PERFORMANCE OF VOLTAGE SOURCE MULTILEVEL INVERTER - FED INDUCTION MOTOR DRIVE USING SIMULINK

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ABSTRACT

This paper deals with performance of voltage source multilevel inverter-fed induction motor drive. A Voltage source inverter (VSI) is compared with multilevel inverter. A conventional Voltage Source Inverter-fed induction motor drive is modelled and simulated using matlab simulink and the results are presented. Multilevel inverter employing Selective Harmonic Elimination (SHE) method is also simulated and the corresponding results are presented. The FFT spectrum for the outputs is analyzed to study the reduction in harmonics.

Keywords: induction motor, voltage source multilevel inverter, Matlab, Simulink.

1. INTRODUCTION

In many industrial applications, traditionally, DC motors were the work horses for the Adjustable Speed Drives (ASDs) due to their excellent speed and torque response. But, they have the inherent disadvantage of commutator and mechanical brushes, which undergo wear and tear with the passage of time. In most cases, AC motors are preferred to DC motors, in particular, an induction motor due to its low cost, low maintenance, lower weight, higher efficiency, improved ruggedness and reliability. All these features make the use of induction motors a mandatory in many areas of industrial applications. The advancement in Power electronics and semiconductor technology has triggered the development of high power and high speed semiconductor devices in order to achieve a smooth, continuous and step less variation in motor speed. Applications of solid state converters/inverters for adjustable speed induction motor drive are wide spread in electromechanical systems for a large spectrum of industrial systems. Comparison of fundamental and high frequency carrier based techniques for NPC inverters is given by Feng, 2000. Influence of number of stator windings on the characteristics of motor is given by Golubev, 2000. Modified CSI based induction motor drive is given by Gopukumar, 1984. Multilevel inverter modulation schemes to eliminate common mode voltage is given by Zhang, 2000. Modulation schemes for six phase induction motor are given by Mohapatra, 2002. Improved reliability in solid state ac drives is given by Thomas, 1980. Multilevel converters for large electric drives are given by Peng, 1999. Active harmonic elimination for multilevel inverters is given by Tolbert, 2006. The inverters are either Current Source Inverter (CSIs) or Voltage Source Inverters (VSIs). Current source inverters are widely used for the implementation of fully generative induction machine variable speed drives. An important and attractive feature of CSI is its good fault protection capability and the inherent regeneration capability. However, a CSI-fed induction motor suffers from severe torque pulsations, especially at low speeds, which manifest themselves in cogging of the shaft. The usual technique of overcoming such problems in Voltage Source Inverters (VSIs) is to pulse width modulate the input voltage waveforms. Pulse width modulated voltage source inverters are invariably used for AC/DC/AC conversion to provide a variable ac voltages to the induction motor. However, inverter fed induction motor suffers from the presence of significant amount of harmonics which causes undesired motor heating, torque pulsation and EMI (Shivakumar *et al.*, 2001). The reduction in harmonics calls for large sized filters, resulting in increased size and cost of the system. However, the advancements in the field of power electronics and microelectronics made it possible to reduce the magnitude of harmonics with multilevel inverters, in which the number of levels of the inverters are increased rather than increasing the size of the filters (Juan Dixon *et al*., 2006). The performance of multilevel inverters will be better than a classical inverter. The THD for multilevel inverters will be lower than that of a classical inverter (Chunmei Feng *et al*., 2000).

2. VARIABLE FREQUENCY CONTROL OF INDUCTION MOTOR

Synchronous speed of Induction Motor is directly proportional to the supply frequency. Hence, by changing the frequency, the synchronous speed and the motor speed can be controlled below and above the normal full load speed. The voltage induced in the stator, E is proportional to the product of slip frequency and air gap flux. The motor terminal voltage can be considered proportional to the product of the frequency and flux, if the stator voltage is neglected. Any reduction in the supply frequency without a change in the terminal voltage causes an increase in the air gap flux. Induction motors are designed to operate at the knee point of the magnetization characteristic to make full use of the magnetic material. Therefore the increase in flux will saturate the motor. This will increase the magnetizing current, distort the line current and voltage, increase the core loss and the stator copper loss, and produce a high pitch acoustic noise. While any increase in flux beyond rated value is undesirable from the consideration of saturation effects, a decrease in flux is also avoided to retain the torque capability of the motor. Therefore, the variable frequency control below the rated frequency is generally carried out by reducing the machine phase voltage, V, along with the frequency in such a manner that the flux is maintained constant. Above the rated frequency, the motor is operated at a constant voltage because of the limitation imposed by stator insulation or by supply voltage limitations.

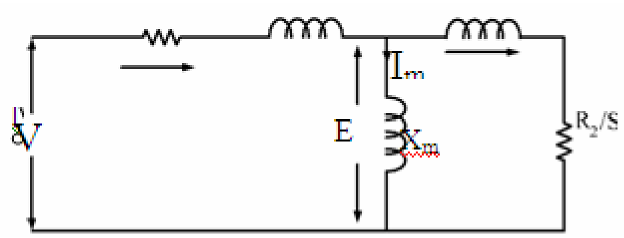


Figure-1. Operation below the rated frequency (K<1).

Per unit frequency k is given by

$K = f/f_{rated}$ --------- (1)

Where

f = operating frequency
f_{rated} = rated frequency of the motor

It is generally preferred to operate the motor at a constant flux. The motor will operate at constant flux if I_m is maintained constant at all operating points. The equation at the rated condition of motor operation;

$$I_m = \frac{E_{rated}}{X_m} = \frac{E_{rated}}{f_{rated}} \frac{1}{2\pi Lm}$$

Where L_m = magnetizing inductance.

When the motor is operated at a frequency f, then

$$I_m = \frac{E}{K.X_m} = \frac{E}{K.f_{rated}} \frac{1}{2\pi Lm}$$

By the comparison of equations, I_m will stay constant at a value equal to its rated value, if

$E = K.\ E_{rated}$

So the flux will remain constant if the back emf changes in the same ratio as the frequency, in otherwords, when (E/f) ratio is maintained constant.

Motor operation for a constant (E/f) ratio and at frequency f, So the flux will remain constant if the back emf changes in the same ratio as the frequency, in other words, when (E/f) ratio is maintained constant.

Motor operation for a constant (E/f) ratio and at frequency f,

$$I_2 = \frac{K.E_{rated}}{\sqrt{(R_2)^2 + (Kx_2)^2}} = \frac{E_{rated}}{\sqrt{R_2^2/KS^2 + X_2}}$$
…………(2)

Where $S = \frac{K.\ \omega_s - \omega r}{K\ \omega_s}$

Note that w_s is the synchronous speed at the rated frequency.

Now, the developed torque is:

$$T = \frac{3}{K\omega_s} I_2^2 R_2/S$$

$$T = \frac{3}{\omega_s} \frac{E^2_{rated} R_2 (KS)}{R_2^2/(KS)^2 + X_2^2}$$
----------- (3)

Now, E is maintained constant for a given frequency. The power transferred across the air-gap will be maximum at a slip S_m for which

$K.X_2 = \pm R_2/S_m$ or $S_m = \pm R_2/KX_2$

$$\therefore \quad T_{max} = \pm \frac{3}{2\omega_s} \times \frac{E^2_{rated}}{X_2}$$

So, for a variable frequency control the breakdown torque remain constant for all frequencies.

3. MULTILEVEL INVERTER

Multilevel inverters have drawn tremendous interest in the power industry. They present a new set of features that are well suited for use in reactive power compensation. Multilevel inverters will significantly reduce the magnitude of harmonics and increases the output voltage and power without the use of step-up transformer.

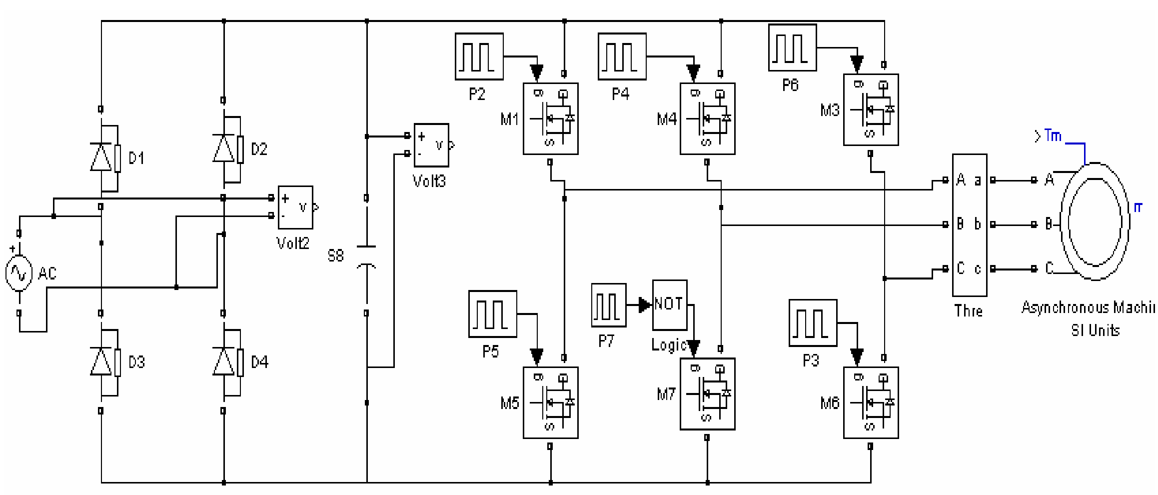
A multilevel inverter consists of a series of H-bridge inverter units connected to three phase induction motor. The general function of this multilevel inverter is to synthesize a desired voltage from several DC sources. The AC terminal voltages of each bridge are connected in series. Unlike the diode 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, one of the very efficiently used control strategies is the space vector based control, which can be implemented using digital signal processor. Literature [1] to [12] does not deal with the performance and comparison of VSI with multilevel inverter system. This work compares VSI system with multilevel inverter system.

4. SIMULATION RESULTS

VSI fed induction motor drive is shown in Figure-2a. The diode rectifier with capacitive filter acts as the voltage source. Three phase inverter operating in 120^0

mode is used to feed the induction motor drive. Phase voltage waveforms are shown in Figure-2b and the stator phase currents are shown in Figure-2c. Variation in speed is shown in Figure-2d. The speed increases and settles at 1470 rpm. FFT analysis is done for the current and the corresponding spectrum is shown in Figure-2e. It can be seen that the magnitude of fundamental current is 28 Amperes. The total harmonic distortion is 12.8 percent,

Multilevel inverter fed induction motor drive is shown in Figure-3a. The circuit elements of one phase of the inverter are shown in Figure-3b. The firing pulses given to the second inverter are displaced by 36^0 with respect to the firing pulses given to the first inverter. Phase voltages are shown in the Figure-3c. The stator currents are shown the Figure-3d. The variation in rotor speed is shown in the Figure-3e. The magnitude spectrum for the stator current is shown in the Figure-3f. It can be seen that the THD value is 7.4 percent. Therefore THD is reduced by 42 percent. From the spectrum, it can be seen that the amplitude of low frequency components are higher than the high frequency components.



Diode rectifier Link filter PWM inverter

Figure-2a. VSI- Fed induction motor drive

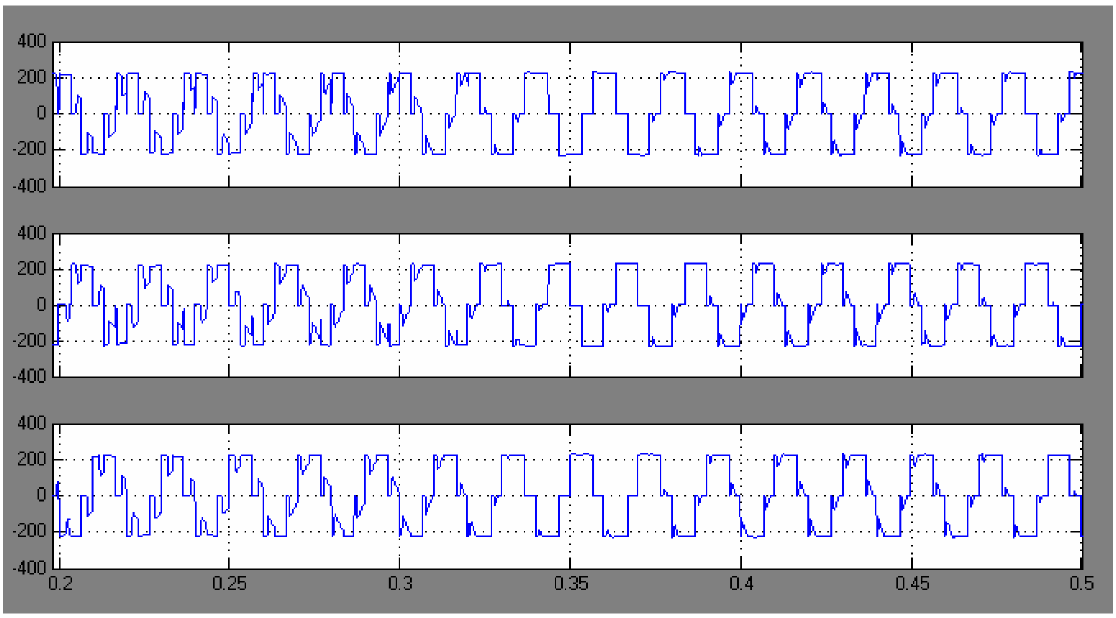


Figure-2b. Phase voltage waveforms.

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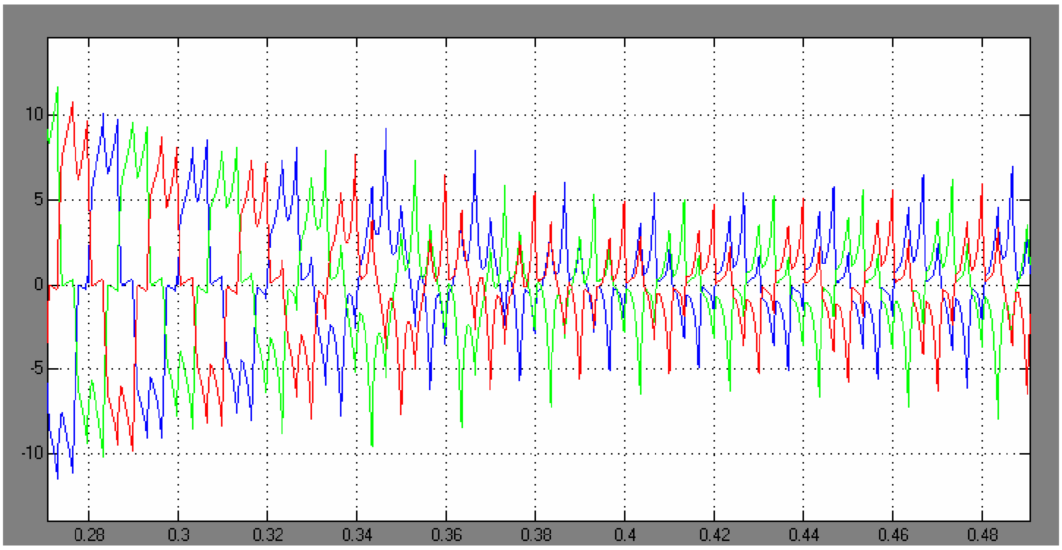

Figure-2c. Stator current.

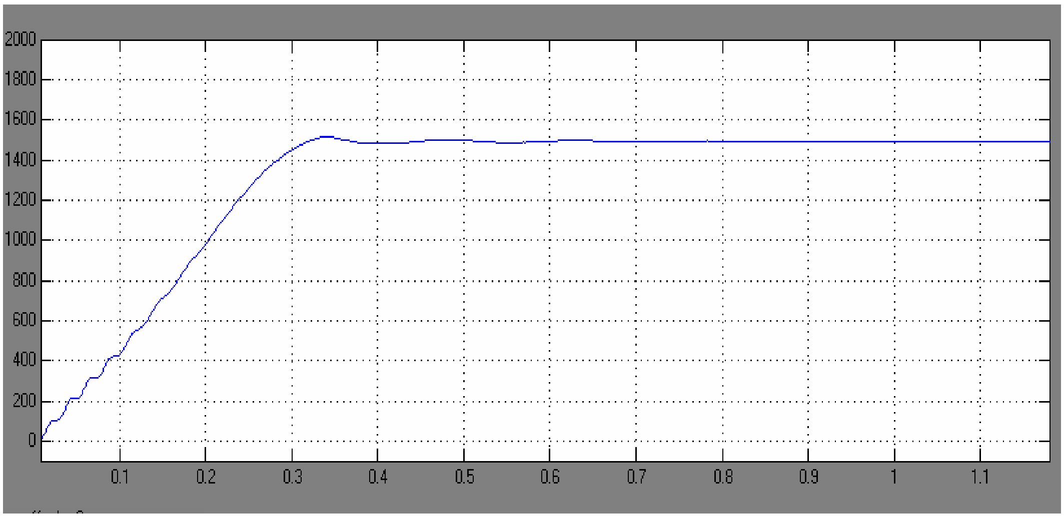

Figure-2d. Rotor speed in RPM.

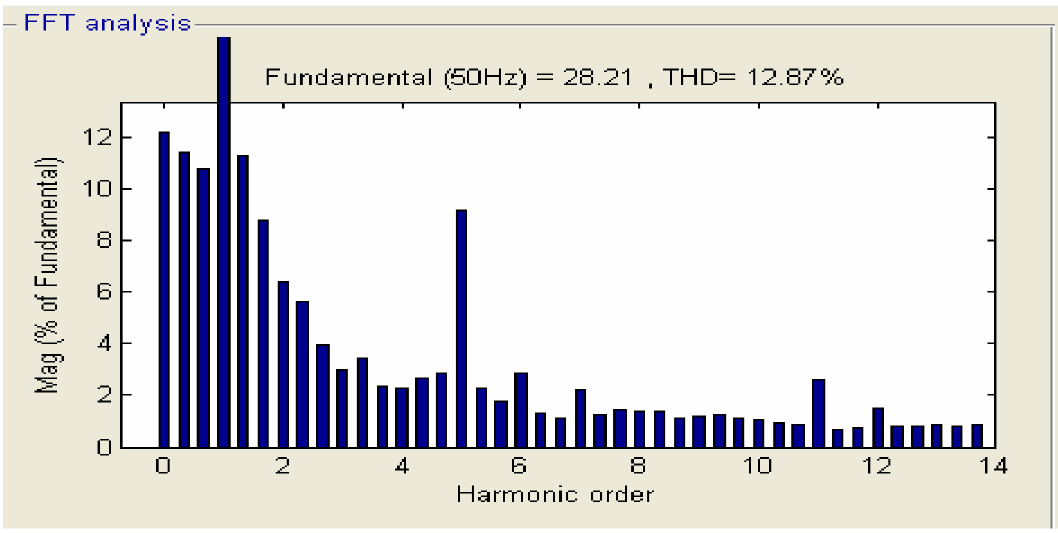

Figure-2e. FFT analysis for the current.

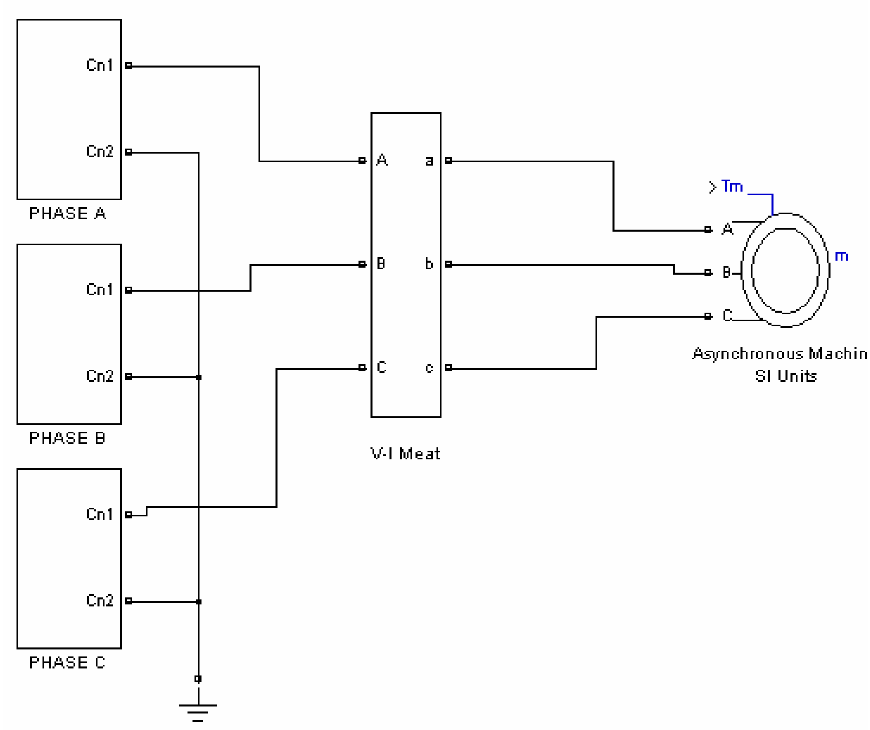

Figure-3a. Three phase multilevel inverter -fed induction motor.

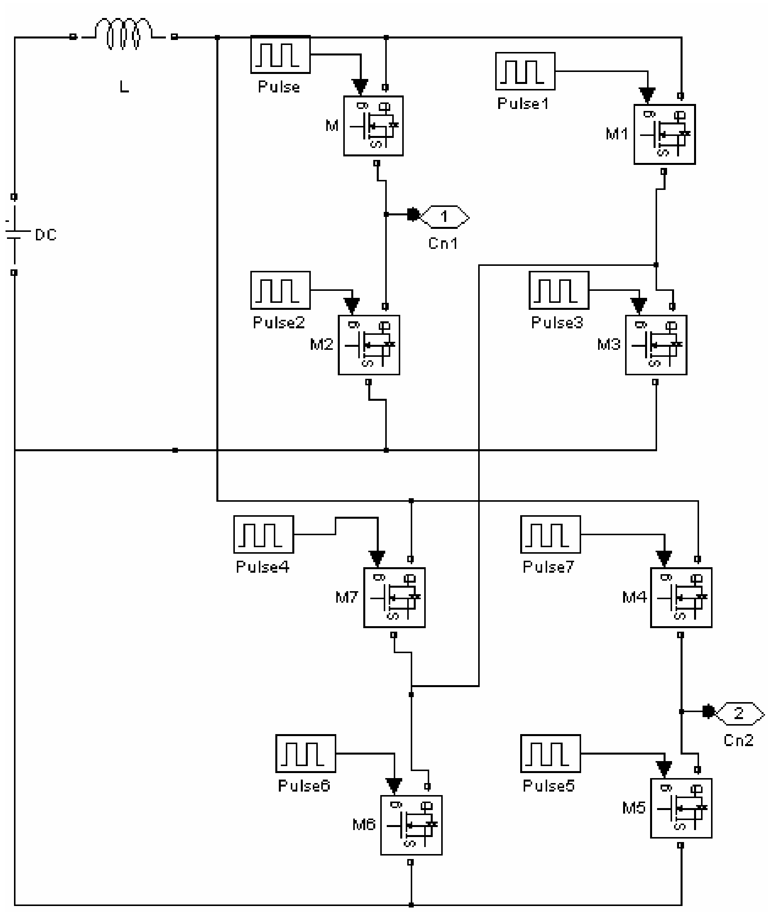

Figure-3b. Circuit for one phase.

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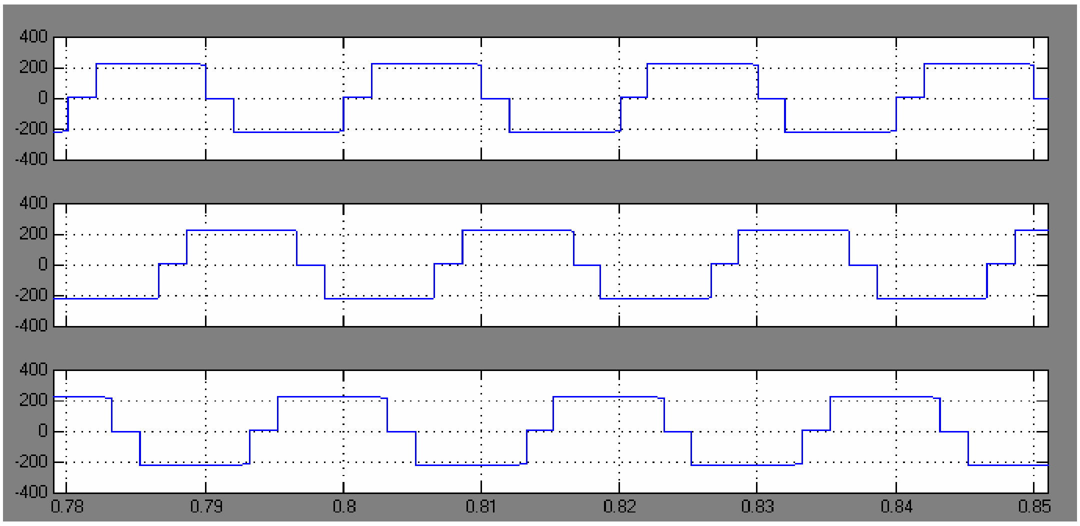

Figure-3c. Phase voltages.

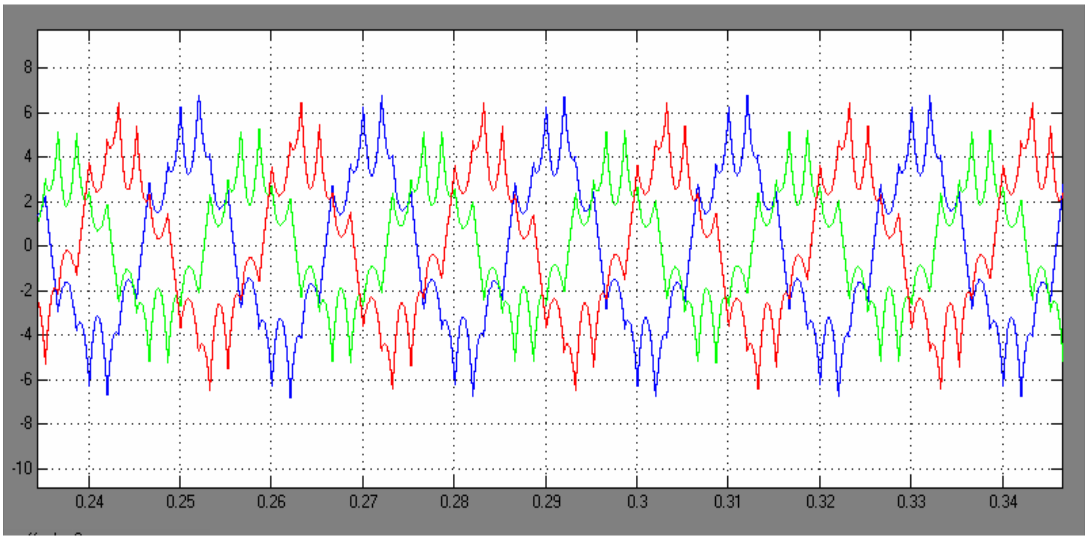

Figure-3d. Stator current waveforms.

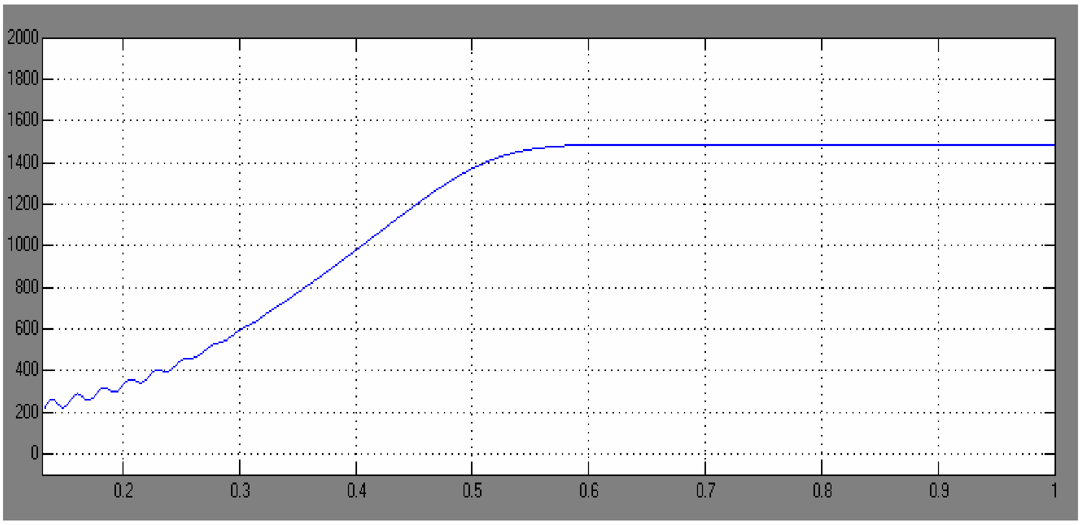

Figure-3e. Rotor speed in RPM.

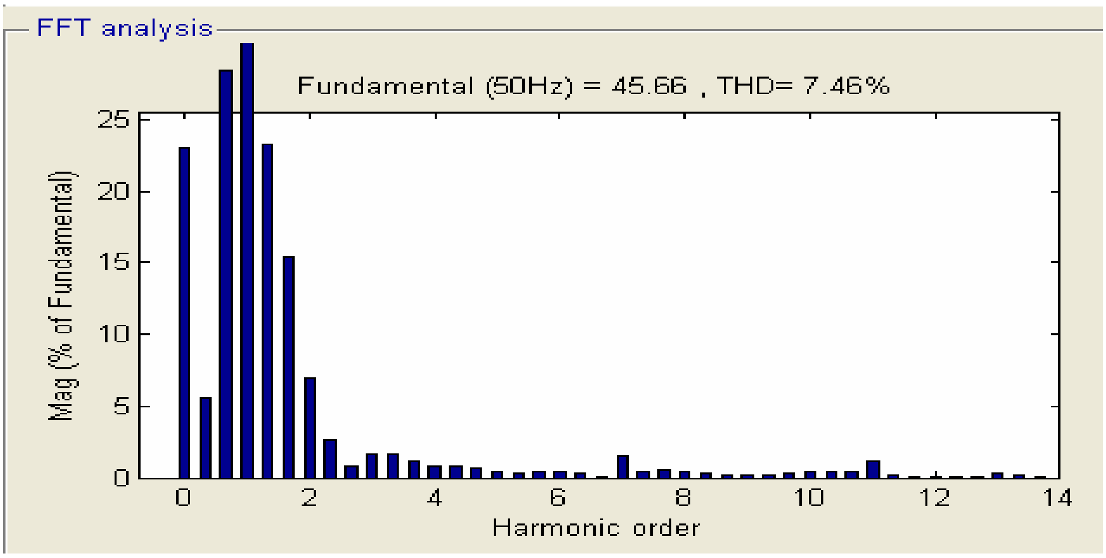

Figure-3f. FFT analysis for stator current.

5. CONCLUSIONS

Multilevel inverter fed induction motor drive is simulated using the blocks of Simulink. The results of multilevel inverter system are compared with the results of VSI based drive system. It is observed that the total harmonic distortion produced by the multilevel inverter system is less than that of VSI fed drive system. Therefore the heating due to multilevel inverter system is less than that of VSI fed drive system. The simulation results of voltage, current, speed and spectrum are presented. This drive system can be used in industries where adjustable speed drives are required to produce output with reduced harmonic content. The scope of this work is the modeling and simulation of multilevel inverter and VSI fed induction motor drive system. Experimental investigations will be done in future. Multilevel inverter system is better than VSI fed drive system due to the reduced value of THD.

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