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Research Paper

OPEN LOOP RESPONSE OF INVERTER-FED THREE-PHASE INDUCTION MOTOR DRIVE

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This paper presents open loop response of inverter-fed three-phase induction motor drive. The inverter switches are fired by Sinusoidal Pulse Width Modulation Technique (SPWM). The integrated model of inverter-fed induction motor is developed in Matlab/Simulink environment. The open loop response of the dive is analyzed for varying torque conditions. Simulation results of output voltage of inverter, stator current, motor torque and speed of the 3-phase induction motor are analyzed.

Keywords: Modeling, Open-loop response, SPWM, Three-phase induction motor

INTRODUCTION

Three phase induction motors are most widely used for the industrial control and automation. It is often required to control the output voltage of the inverter for the constant voltage/ frequency control of an induction motor. The sinusoidal PWM technique is most popular that provides the four quadrant operation and the harmonic elimination in both the open and the closed loop applications .Three phase induction motors are more reliable, robust, and highly durable and also need less maintenance. When the power is given to an induction motor, it runs at its rated speed. Three phase induction motors are normally used, since the standard power supply is three phase. However, when fed by an inverter, there is no need of fixed number of phases. Modelling of three phase induction motor is reported in Selmon (1993). Different n-phase induction motor drive approach analysed in Renukadevi and Rajambal (2011). This paper discusses modelling, control and the hardware implements. The different Sinusoidal pulse width modulation technologies are discussed in Luigi Malesani and Paolo Tomasin, Corino and Romero, Takahashi and Noguchi (1986), Kolar *et al.* (1991), Ashutosh Zhao and Lipo (1996), Mishra and Prashant Choudhary (2012) and Sharma and Tali Nagwani (2014). Compared to other Pulse width modulation techniques, sinusoidal pulse modulation is

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easy to implement in a digital platform. Most of the individual drives are used from sinusoidal pulse width modulation SPWM. Comparison of different PWM techniques is described in Renukadevi and Rajambal (2012).

MODELING OF THREE-PHASE INDUCTION MOTOR

High performance drive control, such as vector or field oriented control is based on the dynamic D-Q model of the machine. Three phase machine can be represented as a two phase equivalent with d_s-q_s corresponding to stator direct and quadrature axes that are fixed on the stator axis and d_r-q_r corresponding to rotor direct and quadrature axes that are rotating with a fixed speed on the rotor axis. The effect of time varying inductance can be eliminated by referring the stator and rotor variables to a common reference frame which rotates at any speed. A three phase induction motor can be modeled by the following steps as follows. A 3Φ inverter with its pulse given through SPWM technique is used to provide a 3Φ supply to the induction motor

$$V_a = V\cos\theta_e$$
$$V_b = V\cos(\theta_e - \alpha) \qquad ...(1)$$
$$V_c = V\cos(\theta_e - 2\alpha)$$

where

$$\alpha = \frac{2\pi}{3}, \theta_e = \int \omega_e$$

The first two rows of the matrix define variables that will lead to fundamental flux and torque production. The last row defines the zero sequence components. Equations for pairs of x-y components are completely decoupled and do not contribute to torque production when sinusoidal distribution of the flux around the air-gap is assumed. Stator variables in stationary reference frame are transformed to synchronous reference frame. In this transformation the q-axis of the voltage variable is aligned to zero and only the d-axis variable is present for easy control.

$$\begin{pmatrix} V_{ds} \\ V_{qs} \end{pmatrix} = \begin{pmatrix} \cos\theta_e & \sin\theta_e \\ -\sin\theta_e & \cos\theta_e \end{pmatrix} * \begin{pmatrix} V_{ds} \\ V_{qs} \end{pmatrix} \qquad ...(2)$$

The stator and the rotor voltage equations in synchronous reference frame are given by Equations (3) and (4)

$$V_{ds}{}^e = i_{ds}{}^e R_s + \frac{d}{dt}\psi_{dr}{}^e - \omega_e \psi_{qs}{}^e$$
$$V_{qs}{}^e = i_{qs}{}^e R_s + \frac{d}{dt}\psi_{qr}{}^e + \omega_e \psi_{ds}{}^e \qquad ...(3)$$

$$V_{dr}{}^e = i_{dr}{}^e R_r + \frac{d}{dt}\psi_{dr}{}^e - (\omega_e - \omega_r)\psi_{qr}{}^e$$
$$V_{qr}{}^e = i_{qr}{}^e R_r + \frac{d}{dt}\psi_{qr}{}^e - (\omega_e - \omega_r)\psi_{dr}{}^e \qquad ...(4)$$

Flux Expressions are obtained by rearranging the Equations (3) and (4)

$$\psi_{ds}{}^e = \int V_{ds}{}^e - i_{ds}{}^e R_s + \omega_e \psi_{qs}{}^e$$
$$\psi_{qs}{}^e = \int V_{qs}{}^e - i_{qs}{}^e R_s - \omega_e \psi_{ds}{}^e$$
$$\psi_{ds}{}^e = \int V_{ds}{}^e - i_{ds}{}^e R_s + (\omega_e - \omega_r)\psi_{qr}{}^e \qquad ...(5)$$
$$\psi_{qs}{}^e = \int V_{qs}{}^e - i_{qs}{}^e R_s - (\omega_e - \omega_r)\psi_{dr}{}^e$$

Current expression in terms of flux linkage and leakage inductance of the motor

$$i_{qs}{}^e = \frac{\psi_{qs}{}^e[L_{lr} + L_m] - L_m \psi_{qr}{}^e}{(L_{ls}L_{lr} + L_{ls}L_m + L_m L_{lr})}$$

$$i_{ds}^{e} = \frac{\psi_{ds}^{e}[L_{lr} + L_{m}] - L_{m}\psi_{dr}^{e}}{(L_{ls}L_{lr} + L_{ls}L_{m} + L_{m}L_{lr})}$$

$$i_{qr}^{e} = \frac{\psi_{qr}^{e}[L_{ls} + L_{m}] - L_{m}\psi_{qs}^{e}}{(L_{ls}L_{lr} + L_{lr}L_{m} + L_{m}L_{ls})} \quad ...(6)$$

$$i_{dr}^{e} = \frac{\psi_{qr}^{e}[L_{ls} + L_{m}] - L_{m}\psi_{ds}^{e}}{(L_{ls}L_{lr} + L_{lr}L_{m} + L_{m}L_{ls})}$$

Transformation of stator current in synchronous reference frame to stationary reference frame

$$\begin{pmatrix} i_{ds}^{s} \\ i_{qs}^{s} \end{pmatrix} = \begin{pmatrix} \cos\theta_{e} & -\sin\theta_{e} \\ \sin\theta_{e} & \cos\theta_{e} \end{pmatrix} * \begin{pmatrix} i_{ds}^{e} \\ i_{qs}^{e} \end{pmatrix} \quad ...(7)$$

To obtain the three phase stator current from the stator currents in stationary reference frame by 2Φ to 3Φ transformation

$$i_{a} = i_{qs}^{s}\cos\theta_{e} + i_{ds}^{s}\sin\theta_{e}$$

$$i_{b} = i_{qs}^{s}\cos(\theta_{e} - \pi) + i_{ds}^{s}\sin(\theta_{e} - \pi) \quad ...(8)$$

$$i_{c} = i_{qs}^{s}\cos(\theta_{e} - 2\pi) + i_{ds}^{s}\sin(\theta_{e} - 2\pi)$$

Electromechanical torque and rotor speed of the five phase induction motor is obtained by (9) and (10) respectively

$$T_{e} = p * L_{m} * (i_{qs}i_{dr} - i_{ds}i_{qr})$$
$$= p * (\psi_{qs}i_{dr} - \psi_{ds}i_{qr}) \quad ...(9)$$

$$\omega_{r} = \int \frac{p}{2} * \frac{(T_{e} - T_{l} - B)}{J} dt \quad ...(10)$$

SINUSOIDEL PULSE WIDTH MODULATION

Figures 1 and 2 shows the power circuit and block diagram of three phase voltage source inverter fed induction motor drive. The circuit consists of 3 half-bridges, which are mutually displaced by $2\pi/3$ degrees to generate the

Figure 1: Power Circuit of 3-Phase VSI

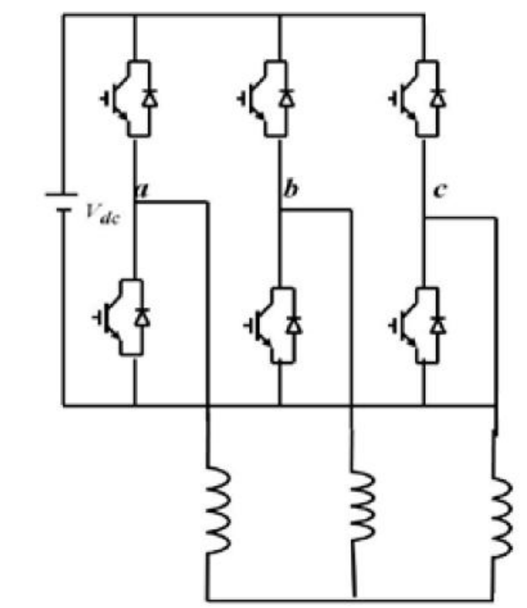
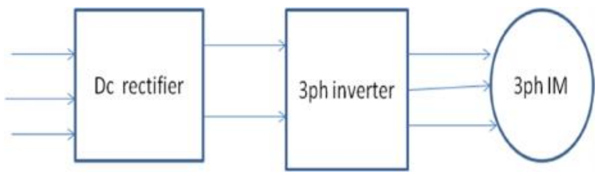


Figure 2: Block Diagram Representation of 3-Phase Inverter Fed Induction Motor Drive



3-phase voltage waves. The input dc supply is obtained from a single phase or 3-phase utility power supply through a diode-bridge rectifier. The voltages V_a, V_b, V_c, are the inverter pole voltages connected to load terminals. The inverter switched are triggered by SPWM technique.The energy that a switching power converter delivers to a motor is controlled by Pulse Width Modulated (PWM) signals applied to the gates of the power transistors. PWM signals are pulse trains with fixed frequency and magnitude and variable pulse width. There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from period to period according to a modulating signal. When a PWM signal is applied to the gate of a power transistor, it causes the turn on and turn off intervals of the transistor to change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load depends mostly on the modulating signal.

Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing this is by pulse-width modulation control used within an inverter. In this method, a fixed dc input voltage is given to the inverter and a controlled ac output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as Pulse-Width Modulation (PWM) Control.

SIMULATION RESULTS

A simulation is performed in order to prove the efficiency of inverter fed three phase induction motor drive in terms of load torque, speed, stator current and voltage. The simulation result of three-phase induction motor is shown in Appendix. The simulation model developed in Matlab/Simulink environment. Simulation results are obtained for different torque conditions of induction motors. In the simulation the dc link voltage is set to 400 V and the modulation index M is set to 0.85. The switching frequency of the VSI is chosen as 10 kHz and the reference fundamental frequency is kept equal to 50 Hz. Figure 3 shows the output voltage of 3-phase inverter. The output of the inverter is fed to the three phase induction motor at rated torque condition. Figure 4 shows the simulation results of three phase induction motor at rated torque condition. Figure 4a shows that the stator current initially starts to oscillate up to 1 sec, and then it is settled. The speed of the three phase induction motor gradually increases from zero to rated speed is shown in Figure 4b. Figure 4c shows the motor torque at rated conditions. It is seen

Figure 3: Inverter Output Voltage

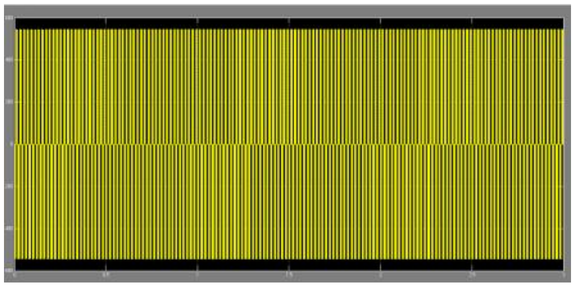


Figure 4: Open Loop Response at Rated Condition (a) Stator Current (b) Speed (c) Torque

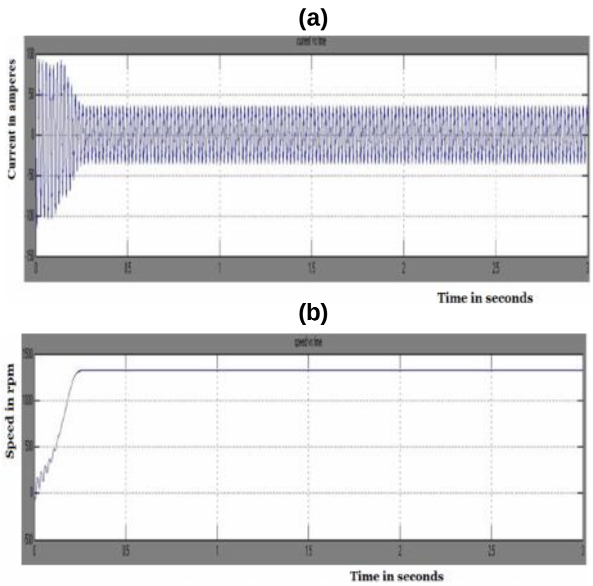


Figure 4 (Cont.)

(c)

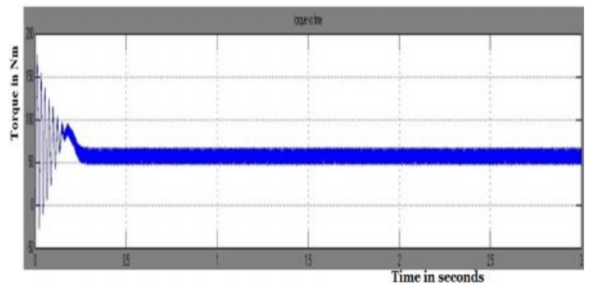
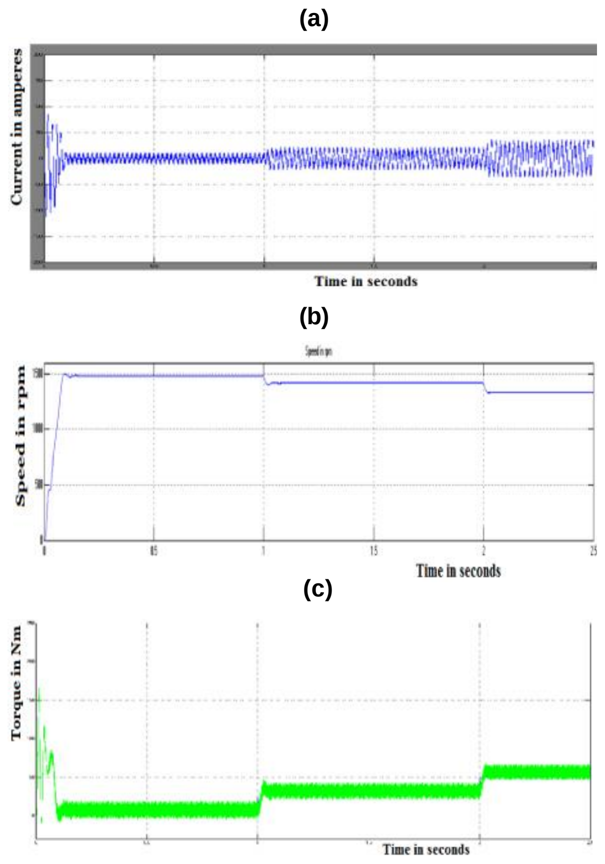


Figure 5: Open Loop Response at Different Torque Condition (a) Stator Current (b) Speed (c) Torque



that the motor torque follows the load torque. Figure 5 shows the simulation results of three phase induction motor at different torque condition are no load, half load and full load conditions 0, 25 Nm and 50 Nm respectively. Figure 5a shows the stator current for different load conditions. It is seen that when increasing load current also increases. The speed of the three phase induction motor gradually increases from no load to rated load speed is shown in Figure 5b. Figure 5c shows the motor torque at different torque conditions. It is seen that the motor torque follows the load torque.

CONCLUSION

This paper is reported for inverter-fed three phase induction motor drive. The modeling of the inverter is discussed in detail. The inverter fed induction motor is developed in Matlab/ simulink. The open loop response of three-phase induction motor is achieved from no load to full-load conditions. From the simulation results, the output voltage, stator current, speed and torque are found. When increasing load, the stator current is increased gradually, speed is slightly reduced and motor torque tracks the load torque.

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APPENDIX

Parameters of Three-Phase Induction Motor

Parameters	**Values**
Power	7.5K W(10 hp)
Voltage	400 V
Frequency	50 Hz
No. of poles	4
Stator resistance (Rs)	0.7384 ohm
Rotor resistance (Rr)	0.7402 ohm
Stator inductance (Ls)	0.003045 H
Rotor inductance (Lr)	0.003045 H
Mutual inductance (Lm)	0.1241 H
Inertia (J)	0.0343 kg.m^2
Friction (F)	0.000503 N.m.s