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An Advanced Filter Topology and Effects for compensating common Mode Voltage in Vehicular Induction Motor Drives

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Abstract: Recently the utilization of electric vehicle technology increasing drastically, because of environmental changes arises throughout the globe. Based on these issues, this paper focuses on the drive used in the electric vehicle with more economically. In general electric vehicles the induction motor drives are used, because they have great features, such as high starting torque and high efficiency. The motor drive is driven by the high switching frequency PWM inverter supplied by a dc source or supply, because of this switching frequency common mode (CM) voltage generated at the input of stator motor terminals, creating a shaft voltage through the motor air gap with possible rise in bearing current, leading to premature damage to the motor reliability and lifetime. To compensate this problem an advanced active filter is designed, which will suppress the common mode voltage. And also analyze the impact of electromagnetic interference (EMI) on drive under the test (DUT). The above system will initial executed in the electrical software tools like MATLAB/SIMULATION for confirmation of the results, suitable for electric vehicle applications, especially for induction motor drives.

Keywords: Common mode (CM) voltage, Shunt active filter, Electromagnetic Interference (EMI), Induction Motor drive.

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I.INTRODUCTION

In the present applications of electrical vehicles, high quality output is achieved through the pulse width modulation (PWM) IGBT switches. It creates high switching frequency at the inverter output terminals and generates common-mode voltages at drive input side. This common mode voltage produces shaft voltage therefore produces bearing currents through stray capacitances. Amplitude of the shaft voltage and bearing current influence the electromagnetic interference (EMI) problems. It also leads to severe damage to the insulation of the motor i.e. life time and reliability of the motor [1].

Several literatures exhibit that the suppression of the common mode voltage in the induction motor drive fed by high voltage dc supply [2-4]. They have proposed the common mode active filters to mitigate the common mode voltage at the input motor terminals. Two kinds of methodologies are proposed to synthesis the common mode voltage, one of them is the passive circuitry [5], it consists of simply resistors, inductors, capacitors and common mode chokes. The values of those parameters are depending on the length of the cable from inverter and motor [6]. The second methodology is used to mitigate the common mode voltage on the inverter fed induction motor drive with an active circuitry. This is the one of the most effective processes used in the industrial drives in the last five years. Generally, it eliminates the mirror image of common mode voltage, i.e. shaft voltage and the bearing currents [7-10]. This active circuit canceller contains different parts for detection and reinjection of the voltage in the line, this detection circuit consisting of star connected capacitors, Darlington pair of transistors, a four winding transformer and additional dc power supply. This circuit focuses on the common mode voltage detection at the inverter output, transfer of the common mode voltage by a voltage follower amplifier to a common mode transformer and reinjection of the compensated voltage through CMT [11-15].

In this paper, a dc power supply of 575V is derived from an ac power supply for reduction of the cost. This is proposed for the suppression of common mode voltage and thereby shaft voltage and bearing currents will be reduced. The proposed methodology is simulated using MATLAB and executed experimentally further.

A high frequency model induction motor is used throughout the simulation. According to the CISPR model, a dedicated 600V high voltage dual-LISN [16-17] is designed and built for the simulation, Also concentrated on the active common mode voltage canceller (ACMVC) for compensating the common mode voltage. The present literature represents that the emitter follower realized by transistors (at present, bipolar p-n-p transistors with more than 400V are not available) instead of MOS-FET transistors are implemented in this investigation. The proposed methodologies are supposed to be implemented in electric vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles and fuel-cell vehicles that improves the overall system reliability and also reduces the cost and size.

This paper is organized in different sections, introduction of the work is presented in section I. In section II, the design considerations of the high voltage dual channel Line impedance stabilization network (LISN), standards for comparison of results with the CISPR, circuit configurations, mathematical design features are explained. Section III describes design considerations for high frequency induction motor model to make it suitable for measurement of common mode ground currents, and its equivalent circuits with values. In section IV, design features for the common mode voltage active canceller (CMVAC), its circuit configurations, and CMT are described. Section V describes the results obtained in simulation. The outcomes of the work are concluded in section VI.

II. LINE IMPEDANCE STABILIZATION NETWORK DESIGN CHARACTERISTICS

The Line impedance stabilization network is a low pass filter placed between AC or DC power source and the equipment under test (EUT) to create known impedance as per complying standard for the measurement of conducted emission. This provides a Radio frequency (RF) noise measurement port. It also isolates the unwanted RF signals from the power source when pre-filter is included. Specifications of The LISN are presented in Table 1.

The LISN is generally used in the repeatable and accurate measurements of the conducted emissions generated by the high switching frequency inverters. Two identical LISNs are placed in the same metal structure (line and neutral). As per the standards of CISPR, the values of the line and neutral LISNs are inductance (L) of 5μH, capacitor (c1) with 1μF on the mains side. A 50Ω resistance, output measuring instrument, and coupling capacitor c of 0.1μF are placed on the drive under test side (DUT). [19-20],

The Figure 1 shows the circuit model of the high voltage dual channel LISN, which is built on dedicated earthing. More or less each of LISN must meet the standard impedance curve defined by CISPR16-1[20-21] as shown in Figures 2-4. And also the ideal impedance curve and measured impedance curves at the line and neutral are represented in Figure 2, Figure 3, and Figure.4. These curves are measured by Rohde and Schwarz vector network analyzer ZVRE.

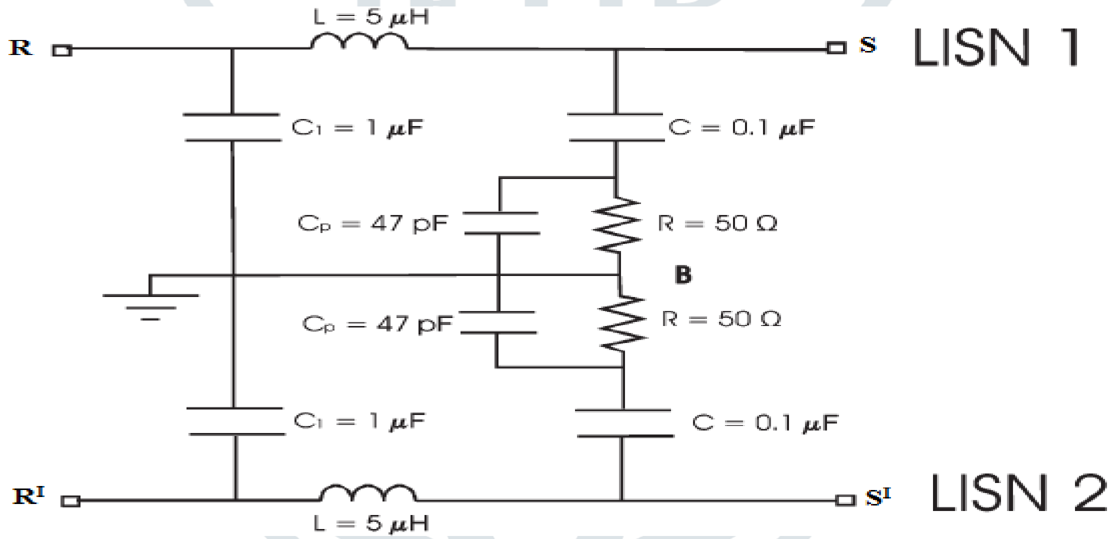


Fig: Circuit model of high voltage dual Line Impedance Stabilization Network

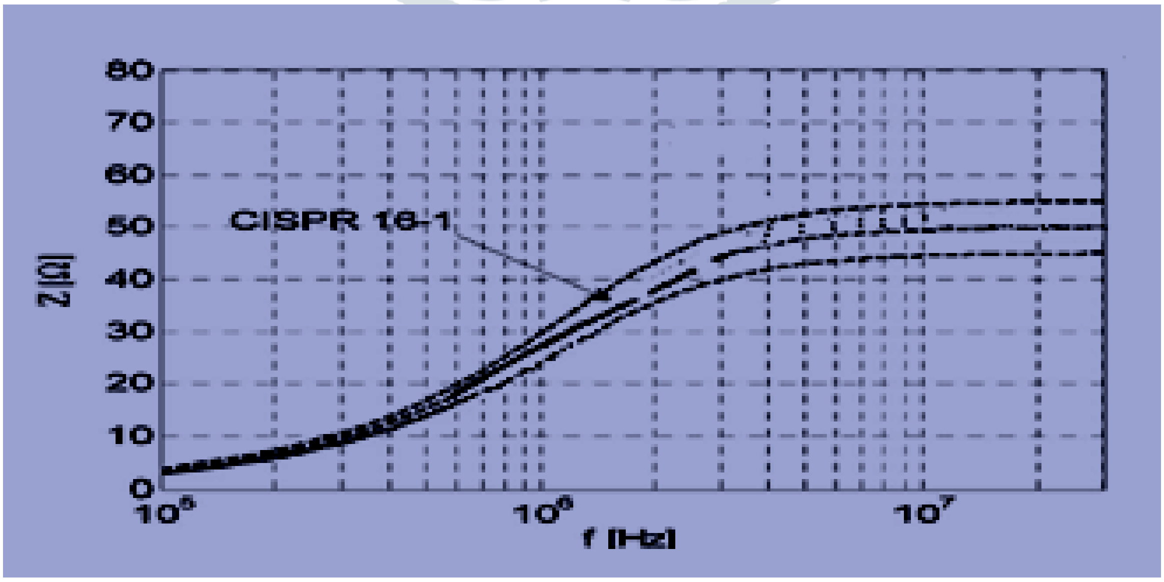


Fig2: Ideal impedance curve of the LSIN as for CISPR16-1

Table 1: specifications of LISN

Topic	Performance Specifications
Frequency	9 KHz – 30 MHz
AMN Impedance	(50 mH + 5 Ω) ∥ 50 Ω
Maximum current	AC / DC 16A
Standard	CISPR 16-1-2
Maximum voltages	AC:250V, 50/60Hz, DC:600V DC
RF Output	50Ω to connect RF output to EMI receiver
EUT Terminal	Output: 3 pin standard socket

III. HIGH FREQUENCY INDUCTION MOTOR MODEL

As a matter of fact, AC drives are more popular because of developments in power electronics in the electrical drives, reduced cost and other maintenance problems. In most of the cases, squirrel cage induction motors are used to avoid inertia and also for easy control of stator in vehicle applications. In this work, 3-Φ, induction motor with rated values of voltage: 415V (±10V), frequency: 50Hz (±5Hz) current: 2.5A, is used for smooth execution.

Similarly for carryout the simulation work the high frequency model of induction motor are designed, which is considered in the literature [1], [18] and several HF models are discussed in [22]. In general common mode currents are measured at the high frequencies only, that's why representation of motor model in high frequency circuit as not at all a problem. High frequency model of an induction motor with simulation values (MATLAB) as shown in fig.5.

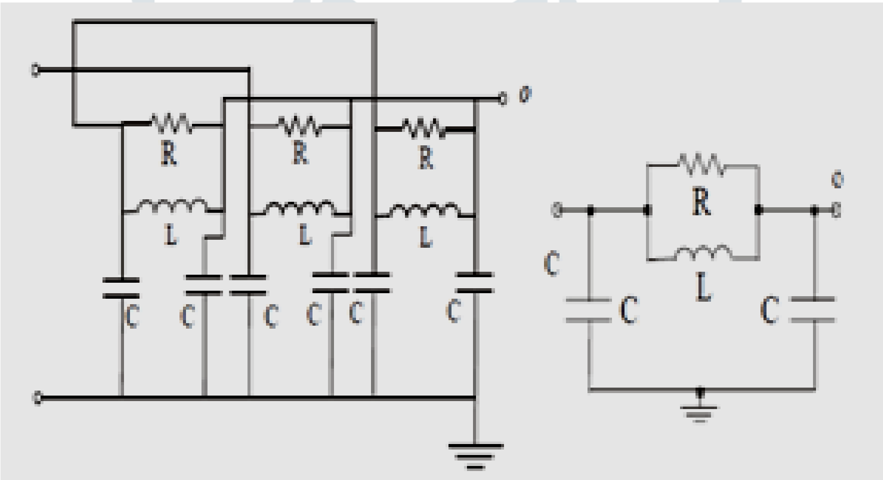


Fig3: High frequency circuit of the induction motor single winding

So many literatures give different values for the motor winding parameters, such as stray capacitances, winding inductances and resistances. Out of all M.C. Di Piazza. Et. al [23] represents more accurate values and she was inspiration for me to motivate towards electric vehicle research area. Those values as given below

Parameter	Value
R	640 Ω
L	1.60 mH
C	899 pF

Table2: Induction motor per phase winding parameters

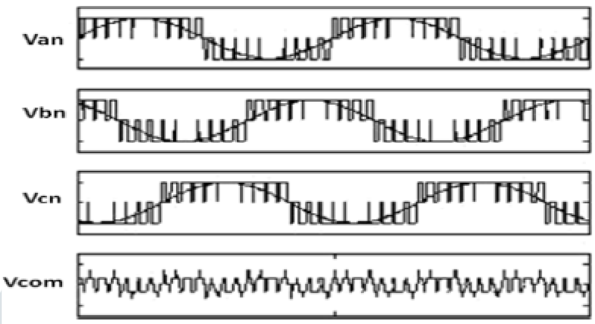
IV. DESIGN OF CMV ACTIVE CANCELLER CIRCUIT

I. Common mode voltage

An average voltage available at neutral point with respect to ground is called as common mode voltage or a voltage that appears in common at both input terminals of a device with respect to the output reference usually ground. Mathematically represents

$$Vm = \frac{[Van+Vbn+Vcn]}{3} \quad (1)$$

In the above equation Van, Vbn and Vcn are the phase voltages generated by the PWM inverter. The waveform of common mode voltage is schematically shown on Figure below. The common mode voltage can be measured between star point of stator winding of an induction motor and the ground.



Generally the common mode analysis without long cable is considered [24], the terminal voltages at the motor would be same as at the inverter output. Therefore common mode voltage

$$Vcm = \frac{Va+Vb+Vc}{3} \quad (2)$$

Where $Va = Va,o + Vo,n$ (3)

$$Vb = Vb,o + Vo,n \quad (4)$$

$$Vc = Vc,o + Vo,n \quad (5)$$

Substituting equations (3)-(5 in equation (2), we have

$$Vcm = \frac{Va,o+Vb,o+Vc,o}{3} + Vo,n \quad (6)$$

Summation of inverter output voltage

$$Vcm = \pm \frac{Vd}{6} + (Vo,n) \quad (7)$$

In this project the length of the cable is very small, that's why not considering any calculations regarding with cable. The effects of common mode voltage on induction motor fed by high switching frequency PWM inverter was more severe. This common mode voltage is the major reason to create a shaft voltage, and resulting bearing currents are produced in the system. Therefore premature damage to the both life time as well as the reliability of the motor. To protect the drive from these abnormalities common mode voltage active cancellers are implemented in early stages to protect the motor.

II. Common mode voltage active canceller

As matter of fact, the common mode voltage was the major reason for shaft voltage. Therefore to neutralize this common mode voltage, an active voltage canceller was designed. This is used mainly to remove the common mode voltage. It works in the following steps; initially it detects the common mode voltage from the output of the inverter by three star connected capacitors, and transferred through the push-pull emitter follower in Darlington configuration and reproduced at the primary of the Common mode transformer.

The Design details of the common mode voltage active canceller (CMVAC) as shown in Fig.6. it consisting of star connected capacitors, C reasonable 0 to 10nF are preferable and C^{I}, which is three times of C, DC voltage source and finally the common mode transformer.

According to the [2], the schematic of a feedback voltage-sensing voltage-compensating active filter shown in fig.4, the common mode voltage active filter works

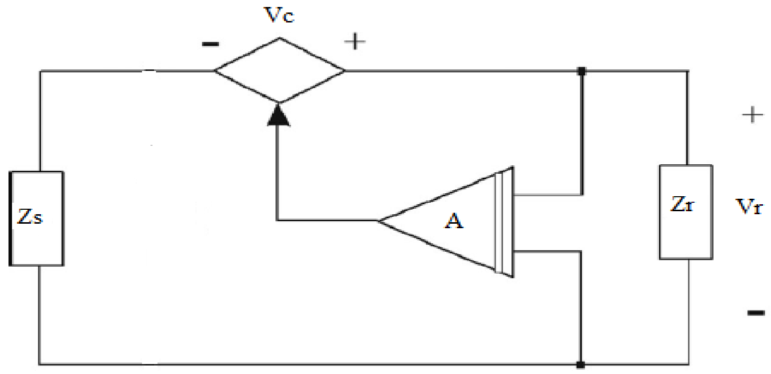


Fig 4: Voltage sensing and voltage compensation

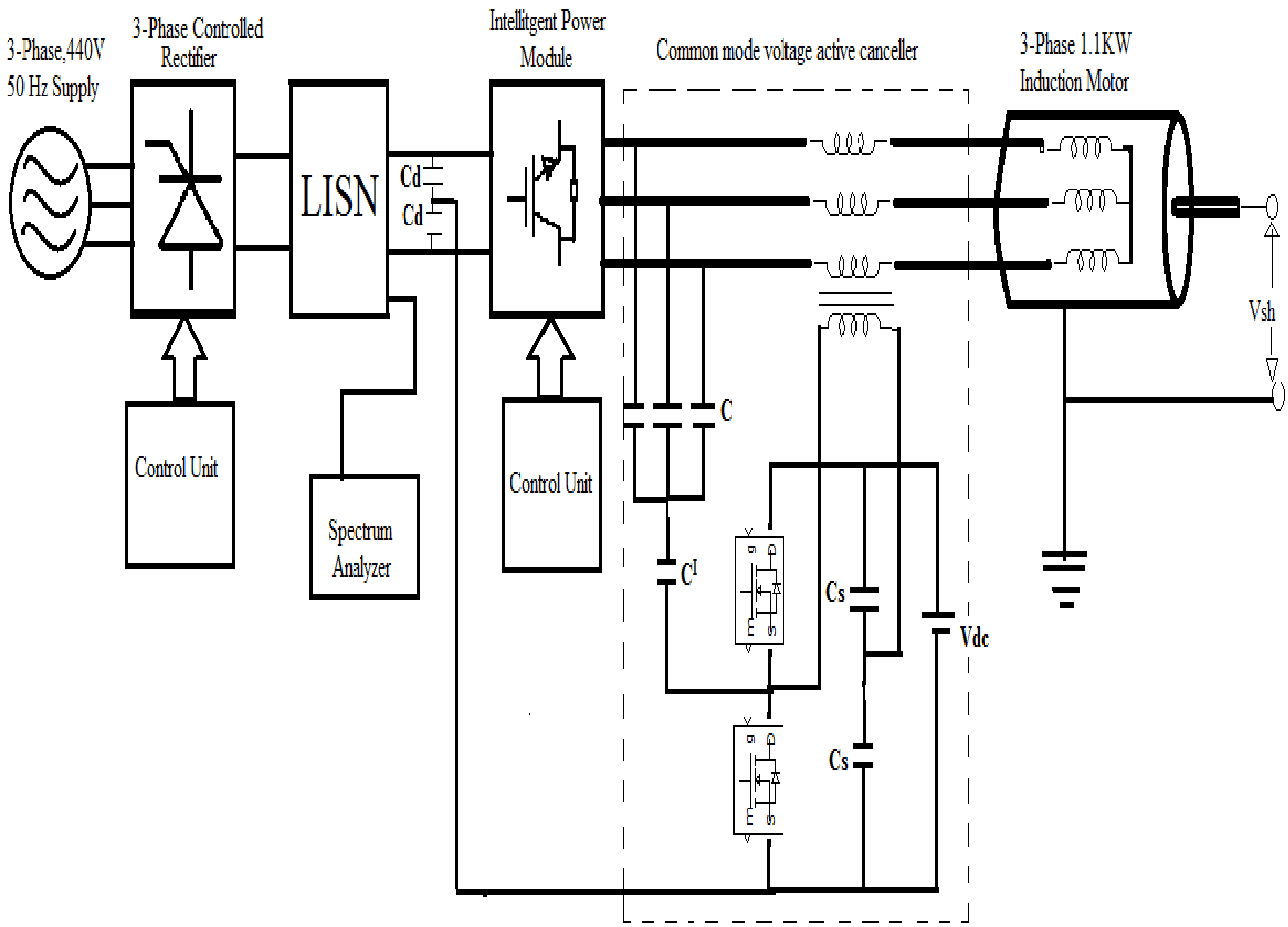


Fig5: An over view of the proposed configuration with common mode voltage active canceller

V. SIMULATION RESULTS

I. Simulated results without filter

For the proposed system in Fig.5 was simulated for both the cases such as without and with active common mode voltage canceller circuits in the MATLAB/SIMULINK as shown in figures. All the results are proposed for without and with filter circuits as shown.

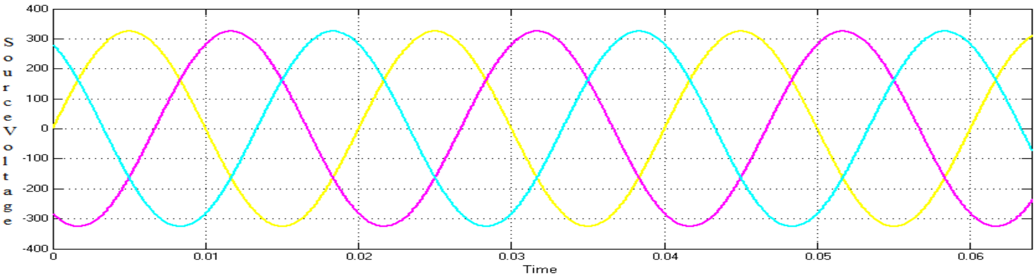


Fig:6 Three phase source voltages

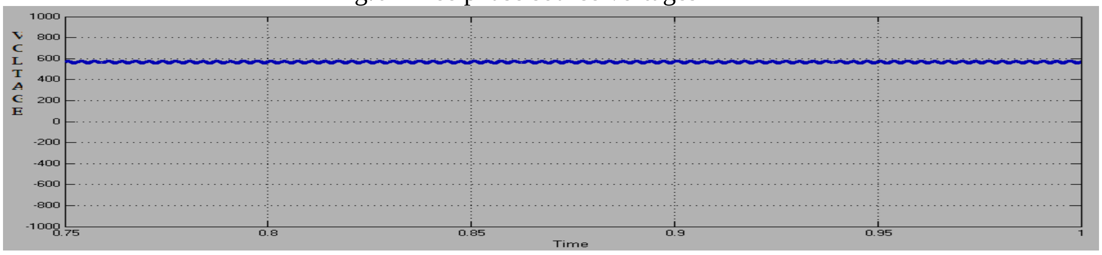


Fig7: 3-phase controlled rectifier output voltage

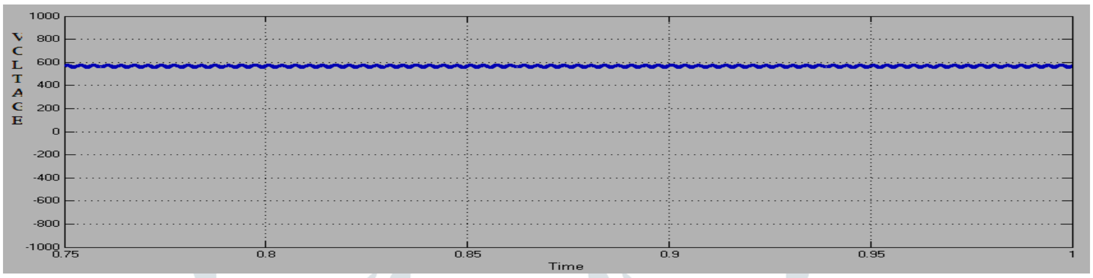


Fig 8: Output of the Line impedance stabilization network

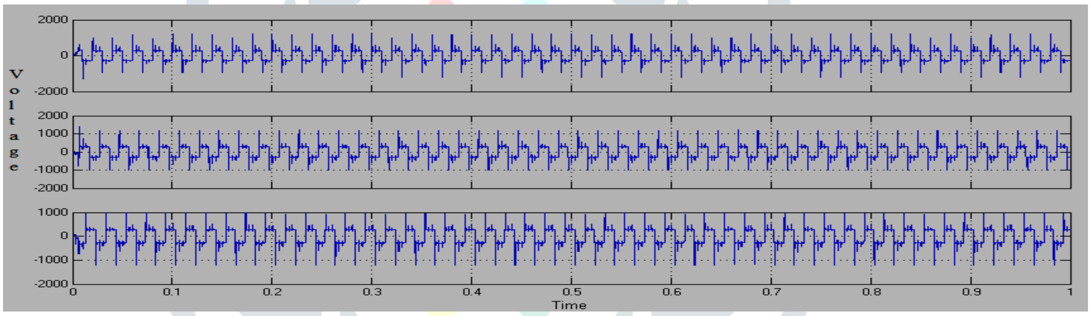


Fig 9: Inverter output voltages of the 3-phases

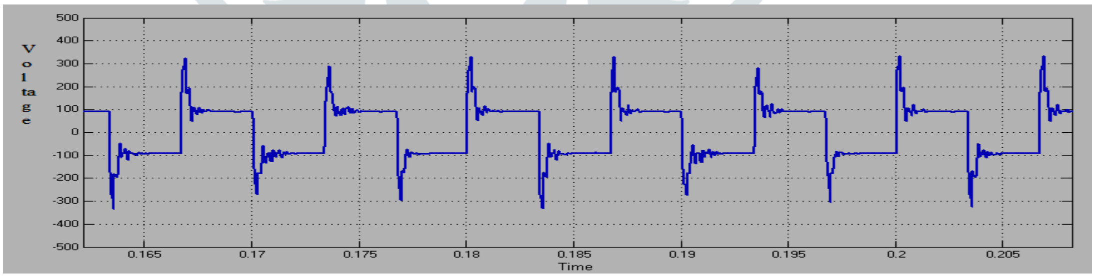


Fig10: Common mode voltage without filter

II. Simulated results with filter

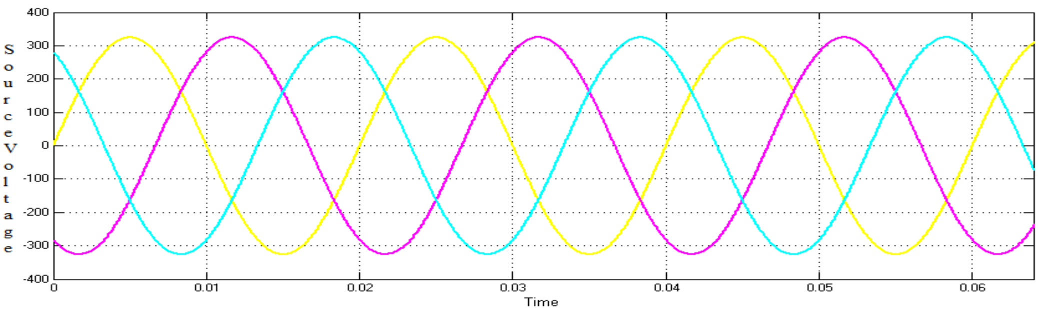


Fig:11 Three phase source voltages

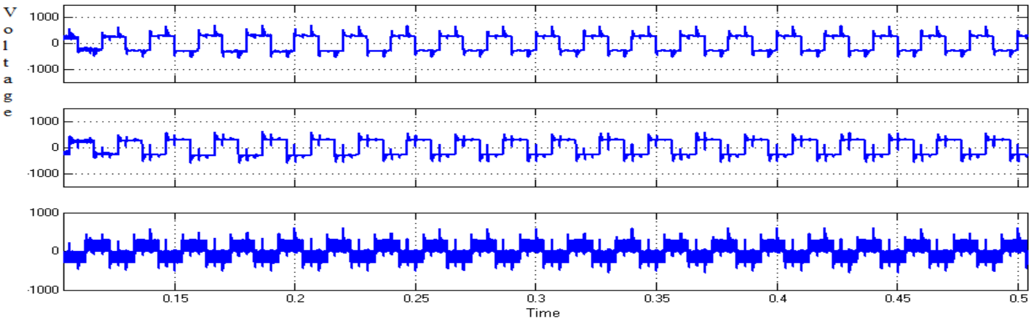


Fig 12: Inverter output voltages of the 3-phases

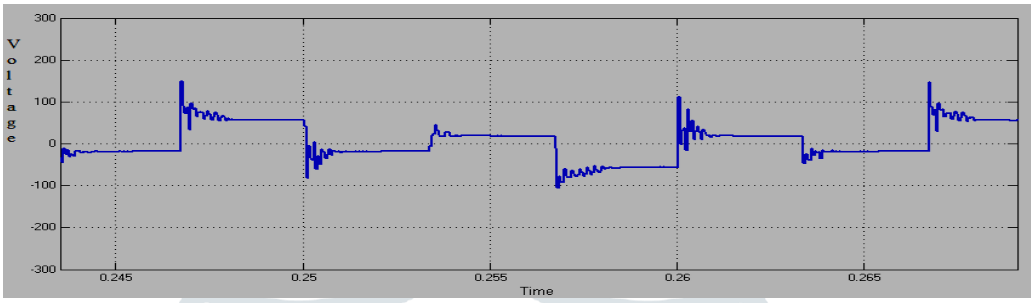


Fig13: Common mode voltage with filter

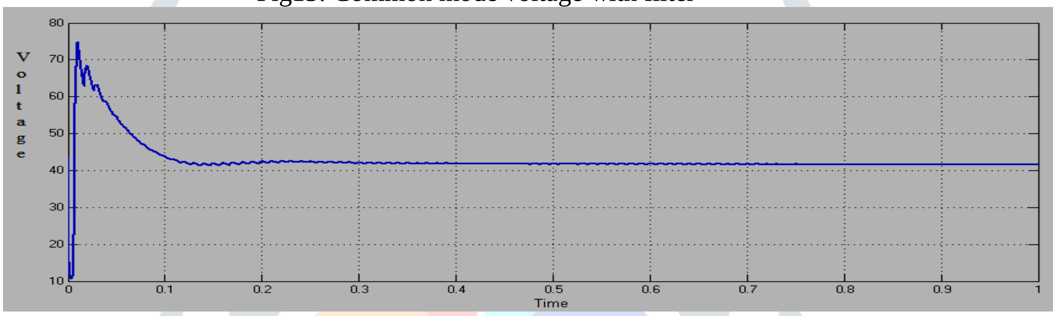


Fig14: Common mode running RMS voltage

VI. CONCLUSION

In this paper, a common mode voltage active canceller (CMVAC) has been developed, which is capable of neutralizing a common-mode voltage generated by high switching frequency PWM inverter. The common mode emissions towards the DC power supply mains are also tested by employing a high voltage dual channel dc LISN designed and build for the simulation purpose. This configuration has been simulated, therefore all the results such as common mode voltage, shaft voltages, common mode EMI those are suppressed satisfactorily. Future scope of the work will execute the prototype common mode voltage active canceller (CMVAC) construction and verify for a 1.1 kW 3-Φ induction motor drive using high switching frequency IGBT inverter.

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