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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

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ABSTRACT

In earlier days the Induction Motor is considered to be a constant speed motor. But with the advent of microprocessor / microcontroller the speed of the induction Motor (IM) can be varied within certain limits. The 2-level inverter controlled by microcontroller, using the space vector modulation technique is used. The output of the inverter will not be sinusoidal and hence there exists a common mode voltage (CMV) between the star point of stator winding of the IM and the common ground. This produces Electromagnetic interference (EMI) and causes the disturbance to the nearby communication and measuring equipments. In addition, the CMV induces voltage at the shaft resulting in the flow of current from the shaft to the common ground through the bearing. The voltages and currents are recorded using Agilent make mixed signal oscilloscope (MSO). In addition necessary isolation module, high frequency current probes, Hall sensor and Line Impedance Stabilization Network (LISN) are also used while conducting the experiment. Simulation has been carried out using MATLAB/Simulink and the signal analysis software is used to perform Fast Fourier transform (FFT) of the experimental results. The results obtained can be compared with Federal communication committee (FCC) and special committee on radio interference (CISPR) standards.

Keywords: Common mode voltage, shaft voltage, space vector modulation, variable speed induction motor drive, voltage source inverter.

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I. INTRODUCTION

It is a fact that if the 3Φ inverter is fed from a single DC source it is impossible to get zero voltage at the neutral point of the stator of the IM winding or the 3Φ load [1]. The voltage at the neutral point of the 3Φ load with respect to the common ground is called CMV [1, 2 & 14]. Due to the presence of CMV there will be a voltage induced in the shaft of the IM.

The 3Φ inverter is widely used in variable speed AC IM drive System and the output of the inverter is the 3Φ AC voltage of desired amplitude and frequency from a fixed DC voltage source. The 2- level inverter has levels of voltages [$\pm 2/3V_{dc}$, $\pm 1/3V_{dc}$]. The 2-level inverter output waveform is a stepped square wave, contain harmonics and to reduce the harmonics in the output waveform of the 3Φ inverter, multilevel inverter concept is widely used.

The earlier researchers [3, 4] found that there will be a premature / frequent failure of the bearing used in the speed control of IM using inverter, than operating the motor with sinusoidal mains at supply frequency of 50/60 Hz . From the references [3, 4, 5, 6, & 7] the inverter fed IM bearings have more probability of failing than mains operated 50/60Hz supply. Also in the year 1924 P. Alger and H. Samson [14] have discussed about the shaft currents in electric machines.

The concept of currents flowing from the shaft to the ground through the bearing in variable speed drive systems using Converter-Inverter is due to the existence of CMV and also by fast switching of the inverter devices has been reported for almost a decade ago [8,9, & 10]. It has also been reported by Annette Muetze et al. [4] shaft to ground currents can be due to the influence of CMV and the capacitance between stator and rotor windings with high dv/dt at the input of the IM terminals [3,4 & 11]. In addition, B. Muralidhara etal [1] has reported about the existence of CMV and hence shaft voltage, resulting in flow of current to the common ground. D. Busse etal. [7], in the year 1997 discussed about the characteristics of shaft voltage and bearing currents. As summarized by Chen etal. [8 & 12] there are three general types of motor bearing currents (stator to rotor bearing current, stator winding to ground current, rotor to shaft current) that can be associated with pulse width modulation (PWM) VSI drive [4, 6 & 11]. Therefore for the safe operation of the motor bearing connected with inverter system, it is essential to reduce the shaft voltage and there by the current flows from shaft to the ground [13]. To reduce the shaft voltage it is necessary to measure and reduce the CMV.

II CMV, SHAFT VOLTAGE AND SUM OF PHASE CURRENT ETC, IN INVERTER DRIVEN AC IM

In a 3Φ AC system, the CMV can be defined as the voltage between the common ground and the star point of the load. It is important to define the CMV in mathematical terms in order to compare its characteristics among different types of source and load combinations. In a 3Φ system, the phase to neutral voltages (V_{A-n}, V_{B-n} and V_{C-n}) can be written as the sum of the voltages to the star point of the load and the star point of the load to common star point (V_{N-n}). Since in a balanced system, the sum of all three phase-to-neutral voltages is zero, the voltage from the neutral to ground (CMV) can be defined in terms of phase to ground voltage as shown in Fig.(1).

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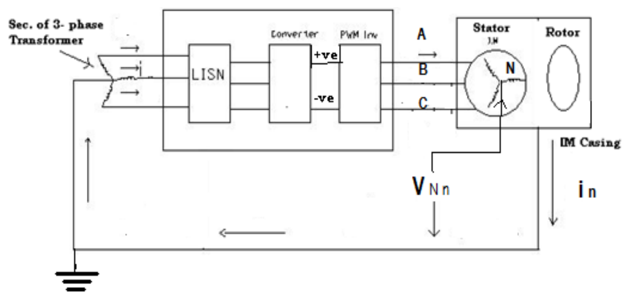

: $V_{A\text{-}n} = V_{AN} + V_{N\text{-}n}$ (1)

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

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

For balanced three phase system

: $V_{AN} + V_{BN} + V_{CN} = 0$

: $V_{N\text{-}n} = (V_{A\text{-}n} + V_{B\text{-}n} + V_{C\text{-}n}) / 3$

:CM current "I_{lg}" $= C \frac{dv}{dt}$

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

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

III THE PROPOSED WORK

Simulation, experiment of two level inverter using SVM for the speed control of induction motor , has been done with the measurement of CMV, Phase voltage, sum of phase currents, shaft induced voltage and the current flowing from the shaft to the common ground using Agilent MSO, isolation modules, high frequency current probes,LISN and Hall effect sensor. The inverter is built using the IGBT/MOSFET devices, DC link capacitors and other electronic components.

SVM methodologies have the advantages of more output voltage when compared to sine triangle pulse width modulation (SPWM) method [15]. The advantage of using the SVM is that the gating signal for the power devices can be easily programmed using µ-controllers / digital signal processor (DSP) and offers improved dc bus utilization [16] reduced switching losses and lower total harmonic distortion.

IV EXPERIMENTAL SETUP

The Fig.1 shows the schematic diagram, Fig. (2 & 3) shows the simulation and the experimental circuit. The Fig.6 shows the photograph of the experimental setup. In the inverter, the IGBT/ MOSFET are used as devices with necessary snubber circuit. The microcontroller output after isolation is given to the gate of the devices [15, 2 and 14]. The microcontroller is programmed for different frequencies of operation of the IM and the typical output of the microcontroller is given in the Fig. (4b). While running the IM with the above said setup the shaft voltage, CMV, phase voltage, the current flowing from shaft to common ground and the sum of phase current are recorded using the high frequency current probe and Agilent MSO/DSO for further analysis. The necessary FFT has been done in simulation using MATLAB and for the experimental results the Origin signal Analysis software was used. At the end, the results are discussed showing that the sum of phase current and the bearing current are same in magnitude and phase. Also the CMV and the shaft voltage are in the same phase, for different frequencies of operation of the IM viz 30Hz, 40Hz and 50Hz. The currents are measured using the Hall sensors, High frequency current probe and the recorded wave-form is given in the Fig.(7a) & (7b)

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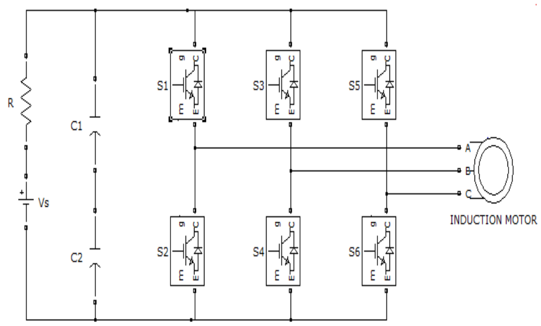

Fig.2 Simulation Circuit diagram

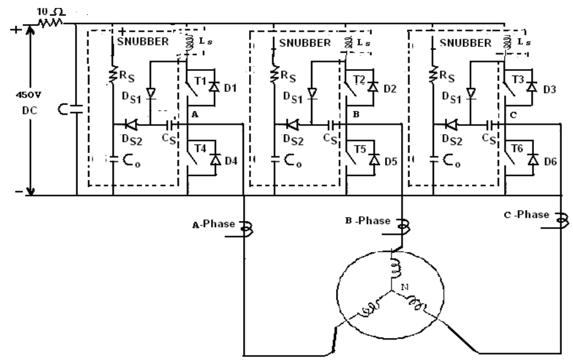

Fig.3 Experimental set up Circuit diagram

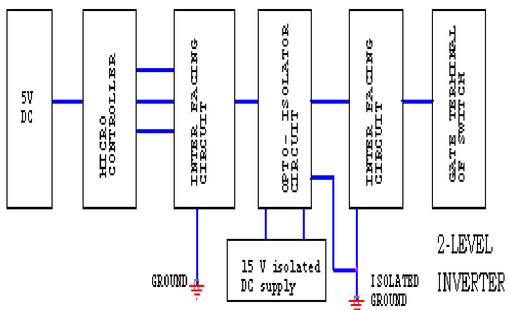

Fig. (4a).Block diagram of gate drive circuit micro controller

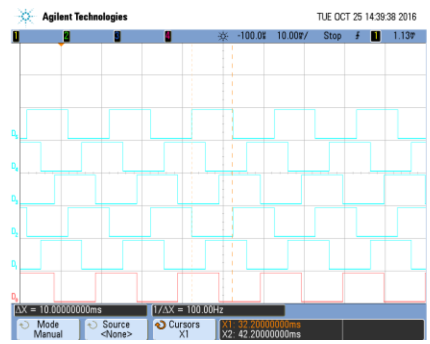

Fig. (4b).Gate pulses generated for Inverter using

4.1 Simulation

The MATLAB / Simulink is used to simulate the circuit shown in the Fig.2. The results are recorded and shown in Fig. (5)

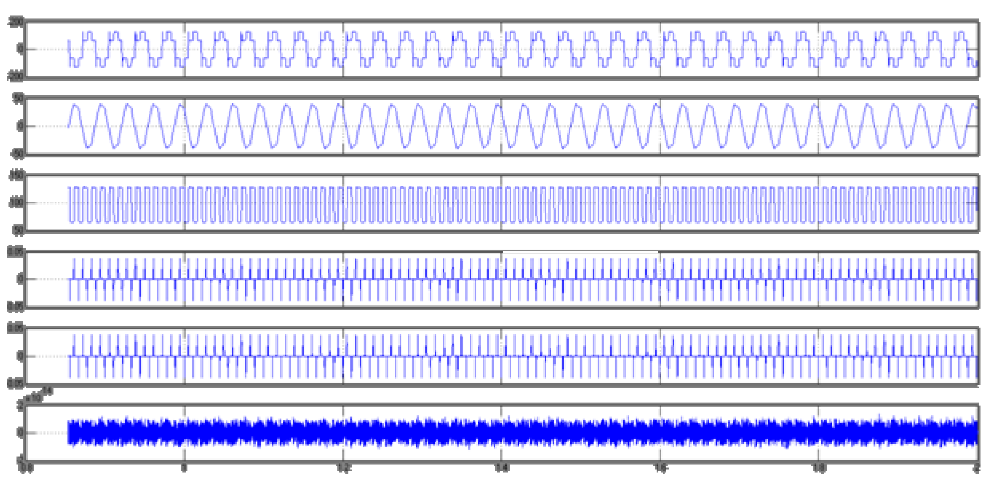

Fig. (5). [top to bottom] Simulation, 30Hz. Ch-1:ph voltage, Ch-2: line current, Ch-3: CMV, Ch-4: Sum of ph current, Ch-5:bearing current, Ch-6: Sum of ph Ct. – Bearing Ct.[(ch-4)-(ch-5)]

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Fig. (6). Photograph of Experimental Setup.

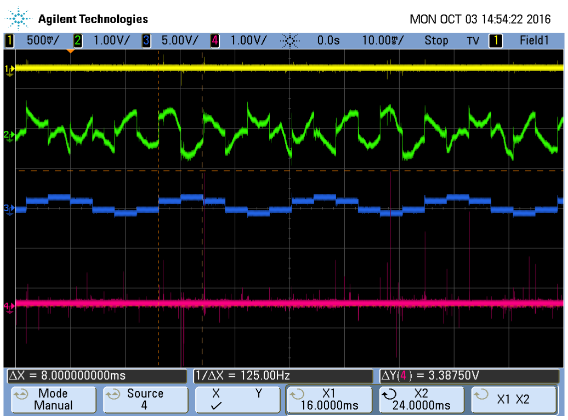

Fig.(7a): Ch 1: (200:1)Shaft Voltage, Ch 2:(200:1) CMV, Ch 3:(200:1) Phase Voltage, Ch 4:(1:1) Bearing Current (in terms of Voltage). (H.F probe voltage)

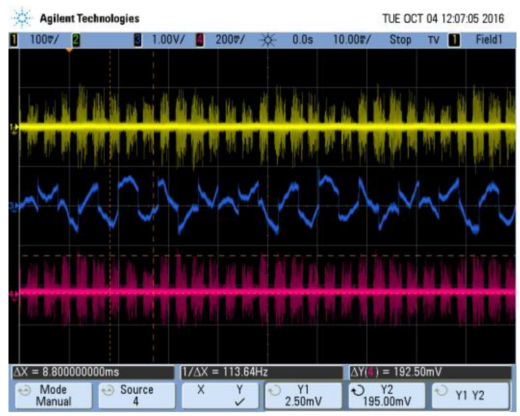

Fig.(7b): Ch 1: (1:1) Sum of Phase Current,(in terms of Voltage) Ch 3: (200:1) CMV, Ch 4: (1:1) Bearing Current (in terms of Voltage). (H.F probe voltage)

V SIMULATION AND EXPERIMENTAL RESULTS

The block diagram of the gate drive circuit is shown in Fig. (4a) and the experimental circuit is shown in Fig. (3). Fig. (4b) shows the gating pulses generated by the microcontroller. The phase Voltage, shaft Voltage, CMV, current from the shaft to common ground through the bearing and sum of phase current (at the instant when the current flows from shaft to ground the shaft Voltage reduced to very minimum) are recorded as shown in Fig (7a & 7b). The simulated FFT and the experimental (exptl.) results are shown in Fig (8a) to (12g).

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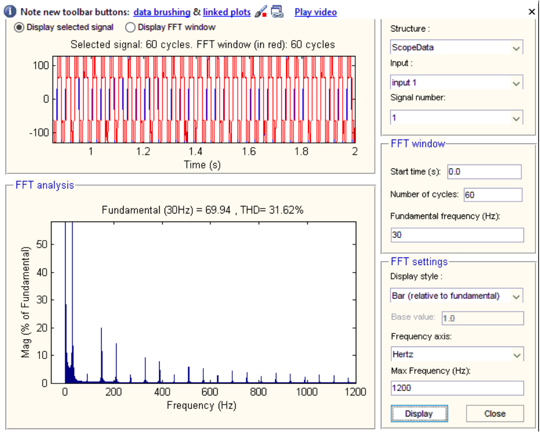


Fig.(8a): FFT of Phase Voltage (30Hz)

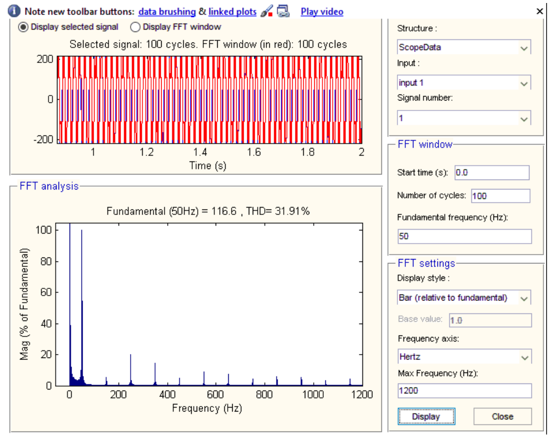
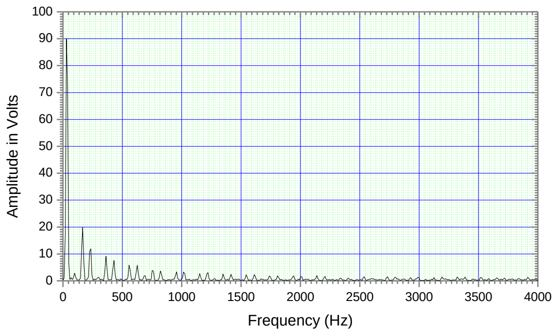


Fig.(8b): FFT of Phase Voltage (50Hz)



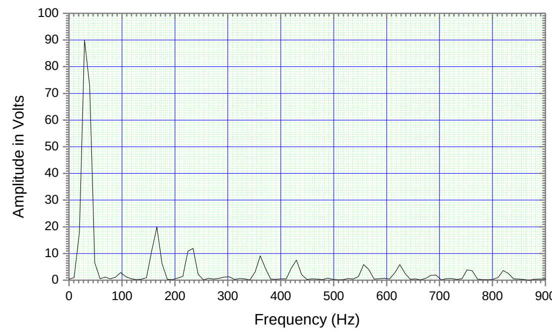
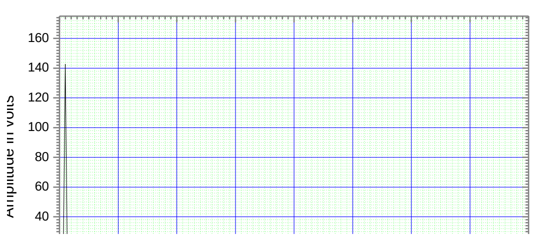


Fig.(8c): FFT of Phase Voltage (Exptl.)(30Hz) Fig.(8d): FFT of Phase Voltage (Exptl.) (30Hz) Expanded Y-axis



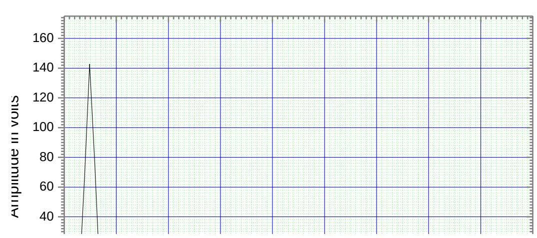


Fig. (8e): FFT of Phase Voltage (50Hz) (Exptl.) Expanded

Fig. (8f): FFT of Phase Voltage (50Hz)

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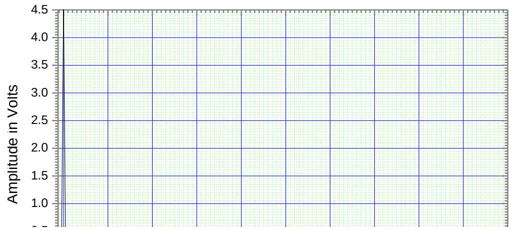


Fig. (9a) FFT of Shaft Voltage (30Hz) (Exptl.)

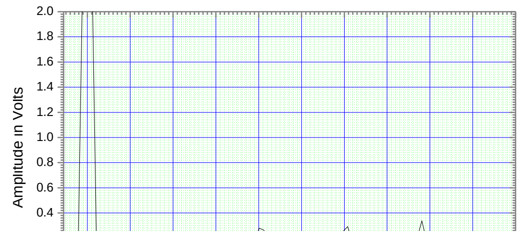


Fig.(9b) FFT of Shaft Voltage (30Hz) Expanded (Y- axis)

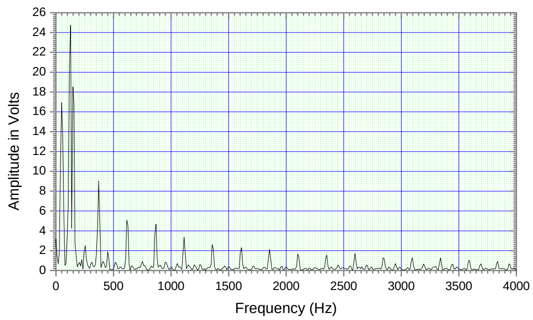


Fig. (9c) FFT of Shaft Voltage (40Hz) (Exptl.)

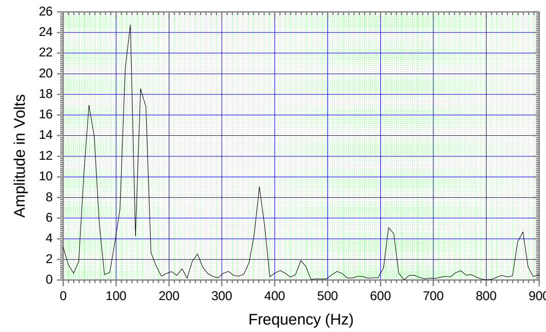


Fig. (9d) FFT of Shaft Voltage (40Hz) Expanded (Y- axis)

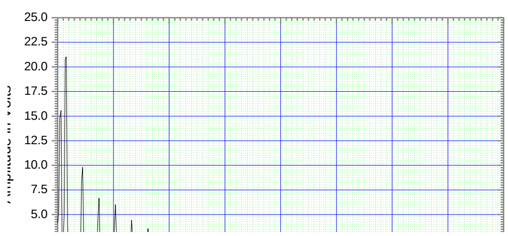


Fig. (9e) FFT of Shaft Voltage (50Hz) (Exptl.)

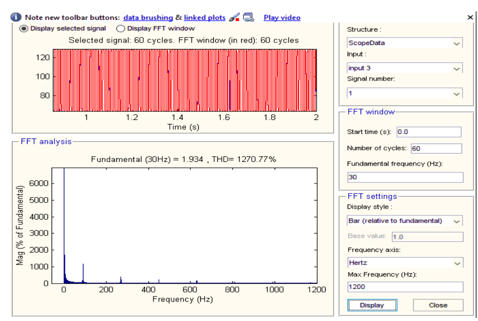
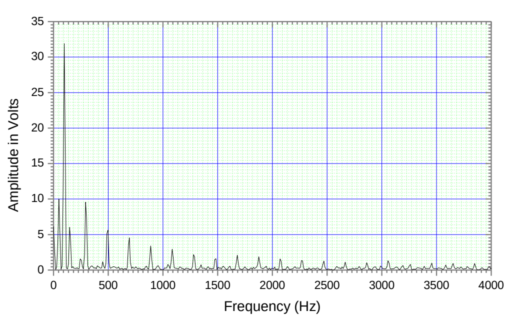


Fig.(10a) FFT of CMV(30Hz)



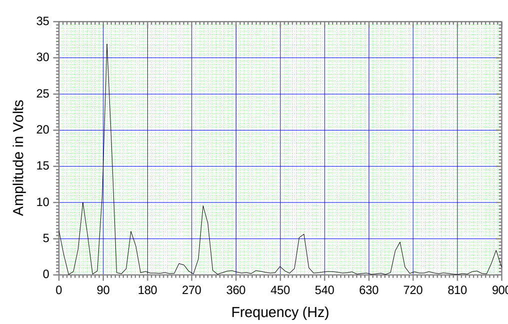


Fig.(10b) FFT of CMV (30Hz) (Exptl.)

Fig.(10c) FFT Of CMV (30Hz)Expanded (Y-axis)

(Exptl.)

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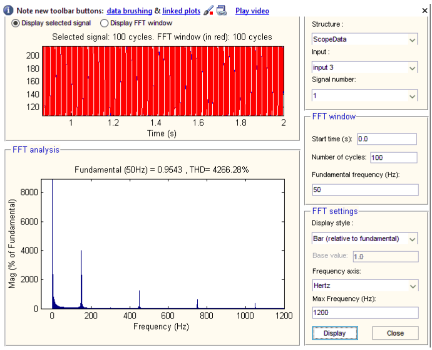

Fig. (10d) FFT of CMV(50Hz)

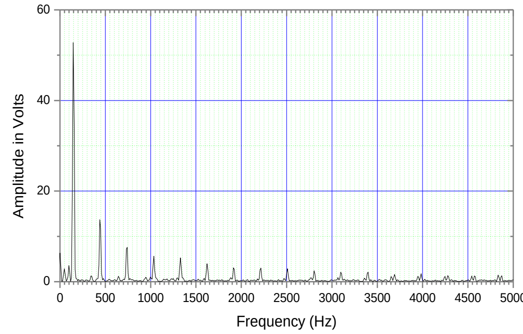

Fig.(10e) FFT of CMV (Exptl.) (50Hz)

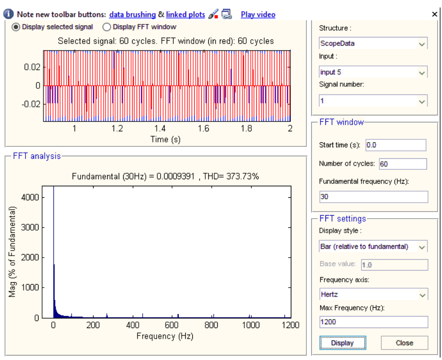

Fig.(11a) FFT of Bearing Current (30Hz)

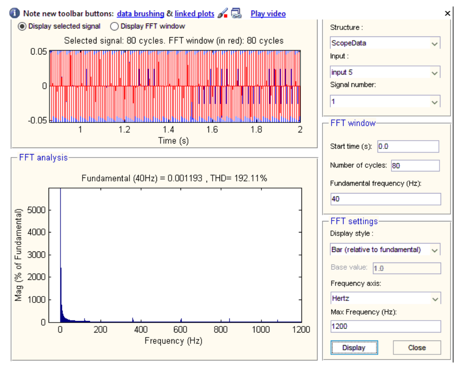

Fig.(11b) FFT of Bearing Current (40Hz)

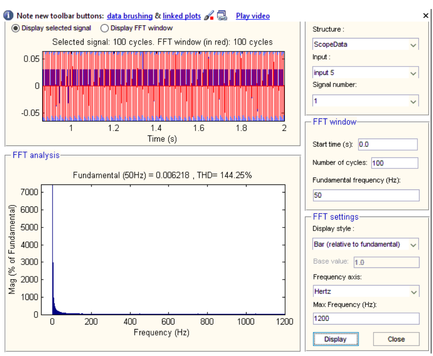

Fig.(11c) FFT of Bearing Current (50Hz)

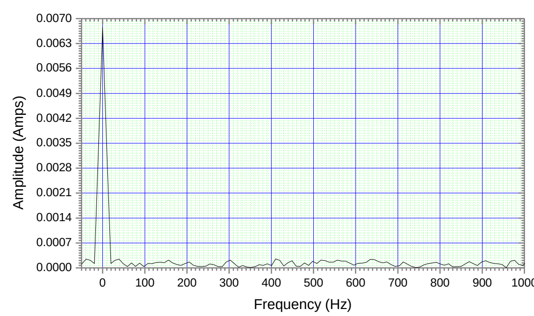

Fig.(11d) FFT Of Bearing Current(Exptl.) (30Hz)

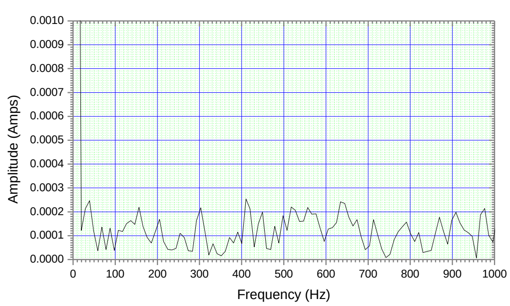

Fig.(11e) FFT Of Bearing Current (Exptl.) (30Hz) (Expanded Y-axis)

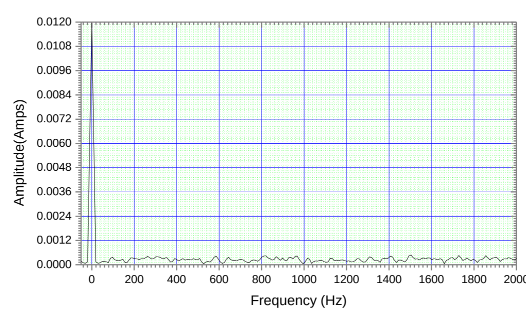

Fig.(11f) FFT of Bearing Current(50Hz)

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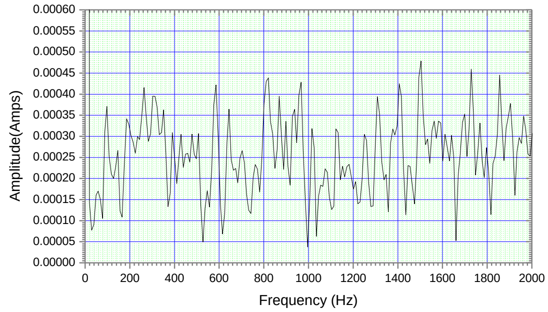

Fig.(11g) FFT of Bearing Current(50Hz) Expanded (Y-axis)

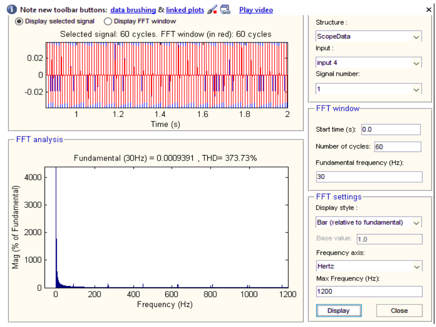

Fig.(12a) FFT of Sum Of Ph Current.(30Hz)

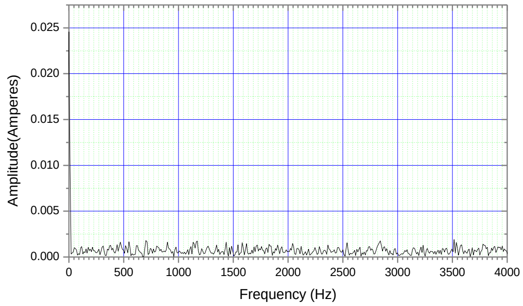

Fig.(12b) FFT of Sum Of Ph Current.(Exptl.) (30Hz)

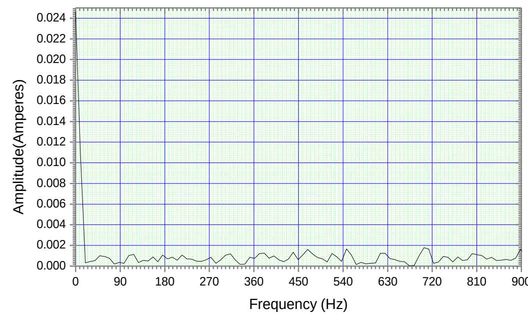

Fig.(12c) FFT of Sum Of Ph Current. (30Hz) expanded.

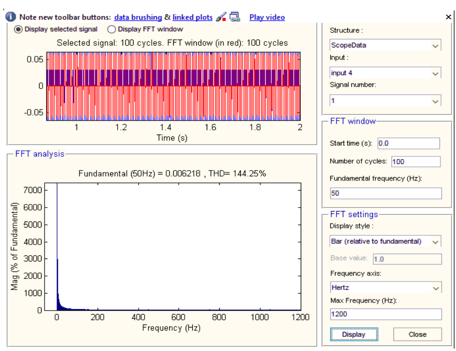

Fig.(12d) FFT of Sum Of Ph. Ct.(50Hz)

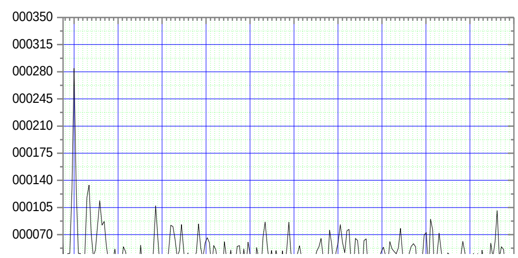

Fig.(12e) FFT of Sum Of Ph Ct.(Exptl.) (40Hz)

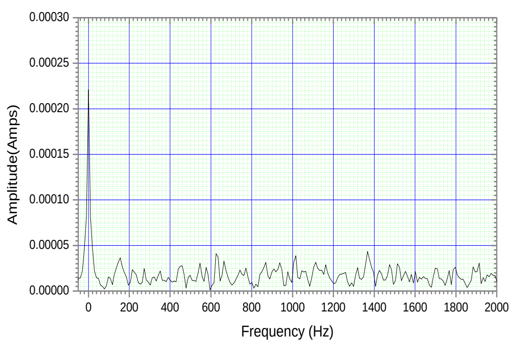

Fig.(12f) FFT of Sum Of Ph Ct.(Exptl.) (50Hz) expanded

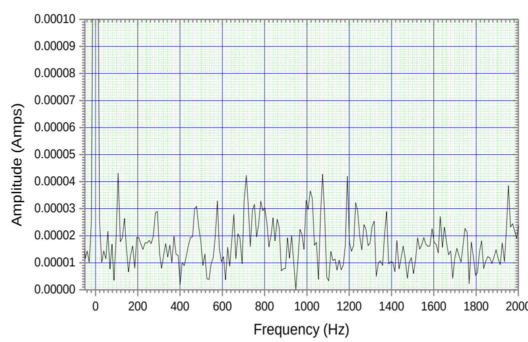

Fig.(12g) FFT of Sum Of Ph Ct.(Exptl.) (50Hz)

VI CONCLUSION AND DISCUSSION

In Fig (8a- 8f) shows the phase voltage, it is clear from the simulated and the experimental graphs that the harmonic frequencies coincide. The magnitude in the experimental waveform shows 90V at the fundamental (simulated ~95V), the subsequent harmonic voltages (5^{th}, 7^{th}, 11^{th}, 13^{th} and so on) in simulation and in the experimentation reduces appreciably and will not have much effect. The shaft induced voltage in Fig. (9a-9e) (exptl. only) shows a maximum of 4V at the fundamental and it reduces with increasing in frequency. Fig.(10a-10e) shows the FFT of simulation and experimental values of CMV. The shaft voltage frequency will be three times the fundamental frequency and is in phase with the CMV. Observing the exptl. results it can be concluded that with increase in (In 30Hz operation the experimental value of CMV is ~32V and for 50 Hz it is ~52V) operating frequency the CMV is increased. Fig. (11a-11g) shows the simulated and the experimental values of FFT of bearing current. High frequency current probe is used to capture the current while doing the experiment and ~100nF is used in series with the CMV to ground to measure the bearing current in simulation. The value of capacitor is taken from the literature [18]. High value of current is not advisable since the premature bearing failure will occur due to electrical discharge machining in the inner race of the bearing [4, 13]. Fig. (12a-12g) gives the sum of phase currents of the load. The sum of phase current and the bearing current will be more or less the same in magnitude and phase shown in waveform of Fig. (7b). Also same in magnitude and in phase with the common mode current and is not shown.

From the above results it is concluded that the frequency of CMV will be three times the fundamental frequency and the shaft voltage will be of the same frequency as that of CMV. Hence, it is necessary to reduce the CMV and there by the shaft voltage so that the bearing current can be minimized. To reduce the CMV one of the many methods is the multilevel inverter concept.

VII ACKNOWLEDGEMENT

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