International Journal of Electrical and Electronics Engineers
Vol. No. 9, Issue No. 01, January-June 2017
ISSN (O) 2321-2055
ISSN (P) 2321-2045

SIMULATION AND EXPERIMENTAL EVALUATION OF CURRENT HARMONICS UNDER STEADY STATE CONDITIONS OF VARIABLE SPEED INDUCTION MOTOR DRIVE SYSTEM FED BY THREE LEVEL INVERTER

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ABSTRACT

The Induction Motor generally known to be a constant speed motor. In the medium and high voltage industries the Induction Motor is widely used for variable speed drive systems. The speed of induction motor can be controlled within certain constraints due to the advances in digital-technology. The Arduino microcontroller board is used with necessary opto-isolation and electronic circuit to drive the three-level inverter with less switches using space vector modulation method. In an inverter the output is a stepped square wave. Hence at the star point of the three phase load there exists a voltage, produces a current which results in electro-magnetic interference and affects the performance of the adjacent communication and electronic measuring devices. In this paper the authors have discussed the current harmonics under steady state conditions. Simulation has been carried out using MATLAB/Simulink and validated using the experimental work. The voltages and currents are recorded using Agilent make mixed signal oscilloscope. The signal analysis software is used for Fast Fourier transform analysis of experimental work and results are plotted with frequency versus voltage and current.

Keywords: Fast Fourier Transform (FFT), Electro-Magnetic Interference (EMI), Induction Motor (IM), Space Vector Modulation (SVM).

I. INTRODUCTION

The current harmonics in variable speed AC drive systems using Three-level inverter is due to the existence of voltage and due to the fast switching (ON and OFF) action of power semiconductor devices. B. Muralidhara [1] reported, the voltage induced at the star point of an induction motor results in current. The current harmonic analysis of three-level inverter fed IM drive system by B. Biswas [2]. In 1924, Shaft voltages and their resulting currents were reported by Alger [4]. In the year 1996, S. Chen [5] reported the capacitive common mode voltage between stator and rotor due to a switch-mode variable speed motor drive. A. Muetze [6] reported that, the high-frequency (HF) component exists at the common mode voltage. Hence it is necessary to reduce the current harmonics within limits [3] so that there will be less winding insulation problem and reduced power dissipation. The three phase Three-level inverter is used in adjustable speed three phase AC drive System, produces three phase AC output voltage of desired amplitude and frequency from a fixed DC source. In Three-level inverter, it has levels of voltages [$\pm 2/3V_{dc}$, $\pm 1/2V_{dc}$, $\pm 1/3V_{dc,}$ 0], hence the output waveform of Three-level inverter is stepped square wave. The output waveform of an inverter should be Non-sinusoidal. The square wave output contains harmonics to reduce the harmonics in the output of the inverter the multilevel inverter concept is widely used. Multi-level Inverter (MLI) concept in 1981 reported by T. Nabae [7]. There are advantageous in terms of electro-magnetic interference (EMI), power quality, with reduced switching losses used in medium and high voltage applications. The drawbacks are the number of power semiconductor devices, circuit complexity and DC voltages at different levels. The gate pulses to the MOSFET's are generated by the Arduino microcontroller [8] as per the Hexagon of the space vector modulation (SVM).

II. THE PROPOSED WORK

Simulation, experimentation of Three-level inverter using SVM for the speed control of induction motor has been done. The measurement of Line voltage, line current using MSO associated with opto-isolation module, high frequency current probe and Hall effect sensor. The Three-level inverter is built using the nine MOSFET devices, DC link capacitors and necessary electronics components. Fig.1 shows the block diagram of experimental setup circuit.

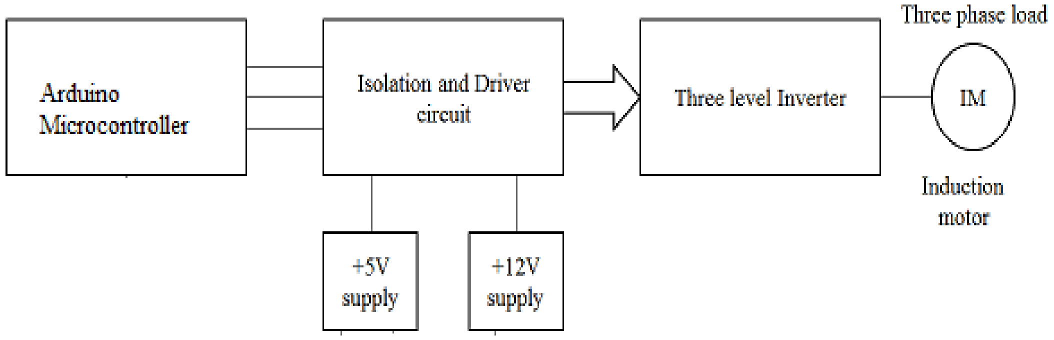

Fig. 1. Block Diagram Of Experimental Circuit

2.1 Space Vector Modulation

The SVM method can be easily implemented to all Multi-level inverters. The vector approach to Pulse Width Modulation was originally developed for three phase inverters is Space Vector Modulation (SVM) [9], [11]. It is one of the better technique for generating more sinusoidal wave that provides higher voltages with lower total harmonic distortion. SVM methodologies have the advantages of more output voltage when compared to sine triangle pulse width modulation method [10]. The advantage of using the SVM is that the gating signal of the power devices can be

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easily programmed using microcontroller and offers improved dc bus utilization, reduced switching losses and lower total harmonic distortion.

The main reason for using multi-level inverters with PWM techniques is to improve the power quality and to reduce the harmonic content present in the power system networks. The principle of a three phase inverter is, the one must be controlled so that at no time, both switches in the same leg cannot be turned on or else the DC supply would be shorted. This constraint may be met by the complementary operation of the switches within a leg. (i.e., if Q1 is on then Q1l is off and vice versa). These works use a typical SVM method, which approximate the output voltage by using the nearest three output vectors. When the reference vector changes from one region to another, it may induce an output vector abrupt change. In addition we need to calculate the switching sequences and switching time of the states at every change of the reference voltage location. Space vector Modulation method is the best PWM technique for Three Phase Voltage Source Inverters for the control of AC Induction Motors. Generally the three phase voltages are

$$V_a = V_m \,\mathrm{Sin}\omega t \qquad (1)$$

$$V_b = V_m \,\mathrm{Sin}(\omega t-2\pi/3) \qquad (2)$$

$$V_c = V_m \,\mathrm{Sin}(\omega t-4\pi/3) \qquad (3)$$

Space vector modulation (SVM) is based on vector selection in the q-d stationary reference frame. The first step in the SVM scheme is to identify the three nearest vectors. The magnitude and angle of the rotating vector can be found by means of Clark's Transformation. To implement the space vector pulse width modulation, the voltage equations in the a-b-c reference frame can be transformed into the stationary d-q reference frame that consists of the horizontal (d) and vertical (q) axes. In general the total harmonics distortion (THD) is mathematically given by

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} H_{(n)}{}^2}}{H_1}$$

Let H(n)= hn , then

$$h_n = \frac{4E}{n\pi} \sum_{k=1}^{S} \cos(n\alpha_k)$$

Fig. (2a) shows vector diagram for Two-level inverter and Fig. (2b) for Three-level inverter using space vector modulation method. Fig. (2c) shows the generalized stepped-voltage waveform for multilevel inverter.

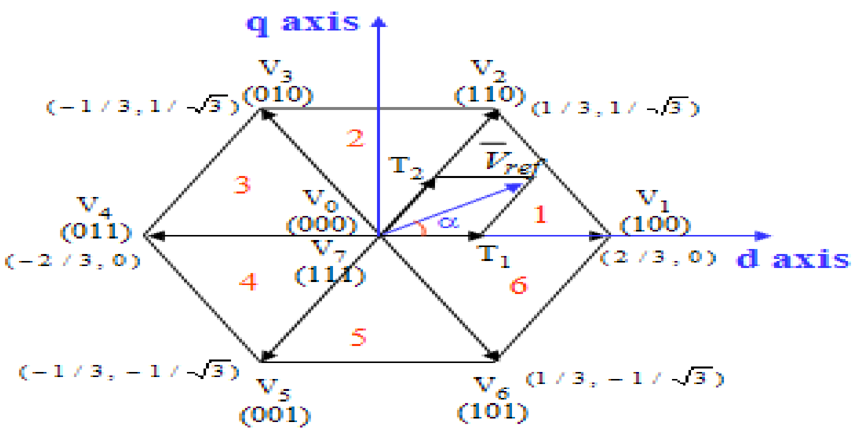

Fig. (2a) Hexagon for Two- level inverter using SVM

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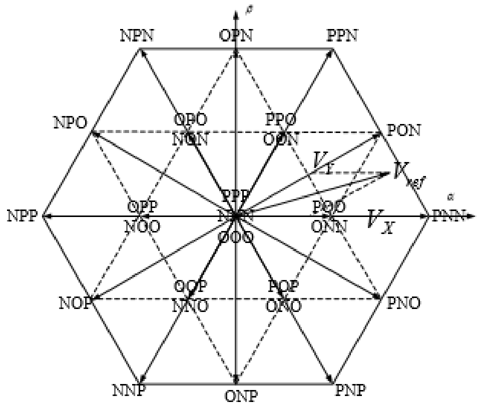

Fig. (2b) Hexagon for of Three-level inverter

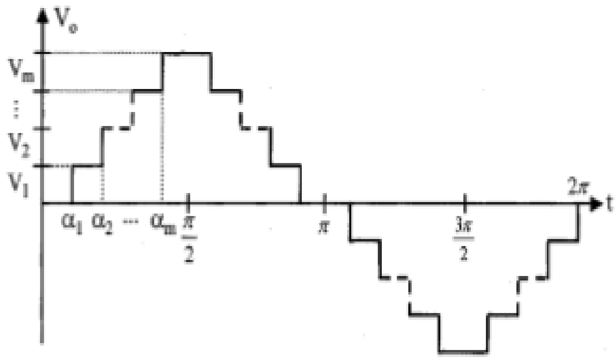

Fig. (2c). Generalized stepped-voltage waveform.

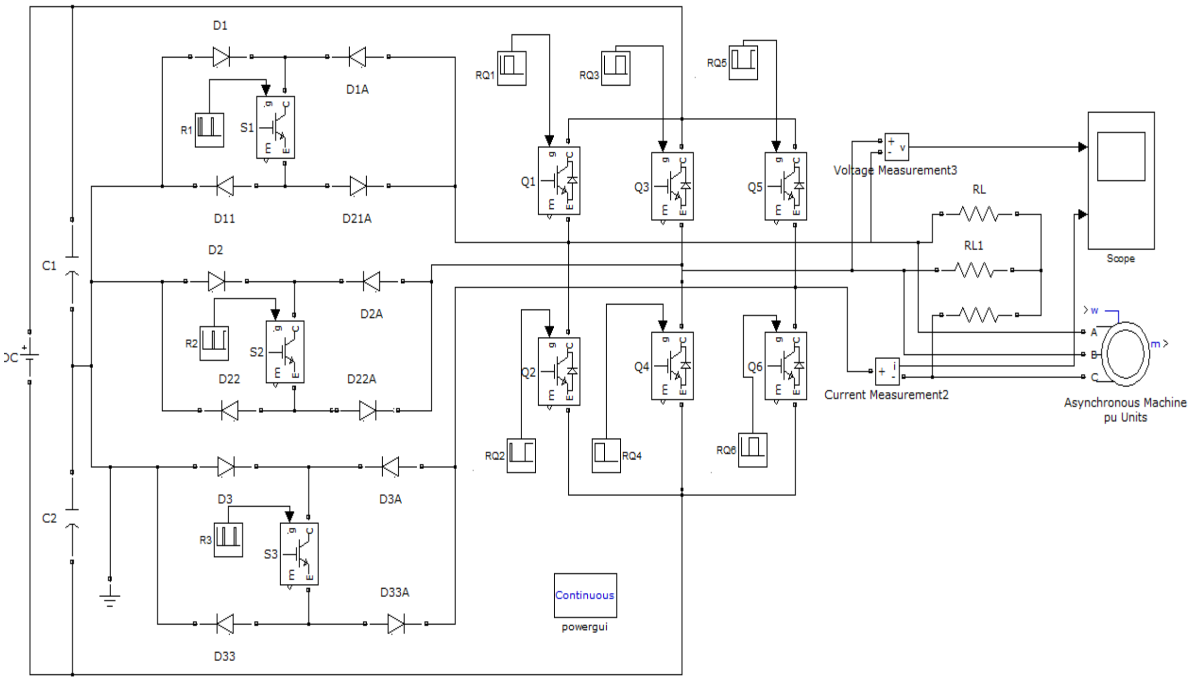

Fig. 3 Simulation set up of Three-level Inverter

III. EXPERIMENTAL SETUP

In the Three-level inverter the MOSFET's are used as switching devices with necessary snubber circuit. The microcontroller output after isolation is given to the gate of the MOSFET's. The simulation and the experimental circuits shown in Fig.3 and Fig.4. The microcontroller is programmed for 40HZ frequency and the output of the microcontroller is given in the Fig. 5. In addition, necessary isolation module, high frequency current probes and line impedance stabilization network are used during the experimentation, the line voltages and line currents are recorded using Agilent mixed signal oscilloscope (MSO). The FFT analysis has been done in simulation using MATLAB/Simulink and the Origin signal analysis software used for experimental results.

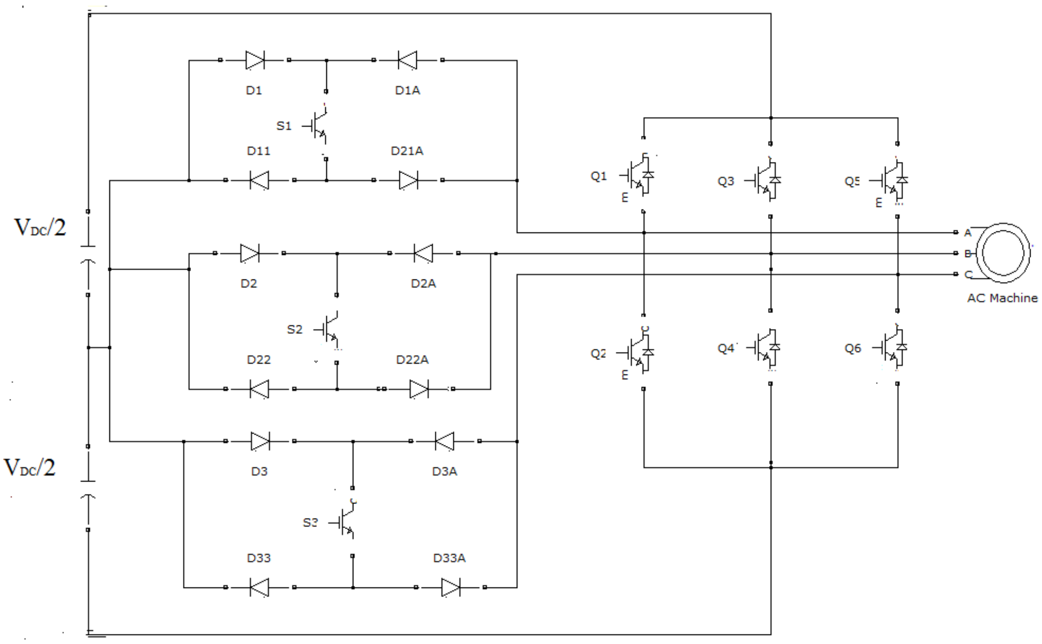

Fig. 4 Experimental set up of Three-level Inverter

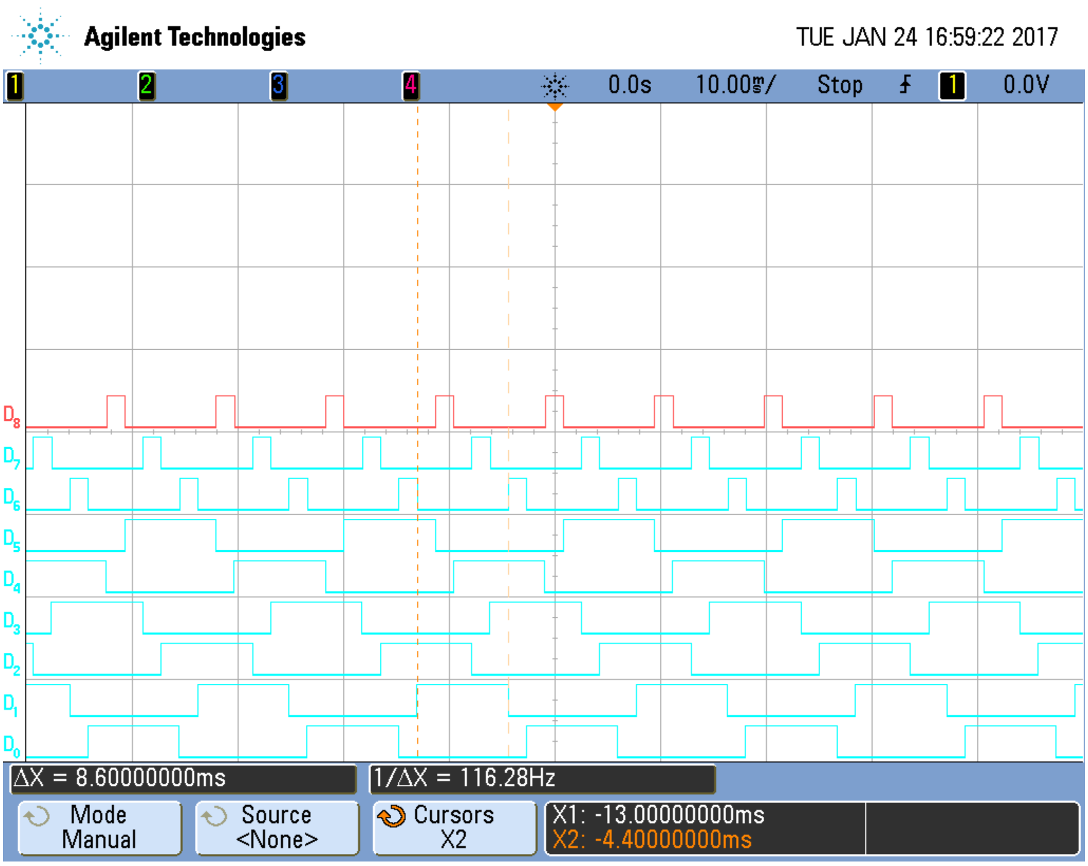

Fig. 5 Gate pulses generated for Three-level Inverter using Microcontroller

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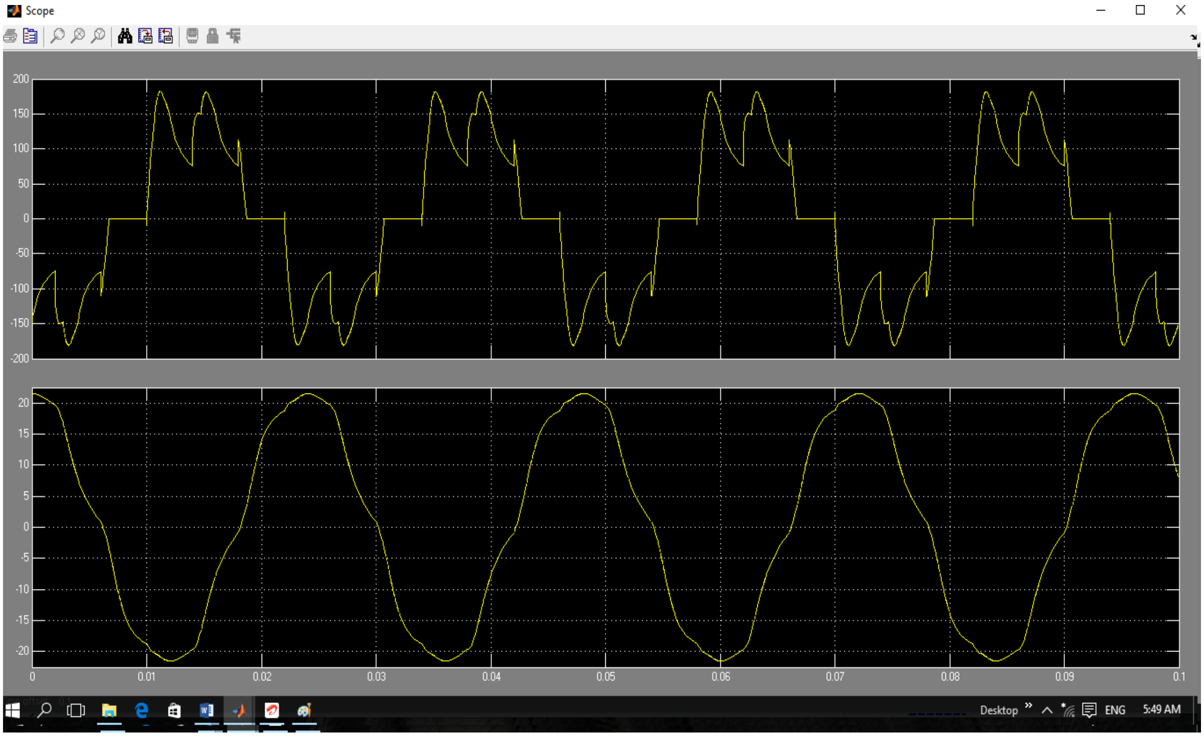
4.1 Simulation: The MATLAB is used to simulate the circuit shown in the Fig.3. The simulated results are given in the Fig. 6.

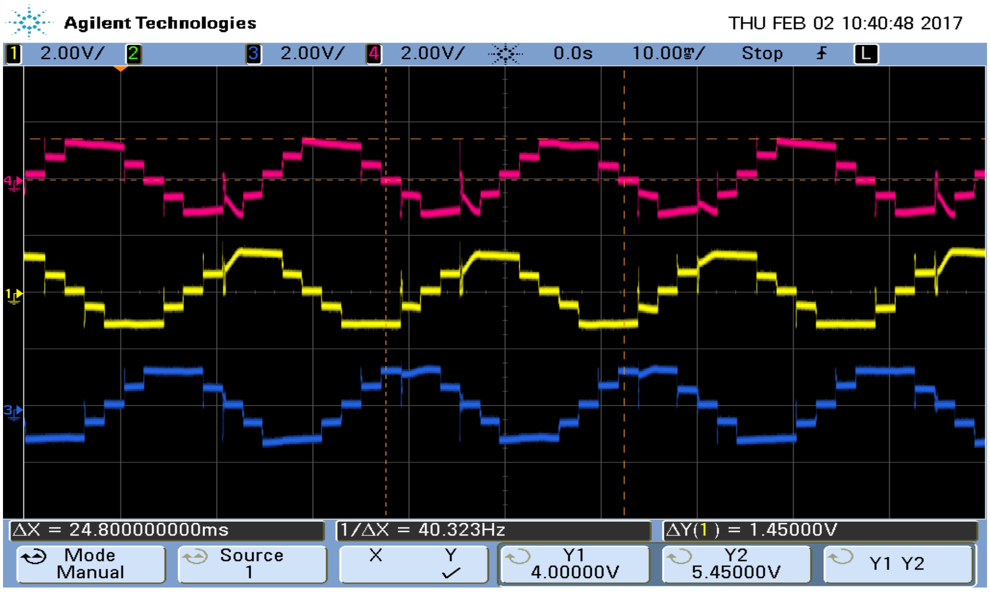


Ch-1: Line Voltage, Ch-2: Line Current,

Fig. 6: Simulation, Three-level Inverter output.

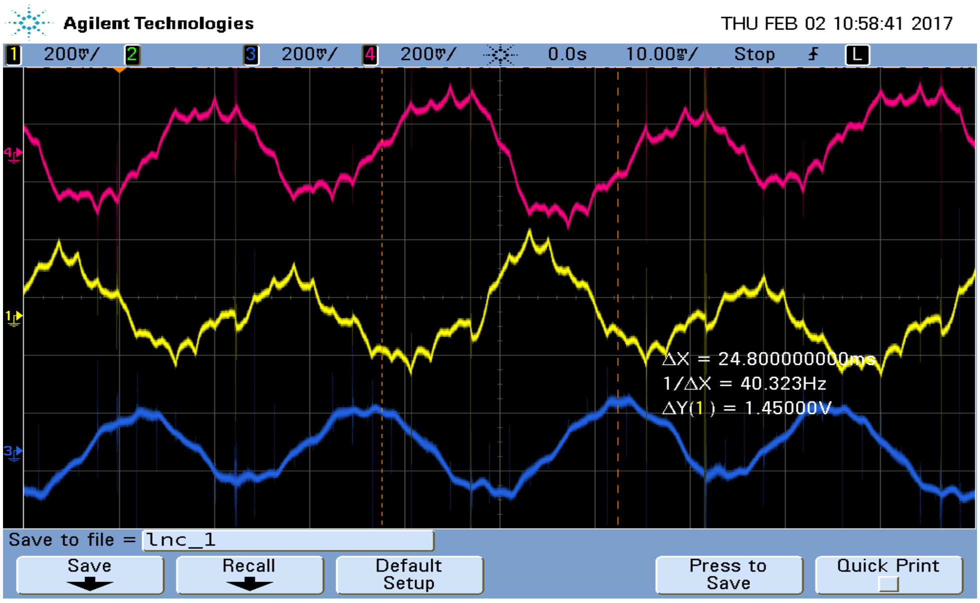
IV. EXPERIMENTAL RESULTS

The line voltages, line currents are recorded shown in Fig. (7a) and (7b) for the experimental work



Ch 1: Line Voltage [200:1], Ch 3: Line Voltage [200:1] Ch 4: line Voltage [200:1]

Fig. (7a). Three-level Inverter output waveforms (Exptl.)



Ch 1: Line Current [1:1], Ch 3: Line Current [1:1], Ch 4: Line Current [1:1]

Fig. (7b). Three-level Inverter output waveforms (Exptl.)

4.1 Results and discussion

The even harmonics and its multiples will be zero since there is symmetry of waveform. The odd triplen harmonics (i.e., 3^{rd}, 6^{th}, 9^{th} harmonic order, etc.) cancel out each other since it circulates in the transformer windings and will not appear in the load. The only odd harmonics present are 5^{th}, 7^{th}, 11^{th} and 13^{th} etc. The harmonic magnitude of voltage will not produce useable torque in 3phase IM drive system and at the same time some harmonics produces heat which is harmful to the winding insulation. Fig. (8a), (8b) shows the simulated FFT analysis of line voltage using the MATLAB and in the Fig. (9a), (9b) shows the FFT from experiment using Origin signal software. Fig. (10a), (10b) shows the simulated FFT analysis of Line current using the MATLAB Simulink and Fig. (11a), (11b) shows the FFT analysis of line current from the experimental work using Origin signal software.

4.2 FFT Analysis

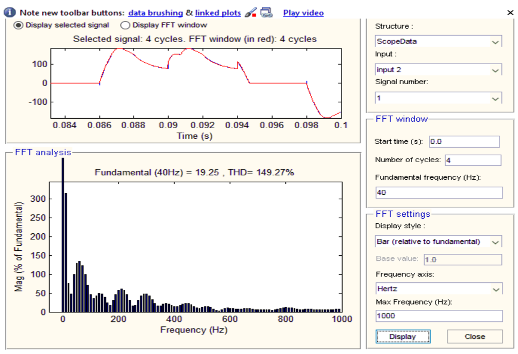


Fig. (8a): FFT of Line Voltage

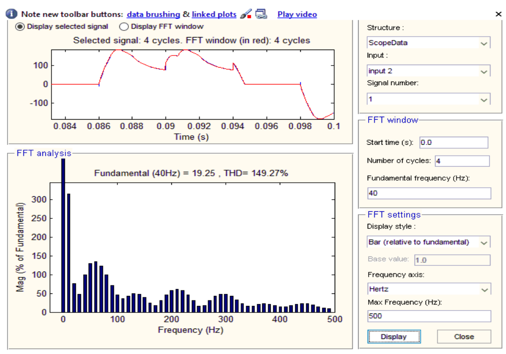


Fig. (8b): FFT of Line Voltage Expanded view

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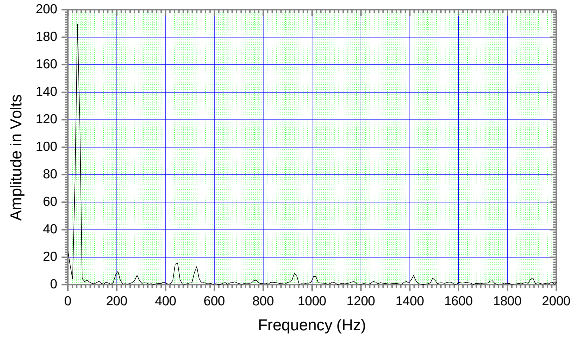

Fig. (9a): FFT of Line Voltage (Exptl.)

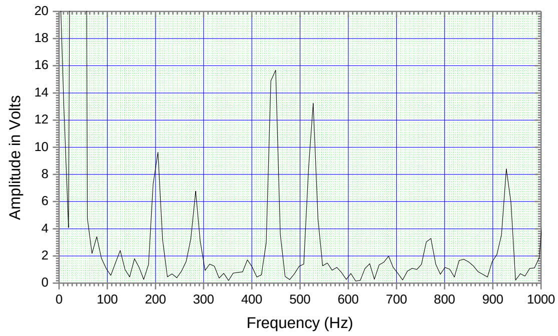

Fig. (9b): FFT of Line Voltage (Exptl.) Expanded view

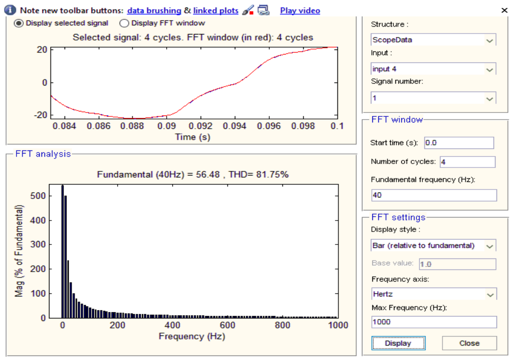

Fig. (10a): FFT of Line Current

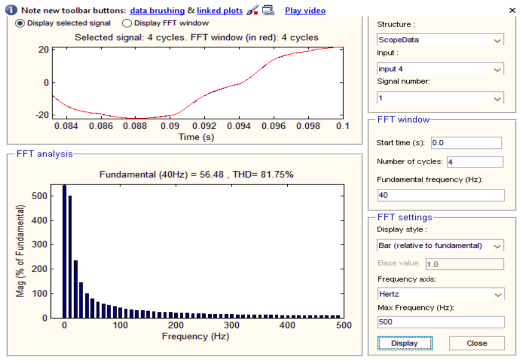

Fig. (10b): FFT of Line Current Expanded view

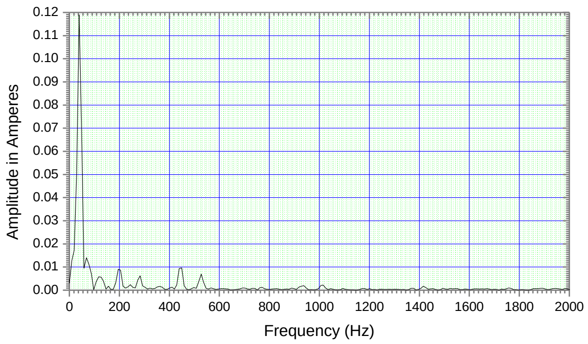

Fig. (11a): FFT of Line Current (Exptl.)

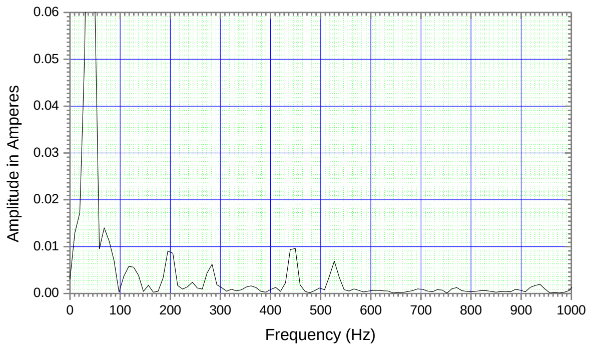

Fig. (11b): FFT of Line Current (Exptl.) Expanded view

V. CONCLUSION

This paper presents a 3phase Three-level inverter with less switches fed IM drive system to analyze the harmonic components of the line voltage and current. It is to be noted that the line voltage harmonics and the line current harmonics under steady state conditions in simulation and the experimental are the same as (5^{th}, 7^{th}, 11^{th} 13^{th} etc),. The harmonics amplitude diminished, when the harmonics frequency increases. In the simulation and experimentation, FFT analysis of the line voltage, line current shows the same values and THD within limits (Exptl., THD is ~6.6%, in Three-level Inverter). Hence it is concluded that the simulation is validated with the experimental work.

VI. ACKNOWLEDGEMENT

The authors are thankful to KRJS Management, Dean, Principal and Head/ECE of Vemana Institute of Technology, Bangalore. Also thankful to Prof. R.Srinivasan and Prof. M. Channa Reddy for their follow-up with guidance and to all the colleagues of ECE and workshop staff for their support in carrying out the experimental work.

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