation of reference frame

Stationary 2 Phase a-b (Stator Frame) to Rotating 2 Phase d-q (rotor Flux frame)

$$i_{sd} = i_{sa} \cos\rho + i_{sb} \sin\rho \text{ ....(17)}$$

$$i_{sq} = i_{sb} \cos\rho - i_{sa} \sin\rho$$

In Matrix form ab-dq and dq-ab Transformations are given by:

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} \cos\rho & \sin\rho \\ -\sin\rho & \cos\rho \end{bmatrix} * \begin{bmatrix} i_{sa} \\ i_{sb} \end{bmatrix} \quad \text{................................(18)}$$

$$\begin{bmatrix} i_{sa} \\ i_{sb} \end{bmatrix} = \begin{bmatrix} \cos\rho & -\sin\rho \\ \sin\rho & \cos\rho \end{bmatrix} * \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} \quad \text{.................................(19)}$$

IV. Modelling Of Indirect Vector Controller

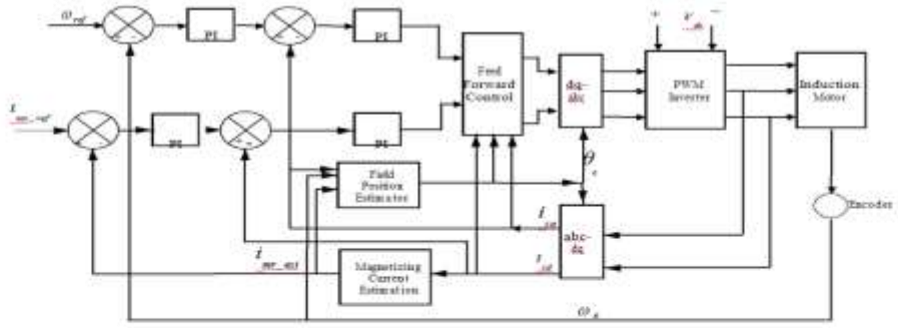

Fig-4.1 block diagram of indirect field oriented control

The decoupled stator voltage equations in rotor flux reference frame are given by equations (20) and(21)

$V_{sd} = R_s i_{sd} + \sigma L_s \frac{di_{sd}}{dt} - \omega_{mr} i_{sq} \sigma L_s + (1-\sigma) L_s \frac{di_{mr}}{dt}$ ....(20)

$V_{sq} = R_s i_{sq} + \sigma L_s \frac{di_{sq}}{dt} + \omega_{mr} i_{sd} \sigma L_s + (1-\sigma) L_s i_{mr} \omega_{mr}$ ....(21)

The decoupled Flux channel and Torque channel equations are given by equations (22) and (23) respectively.

$T_r \frac{di_{mr}}{dt} + i_{mr} = i_{sd}$ ....(22)

$T_e = \frac{2}{3}\frac{P}{2}\frac{L_m}{1+\sigma_r} i_{mr} i_{sq}$ ....(23)

The instantaneous angular speed of rotor flux is given by

$\omega_{mr}(t) = \frac{i_{sq}}{i_{mr} T_r} + \omega_e = \frac{d\rho}{dt}$ ....(24)

Where slip speed is given by

$\omega_{sl} = \frac{i_{sq}}{i_{mr} T_r}$ ....(25)

On integrating equation (24) Field angle (position) ρ and thereby unit vector signals $\cos\rho$ and $\sin\rho$ can be estimated.

The eqn. (22) of flux channel includes only flux component of stator current. So rotor flux can be controlled by varying i_{sd} without affecting i_{sq}. The variation in i_{sd} cause variation in i_{mr} and there by flux Ψ_r. i_{sd} is analogous to field current in a DC motor. Torque channel equation (23) shows that torque can be controlled by varying both i_{sq} and i_{mr} . Since the time constant associated with flux channel T_r is large, torque is controlled by varying i_{sq} by keeping i_{mr} constant at its rated value in order to obtain fast dynamic response. i_{sq} is analogous to armature current in a DC motor.

V. Simulation Results And Discussion

From the fig.5.1, it can be seen that motor has a high starting current and after few seconds it attains normal full load current of 15.3 amperes.

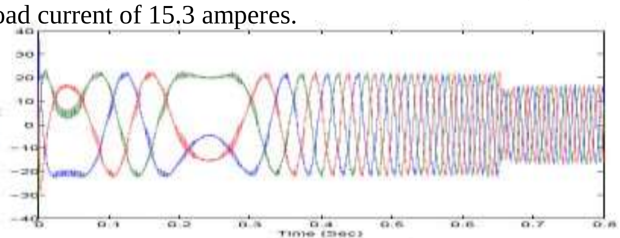

Fig-5.1 Motor Line Current (Full Load Condition 15.3 Amp)

Fig. 5.2 and Fig.5.3 showing the currents in rotor flux reference frame, i.e., in d-q reference frame. It can be seen that they appear as D.C. values in steady state so control variables are steady state D.C. values.

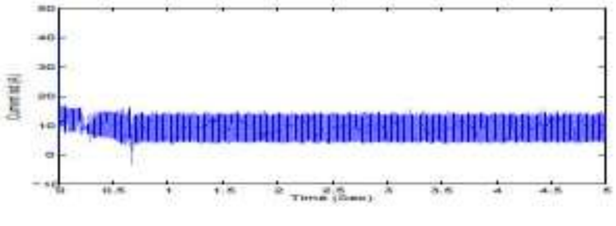

Fig-5.2 Flux Component of Stator Current

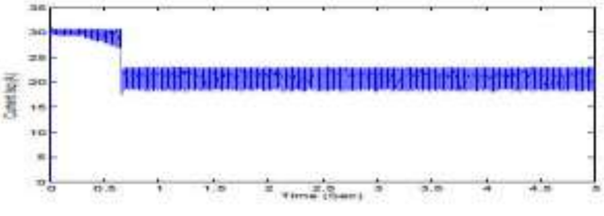

Fig-5.3 Torque Response of Drive at full load (32 N.m.)

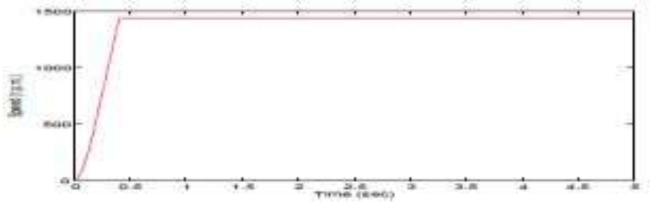

Fig-5.4 Speed Response of Drive at full load
(reference speed = 1440 r.p.m.)

Fig.5.3 and Fig.5.4 showing the torque response and speed response of the drive at full load and reference speed of 1440 r.p.m. It can be seen that the motor attains the rated torque of 32 N.m. after the transient oscillations. Also the speed settles to the reference value of 1440 r.p.m.

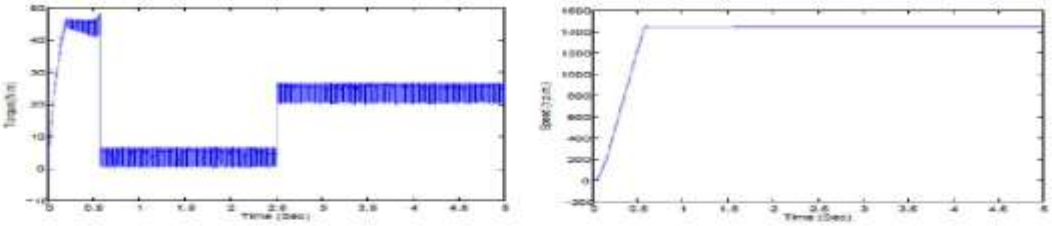

Fig-5.5 Torque and Speed Response for a step change in Load Torque (5-25 Nm) at 2.5 sec

Figure5.5 shows the torque and speed response of the drive for a step change in load torque of (5-25 Nm) at 2.5 sec. with speed command remains unchanged. The main advantage of vector control is shown in this graph i.e. speed of the machine remains constant for change in load torque or any load disturbances. Also it can be seen that the dynamic torque response is very fast for the step change in load torque.

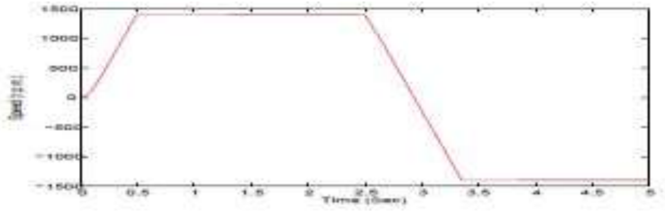

Fig-5.6 Speed Response for a Speed Reversal
(1400 to -1400 rpm) at 2.5 sec.

Figure 5.6 shows the speed response of the drive for a speed reversal command of (1400 to -1400 rpm) at 2.5 sec. it can be seen that response is very fast with a minimum lag determined by the inertia of the rotating system.

VI. Hardware Implementation

The currents are tapped from the inverter output section fed to some transformation module (Clarke and Park). The outputs of the Clark block are indicated with iα and iβ. These two components of the stator current provide the input to the Park transformation that gives the current in the *d,q* rotating reference frame aligned with the rotor flux vector. The exact rotor flux angular position ($\theta_{\lambda r}$) is necessary to calculate the two components ids and i_{qs}. The ids and i_{qs} components are compared to the references i_{dref} (the flux reference) and i_{qref} (the torque reference). The torque command i_{qref} is the output of the speed regulator. The flux command i_{dref} indicates the right rotor flux command for every speed reference within the nominal value. The current outputs are converted into the corresponding voltages V_d and V_q. They are processed into the inverse Park transformation block. The outputs of this are Vα and V_β, which are the components of the stator vector voltage in the α, β orthogonal reference frame and the given to the inverse Clark transformation block getting the vectors V_a, V_b, V_c. These are used to generate the gate signals and fed to the H-bridge inverter. The inverter then drives the motor.

6.1 Implementation of IFOC

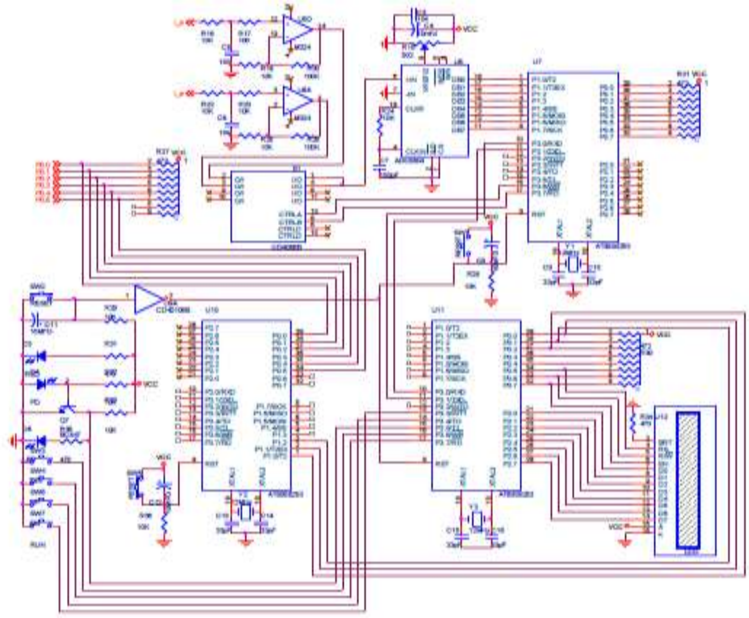

Fig-6.1 circuit diagram of IFOC

It includes two AT89S8253 microcontrollers for the fast performance of IFOC operation. Firs microcontroller performs the Park and Clark transformations, whereas the second microcontroller do the inverse Clark and inverse Park transformations. Tapped currents I_a & I_b are given to the ADC through the MUX for getting the corresponding digital signals. Since microcontroller is a digital controller. The microcontroller1 output will be I_d & I_q will be then given as input to the second microcontroller, where it processed with digital signals corresponding to the speed. The speed signal getting by the use of a tachometer and associated circuitry. Up, down, stop and reverse witches are also operated with the same microcontroller. And an LCD is interfaced with it to display the operation at each time. The vector output of the second microcontroller is given as input to the gate generating microcontroller. This microcontroller will generate 6 pulses at a time for the inverter MOSFET gates.

6.2 Inverter circuit

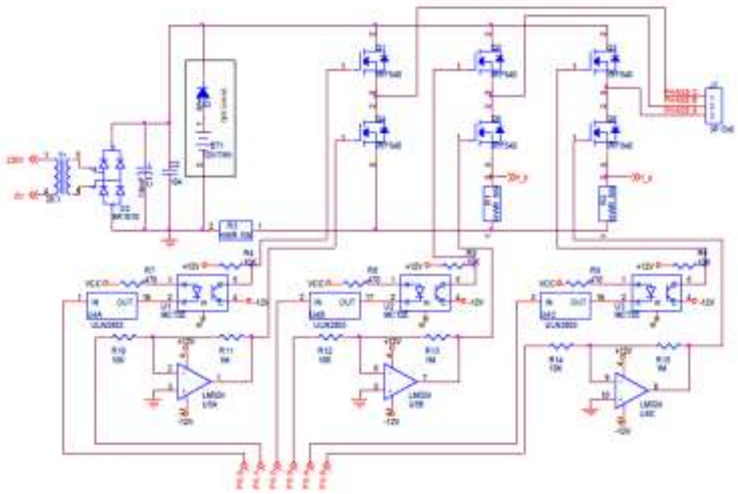

Fig-6.2 , 3–phase inverter circuit diagram

It includes H-Bridge inverter, its source rectifier circuit, optocoupler, op-amp amplifier. A 230V/12V transformer supplying input to the bridge rectifier and its output filtered using a -filter. Upper MOSFETs are driven by optocouplers and lower by op-amp amplifiers. The output of the inverter is the stepped up to 110v using 3 single phase transformers and then given to the motor input.

Fig-7.3, implemented circuit

VII. Conclusion

This paper presented the Indirect Field Oriented Controlled Three Phase Induction Motor Drive. The drive is simulated in MATLAB/SIMULINK and the results are analyzed. The results demonstrate the efficiency of the vector control as compared to scalar control techniques. It is proved that rotor flux lies on d –axis when synchronous reference frame has been chosen. Compared to the D.C. motor, dynamic equations of the Induction Motor have been simplified. In a squirrel cage induction motor the stator phase current is a vector sum of the flux and torque producing the current components. So, in order to achieve a dynamic performance similar to D.C. drive, a decoupling of the stator phase current into direct axis component (flux producing component) and quadrature axis component(torque producing component) is necessary. The decoupling of flux and torque control in an A.C. machine is achieved in this project. This paper makes use of MATLAB/SIMULINK as simulation software. Using this software both steady state and dynamic performance were studied. IFOC of 3 phase induction motor drive is successfully implemented based on the simulation results.

References

[1] Gurmeet Singh and Gagan Singh, “A Fuzzy Pre-Compensated-PI Controller for Indirect Field Oriented Controlled Induction Motor Drive” *Innovative Applications of Computational Intelligence on Power, Energy and Controls with their impact on Humanity (CIPECH,*.2014

[2] Huan Liu and Han Cui “Study on a Sliding Mode Variable Structure Vector Control of Induction Motor Drives” *IEEE Shenyang University of Chemical Technology Shenyang University of Chemical Technology, Shenyang, Liaoning Province, 110142, China*,978-1-4673-1398-8/12/$31.00 ©2012

[3] G. Bhuvaneswari , Bhim Singh and Sandeep Madishetti “Three-Phase, Two-Switch PFC Rectifier Fed Three- Level VSI Based FOC of Induction Motor Drive” *IEEE* 978-1-4673-0766-6/12/$31.00 ©2012

[4] Yen-Shin Lai, “Machine Modelling and Universal Controller for Vector-Controlled Induction Motor Drives”, *IEEE Transactions on energy conversion*, VOL. 18, pp.23-32 March 2003

[5] Bimal K. Bose, “Modern Power Electronics and AC drives”, *Pearson Education Asia.*

[6] R.Krishnan, “Electric Motor Drives Modelling Analysis and Control” *Prentice- Hall of India pvt. Limited, New Delhi*, 2007.

[7] M. WaheedaBeevi, A. Sukeshkumar and Mano Mary Kuriakose, “Efficiency Optimization of Vector Controlled Induction Motor Drives,” *10th National Conference on Technological Trends NCTT09* 6-7 Nov 2009

[8] Ali M.Eltamaly, A.I.Alolah,and Basem M.Badr , “Fuzzy controller for three phase induction motor drives”,*EEE dept.College of Engineering, King Saud University, Riyadh, Saudi Arabia* 2010

[9] Rodolfo Echavada, Sergio Horta, Marco Oliver, ”A Three phase motor drive using IGBT‟s and Constant V/F speed control with slip regulation”, *IEEE* 0-7803-3071-4/95 1995

[10] Y. S. Lai, “Modelling and vector control of induction machine-a new unified approach,” in *Proc. IEEE Power Eng. Soc.Winter Meeting*, 1999, pp. 47–52.