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An Experimental Measurement of Shaft Voltage in Induction Motor driven by three level Inverter

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ABSTRACT

In most of the industries the induction motor is the prime power source. Three phase induction motor has an extremely reliable rugged electromechanical energy conversion device. The speed control of induction motor is essential demand for the process industrial applications. However, there are so many options available for the precise speed control of induction motor. Due to the progress in engineering digital technology the speed of the induction Motor (IM) can be varied within certain limitations. The 3-level inverter with less number of switches controlled by the Arduino microcontroller, using the space vector modulation method for the Volts/Hertz principle. The basic two level inverter is used as main circuit with additional 3-switches. With the availability of high speed power semiconductor devices, the three phase inverters play the key role for variable speed ac motor drives. By this method the output of the inverter will be non-sinusoidal. Hence, there exists a voltage at the star point of the load with respect to common ground of power supply is known as Common Mode Voltage results in shaft voltage, which induces an electromagnetic interference and causes disturbance to the nearby control circuits and electronics measuring instruments. To minimize the Common Mode Voltage a multilevel inverter concept can be used. In this paper the authors have discussed the 3-level inverter with less number of devices used as a main circuit to control the speed of Induction Motor. Space Vector pulse width modulation scheme with Arduino micro-controller using Volts/Hertz principles. In this paper the authors have discussed 3-level with 9 devices by simulation using MATLAB-Simulink and Experiment. Fast Fourier Transform has been done using the signal analysis software.

Index Terms- Common Mode Voltage, Induction Motor, 3-phase voltage source 3-level inverter, Space Vector Modulation.

I.INTRODUCTION

The voltage that exists at the 3-phase inverter output terminals fed to Induction Motor (IM). It is due to the non-sinusoidal output voltage from the inverter. The Common Mode Voltage (CMV) exists in 3-phase Induction Motor (IM) variable speed drive has been reported by B. Muralidhara [1, 2]. The voltage analysis of inverter fed IM drive system that lead to shaft voltage [3]. In 1924, bearing current were recognized by Alger [4, 16] and S. Chen [5] due to the asymmetrical flux through the arbour line loop induces CMV. The high-frequency component that exists at the CMV reported by A. Muetze [6]. Hence it is necessary to minimize the CMV within limits [7] so that there will be reduced shaft voltage results in low bearing current and the reduced insulation problem of the winding. The three phase multi-level inverter concept is widely used in variable speed AC IM drive Systems. In 2- level and 3- level inverter, the output waveform of inverter is stepped square wave. The output waveform of an inverter should be sinusoidal for efficient operation. The complexity of circuit in 3-level inverter with 12 devices is more compared to 3-level inverter with 9 devices.

A. Nabae [8] in 1981 discussed the Multi-level inverter (MLI) concept. The advantages are with low switching losses, Electromagnetic Interference (EMI), power quality, used in medium and high voltage process oriented industrial applications. The drawbacks are the number of switching devices, the DC voltage levels and complexity in control circuits. The Arduino microcontroller [9] board has been used with opto-isolation interfacing modules and 3-phase H-bridge circuit with 9-switching devices for 3-level inverter as per Space Vector pulse width modulation Method.

II. COMMON MODE VOLTAGE

The Common Mode Voltage of inverter driven IM is represented in mathematical form. In three-phase AC loads, to analyze its characteristics under different types of source and load combinations. The phase to ground voltages can be written as the sum of the phase voltages and the voltage across the star point of the load to the common ground of power supply source. In a 3-phase sinusoidal balanced system the sum of all three phase-to-neutral voltages is equal to zero. The sum of all three phase-to-neutral voltages is the voltage from the star point of load to common ground of power supply can be defined in terms of phase to ground voltage as shown in Fig.1.

$$V_{A-n} = V_{AN} + V_{N-n} \quad -- (1)$$

$$V_{B-n} = V_{BN} + V_{N-n} \quad -- (2)$$

$$V_{C-n} = V_{CN} + V_{N-n} \quad -- (3)$$

For balanced three phase load $\sum_V = 0$

$$V_{AN} + V_{BN} + V_{CN} = 0 \quad -- (4)$$

$$V_{N-n} = [(V_{A-n} + V_{B-n} + V_{C-n}) / 3] \quad -- (5)$$

$$\text{CM current "}I_{lg}\text{"} = C\frac{dv}{dt} \quad -- (6)$$

Where "C" is the total capacitance in the system.

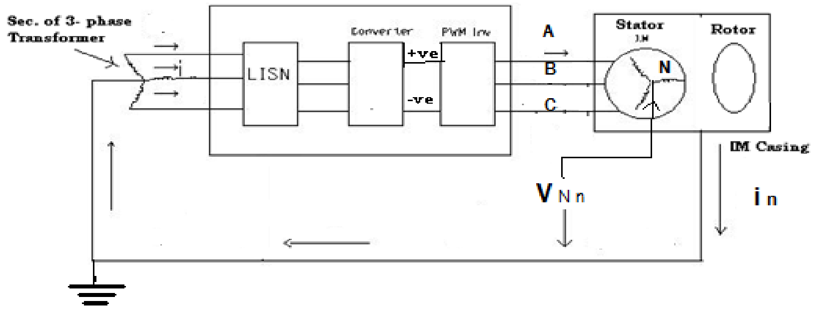

Fig.1: Schematic diagram of Inverter fed IM with voltage as EMI source

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III. SPACE VECTOR MODULATION

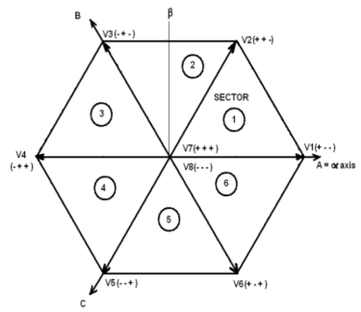
The Space Vector method (SVM) is used in experimental work, which produces the output voltage by using the three nearby adjacent voltage output vectors. When one of the reference voltage vector moves from one sector to another, results in an output voltage vector abrupt change. In addition it is essential to find the switching patterns and the time of the states with variation of the reference voltage. The variation in DC bus voltage can be reduced, the ratio V/f of IM is maintained constant by compensating for regulation in inverters. SVM treats sinusoidal voltage as a rotating constant amplitude vector rotating with constant frequency. This PWM technique represents the reference voltage by a combination of the eight switching patterns in a Hexagon. The a-b-c reference frame can be transformed into the stationary d-q reference frame that consists of the horizontal (α) and vertical (β) axes (Coordinate Transformation). The 3-phase voltage vector is transformed into a vector in the stationary α-β coordinate frame represents the spatial vector sum of the 3phase voltages. The voltage vectors (V_1-V_6) divide the hexagon plane into six sectors(i.e., sector-1 to sector-6) which is generated by two adjacent non-zero vectors. Fig.2 shows the switching vectors of 2-level inverter in hexagon. The three phase voltages are

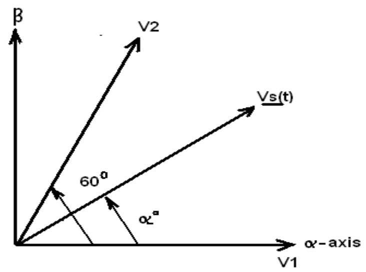
$$V_a = V_m \, \mathrm{Sin}\omega t \qquad \text{-- (7)}$$

$$V_b = V_m \, \mathrm{Sin}(\omega t - 2\pi/3) \qquad \text{-- (8)}$$

$$V_c = V_m \, \mathrm{Sin}(\omega t - 4\pi/3) \qquad \text{-- (9)}$$

SVM is a good technique for generating a fundamental approximate sine wave output that provides a higher output voltage to the 3-phase IM and with lower THD. when compared to sinusoidal PWM. The switching vectors and sectors is shown in the Fig.(2-3). Table I shows the switching sequence of vectors for 2-level 3Φ inverter. The Hexagon for the 3-level 3Φ inverter is shown in Fig.4, Table II and III shows the switching ON/OFF details of 3-level inverter.





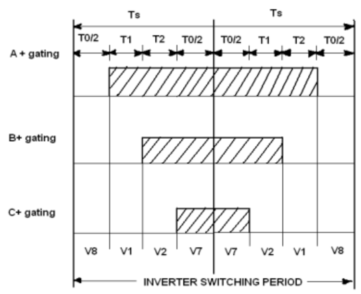


Fig.2a Switching vectors **Fig.2b Sampled reference vector in sector-1** **Fig.3 SVM pattern in Sector-1**

TABLE I

Switching vectors for 2-level Inverter using SVM Inverter

Vector	A	B	C	A	B	C	V_{AB}	V_{BC}	V_{CA}
V_0[000]	0	0	0	1	1	1	0	0	0
V_1[100]	1	0	0	0	1	1	$+V_D$	0	$-V_{DC}$
V_2[110]	1	1	0	0	0	1	0	+V	$-V_{DC}$
V_3[010]	0	1	0	1	0	1	$-V_{DC}$	+V	0
V_4[011]	0	1	1	1	0	0	$-V_{DC}$	0	$+V_{DC}$
V_5[001]	0	0	1	1	1	0	0	-	$+V_{DC}$

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V_6[101]	1	0	1	0	1	0	$+V_D$	-	0
V_7[111]	1	1	1	0	0	0	0	0	0

Note: 1 means ON, 0 means OFF [top switch of 3phase inverter]

TABLE II

Switching vectors for 3-level 3Φ

Switching states	S_{1x}	S_{2x}	S_{3x}	S_{4x}	S_{xN}
P	ON	ON	OFF	OFF	Vdc/2
O	OFF	ON	ON	OFF	0
N	OFF	OFF	ON	ON	-Vdc/2

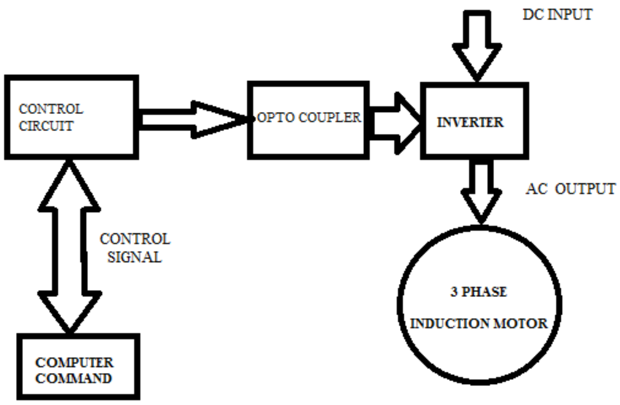

Fig.4a Schematic Block diagram

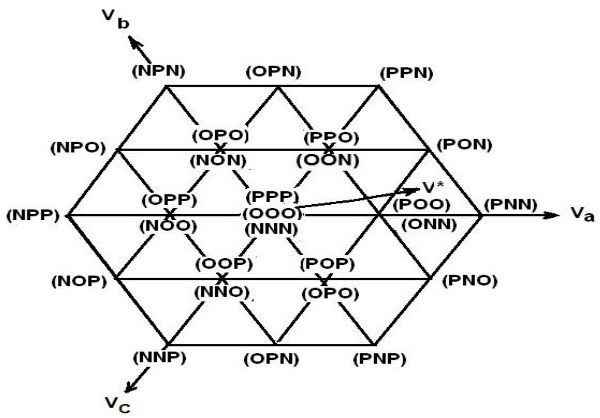

Fig.4b Switching vectors and sectors for 3-level

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TABLE-III

Switching Sequence of 3-level inverter

Step Duration	Q1	Q2	Q3	Q4	Q5	Q6	S1	S2	S3
Δt1	0	1	0	1	1	0	0	0	0
Δt2	0	0	0	1	1	0	1	0	0
Δt3	1	0	0	1	1	0	0	0	0
Δt4	1	0	0	1	0	0	0	0	1
Δt5	1	0	0	1	0	1	0	0	0
Δt6	1	0	0	0	0	1	0	1	0
Δt7	1	0	1	0	0	1	0	0	0
Δt8	0	0	1	0	0	1	1	0	0
Δt9	0	1	1	0	0	1	0	0	0
Δt10	0	1	1	0	0	0	0	0	1
Δt11	0	1	1	0	1	0	0	0	0
Δt12	0	1	0	0	1	0	0	1	0

IV. THE PROPOSED WORK

Simulation and experiment of 3-level inverter with 9 devices using SVM for the speed control of 3 phase induction motor are reported. The measurement of Phase voltage, Line Voltage, CMV, Shaft voltage and line current has done using Agilent MSO associated with isolation module, interface circuits, LISN and Hall effect sensor. The 3-level inverter are built using the DC link capacitors, MOSFET devices and necessary electronic circuits. By using the 3-level inverter, the number of devices will be increased to 12 in conventional method from the 2-level inverter with 6 devices. Due to increase in number of devices there will be more complexity in the circuits. The advantage of SVM is that the gating signal of the power devices can be easily programmed using μ-controller and offers improved dc bus utilization [10], reduced switching losses and lower total harmonic distortion. SVM has the more output voltage when compared to sine triangle pulse width modulation (SPWM) method [11].

V. EXPERIMENTAL SETUP

In our experimental circuit, the MOSFET's are used as switching devices with snubber circuit. The Arduino board output generate gating pulses to the MOSFET's with necessary opto isolation [12, 13, 14].The microcontroller is programmed for 50Hz frequency; the gate pulses generated using the microcontroller are shown in the Fig.9. The necessary FFT analysis has been done in simulation using MATLAB/Simulink and for the experimental results using signal Analysis software. The FFT analysis has been done using Comma separated values format using origin signal software. The Fig.1 shows the schematic block diagram. Fig.5a shows the experimental photograph of three level inverter. The simulation and the experimental circuits shown in Fig. (5b) and (5c).

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Fig.5a Experimental set up photograph of 3-level inverter circuit

VI. SIMULATION AND EXPERIMENTAL RESULTS

The simulation and experimental circuits is shown in Fig.(5a), (5b), the gating pulses generated by the Arduino board shown in Fig. 6. The simulated result waveform shown in Fig. (7a), the phase voltage, line current, Common Mode voltage and shaft voltage are recorded is shown in Fig. (7b). In CMV and shaft voltage, the harmonic frequencies are 3-times the fundamental frequency. Some of the harmonic magnitudes of voltage will not produce useable torque in the IM drive system. These harmonic frequencies produce opposing torque and develops heat in the winding of IM, which are harmful to the winding insulation. Fig. (8, 10, 12) shows the simulated FFT analysis of CMV using the MATLAB Simulink and in the Fig. (9, 11, 13, 14 and 15) shows the results of FFT analysis of Phase Voltage, Line current, CMV and Shaft voltage from the experimental work using Origin signal software.

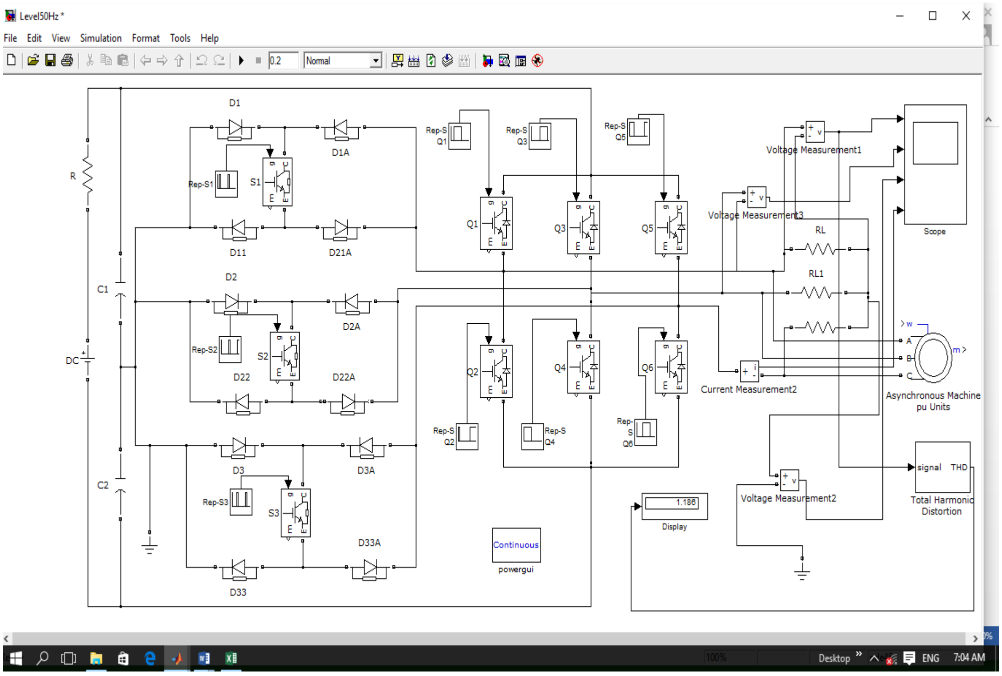

Fig.5b Simulation 3-level inverter circuit

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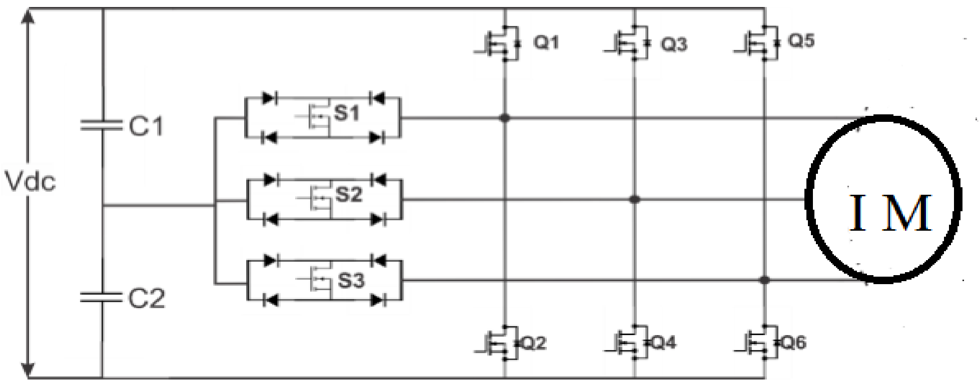

Fig.5c Experimental 3-level inverter Circuit

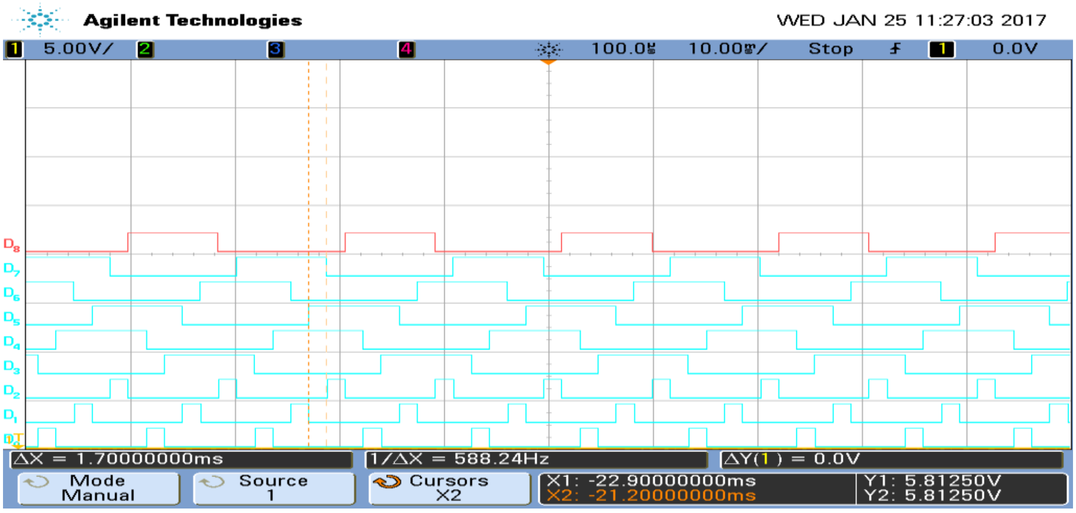

Fig. 6 Gate pulses for 3-level Inverter using SVM PWM technique

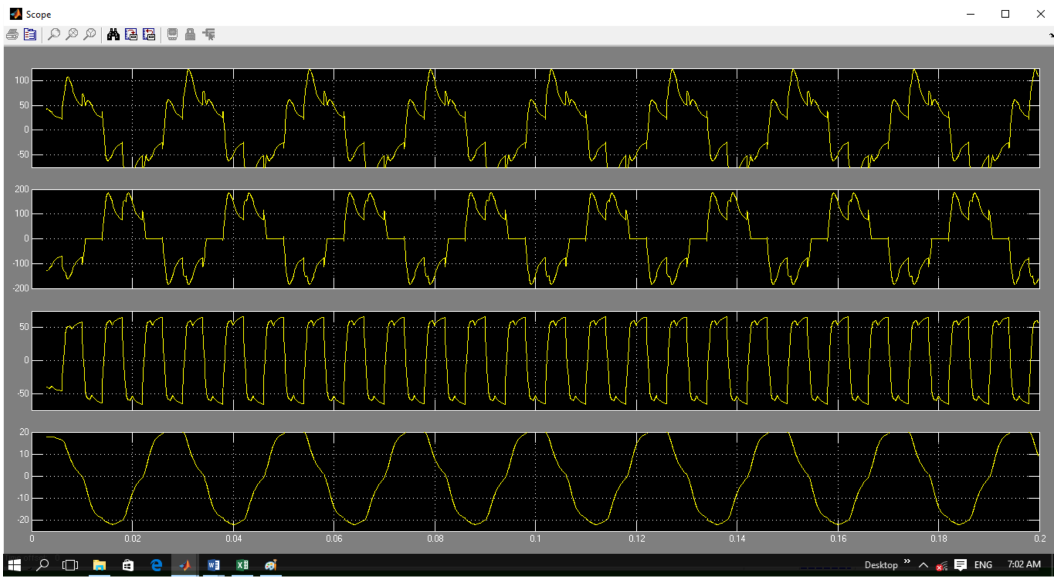

Fig. (7a) Simulation Inverter output waveforms

CH 1 Phase Voltage [200:1], CH 2 Line Voltage [200:1], CH 3: CM Voltage [200:1], CH 4: Line Current [1:1]

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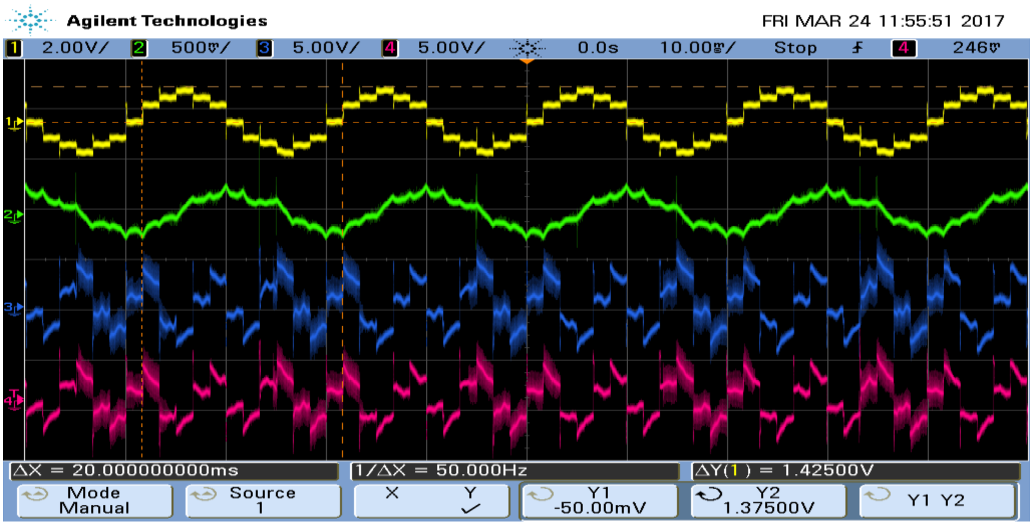
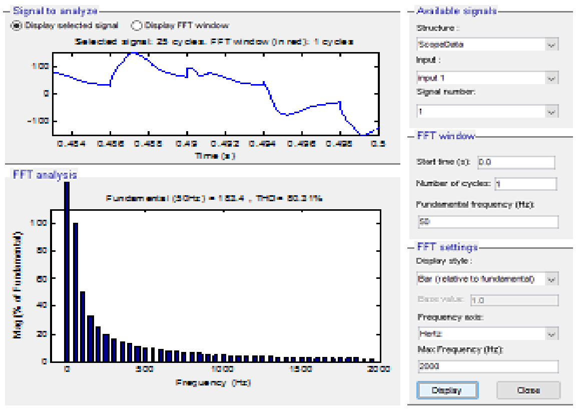


Fig. (7b) Experimental Inverter output waveforms

CH 1 Phase Voltage [200:1], CH 2 Line Current [1:1], CH 3: CM Voltage [200:1], CH 4: Shaft Voltage [200:1]

6.1 FFT Analysis

Simulation **Experiment**



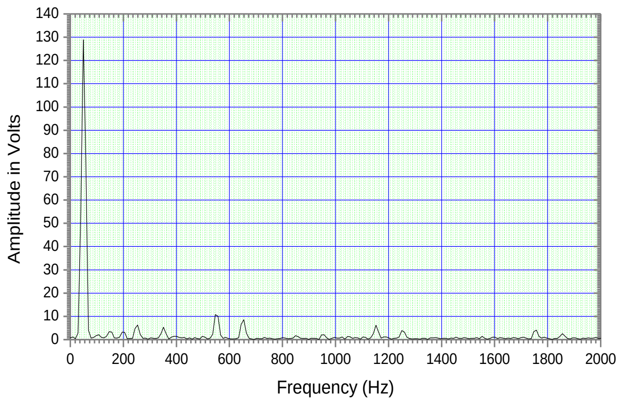
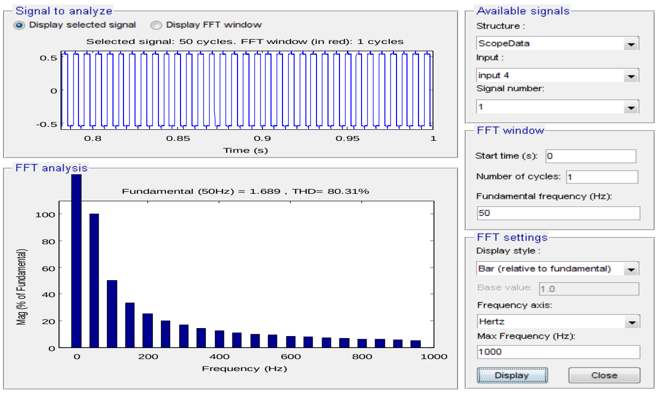


Fig. 8 FFT of Phase Voltage **Fig.9 FFT of Phase Voltage (Exptl.)**



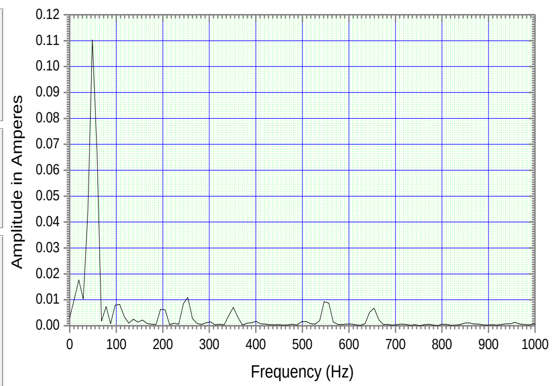


Fig.10 FFT of Line Current **Fig.11 FFT of Line Current (Exptl.,)**

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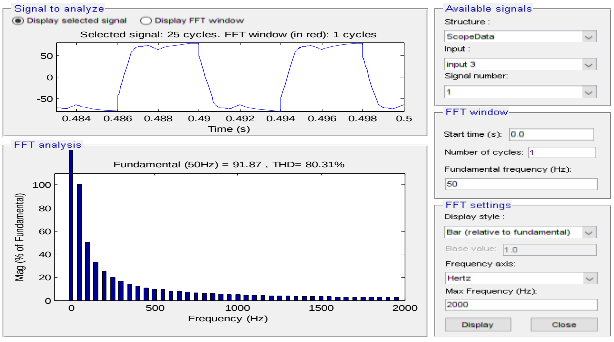

Fig. 12: FFT of CMV

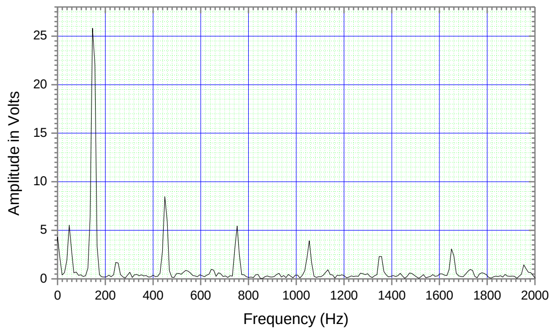

Fig. 13: FFT of CMV (Exptl.)

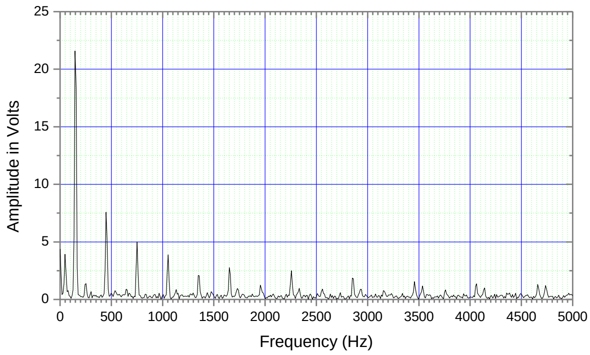

Fig.14 FFT of Shaft Voltage (Exptl.,)

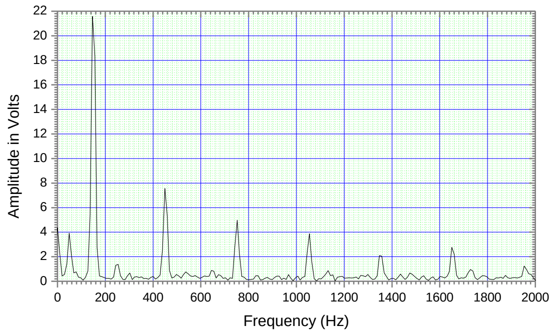

Fig.15 FFT of Shaft Voltage (Exptl. expanded view)

TABLE- IV

Comparison of Simulation and Experimental Results of 3-level inverter fed Induction Motor.

Parameters	3-level (12devices) [15]	3-level (9- devices)
Frequency	40Hz	50Hz
CMV(Simulation)	$155V_{Peak}$	$130V_{peak}$
CMV(Exptl.)	$135V_{peak}$	$116V_{peak}$
Shaft V(Exptl.)	$130V_{peak}$	$110V_{peak}$

VII. CONCLUSION

This paper presents a comparison of 3 phase two-level and 3-level inverter with 9-devices fed IM drive system for the harmonic components of the CMV. The amplitudes of CMV are reduced when the harmonics frequency increases. It has been verified that in the CMV the harmonic frequencies are 3-times the fundamental frequency (For 50Hz, harmonics at 150, 450, and 750Hz… etc.) shown in simulation results in Fig.12 and the experimental results shown in Fig. (13, 15). The CMV and Shaft voltage are in phase and magnitude.

Table III shows the CMV and Shaft voltage at the star point of the load for 50Hz of operation. It is to be noted that the 3-level with 12 devices results are taken from the earlier published work [15]. It is observed from the Table III that the 3-level inverter with 9-devices results have the lowest CMV and Shaft Voltage, when compared to 3-level 12 devices. Hence the harmonic content will also be lower, this would cause low stresses on IM winding insulation and minimizes EMI.

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VIII. ACKNOWLEDGEMENT

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Dr. V Muralidhara[3] obtained his B.E, and M.E degrees from University of Mysore and earned Ph.D. from Kuvempu University. He has a teaching experience of over 40 years inclusive of research as a par at of his Ph.D. Started his teaching career at PES College of Engineering Mandya, served there for 6 years and served for 31 years at Bangalore Institute of Technology [BIT], Bangalore and retired from there as Prof. & Head of EEE. Presently working has an Associate Director at Jain University. His area of interest is Power Systems and HV Engineering. In his credit he has 11 papers published in reputed International conferences and one paper in a Journal. At Present he is guiding five doctorate scholar. email: v.muralidhara@jainuniversity.ac.in)