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MANASA S

EEE Department , DSCE , Bangalore, India, manasa.s.athresha@gmail.com

BALAJI RAMAKRISHNA S

EEE Department , DSCE , Bangalore, India, balajikrishna.s@gmail.com

MADHURA S

EEE Department , DSCE , Bangalore, India, madhu4tulip@gmail.com

MOHAN H M

ECE Department, SJGIT , chickballapur, India, mohanhm@gmail.com

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# DESIGN AND SIMULATION OF THREE PHASE FIVE LEVEL AND SEVEN LEVEL INVERTER FED INDUCTION MOTOR DRIVE WITH TWO CASCADED H-BRIDGE CONFIGURATION

<sup>1</sup>MANASA S, <sup>2</sup>BALAJI RAMAKRISHNA S, <sup>3</sup>MADHURA S & <sup>4</sup>MOHAN H M

<sup>1,2&3</sup>Lecturer, EEE Department , DSCE , Bangalore, India

<sup>4</sup>Lecturer, ECE Department, SJGIT , chickballapur, India

Email: manasa.s.athresha@gmail.com, balajikrishna.s@gmail.com, madhu4tulip@gmail.com & mohanhm@gmail.com

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**Abstract** - This paper deals with study of Three phase Five Level and Seven Level inverter fed induction motor drive . Both five level and seven level are realized by cascading two H- bridges. 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 Multilevel inverter is used to reduce the harmonics. The inverters with a large number of steps can generate high quality voltage waveforms. The higher 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 five and seven level inverter fed induction motor model is done using Matlab/Simulink. The FFT spectrums for the outputs are analyzed to study the reduction in the harmonics.

**Keywords:** Induction motor, Matlab/simulink, Multilevel inverters, voltage source inverter, Total Harmonic distortion.

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## I. INTRODUCTION

Adjustable Speed Drives (ASDs) are the essential and endless demand of the industries and researchers. They are widely used in the industries to control the speed of conveyor systems, blower speeds, machine tool speeds and other applications that require adjustable speeds. 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.[3],[6],[10].

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. 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 poor quality of output current and voltage of an induction motor fed by a classical two-level inverter is due to the presence of harmonics. The presence of significant amount of harmonics makes the motor to suffer from severe torque pulsations, especially at low speed, which manifest themselves in cogging of the shaft. It will also causes undesired motor heating and Electromagnetic interference [12]. The reduction in harmonics calls for large sized filters, resulting in increased size and the cost of the system. Nowadays multilevel inverters are the promising alternative and cost effective solution for high voltage and high power applications including power quality and motor drive problems. Multilevel structure allows raising the power handling capability of the system in a powerful and systematic way. 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 [11]. The performance of multilevel inverters enhances as the number of levels of the inverter increases.

In this paper three phase Five Level and Seven Level inverter fed induction motor drive are designed and implemented. Both five level and seven level are realized by cascading two H- bridges with equal dc source value for five level and unequal dc source value for seven level which reduces switches for seven level. The simulation of three phase five and

seven level inverter fed induction motor model is done using Matlab/Simulink. The FFT spectrums for the outputs are analyzed to study the reduction in the harmonics.

## II. MULTILEVEL INVERTER

Multilevel inverters have drawn tremendous interest in the power industry. They present a new set of feature 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.[1-4],[10],[13]. This configuration is useful for constant frequency applications such as active front-end rectifiers, active power filters, and reactive power compensation. Choosing appropriate conducting angles for the H bridges can eliminate a specific harmonic in the output waveform. The required conduction angles can be calculated by analyzing the output phase voltage of cascade inverter assuming that four H-bridges have been used, the output voltage  $V_{ao}$  can be given as:

$$V_{ao} = V_{a1} + V_{a2} + V_{a3} + V_{a4} + V_{a5} \dots$$

Since the wave is symmetrical along the x-axis, both Fourier coefficient  $A_0$  and  $A_n$  are zero. Just the analysis of  $B_n$  is required. It is given as:

.

where

$j$  = Number of dc sources

$n$  = odd harmonic order

Therefore, to choose the conducting angle of each H bridge precisely, it is necessary to select the harmonics with certain amplitude and order, which needs to be eliminated. [3],[4],[5] To eliminate 5th, 7th, and 11th harmonics and to provide the peak fundamental of the phase voltage equal to 80% of its maximum value, it needs to solve the following equation with modulation index  $M = 0.8$ :

$$\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) + \cos(5\alpha_4) = 0$$

$$\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) + \cos(7\alpha_4) = 0$$

$$\cos(11\alpha_1) + \cos(11\alpha_2) + \cos(11\alpha_3) + \cos(11\alpha_4) = 0$$

$$\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) + \cos(\alpha_4) = 0.8 \times 4$$

## III. FIVE LEVEL AND SEVEN LEVEL INVERTER CIRCUITS USING ONLY TWO CASCADED H- BRIDGES.

There are several types of multilevel inverters but the one considered in this paper is the cascaded multilevel inverter (CMI). The structure of the CMI is not only simple and modular but also requires the least number of components compared to other types of multilevel inverters. This in turn, provides the flexibility in extending the CMI to higher number of levels without increase in circuit complexity as well as facilitates packaging.

### A. Single phase structure of a five level Cascaded Multilevel inverter

A single-phase structure of an m-level cascaded inverter is illustrated in Fig 1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs,  $+V_{dc}$ , 0, and  $-V_{dc}$  by connecting the dc source to the ac output by different combinations of the four switches, S11, S12, S13, and S14. To obtain  $+V_{dc}$ , switches S11 and S14 are turned on, whereas  $-V_{dc}$  can be obtained by turning on switches S12 and S13. By turning on S11 and S12 or S13 and S14, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs.

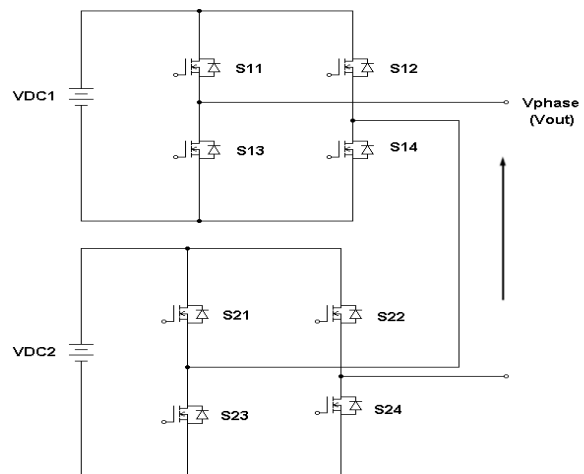
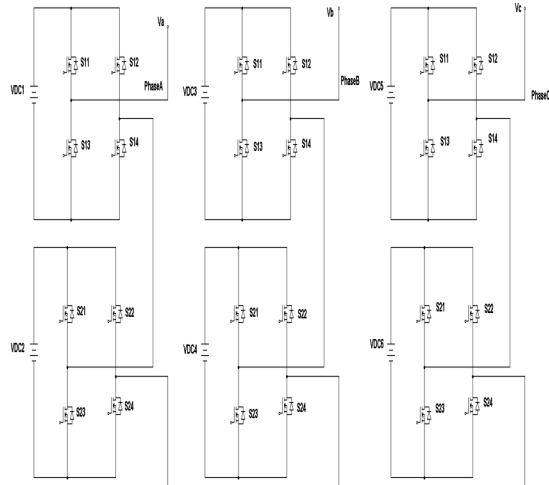


Fig. 1 Single Phase Structure of Cascaded Multilevel inverter

The structure shown in Fig.1 is used to produce Five Level Inverter output voltage by giving same DC source value and Seven Level Inverter output voltages by giving unequal DC source value. Here for Five Level output 225V is given for both upper and lower H-bridge and for Seven Level output 150V and 300V is given for upper and lower H-bridge respectively.

**B. Three phase structure of Cascaded Multilevel Inverter**

The Three Phase Structure of Cascaded Multilevel inverter is illustrated in Fig.2. Each dc source is connected to an inverter. Each inverter level can generate three different voltage outputs,  $+V_{dc}$ , 0, and  $-V_{dc}$  using various combinations of the four switches. The ac outputs of the different full bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs.



**Fig. 2 Three Phase Structure of Cascaded Multilevel inverter.**

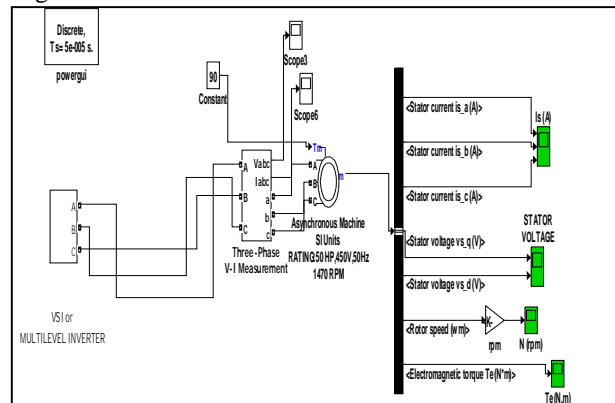
**III. INDUCTION MOTOR DRIVE**

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.

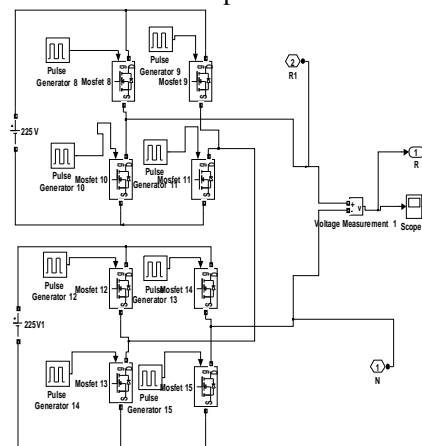
**IV. SIMULATION MODEL AND RESULTS**

Multilevel inverter fed induction motor drive inverter is implemented in MATLAB SIMULINK which is shown in Fig.3. The MATLAB SIMULINK model of Single leg of five level Cascaded Multilevel inverter using two H-bridge configuration is shown in Fig.4.



**Fig. 3 Matlab/Simulink model of Multilevel Induction Motor drive.**

The single phase five level inverter output is shown in Fig.5. The three phase five level inverter output phase voltage after feeding to induction motor is shown in Fig.6. The stator currents with respect to three phases are shown in Fig.7. The Variation in speed is shown in Fig.8. The speed increases and settles at 1470 rpm. The Torque is shown in Fig.9. FFT analysis is done for the voltage and current and the corresponding spectrum is shown in Fig.10 and Fig.11 respectively. It can be seen that the magnitude of fundamental voltage for five level inverter fed induction motor drive is 222.4 Volts. The total harmonic distortion is 4.95 percent and the magnitude of fundamental current is 97.93 Amperes. The total harmonic distortion is 1.57 percent.



**Fig. 4 Matlab/Simulink model of single leg of three phase Five level Multilevel Inverter.**

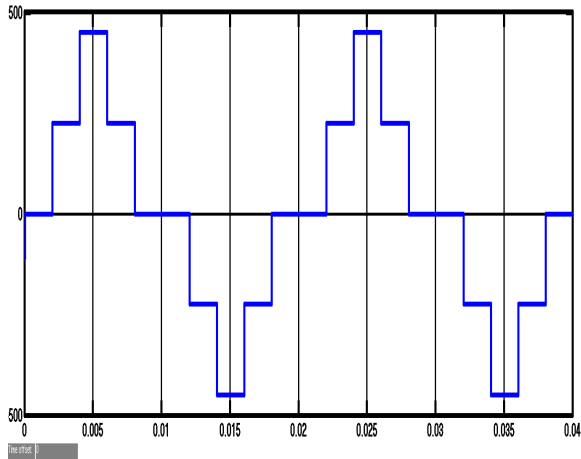


Fig. 5 Single phase five level inverter output

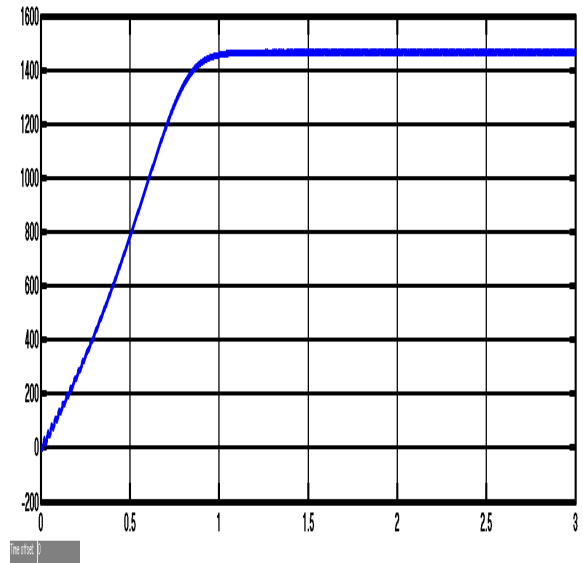


Fig. 8 Variation in speed

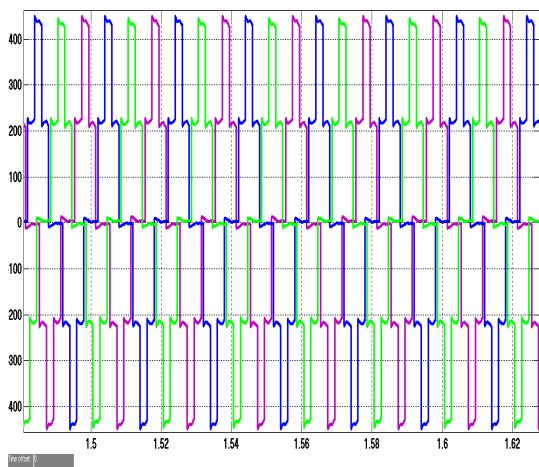


Fig. 6 Three phase five level inverter output phase voltage after feeding to induction motor

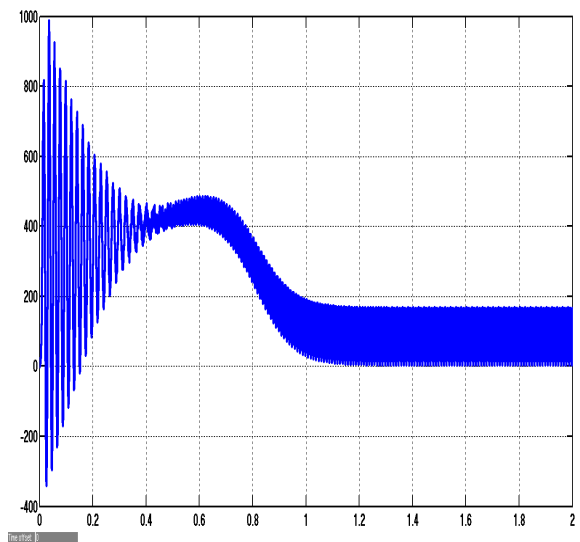


Fig. 9 Variation in Torque

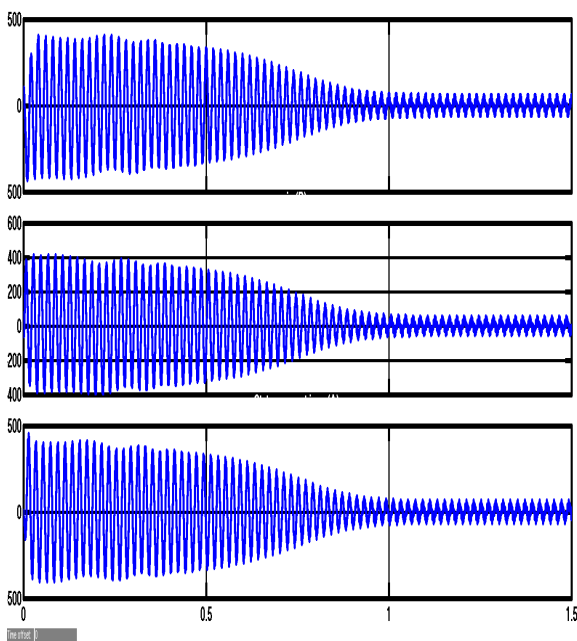


Fig. 7 Stator currents with respect to three phases

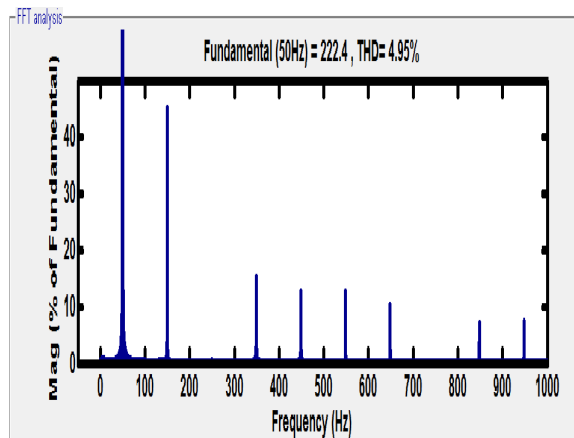


Fig. 10 FFT analysis of Voltage

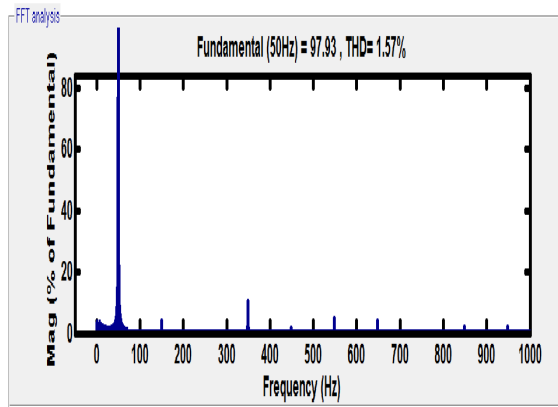


Fig. 11 FFT analysis of Current

The MATLAB SIMULINK model of Single leg of seven level Cascaded Multilevel inverter using two H-bridge configuration is shown in Fig.12

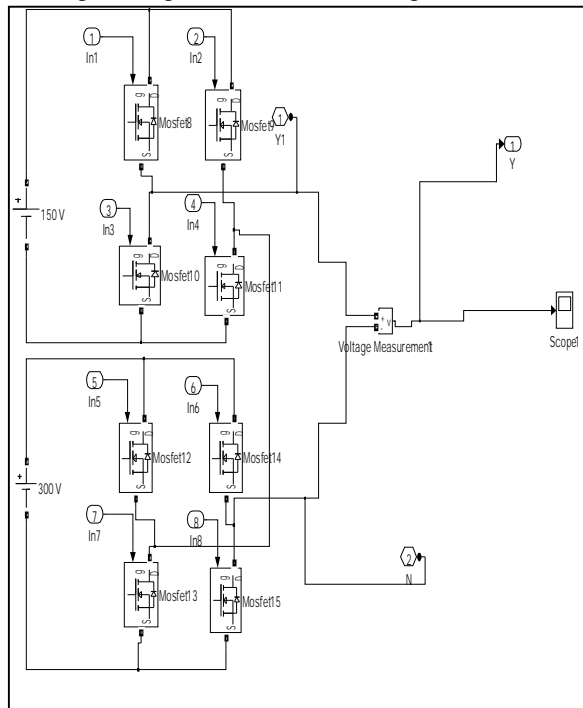


Fig. 12 Matlab/Simulink model of single leg of three phase seven level Multilevel Inverter.

The single phase seven level inverter output is shown in Fig.13. The three phase seven level inverter output phase voltage after feeding to induction motor is shown in Fig.14. The stator currents with respect to three phases are shown in Fig.15. The Variation in speed is shown in Fig.16. The speed increases and settles at 1470 rpm. The Torque is shown in Fig17. FFT analysis is done for the voltage and current and the corresponding spectrum is shown in Fig.18 and Fig.19 respectively. It can be seen that the magnitude of fundamental voltage for five level inverter fed induction motor drive is 234.4 Volts. The total harmonic distortion is 3.51 percent and the magnitude of fundamental current is 91.15 Amperes. The total harmonic distortion is 1.01 percent.

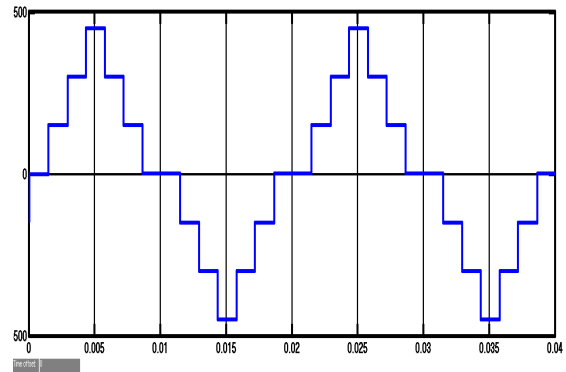


Fig. 13 Single phase seven level inverter output

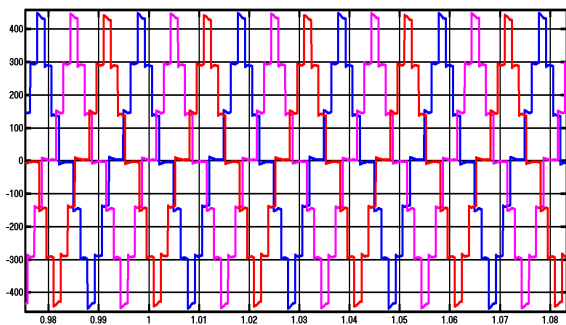


Fig. 14 Three phase seven level inverter output phase voltage after feeding to induction motor

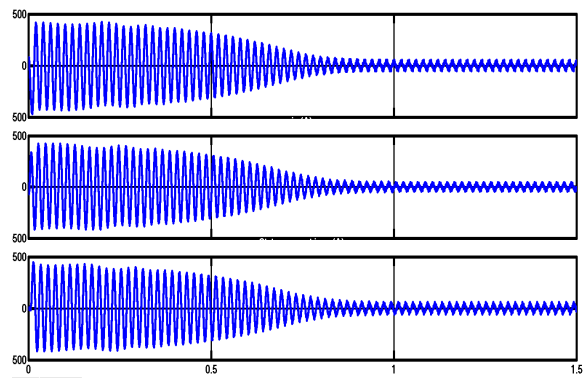


Fig. 15 Stator currents with respect to three phases

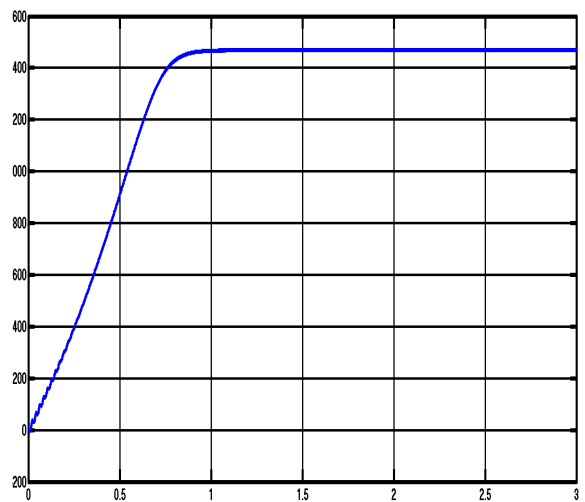


Fig. 16 Variation in speed

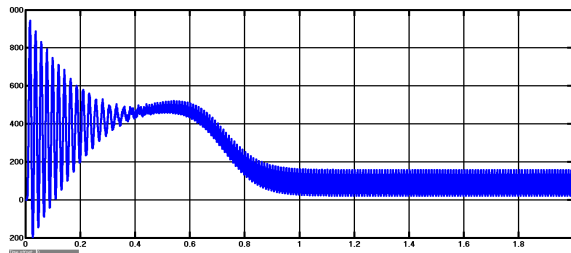


Fig. 17 Variation in Torque

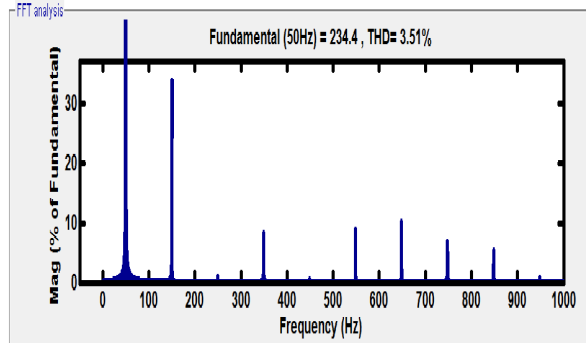


Fig. 18 FFT analysis of Voltage

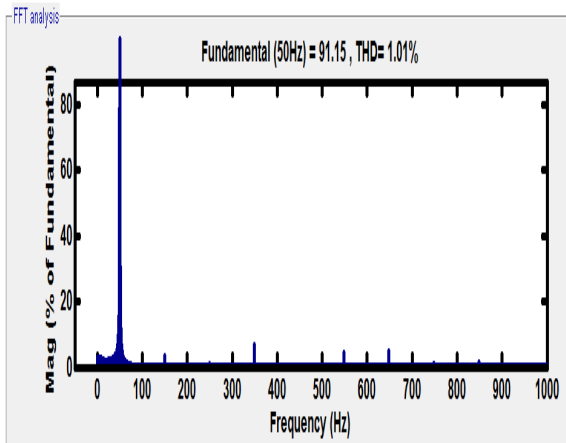


Fig. 19 FFT analysis of Current

The results are tabulated in Table I below.

TABLE I. THD ANALYSIS OF FIVE AND SEVEN LEVEL INVERTER WHEN FED TO INDUCTION MOTOR DRIVE

Parameter s	Multilevel inverter	
	Five level Inverter	Seven level Inverter
Voltage Level	222.4	234.4
THD for Voltage	4.95%	3.51%
Current Level	97.93	91.95
THD for Current	1.57%	1.01%

## VI. CONCLUSION

Five level and Seven level inverter fed induction motor drive are simulated using the blocks of simulink. The results of five level and seven level systems are compared. It is observed that the total harmonic distortion produced by the seven level inverter system is less than that of a five level inverter

fed drive system. Therefore the heating due to seven level inverter system is less than that of a five level inverter 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 five level and seven level inverter fed induction motor drive systems. Experimental investigations will be done in future. Seven level inverter system is a viable alternative since it has better.

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