Simulation and analysis of multilevel inverter fed induction motor drive

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Abstract: This paper presents the simulation of three phase nine level inverter fed induction motor drive. The poor quality of voltage and current of a conventional inverter fed induction machine is due to the presence of harmonics and hence there is significant level of energy losses. The nine level inverter is used to reduce the harmonics. The inverters with a large number of steps can generate high quality voltage waveforms. The nine levels can follow a voltage reference with accuracy and with the advantage that the generated voltage can be modulated in amplitude instead of pulse-width modulation. An active harmonic elimination method is applied to eliminate any number of specific higher order harmonics of multilevel converters with unequal dc voltages. The simulation of three phase nine level inverter fed induction motor model is done using Simulink.

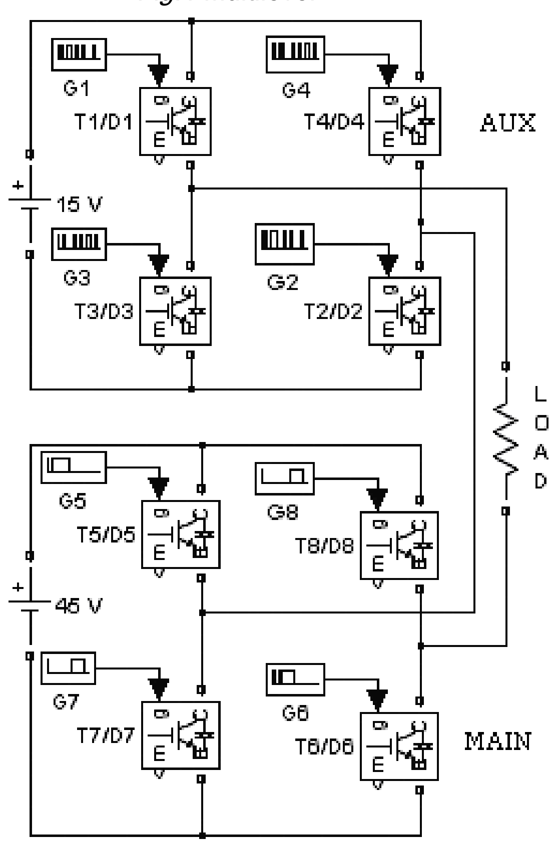
Keywords: Induction motor, multilevel converter, PWM.

Introduction

Power Electronics is playing an important role in the torque and speed control of motor drive. Variable speed AC induction motor drives are replacing the conventional DC Drives in industrial drive environment (Thomas M Jahns, 1980). DC motors have excellent speed and torque response, they have inherent disadvantage of commutator and mechanical brushes, which undergo wear and tear with time. AC induction machines are single excited, mechanically rugged and robust, but speed and torque control of these machines are more complex and involved, compared to DC machines. Induction motors have low starting torque and the motors carry large amplitude of starting currents, star delta starting or pole changing methods were followed (Juan Dixon *et al.*, 2006).

The advent of controlled switches the speed and torque control of induction machines have become relatively easier. A voltage source inverter can run the induction by applying three phase square wave voltages to the motor stator winding (Tolbert *et al.*, 1999). A variable frequency square wave voltage can be applied to the motor by controlling the switching frequency of the power semiconductor switches. The square wave voltage will induce low frequency harmonic torque pulsation in the machine. Also variable voltage control with variable frequencies of operation is not possible with square wave inverters (Zhong DuLeon *et al.*, 2006). The recent advancement in power electronics has initiated to improve the level of inverter instead increasing the size of filter. The total harmonic distortion of the classical inverter is very high. The performance of the multilevel inverter is better than classical inverter. In other words the total harmonic distortion for multilevel inverter is low. The total harmonic distortion is analyzed between multilevel inverter and other classical inverter (Chunmei Feng *et al.*, 2000).

Fig.1 Multilevel



Power electronic devices contribute with an important part of harmonics, such as power rectifiers, thyristor converters and static var compensators. Even updated pulse-width modulation (PWM) techniques used to control modern static converters such as machine drives, power factor compensators, do not produce perfect waveforms, which strongly depend on the semiconductors switching frequency. Voltage or current converters, as they generate discrete output waveforms, force the use of machines with special isolation, and in some applications large inductances connected in series with the respective load. Also, it is well known that distorted voltages and currents waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only the power load but also the associated controllers (Shivakumar *et al.*, 2001). All these unwanted operating characteristics associated with PWM converters could be overcome with multilevel converters, in addition to the fact that higher voltage levels can be achieved. The present work was not reported (Juan Dixon *et al.*, 2006).

Nine level converter

A nine level inverter consists of a series of H-bridge inverter units connected to three phase induction motor. The general function of this multilevel inverter is to synthesize a desired voltage from several dc sources. The ac terminal voltages of each bridge are connected in series. Unlike the diode clamp or flying-capacitors inverter, the cascaded inverter does not require any voltage-clamping diodes or voltage balancing capacitors (Somashekhar *et al.*, 2003). This configuration is useful for constant frequency applications such as active front-end rectifiers, active power filters, and reactive power compensation. In this case, the power supply could also be a voltage regulated dc capacitor. One important characteristic of multilevel converters using voltage escalation is that electric power distribution and switching frequency present advantages for the implementation of these topologies (Zhong DuLeon *et al.*, 2006). The Fig.1 shows the multilevel inverter topology.

This paper makes an overview to find the various induction motor drive configurations used in industry (Muhammad H Rashid, 1996; Mohapatra *et al.*,2002). The various control strategies used to improve drive efficiency and various inverters used to control the motor speed, reduce torque ripple, current ripple and reduce harmonic (Haoran Zhang *et al.*, 2000). Also different topologies and control strategies are useful for different situations. One of the very efficiently used control strategies is the space vector based control, which can be implemented using Digital signal processor.

Induction motor model

The speed of the synchronously rotating reference frame model is:

$\omega_c = \omega_s$ =Stator supply angular frequency/rad/sec (1)

and the instantaneous angular position is $\theta_c = \theta_s = \omega_s t$ (2)

the Induction motor model in arbitrary reference frames is given as:

$$v^c_{qs} = (R_s + L_s p) i^c_{qs} + (\omega_c L_s) i^c_{ds} + (L_m p) i^c_{qr} + (\omega_c L_m) i^c_{dr}$$
$$v^c_{ds} = -(\omega_c L_s) i^c_{qs} + (R_s + L_s p) i^c_{ds} + (-\omega_c L_m) i^c_{qr} + (L_m p) i^c_{dr}$$
$$v^c_{qr} = (L_m p) i^c_{qs} + (\omega_c - \omega_r) L_m i^c_{ds} + (R_r + L_r p) i^c_{qr} + (\omega_c - \omega_r) L_r i^c_{dr}$$
$$v^c_{dr} = -(\omega_c - \omega_r) L_m i^c_{qs} + (L_m p) i^c_{ds}$$
$$+(-(\omega_c - \omega_r) L_r) i^c_{qr} + (R_r + L_r p) i^c_{dr} \quad (3)$$

In Synchronous Reference frames

$$\begin{bmatrix} v^e_{qs} \\ v^e_{ds} \\ v_o \end{bmatrix} = \left[T^e_{abc}\right] \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} \quad (4)$$

where $v_{as} = V_m \sin\omega_s t$

$v_{bs} = V_m \sin(\omega_s t\text{-}2*pi/3)$

$v_{cs} = V_m \sin(\omega_s t\text{-}4*pi/3)$

$$T^e_{abc} = \frac{2}{3}\begin{pmatrix} \cos\theta_s & \cos(\theta_s - 2\pi/3) & [\cos(\theta_s - 2\pi/3)] \\ \sin\theta_s & \sin(\theta_s - 2\pi/3) & \sin(\theta_s + 2\pi/3) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

substituting these and solving for the d and q axes stator voltages in the synchronous reference frames yields:

$$\begin{bmatrix} v^e_{qs} \\ v^e_{ds} \\ v_o \end{bmatrix} = \left[T^e_{abc}\right] \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} 0 \\ v_m \\ 0 \end{bmatrix} \quad (5)$$

The d and q axes stator voltages are dc quantities, hence the response will be d.c. quantities, because the system is linear. Hence:

$$p i^e_{ds} = p i^e_{qs} = p i^e_{qr} = p i^e_{dr} = 0 \quad (6)$$

substituting Equation 6) into the system equation gives:

$$R_s i^e_{qs} + \omega_s L_s i^e_{ds} + \omega_s L_m i^e_{dr} = 0$$
$$-\omega_s L_s i^e_{qs} + R_s i^e_{ds} - \omega_s L_m i^e_{qr} = V_m \quad (7)$$
$$\omega_{s_1} L_m i^e_{ds} + R_r i^e_{qr} + \omega_{s1} L_r i^e_{dr} = 0$$
$$-\omega_{s1} L_m i^e_{qs} - \omega_{s_1} L_r i^e_{dr} + R_r i^e_{dr} = 0$$

where $\omega_{s1} = \omega_s - \omega_r$ =slip speed

the currents are solved by inverting the impedance matrix and pre-multiplying with the input voltage vector.

The electromagnetic torque is given as:

$$T_e = \frac{3}{2}\frac{P}{2} L_m (i^e_{qs} i^e_{dr} - i^e_{ds} i^e_{qr}) \quad (8)$$

the actual phase currents are obtained as:

$$i_{abc} = \left[T^{-1}_{abc}\right] i^e_{qdo} \quad (9)$$

The motor drive power circuit model was developed as shown in Fig.2 for simulation work using Simulink.

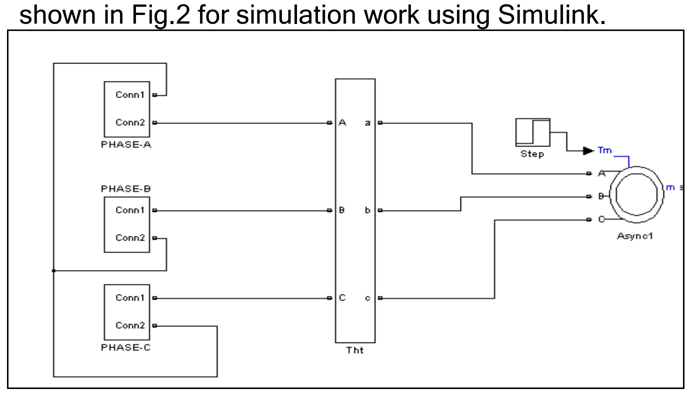


Fig.2. Power circuit model of induction motor

Simulation Results

The simulation of nine level inverter fed induction motor model was done using Simulink. The simulation results of voltage, current, motor speed and FFT spectrum were presented. The inverter output voltage is shown in Fig.3 and the current is shown in Fig.4. The motor currents are shown in Fig.5 and the motor speed is as shown in Fig.6. The FFT analysis for the motor drive system was also done as shown in Fig.7. It is seen that the percentage of harmonics in the multilevel inverter fed motor drive system is less compare to classical inverter system.

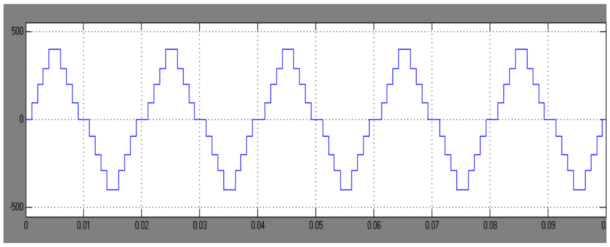


Fig.3 Inverter output voltage

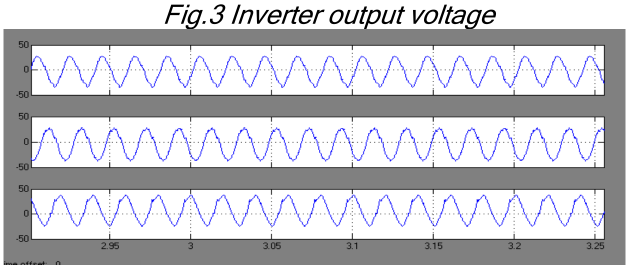


Fig.4 Inverter output current

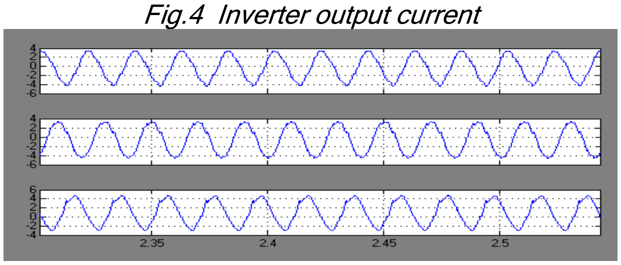


Fig. 5 Stator current output

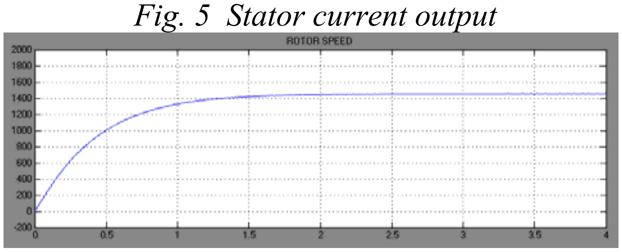


Fig. 6. Rotor speed

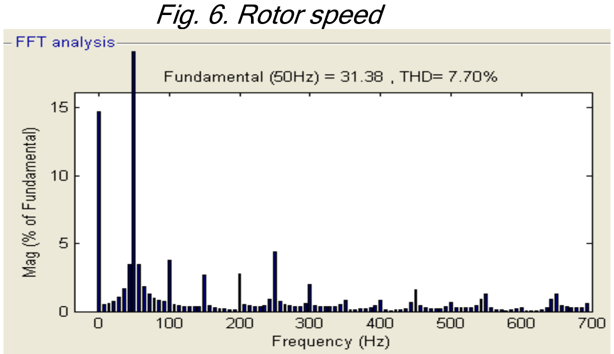


Fig. 7. FFT spectrum

Conclusion

The modeling of nine level inverter fed induction motor drive was done and simulated using Simulink. The total harmonic distortion is very low compared to that of classical inverter. The simulation result shows that the harmonics have been reduced considerably. The nine level inverter fed induction motor system has been successfully simulated and the results of voltage waveforms, current waveforms, motor speed and frequency spectrum for the output were obtained. The inverter system can be used for industries where the adjustable speed drives are required and significant amount of energy can be saved as the system has less harmonic losses.

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