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Indirect field oriented control of induction motor with 3-level and 5-level inverter

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Abstract— Different methods have been proposed for controlling the induction motor drives .however, based on applications and machine ratings variety of methods have been reported in the literatures. The field oriented control strategies can be remarkably used for high performance ac drives. For improving the dynamic performance of induction motor drive, indirect field oriented control method has widely accepted for improved dynamic performance of induction motor drive. This paper presents indirect field oriented control (IFOC) fed induction motor drive with multilevel inverter topology. Comparison of three levels and five level inverter is also carried out. It can be seen that a five level inverter topology is a more stable and optimum performance can be achieved.

Keywords— Indirect field-oriented control, electric drives, induction machines, controller parameters, multilevel inverter.

I. INTRODUCTION

The development of induction motor drive reaches its peak in recent years. Induction machine is used as induction motor and induction generator. Induction motors are extensively used in industry. Induction generators have been widely used for wind power generators. In industry induction motor drive are used as a variable speed drive in a wide power range.

Different methods are used for induction motor control. Scalar control, vector control or field oriented control, adaptive control are used for induction motor control. Fundamental of scalar control technique is to varying frequency and amplitude of fundamental supply voltage. It is easy to implement but one problem is that it have an inferior performance. Scalar control method provides poor dynamic response. This method has limited speed accuracy in the low speed range [2].

Vector control also named as a field oriented control is also a significant method in area of motor controlling. This method came in a picture from 1970s. Vector controlled demonstrated that one could control induction motor same as of separately excited DC motor. This method has a two-type direct control as well as indirect control. Flux position information is required in direct control method and it can be directly measure from other motor quantities [5]. In some cases flux sensor has to install in motor. Due to modification in a motor construction direct control method is not suitable for general purpose Industrial motors [3].

Indirect field oriented control method works differently than direct control [2]. In this method, motor and inverter dynamics are used for estimation of flux. This method is categorized in a three type based on a stator, air-gap and a rotor flux orientation [10]. Indirect method is a robust and stable for entire control range.

Proportional-integration control is used to regulate the motor state. This method is very sensitive to parameter variation. This method requires relatively complicated calculation. Algorithm of this method contain or nonlinearity [8].

Multilevel inverter is also used for controlling of induction motor drive. Different topologies are used with a multilevel inverter. As the level of inverter increase the overall performance is improved but at the same time high level of inverter leads to more complexity [4]. Harmonics are also big problem but by proper PWM technique harmonics can be mitigated at a satisfactory level.

This paper describes an approach of indirect field oriented control of induction machine with three level and five level inverter. Proposed Method can be applied in a control of induction generator also. Section II presents a model of induction motor. In section III control strategies is designed. Simulation results are present and discussed in Section IV.

II. MODEL OF INDUCTION MOTOR

In scalar control induction motor have a coupling effect which leads to sluggish response. In case of high order system there is a chance to system instability. This problem can be resolved by vector control. Vector control is also known as a decoupling control or orthogonal control. Induction motor modelling is necessary. Induction motor model is established using rotating field reference frame.

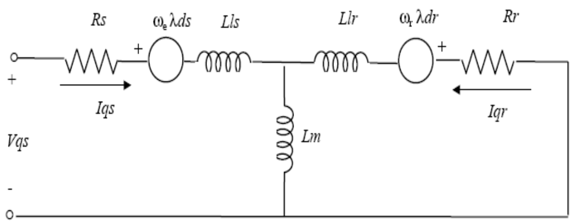

Fig 4.3: Q-axis Circuit

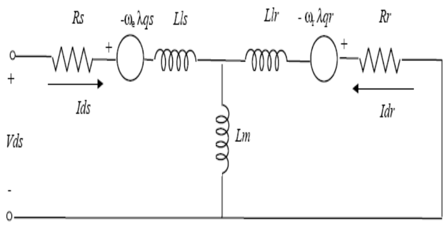

Fig 4.4 D-axis Circuit

For dynamic simulation of induction motors one may prefer to use the standard form of differential equation as PX=AX+BU (1)

For Equation, matrix quantities on the above equation are as follows

$$X = \begin{bmatrix} I_{qs} \\ I_{ds} \\ I_{qr} \\ I_{dr} \end{bmatrix} \qquad U = \begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} \qquad B = 1/\Delta \begin{bmatrix} L_r & 0 & -L_m & 0 \\ 0 & L_r & 0 & -L_m \\ -L_m & 0 & L_S & 0 \\ 0 & -L_m & 0 & L_S \end{bmatrix} \quad (2)$$

$$A = 1/\Delta \begin{bmatrix} R_s I_r & \omega_e I_s L_r - \omega_r L_m^2 & -R_r L_m & \omega_0 L_m L_r \\ -\omega_e I_s L_r + \omega_r L_m^2 & R_s I_r & -\omega_0 L_m L_r & -R_r L_m \\ -R_s L_m & -\omega_0 L_m L_s & R_r I_s & \omega_r I_s L_r - \omega_e L_m^2 \\ \omega_0 L_m L_s & -R_s L_m & -\omega_r I_s L_r + \omega_e L_m^2 & R_r I_s \end{bmatrix} \quad (3)$$

In the above equation, $\Delta = L_s L_r - L_m{}^2$. Another set of equations are required that include flux linkage variables to explain the concept of vector control. By translating dq space equations in d-q coordinate on a synchronous frame, we have the following equations. Both stator and rotor voltage equations are,

$$V_{qs} = R_s I_{qs} + p\lambda_{qs} + \omega_s \lambda_{ds} \quad (4) \qquad V_{ds} = R_s I_{ds} + p\lambda_{ds} + \omega_s \lambda_{qs} \quad (5)$$

$$0 = R_r I_{qr} + p\lambda_{qr} + \omega_r \lambda_{dr} \quad (6) \qquad 0 = R_r I_{dr} + p\lambda_{dr} - \omega_r \lambda_{qr} \quad (7)$$

Where flux linkage variables are defined by $\lambda_{ds} = L_s I_{ds} + L_m I_{dr}$ (8)

$$\lambda_{qs} = L_s I_{qs} + L_m I_{qr} \quad (9) \qquad \lambda_{qr} = L_m I_{qs} + L_r I_{qr} \quad (10)$$

$$\lambda_{dr} = L_m I_{ds} + L_r I_{dr} \quad (11)$$

When induction motors are controlled by a vector drive, control computation is mostly done in the synchronous frame. By combining equations we have

$$\begin{bmatrix} Y_q \\ Y_d \\ 0 \end{bmatrix} = (2/3) \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta + 2\pi/3) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} Y_a \\ Y_b \\ Y_c \end{bmatrix} \quad (12)$$

And its inverse transform is given

$$\begin{bmatrix} Y_a \\ Y_b \\ Y_c \end{bmatrix} = (2/3)\begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-2\pi/3)\sin\theta & \sin(\theta-2\pi/3) & 1 \\ \cos(\theta+2\pi/3) & \sin(\theta+2\pi/3) & 1 \end{bmatrix}\begin{bmatrix} Y_a \\ Y_b \\ Y_c \end{bmatrix} \quad (13)$$

Regardless of reference frame, instantaneous terms of space vectors, by

$P_i = (3/2)\,\mathrm{Re}(V_s I_s),$ (14) $\qquad P_i = (3/2)[V_{ds} I_{ds} + V_{qs} I_{qs}].$ (15)

The reactive power Q_i can also be defined as $Q_i = (3/2)\,\mathrm{Im}(V_s I_s),$ (16)

$Q_i = (3/2)[V_{qs} I_{ds} - V_{ds} I_{qs}]$ (17)

The output power and torque can be seen as equations (18), (19) and (20).

$P_0 = (3/2)\omega_0\,\mathrm{Im}(\lambda_r I_r)$ (18) Since torque is the above power divided by the rotor speed,

$T_0 = (3/4)P\,\mathrm{Im}(\lambda_r I_r)$ (19) $\qquad T_0 = (3/4)P\{\lambda_{qr} I_{dr} - \lambda_{dr} I_{qr}\}$ (20)

where *P* is the number of poles. In terms of *d-q* variables.

III. MATHEMATICAL MODEL OF INDIRECT VECTOR CONTROL OF INDUCTION MOTOR

The unit vector signal is determined as:

$R_r I_{qr} + \frac{d}{dt}\lambda_{qr} + (\omega_e - \omega_r)\lambda_{dr} = 0$ (22) $\qquad R_r I_{dr} + \frac{d}{dt}\lambda_{dr} + (\omega_e - \omega_r)\lambda_{qr} = 0$ (23)

The rotor flux linkage equation written as: $\lambda_{qr} = L_m I_{qs} + L_r L_{qs}$ (24)

$\lambda_{dr} = L_m I_{ds} + L_r L_{ds}$ (25)

Therefore, the rotor d-q currents are: $I_{dr} = \frac{1}{L_r}\lambda_{dr} - \frac{L_m}{L_r} I_{ds}$ (26)

$I_{qr} = \frac{1}{L_r}\lambda_{qr} - \frac{L_m}{L_r} I_{qs}$ (27)

The rotor currents can be further written in the form of rotor flux linkages:

$\frac{d\lambda_{dr}}{dt} + \frac{R_r}{L_r}\lambda_{dr} - \frac{L_m}{L_r} R_r I_{ds} - \omega_{sl}\lambda_{qr} = 0$ (28) $\qquad \frac{d\lambda_{qr}}{dt} + \frac{R_r}{L_r}\lambda_{qr} - \frac{L_m}{L_r} R_r I_{qs} - \omega_{sl}\lambda_{dr} = 0$ (29)

Where, $\omega_{sl} = \omega_e - \omega_r$

For decoupling control

$\lambda_{qr} = 0$ (30) $\qquad \frac{d\lambda_{qr}}{dt} = 0$ (31)

IV. SIMULATION RESULTS

A Simulation model of an indirect-vector-controlled (IVC) 3-phase 7.5 KW, 50Hz induction motor drive is shown in Fig.1 fed by 3-level inverter. Fig. 2 shown a simulation model of an indirect-vector-controlled 3-phase 7.5 KW , 50Hz induction motor drive fed by 5-level cascaded inverter using PWM Hysteresis current control technique.

TABLE I

Parameters of induction motor

Rotor Type	Squirrel cage
Reference frame	Synchronous
synchronous speed	1500 rpm
rated speed	1440 rpm
Nominal Power	7.5 KW
Voltage Line to Line	400 V
Frequency	50 Hz
Stator resistance	0.7384 ohm
Stator inductance	0.00305 H
Rotor resistance	0.640 ohm
Rotor inductance	0.003045 H
Mutual inductance	0.2141 H
Inertia	0.0143
Friction factor	0.000403
Number of poles	4

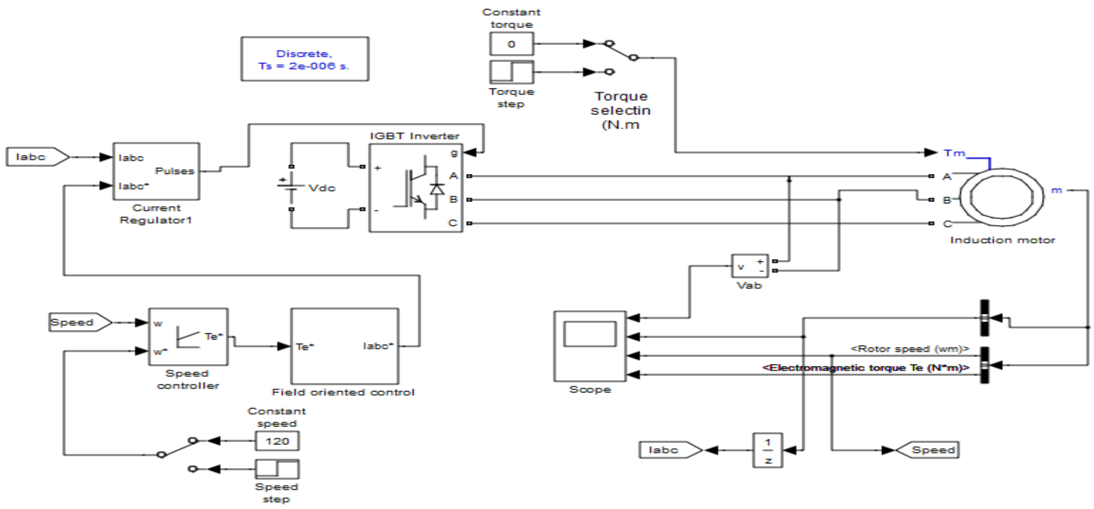

Fig.1Simulation Model of Indirect Field Oriented Control of Induction Motor Using 3-Level Inverter.

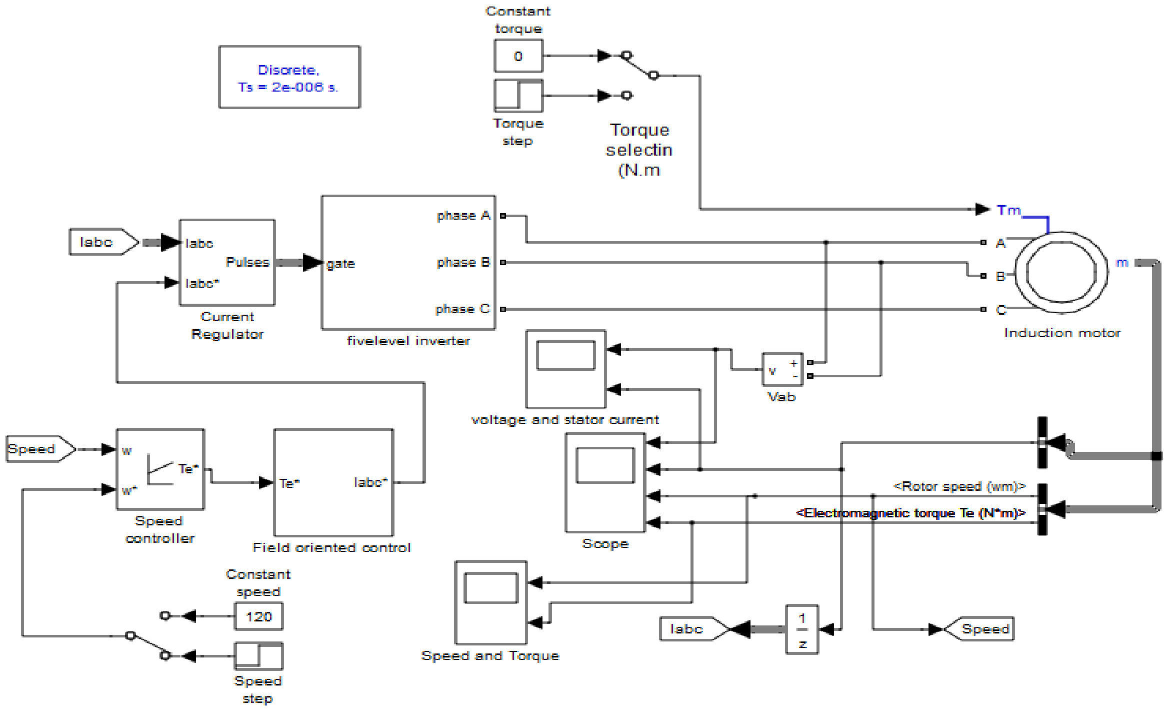

Fig.2 Simulation Model of Indirect Field Oriented Control of Induction Motor Using 5-Level Inverter.

When Step Speed is apply with Simulation Time =3 sec, Initial Value =90 rad/sec,final Value =130 rad/sec

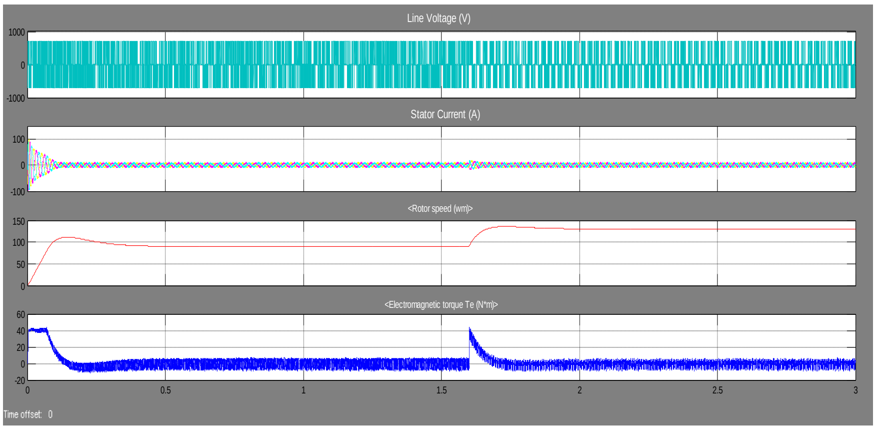

Fig. 3 Waveform of IFOC of IM using 3-level inverter when Step Speed apply

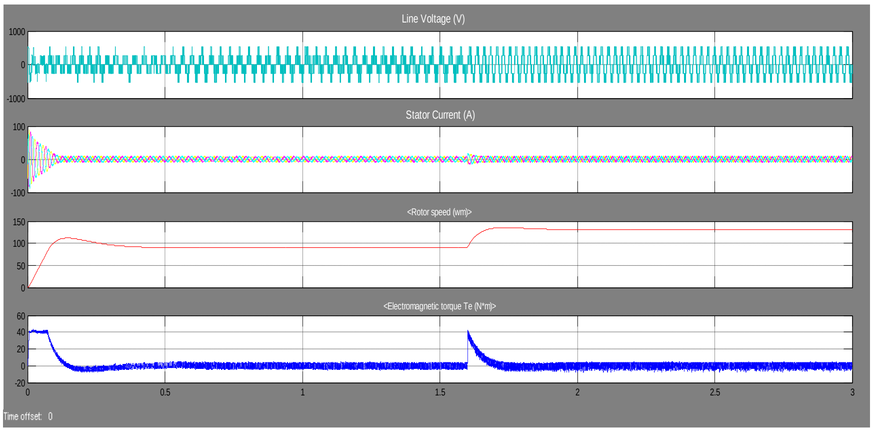

Fig. 4 Waveform of IFOC of IM using 5-level Cascaded Inverter when Step Speed apply

.When Step Torque is apply constant Speed =120 rad/sec, Simulation Time =3 sec, Initial Value =0 rad/sec, Final Value =30 rad/sec, Step time =1.6 sec

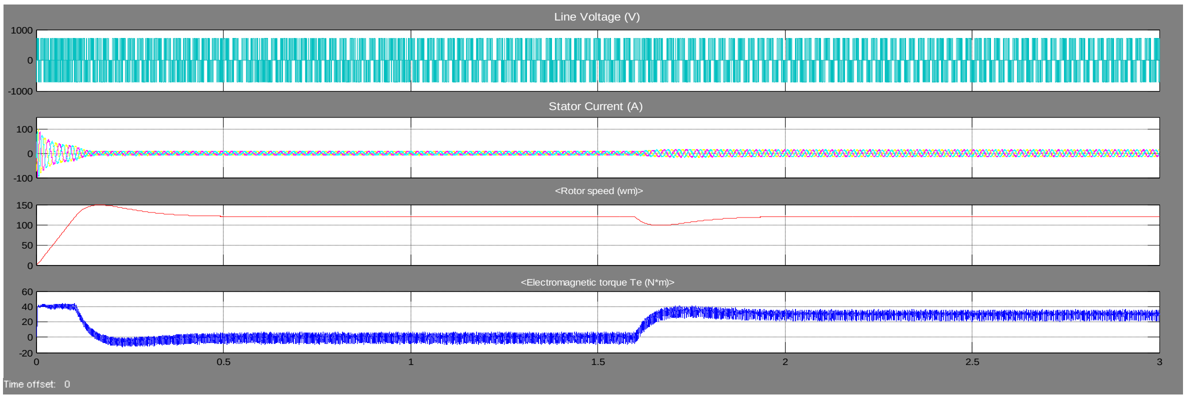

Fig. 5 Waveform of IFOC of IM using 3-level Inverter when Step Torque apply

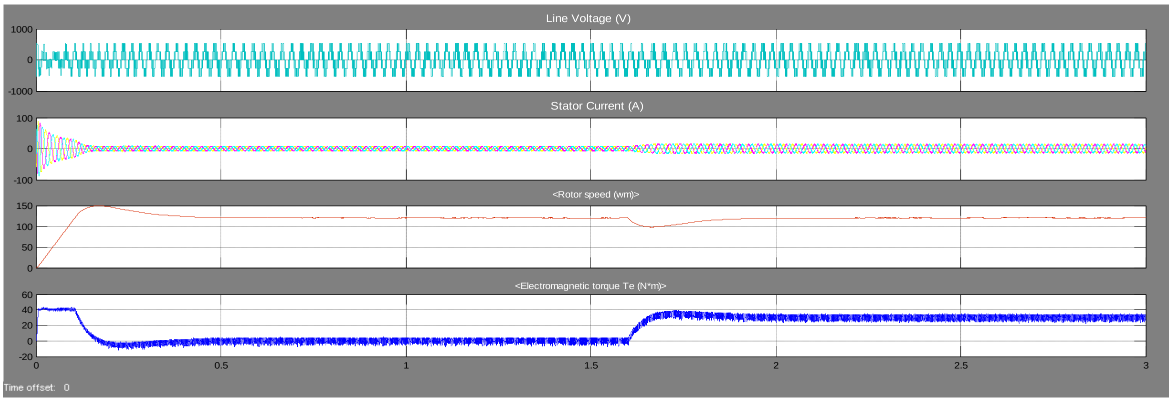

Fig. 6 Waveform of IFOC of IM using 5-level Cascaded Inverter when Step Torque apply

Table 2

Simulation results with 3-level inverter configuration:

Parameter	Value
RMS value of voltage	118.999465V
Average value of voltage	96.3134V
Positive peak value	199.98
Negative peak	-199.98
Fundamental component	159.7
Fifth harmonic component	4.45
Total harmonics distortion	0.3315

TABLE-3

Simulation results with 5-level inverter configuration:

Parameter	Value
RMS value of voltage	174.088V
Average value of voltage	152.192V
Positive peak value	299.92
Negative peak	-299.92
Fundamental component	239.075
Fifth harmonic component	0.645
Total harmonics distortion	0.2459

Table IV

Comparison of Simulation results with 3-level and 5 level inverter configuration

Parameter	Value	Value
RMS value of voltage	118.999465V	174.088V
Average value of voltage	96.3134V	152.192V
Positive peak value	199.98	299.92
Negative peak	-199.98	-299.92
Fundamental component	159.7	239.075

V. CONCLUSIONS

In this paper cascaded 5-level inverter fed 3-phase 400V, 50Hz Induction motor speed is controlled by Indirect Field Oriented control method (IFOC). 5-level cascaded inverter fed Induction motor drawn less harmonic current and voltage compare to 3-level inverter fed Induction motor. Increase the number of level of inverter, decrease the harmonic current and voltage drawn by Induction motor. Indirect Field Oriented control had a faster speed response and less transient oscillations in terms of voltage, current, and torque. Therefore, it gives better performance. The amplitudes of the transients are completely controlled by the IFOC method. With the use of IFOC control method we get the smoother speed control of the induction motor. So, Induction motor operates like a separately excited dc motor.

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