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Research Article

Modeling of Inverter Fed Five Phase Induction Motor using V/f Control Technique

Palak Sharma†*, Manish Kurwale† and Ganesh Barve‡

†Department of Electrical Engineering, RTMNU, RGCER,Nagpur,India
‡MSEDCL, Washim,Maharashtra,India

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Abstract

Multiphase Variable-speed motor drivers have substantially grown with the advancement in power electronics in the beginning of this century. Reference frame theory concept is used for analysis & performance of five phase induction machine. Traditionally three phase supply is produced and therefore Multiphase inverter is used to provide multiphase supply for multiphase supply. Simulation model of five phase induction machine in dqxyo axis based on mathematical modeling & it's controlling using V/f Control Technique is modeled using simpower system block-set of Matlab/simulink. Spwm Technique is used to generate the pulses for the inverter.

Keywords*: Inverter, Spwm Technique, Five phase Induction Motor, V/f Control.*

1. Introduction

Induction Machine are one of the most frequently used machine in industries due its reliability, low cost, high efficiency, low maintenance, ruggedness. The advent of cheap & fast switching power electronics devices induction machine has become easier & flexible also the number of phases of machine has become a design parameter (AtifIqbal,2010). Multi-Phase Machines are AC machines characterized by a stator winding composed of generic number of phases. Multiphase machine has several advantages over the traditional three phase machine such as reducing the amplitude, increasing the frequency of torque pulsation, reducing the rotor harmonic, high fault tolerance and higher reliability (E.Levi,2007). Earlier multiphase motor were not used widely because of the drawback that the supply for the multi phase motor was not available. Advancement in Power Electronics has increased the interest in Multi-phase machine tremendously as high power electronic devices are used as a switch in voltage source inverter (VSI). The multiphase drive has special applications where high reliability is demanded such as locomotive traction, electric/hybrid vehicles, high power industrial application, electric energy generation, electric ship propulsion (AtifIqbal,2010).

In this paper mathematical modeling of five phase induction motor in rotating reference frame is carried out & its speed control using V/f Control strategies is described.

*Corresponding author: **Palak Sharma; Ganesh Barve** is working as Assistant Engineer

2. Motor Drive Control Scheme

A simplified scheme of V/f controlled five phase induction motor is represented in fig 1,block mainly consist of dc source, inverter, five phase induction motor, close loop v/f control. Principal behind this control scheme is to keep flux constant under all operating condition. The speed loop error is given to PI controller & limiter to limit the error to which is added the motor speed so as to obtain required speed signal to generate the frequency command and corresponding voltage command which is given to the inverter to implement V/f scheme.

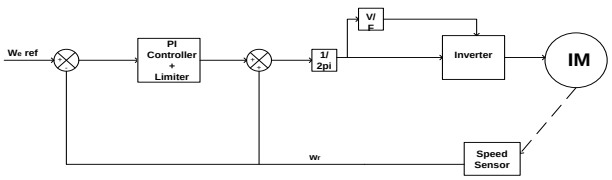

Fig.1V/f control Scheme for five phase induction motor

3. Induction Motor Model

Theory of electrical machine provides sufficient mean to deal with mathematical representation of induction motor with number of phases on both stator and rotor. Three phase machine are normally designed with distributed stator winding that gives nearly sinusoidal magneto-motive force distribution which is supplied

with sinusoidal current, however the spatial MMF distribution is never perfect sinusoidal and has some spatial harmonics. Multiphase machine shows more versatility in this respect as nearly sinusoidal MMF distribution requires use of more than one slot per pole per phase. For a five phase four pole machine it requires a minimum of 40 slots for this purpose (AtifIqbal,2010). In five phase induction machine model, it is assumed that the machine winding are sinusoidally distributed and the flux path is liner (Hamid A. Toliyat,1998). The machine equations are transformed into an arbitrary frame of reference rotating at angular speed.

The dynamic equation of five phase induction motor is shown below:-

$$\begin{bmatrix} V_q \\ V_d \\ V_x \\ V_y \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{5}\right) & \cos\left(\theta-\frac{4\pi}{5}\right) & \cos\left(\theta+\frac{4\pi}{5}\right) & \cos\left(\theta+\frac{2\pi}{5}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{5}\right) & \sin\left(\theta-\frac{4\pi}{5}\right) & \sin\left(\theta+\frac{4\pi}{5}\right) & \sin\left(\theta+\frac{2\pi}{5}\right) \\ \cos\theta & \cos\left(\theta+\frac{4\pi}{5}\right) & \cos\left(\theta-\frac{2\pi}{5}\right) & \cos\left(\theta+\frac{2\pi}{5}\right) & \cos\left(\theta-\frac{4\pi}{5}\right) \\ \sin\theta & \sin\left(\theta+\frac{4\pi}{5}\right) & \sin\left(\theta-\frac{2\pi}{5}\right) & \sin\left(\theta+\frac{2\pi}{5}\right) & \sin\left(\theta-\frac{4\pi}{5}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \\ V_d \\ V_e \end{bmatrix} \quad (1)$$

$$\begin{aligned} V_{ds} &= R_s i_{ds} - \omega_a \psi_{qs} + p\psi_{ds} \\ V_{qs} &= R_s i_{qs} + \omega_a \psi_{ds} + p\psi_{qs} \\ V_{xs} &= R_s i_{xs} + p\psi_{xs} \\ V_{ys} &= R_s i_{ys} + p\psi_{ys} \\ V_{0s} &= R_s i_{0s} + p\psi_{0s} \end{aligned} \quad (2)$$

$$\begin{aligned} v_{dr} &= R_r i_{dr} - (\omega_a - \omega)\psi_{qr} + p\psi_{dr} \\ v_{qr} &= R_r i_{qr} - (\omega_a - \omega)\psi_{dr} + p\psi_{qr} \\ V_{xr} &= R_r i_{xr} + p\psi_{xr} \\ V_{yr} &= R_r i_{yr} + p\psi_{yr} \\ V_{0r} &= R_r i_{0r} + p\psi_{0r} \end{aligned} \quad (3)$$

Eq-2 gives the stator side voltage while Eq-3 gives the rotor side equation.

$$\begin{aligned} \psi_{ds} &= (L_{ls} + L_m) i_{ds} + L_m i_{dr} \\ \psi_{qs} &= (L_{ls} + L_m) i_{qs} + L_m i_{qr} \\ \psi_{xs} &= L_{ls} i_{xs} \\ \psi_{ys} &= L_{ls} i_{ys} \\ \psi_{0s} &= L_{ls} i_{0s} \end{aligned} \quad (4)$$

Eq-4 gives the flux equation of stator side of five phase induction motor.

$$\begin{aligned} \psi_{dr} &= (L_{lr} + L_m) i_{dr} + L_m i_{ds} \\ \psi_{qr} &= (L_{lr} + L_m) i_{qr} + L_m i_{qs} \\ \psi_{xr} &= L_{lr} i_{xr} \\ \psi_{yr} &= L_{lr} i_{yr} \\ \psi_{0r} &= L_{lr} i_{0r} \end{aligned} \quad (5)$$

Eq-5 gives the flux equation of rotor side of five phase induction motor.

From the above equations, the torque and rotor speed can be determined as:

$$T_e = \frac{5}{2}\left(\frac{P}{2}\right)\frac{1}{w_b}\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right) \quad (6)$$

$$\omega_r = \int \frac{P}{2J}\left(T_e - T_L\right) \quad (7)$$

Where P is the number of Poles; J moment of Inertia; TL Load Torque; Te Electromechanical Torque; ω_r is the Rotor Speed.

The difference between the five-phase Induction Motor Mathematical modelling and the corresponding three phase Induction Motor Mathematical modelling is the presence of x-y component equations. Rotor x-y components are fully decoupled from d-q components and one from the other. Since rotor winding is short-circuited, x-y components cannot appear in the rotor winding. Zero sequence component equations is due to short-circuited rotor winding and star connection of the stator winding. Stator x-y components are decoupled with d-q components and only d-q axis current components are generated, the equations for x-y components can be omitted.

Thus the mathematical modeling of the five-phase induction motor in an arbitrary reference frame becomes identical to the mathematical modelling of a three phase induction motor. The inputs to the motor are the five-phase voltage supply obtained from voltage source inverter.

In the modeling of induction motor five phase supply of the induction motor is transformed into d-q axis using transformation equation-1.Once the supply voltage is converted into Vq&Vd is applied to obtain iqs, ids, iqr, idr, Te, rotor speed

4. Voltage Source Inverter

The basic power circuit topology of five phase VSI is shown in fig 2. IGBT is used as the power switches. The anti parallel diodes provides reverse current path such that when a particular IGBT is gated on, one output terminal and one input terminal will be connected.

In multiphase inverter we can generate n number of phase, as each leg of the inverter represent the phase, thus by increase the number of leg in the inverter we can increase the number of phases. For the five phase motor we require five leg inverter. The input to the inverter is a dc supply. The topology of five phase inverter is shown in fig 3

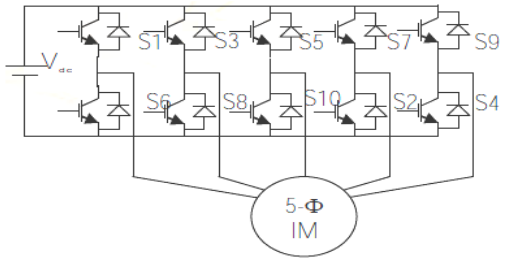

Fig.2 Basic Circuit Topology of Inverter Fed Five phase Induction Motor

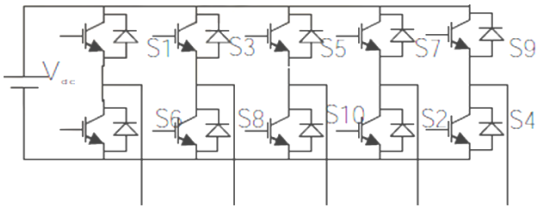

Fig.3 Five Phase Inverter

In five phase inverter three switches from the upper switches and two from the lower switches are turned on at a time and vice versa. The two switches which form the leg of the inverter are complimentary to each other, for example when switch S1 is on Switch S6 is off so as to avoid short circuit. The switching sequence & the mode of operation of a five phase inverter is shown in table below:-

Table 1 Mode of Operation of Five Phase Inverter

Mode	Switch ON
9	1,7,8,9,10
10	8,9,10,1,2
1	9,10,1,2,3
2	10,1,2,3,4
3	1,2,3,4,5
4	2,3,4,5,6
5	3,4,5,6,7
6	4,5,6,7,8
7	5,6,7,8,9
8	6,7,8,9,10

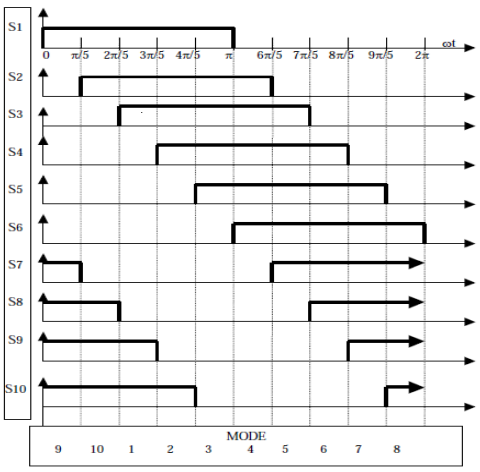

Fig.4 Switching Sequence of Five Phase Inverter

Sinosoidal pulse width modulation (SPWM) techique is used to generate the pulses power electronic switch i.e. IGBT. In this technique a carrier wave is compared with the sine wave. Simulink model of SPWM technique & its output is shown below:-

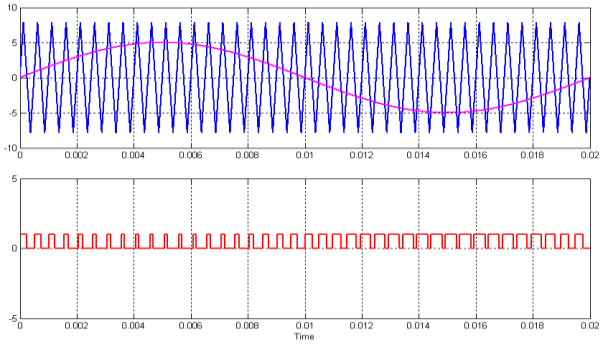

Fig.5 Output of SPWM Technique

5. Speed Control Technique

Speed Control of induction motor is classified as scalar control & vector control. Scalar control deals with magnitude and frequency of voltage, current and flux linkage space vectors are controlled. Where as in vector control it not only depends on magnitude and frequency but also on instantaneous positions of voltage, current and flux space vectors are controlled. Scalar control technique is further classified as Voltage/frequency (V/f) control, Stator current and slip frequency control. V/f scalar control technique of induction motor is implemented.The basic principle behind this control strategy is to keep the flux constant under all operating conditions. The base speed of the induction motor is directly proportional to the supply frequency and the number of poles of the motor. Since the number of poles is fixed by design, the best way to vary the speed of the induction motor is by varying the supply frequency. The torque developed by the induction motors is directly proportional to the ratio of the applied voltage and the frequency of supply. By varying the voltage and the frequency, but keeping their ratio constant, throughout the speed range. V/f control technique can be classfied as open loop and Close loop technique.

In close loop V/f control, rotor speed of the induction motor is sensed using speed sensor and is feed back in the circuit so as to have precise speed. In this block reference speed weref is compared with the rotor speed and the error i.e. the difference between the reference speed and rotor speed is given to the PI controller and limiter. The purpose of PI controller is to minimize the error while that of the limiter is to regulate or limit the slip speed to the maximum allowable slip speed. This slip speed is then added with the rotor speed to obtain the stator frequency command. After adding the slip speed and the electrical rotor speed, it is then converted into frequency and from the frequency voltage is generated with the help

of V/F constant gain. This frequency and voltage is given to the Spwm inverter. The block diagram of close loop V/f control is shown in fig 6

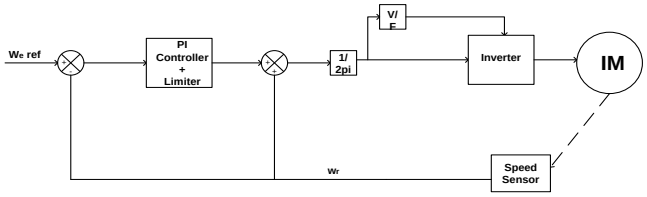

Fig.6 Close Loop V/F Speed Control Technique

6. Result

Induction Motor shown in the model is tested for the parameter shown in table 2 and the result are shown in fig 6,7,8,9.

Table 2 Mode of Operation of Five Phase Inverter

Sr.No	Description	Rating
1.	Hp	3
2.	Pole	4
3.	Inverter Voltage	350V
4.	Frequency	50Hz
5.	Stator Resistance	1.26
6.	Rotor Resistance	1.03
7.	Stator Impedance	1.495
8.	Rotor Impedance	0.5340
9.	Magnetizing Impedance	47.515
10.	Moment Of Inertia	0.0040

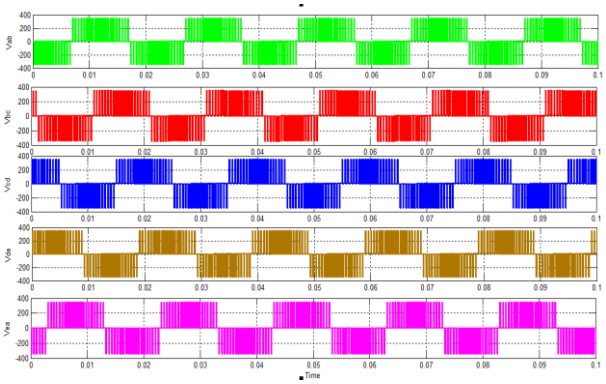

Fig.6 Output Line Adjacent Voltage

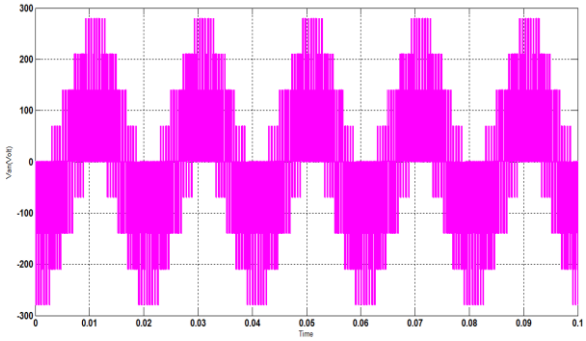

Fig.7 Output Phase Voltage

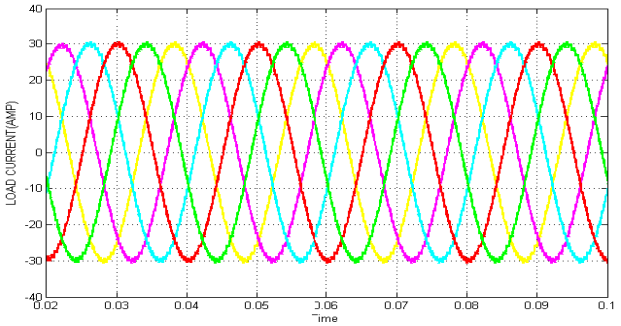

Fig.8 Output Current

Fig 6 shows the line adjacent voltage V_{ab},V_{bc},V_{cd},V_{de},V_{ea} of five phase inverter using SPWM technique, fig 7 shows the phase voltage of phase a of five phase Voltage & fig 8 shows the output current of five phase induction motor.

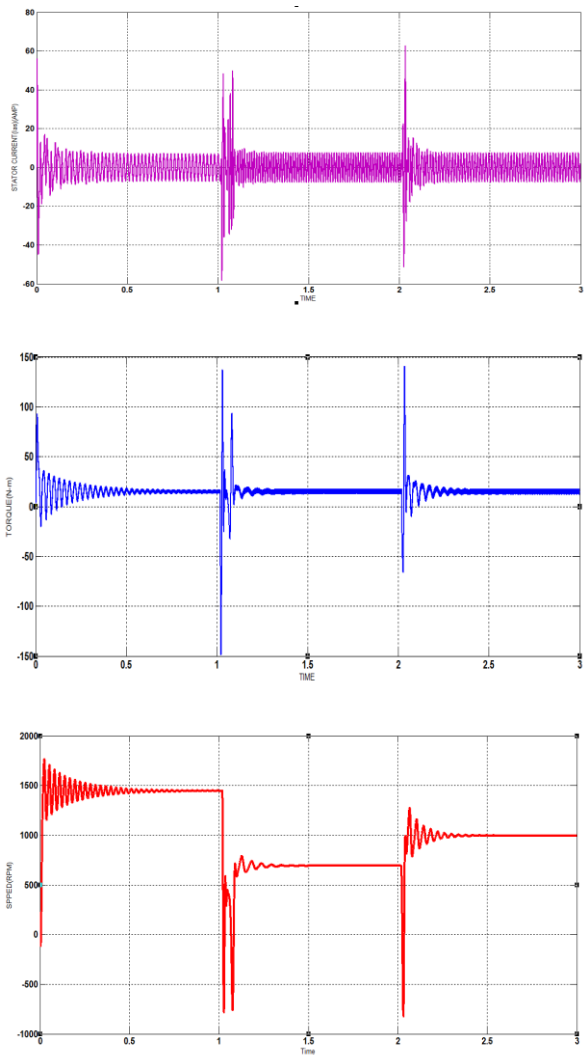

Fig.9 Machine Variables (current, TorqueSpeed) during Close Loop V/F Speed Control of Five Phase Induction Motor

Reference speed is compared with the rotor speed and the difference between both the speeds is known as error, this error is given to PI controller, the purpose of

PI controller is to minimize the error. Limiter is used to limit or regulate the slip speed to maximum allowable slip speed. The output of the limiter is then converted to frequency and from frequency voltage is generated, this generated voltage and frequency is used to generate the pulses for the spwm inverter. Fig 9 shows the output waveform of closed loop V/F speed control of five phase induction motor

Conclusions

In this model Implementation and Dynamic simulation of a five phase induction motor fed from five level inverter using Matlab is studied. A reference speed of 314 rad is given initially then it is step changed to 157 rad, 220 rad at time t=0,1,2respectively. The model was tested for 3hp motor, 50Hz. The result obtain are satisfactory.

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