Simulation and Experimental Validation of Common Mode Voltage in Induction Motor driven by Inverter using Arduino Microcontroller

Reddy Sudharshana K, A Ramachandran, V Muralidhara, R Srinivasan

Abstract- Generally the Induction Motor is known to be a constant speed motor. It is the prime power drive in industrial Applications. But due to the progress in engineering technology the speed of the Induction Motor can be varied within certain limitations. There are many techniques to control and run the machine in Variable speed drive applications. The basic method is 2-level inverter controlled by the microcontroller, using the space vector modulation method. By this method the output of the inverter will be Non- sinusoidal and hence at the star point of the load there exists a Voltage with respect to ground and it is known as Common Mode Voltage, induces electromagnetic interference which causes disturbance to the nearby communication and electronics equipment. To reduce the Common Mode Voltage a higher level of inverter 3-level can be used. By using the 3-level inverter the number of devices will be increased to twelve from six for 2-level. There is a method with less number of devices, nine for 3-level inverter, which gives better performance in terms of Common Mode Voltage than the 3-level method with twelve devices. In this paper the authors have discussed the 2-level, 3-level with twelve devices and 3-level with nine devices by simulation using MATLAB-Simulink and by Experiment. For 3-level inverter twelve devices, the Common Mode Voltage values are taken from the earlier published results. Fast Fourier transform has been done using the signal Analysis software and results are plotted with frequency versus voltage. The Phase Voltage, Line voltage and Common Mode Voltage are measured using Agilent make mixed signal oscilloscope. In the conclusion, the Common Mode Voltage values are compared with different operating frequencies of Induction Motor is shown in the table.

Index Terms- Common Mode Voltage, Induction Motor, Three phase voltage source 3-level/2-level inverter, Space Vector Modulation.

Manuscript received Feb 16 2017; Revised Mar 04 2017.

1. Reddy Sudharshana K, *Research Scholar, Electrical and Electronics Engineering, Jain University, Bangalore (India),* email: reddy3690@gmail.com

2. A Ramachandran, Scientist (Retd), National Aerospace Lab, Bangalore, *Prof., ECE, Vemana Institute of Technology, Bangalore (India),* email: arama1947@gmail.com

3. V Muralidhara, *Associate Director, Electrical and Electronics Engineering, Jain University, Bangalore (India),* email: v.muralidhara@jainuniversity.ac.in

4. R.Srinivasan, *Prof., ECE, Vemana Institute of Technology, Bangalore (India)*, email:rsrini47@gmail.com

I.INTRODUCTION

The Common Mode Voltage (CMV) exists in three phase Induction Motor (IM) adjustable speed drive using three phase inverter and is due to the non-sinusoidal output voltage from the inverter. The existence of CMV has been reported by B. Muralidhara [1], [2].The CMV analysis of inverter fed IM drive system that lead to shaft voltage and bearing current were recognized by Alger [3] in the year 1924 and S. Chen [4] in 1996. Due to the asymmetrical flux through the arbour line loop (the shaft loop) induces CMV. A. Muetze [5] reports the high-frequency (HF) component that exists at the CMV. Hence it is necessary to minimize the CMV within limits [6] so that there will be reduced bearing current and the insulation problem of the winding.

The three phase 2-level and 3-level inverter is widely used in variable speed AC three phase IM drive Systems, which produce three phase AC output voltage of desired amplitude and frequency from a fixed DC voltage source. 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 [7] 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 industrial applications. The drawbacks are complexity in circuits, the number of switching devices and various DC voltage levels. The Arduino [8] board that has been used to generate gate pulses is interfaced with necessary opto-isolation modules and three phase H-bridge circuit is used to drive the switching devices of 2/3-level inverter as per the Hexagon of the Space Vector Modulation (SVM) shown in Fig.2.

II. CMV IN INVERTER DRIVEN THREE PHASE IM

The CMV is represented in mathematical form, to analyze its characteristics among various types of source and load combinations. In three phase AC loads, 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 the source power supply. The sum of all three phase-to-neutral voltages is zero in a three phase sinusoidal

ISBN: 978-988-14047-4-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

balanced system; the voltage from the star point of load to common ground can be defined in terms of phase to ground voltage as shown in Fig.1.

$$V_{A\text{-}n} = V_{AN} + V_{N\text{-}n} \quad \text{-- (1)}$$
$$V_{B\text{-}n} = V_{BN} + V_{N\text{-}n} \quad \text{-- (2)}$$
$$V_{C\text{-}n} = V_{CN} + V_{N\text{-}n} \quad \text{-- (3)}$$

For balanced 3 phase system, $\sum_V = 0$

$$V_{AN} + V_{BN} + V_{CN} = 0 \quad \text{-- (4)}$$
$$V_{N\text{-}n} = [(V_{A\text{-}n} + V_{B\text{-}n} + V_{C\text{-}n}) / 3] \quad \text{-- (5)}$$

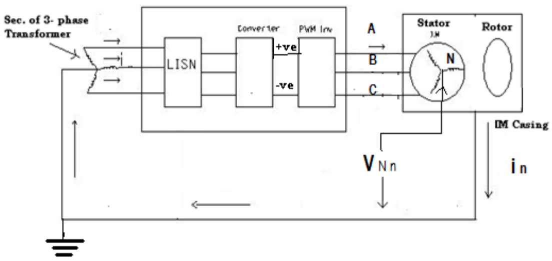


Fig.1, Schematic diagram of Inverter fed IM with CMV as EMI source.

III. SPACE VECTOR MODULATION

The experimental work uses a Space Vector Modulation (SVM) method, which produces the output voltage by using the three nearby output vectors. When one of the reference vector moves from one sector to another, results in an output vector abrupt change. In addition it is necessary to find the switching patterns and switching time of the states at each change of the reference voltage. The main advantages are to overcome the variation in DC bus voltage, 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 Pulse width modulation (PWM) technique represents the reference voltage V_{ref} 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 three phase voltage vector is transformed into a vector in the stationary α-β coordinate frame represents the spatial vector sum of the three phase 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

$$Va = Vm\ \mathrm{Sin}\omega t \quad \text{-- (6)}$$
$$Vb = Vm\ \mathrm{Sin}(\omega t\text{-}2\pi/3) \quad \text{-- (7)}$$
$$Vc = Vm\ \mathrm{Sin}(\omega t\text{-}4\pi/3) \quad \text{-- (8)}$$

SVM is a better technique for generating a fundamental output (~sine wave) that provides a higher output voltage to the three phase IM and Lower Total Harmonic Distortion (THD) when compared to sinusoidal PWM. The switching vectors for 2-level and sectors is shown in the Fig. (2-4).

Table I shows the switching sequence of vectors for 2-level three phase inverter. The Hexagon for the 3-level three phase inverter is shown in Fig.5 and the Table II shows the switching ON/OFF details.

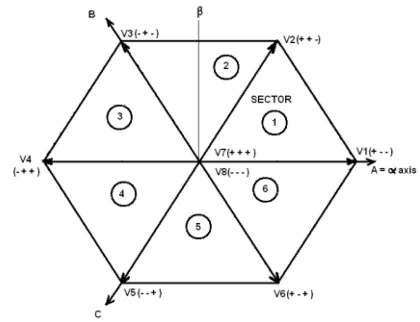


Fig.2 Switching vectors and sectors for 2-level

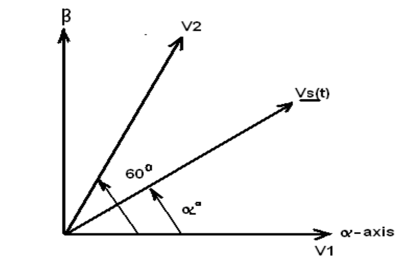


Fig.3 Sampled reference vector in sector-1

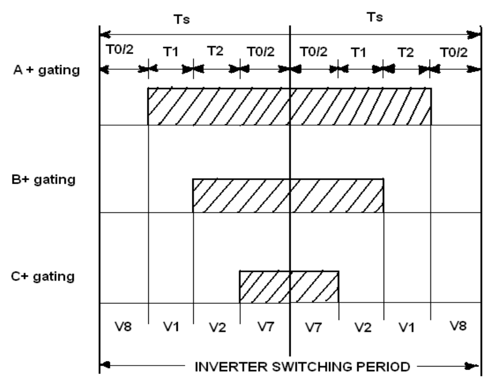


Fig.4 SVM pattern in Sector-1

TABLE I
Switching vectors for 2-level Inverter using SVM

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**	**$+V_{DC}$**	**0**	**$-V_{DC}$**
V_2[110]	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**$+V_{DC}$**	**$-V_{DC}$**
V_3[010]	**0**	**1**	**0**	**1**	**0**	**1**	**$-V_{DC}$**	**$+V_{DC}$**	**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**	**$-V_{DC}$**	**$+V_{DC}$**
V_6[101]	**1**	**0**	**1**	**0**	**1**	**0**	**$+V_{DC}$**	**$-V_{DC}$**	**0**
V_7[111]	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

Note: 1 means ON, 0 means OFF [+ Top switch, - Bottom switch]

ISBN: 978-988-14047-4-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

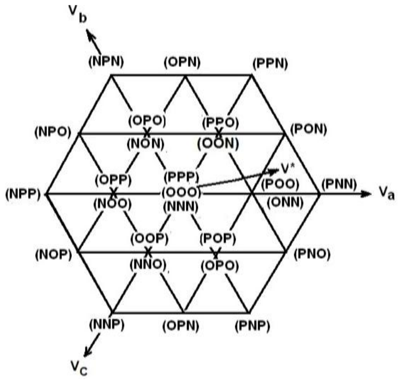


Fig.5 Switching vectors and sectors for 3-level

Table II
Switching vectors for 3-level three phase Inverter

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

IV. THE PROPOSED WORK

Simulation and experiment of 2-level inverter and 3-level inverter with 9 devices using SVM for the speed control of three phase IM are reported. The measurement of Phase voltage, Line Voltage, CMV, line current have been carried out in this paper using Agilent mixed signal oscilloscope (MSO) associated with isolation module, interface circuits, Line Impedance Stabilization Network and Hall Effect sensor. The 2-level and 3-level inverter are built using the DC link capacitors, MOSFET devices and necessary electronic circuits. The advantage of SVM is that the gating signal of the power devices can be easily programmed using Micro-controller offers improved dc bus utilization [9], reduced switching losses and lower THD. The SVM method has the advantage of more output voltage when compared to sine triangle pulse width modulation (SPWM) method [10].

V. EXPERIMENTAL SETUP

In the experimental circuit, the MOSFET's are used as switching devices with snubber circuit. The Arduino board output generates gating pulses to the MOSFET's and the necessary opto-isolation has been done [11], [12], [13]. The microcontroller is programmed for 30Hz, 40Hz and 50Hz frequencies. The necessary FFT analysis has been done in simulation using MATLAB/Simulink and for the experimental results using signal Analysis software. The CMV is analyzed for frequencies 30Hz, 40Hz and 50Hz. The simulation and the experimental circuits are shown in Fig. (6-7) for 3-level, Fig.8 shows for 2-level inverter.

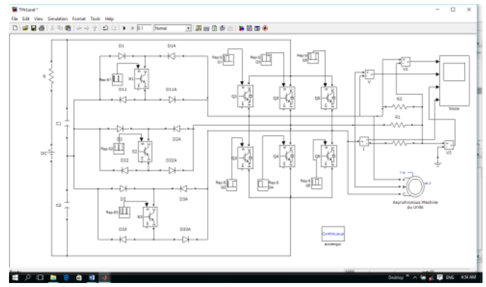


Fig.6 Simulation 3-level three phase inverter circuit

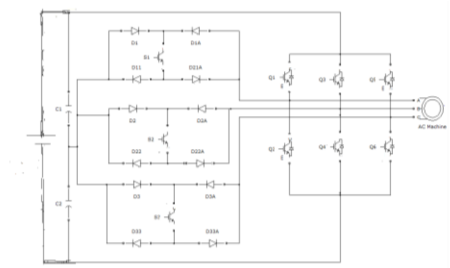


Fig.7 Experimental 3-level three phase inverter Circuit

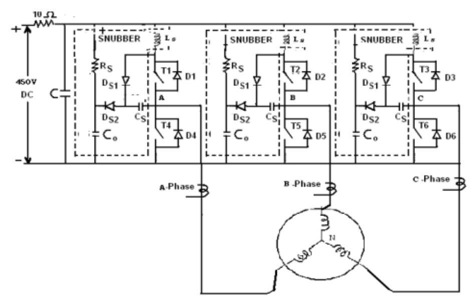


Fig.8 Experimenal 2-level inverter circuit

VI. SIMULATION AND EXPERIMENTAL RESULTS

The gating pulses generated by the Arduino board shown in Fig. 9. The simulated result waveform is shown in Fig. (10a), the experimental phase voltage, line voltage, CMV and line current waveforms are recorded shown in Fig. (10b). In CMV, the harmonic frequencies are three-times the fundamental frequency. The harmonic magnitude of voltage will not produce useable torque in the drive system. Some harmonic frequencies produce opposing torque and heat, which are harmful to the winding insulation of IM.

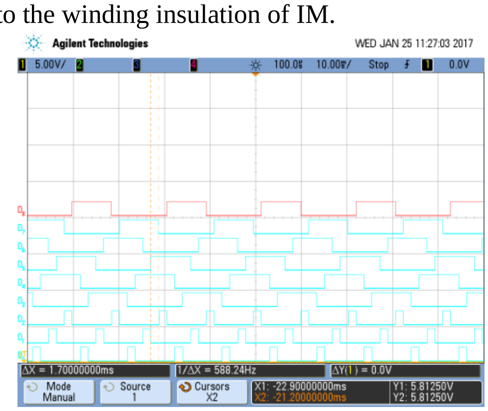
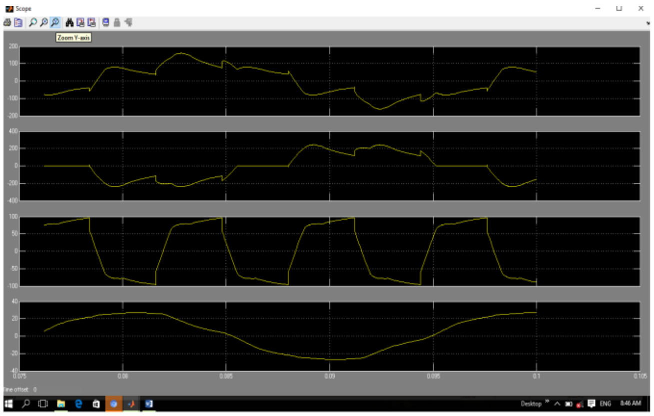
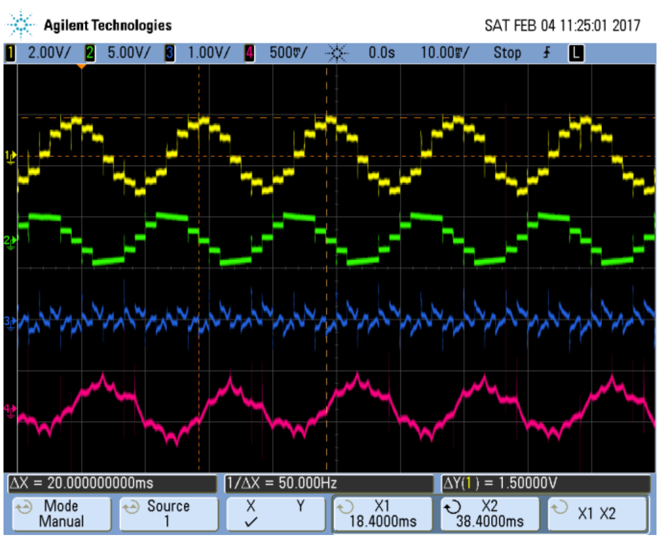


Fig. 9; Gate pulses generated for 3-level Inverter using Microcontroller

Fig. (11a-16a) shows the simulated FFT analysis of CMV using the MATLAB/Simulink and in the Fig. (11b-16b) shows the results of FFT analysis from the experimental work using Origin software.



CH 1 Phase Voltage, CH 2 Line Voltage, CH 3: CMV,
CH 4: Line Current
Fig.(10a) Simulation Inverter output waveforms (3-level 9 devices)



CH 1 Phase Voltage [200:1], CH 2 Line Voltage [200:1],
CH 3: CMV [200:1], CH 4: Line Current [1:1]
Fig. (10b) Experimental Inverter output waveforms (3-level 9 devices)

FFT ANALYSIS

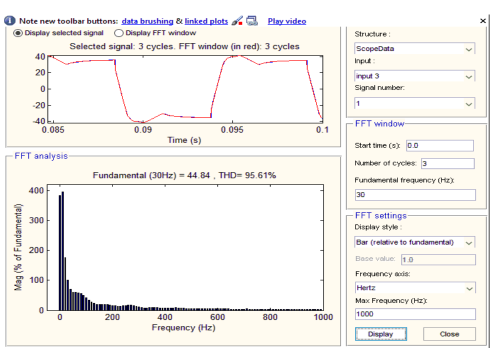


Fig. (11a) FFT of CMV (30Hz, 3-level)

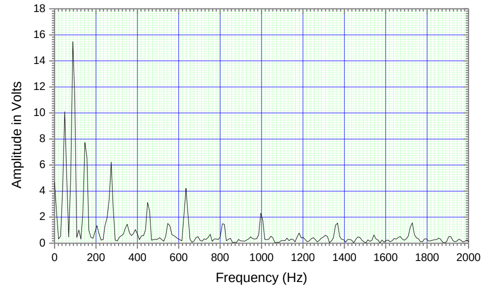


Fig. (11b) FFT of CMV (Exptl. 30Hz, 3-level)

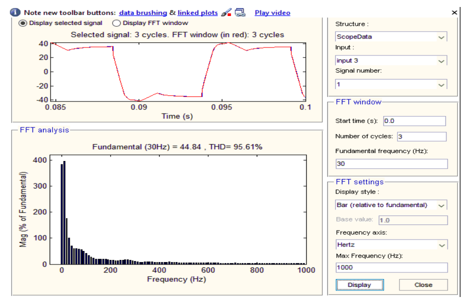


Fig. (12a) FFT of CMV (30Hz, 3-level) with reduced Scale

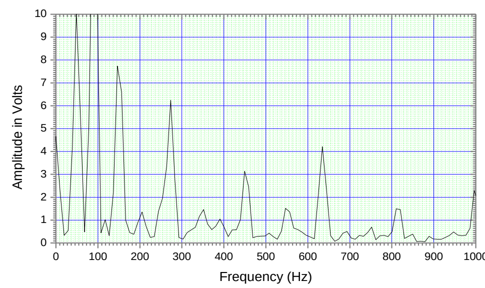


Fig. (12b) FFT of CMV (Exptl. 30Hz, 3-level) with reduced Scale

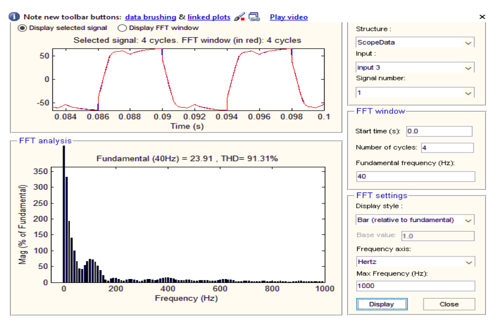


Fig. (13a) FFT of CMV (40Hz, 3-level)

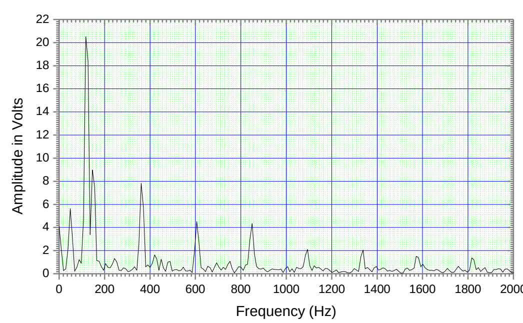


Fig.(13b) FFT of CMV (Exptl. 40Hz, 3-level)

ISBN: 978-988-14047-4-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

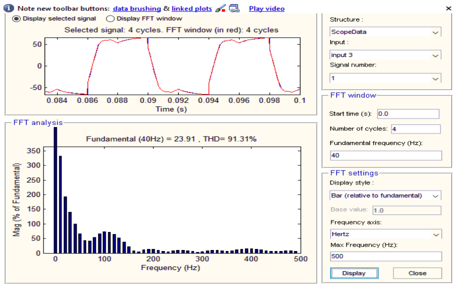


Fig.(14a) FFT of CMV (40Hz, 3-level) with reduced Scale

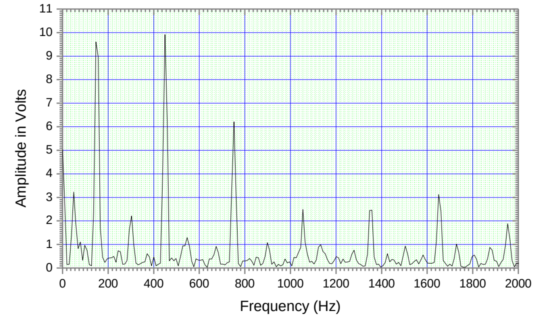


Fig.(15b) FFT of CMV (Exptl. 50Hz, 3-level)

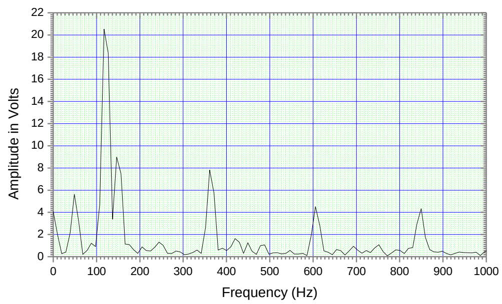


Fig.(14b) FFT of CMV (Exptl. 40Hz, 3-level) with reduced Scale

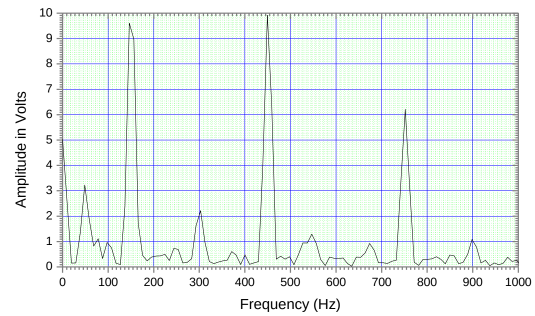


Fig.(16b) FFT of CMV (Exptl. 50Hz, 3-level) with reduced Scale

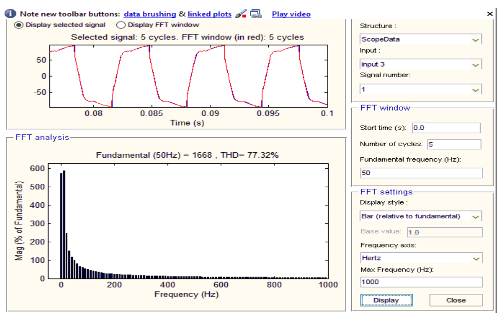


Fig. 15a: FFT of CMV (50Hz, 3-level)

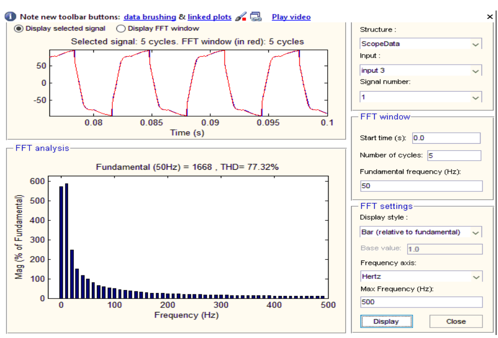


Fig.(16a) FFT of CMV (50Hz, 3-level) with reduced Scale

VII. CONCLUSION

This paper presents the comparison of three phase 2-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 three times the fundamental frequency (For 50Hz, harmonics at 150, 450 and 750Hz… etc.). The Figs. (11a-16a) show the simulation results and the Figs. (11b-16b) show the experimental results. It is observed from the Table III that the 3-level inverter with 9 devices result have the lowest CMV, when compared to 3-level 12 devices and 2-level 6 devices [15], [16]. Hence the harmonic content will also be lower than the others and this would cause less stresses on IM winding insulation.

ACKNOWLEDGEMENT

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

Table III
Comparison of simulation and Experimental Results of 2-level, 3-level inverter fed Induction Motor drive at different frequency

Parameters	2-level (6 devices)			3-level (12 devices) [14]	3-level (9 devices)		
Frequency	30Hz	40Hz	50Hz	40Hz	30Hz	40Hz	50Hz
CMV(Simulation)	110V	155V	162V	155V	110V	105V	100V
CMV(Exptl.)	100V	151.5V	160V	135V	95V	82V	80V

REFERENCES

[1] B Muralidhara, A. Ramachandran, R. Srinivasan, M Channa Reddy "Common Mode Voltage and EMI as the source of Disturbance to Communication Network Caused by Modern AC Motor Drive", Proceedings of 42nd IETE Mid-Term Symposium, dated 15-17, April 2011, Bangalore, India, pp. 90 – 94.

[2] B Muralidhara, A. Ramachandran, R. Srinivasan, and M. Channa Reddy, "Experimental Measurement and Comparison of Common Mode Voltage, Shaft Voltage and the Bearing Current in Two-level and Multilevel Inverter Fed Induction Motor," International Journal of Information and Electronics Engineering vol. 1, no. 3, - pp. 245-250, 2011.

[3] P. Alger and H. Samson "Shaft currents in Electric machines" in Proceeding AIRE Conf. Feb, 1924.

[4] S. Chen, "Bearing current, EMI and soft switching in induction motor drives," Ph.D. dissertation, Univ. Michigan, Ann Arbor, MI, 1996.

[5] A. Muetze and A. Binder, "Systematic approach to bearing current evaluation in variable speed drive systems," "Eur. Trans. Elect. Power", vol. 15, no. 3, pp. 217–227, 2005.

[6] C. R. Paul, "Introduction to Electromagnetic Compatibility Wiley Series in Microwave and Optical Engineering" John Wiley & Sons, Inc.1992.

[7] A. Nabae, I. Takahashi, and H. Akagi, "A New Neutral-point Clamped PWM inverter," IEEE Trans. Ind. Application., vol. IA-17, pp. 518-523, Sept./Oct. 1981

[8] Arduino Manual.

[9] P. Srikant Varma and G.Narayanan, "Space vector PWM as a modified form of sine triangle PWM for simple analog or digital implementation" IETE journal of research, vol.52, no.6,Nov/Dec.2006. pp 435-444.

[10] G. Narayanan, and V.T. Ranganathan, "Synchronised PWM strategies based on space vector approach : Principles of waveform generation", IEEE Proceedings- Electric Power Applications, vol 146 No.3, May 1999, pp. 267-275.

[11] B. K. Bose: "Power Electronics and Variable Frequency Drives: Technology and Applications" IEEE Press and John Wiley & Sons, Inc.

[12] ABB automation Inc., IEEE industry applications Magazine, July, Aug. 1999.

[13] Gary L. Skibinski, Russel J. Kerkman and Dave Schlegel (Rockwell Automation): EMI Emissions of modern PWM AC drives. IEEE Trans. Ind. Application. Nov/Dec.1999. pp-47-81

[14] Muralidhara B. "An Experimental evaluation of 2-level and multilevel inverters used for speed control of IM and study of Common Mode Voltage in both cases". JNTU, Ph.D. Thesis Aug 2013.

[15] Reddy Sudharshana K, A. Ramachandran, V. Muralidhara, "Simulation and Experimental evaluation of Variable speed Induction motor drive fed by VSI and study of Current Harmonics under steady state conditions", IJEEE (ISSN 2321-2055), Volume No. 09,Issue 01, pp.1-10 Jan-June 2017

[16] Chandrashekar S.M, Reddy Sudharshana K, A.Ramachandran and M.Channa Reddy,,"Simulation of Common Mode Voltage, Experimental measurement and Analysis of Shaft Voltage in Variable speed Induction Motor drive fed by VSI based on Space Vector Modulation Method using μ-controller". IJEEE (ISSN 2321-2055), Volume No. 09, Issue 01, Jan-June 2017.

Mr.Reddy Sudharshana K. received the B E, and M. E degree in Electrical engineering from Bangalore University, Bangalore .He is working as an Assistant Professor, Vemana I. T., Bangalore- 560034. India. He has guided many Undergraduate students in Power Electronics field. At present pursing for Ph.D. Degree (Research Scholar) with Jain University, Bangalore, India. He is the member of ISTE, IEEE and Branch counselor, IEEE Student Branch at Vemana I.T. In his credit he has 2 papers published in reputed International conferences / Journal. (email:reddy3690@gmail.com)

Dr.A.Ramachandran obtained his Bachelor's, Master's and doctoral Degree in Electrical Engineering from Bangalore University, Bangalore, India. He was with National Aerospace Laboratories Bangalore, India, as scientist in various capacities, and was working in the areas of Power Electronics & drives for the past 41years. He was heading the Instrumentation & controls group of Propulsion Division, and guided many Bachelors and Masters Degree students for their dissertation work. He has also guided Ph.D., for the dissertation work and earlier worked has principal, after superannuation and at present professor ECE department, Vemana I.T.Bangalore-34, having number of papers to his credit both in the national/international Journals / conferences. (email:arama1947@gmail.com)

Dr.V.Muralidhara 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)

Dr.R Srinivasan obtained his Bachelor's, Master's and doctoral Degree in Electrical Engineering from Indian Institute of Science, Bangalore, India. He was with National Aerospace Laboratory has a Scientist and also with Indian institute of Astro-Physics as Professor. After superannuation he is at present as professor in the ECE department at the Vemana Institute of Technology, Bangalore India.. He has guided many Bachelor's, Master's and Ph.D. Students for the dissertation work. He has also published number of papers in the national/international conferences and Journals.

ISBN: 978-988-14047-4-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)