Modeling and Suppression of EM emission in EV for Electro-Magnetic Compatibility

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***Abstract*— Vehicle transport is a vital part at present, but the polluting nature of the fuel vehicles is a drawback and it has drastic impact on the global climate. To alleviate this consequence the fuel vehicles are replaced by Electric Vehicles (EVs). These have no tailpipe emission, since EVs have Electric Drive System (EDS) in the place of Internal Combustion Engine (ICE). Also EVs are known for its noise free and instant torque operation. However EDS suffer from Electromagnetic Interference (EMI) issue and requires suppression of it, to suffice the limit specified by the standards. This paper focus on modeling and analysis of conducted emission by the EDS and SIMULINK software is used for its implementation. Analysis of result indicate the need for emission suppression which is followed by the application of suppression (filtering). The outcome of inverter control algorithm in the optimization of the EM emission suppression were analyzed.**

Key words: Electric Vehicles (EVs), Electric Drive System (EDS), Electromagnetic Interference (EMI)

I. INTRODUCTION

Transportation has a big part in our day to day life and its influence is demonstrated in terms of dependency by the individuals, business people and government on the transport for resource access and optimal functionality. Over years, the infrastructure and performance of the transport system has been evolved extra-ordinarily and life without modernized transport is difficult even to imagine. All things considered, this paper focus on the decarbanization related to transport system. In other words, transport is vital but its harmful impact (due to fuel based vehicles) on climate needs equal attention for sustainment of life on earth.

The conventional fuel vehicles emit greenhouse gases that cause global warming. The alternative for the fuel vehicles is the arrival of fully electric vehicles (EVs). The EVs have Electric Drive System (EDS) in the place of Internal Combustion Engine (ICE). The EDS is composed of power supply to energize the motor to run the vehicle [1, 2]. The EDS have inverter to convert DC to AC supply for operating the AC motor. Fig.1, depicts the Electric Drive System (EDS) in EV.

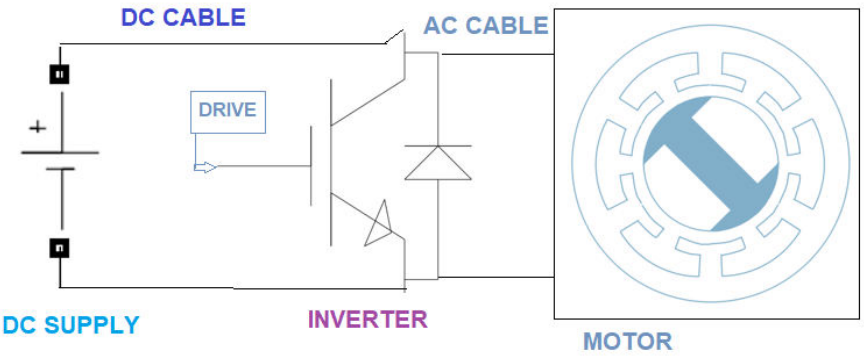

Fig. 1. Electric Drive System (EDS) in EV.

The speed at which inverter switches i.e. turn on and off gives rise to high transition voltage and current (dv/dt and di/dt). These high voltage contains harmonics and create differential mode electromagnetic emission and high current cause common mode electromagnetic emission [3, 11]. In general, common mode current is dominant in generating the conducted electromagnetic emission [4, 6]. Therefore, this necessitates control of the conducted electromagnetic emission to meet the limit. This can be done by modeling and analysis of the EDS in EV for conducted emission compatibility.

Here, the high frequency equivalent circuit model is used to analyze the electromagnetic emission by EDS [5]. The equivalent circuit modeling is based on detailed modeling which is the versatile option for electromagnetic emission analysis. This high frequency equivalent modeling is based on actual motor measurement that gives the impedance of the motor [8]. By separate analysis of both the common mode (CM) and differential mode (DM) impedance of the motor, its equivalent circuit modeling can be carried out over wide frequency band (150 kHz to 30 MHz range for which the emission is prominent). This is followed by the analysis of conducted emission by the EDS for electromagnetic compatibility. To suffice the electromagnetic emission limit specified by the standards, suitable suppression technique is applied to the EDS [9, 10].

II. MEASUREMENTS

The evaluation of conducted electromagnetic emission by the Device under Test (DUT) i.e. EDS involves measurement of the physical quantity that represents the nature of electromagnetic interference exhibited by the DUT [7]. Table I depicts the basic quantities involved in EM emission measurement.

TABLE I: QUANTITIES AND UNITS

Quantities	Units
Frequency	Hz
Bandwidth	Hz
Spectrum Amplitude	V/ Hz
Power Density	Wt./Hz

As per standards, conducted electromagnetic emission measurement is carried out with the help of the device called Line Impedance Stabilization Network (LISN). The LISN is placed between the DUT and the power supply for the measurement of conducted electromagnetic emission. The main purpose of using LISN in electromagnetic emission test is to achieve identical results in any lab, wherever required. In other words, to provide repeatable measurement and it is made possible by the two functionality of the LISN such as: a) providing constant impedance at its ports, so that amplitude of conducted emission by the DUT to be measured is not influenced by the power supply (source) impedance; b) preventing the exterior noise from disturbing the emission measurement. Fig. 2, depicts the Line Impedance Stabilization Network (LISN).

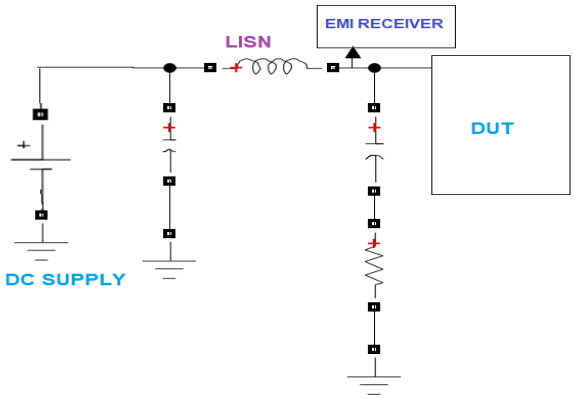

Fig. 2. Line Impedance Stabilization Network (LISN).

III. PROPOSED WORK

The proposed work focus on the analysis of electromagnetic emission by the EDS in EV, followed by the application of suppression i.e. filter to suffice the electromagnetic emission limit for electromagnetic compatibility. The high frequency equivalent circuit model is used to analysis the EM emission by the EDS and the model parameters obtained [2, 4]. The impedance measurement is carried out to obtain the high frequency equivalent model of the EDS. The subsequent RLC lumped circuit model is used for electromagnetic emission analysis of the EDS. The MATLAB – SIMULINK software is used for the implementation of the EDS modeling and EMI analysis. Inverter is the main source of electromagnetic conducted emission generated by the EDS in EV.

During switching operation steep transition voltage and current get generated, which in turn produce common mode and differential mode noise current traveling through the propagation path in

the EV. By the application of filter, the electromagnetic emission level can be reduced. An inverter output LC topology filter is used for reducing the conducted electromagnetic emission by the EDS in EV. LC filter comprise of inductor and capacitor which is placed between the inverter and motor [10]. For further optimization of the electromagnetic suppression, the improved control algorithm for the inverter can be used.

The inverter switching operation is controlled by the pulse width modulation (PWM) technique. This work models two inverter control algorithm such as sine pulse width modulation (SPWM) and space vector pulse width modulation technique and compare its influence on efficient suppression of conducted electromagnetic emission. Fig. 3 and 4, depicts the Simulink implementation of Electric Drive System (EDS) with filter operated under SPWM and SVPWM respectively.

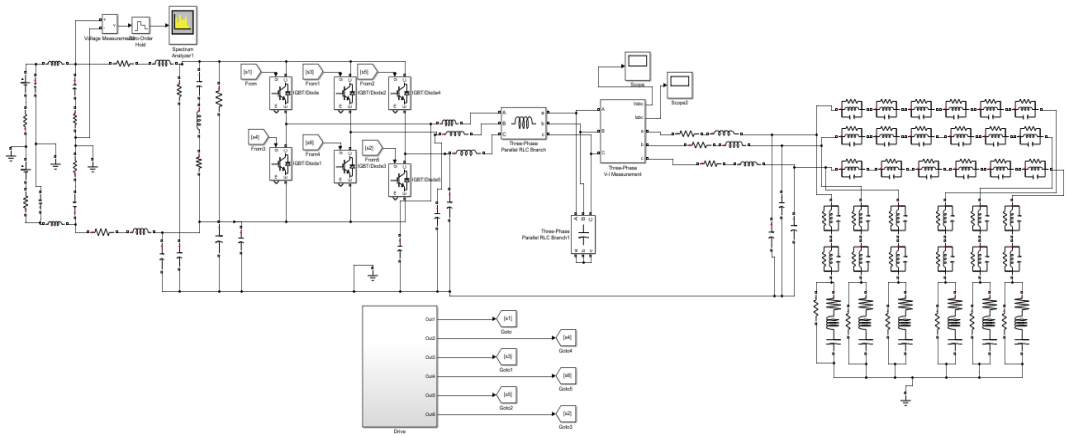

Fig. 3. Simulink – Electric Drive System (EDS) operated under SPWM with filter.

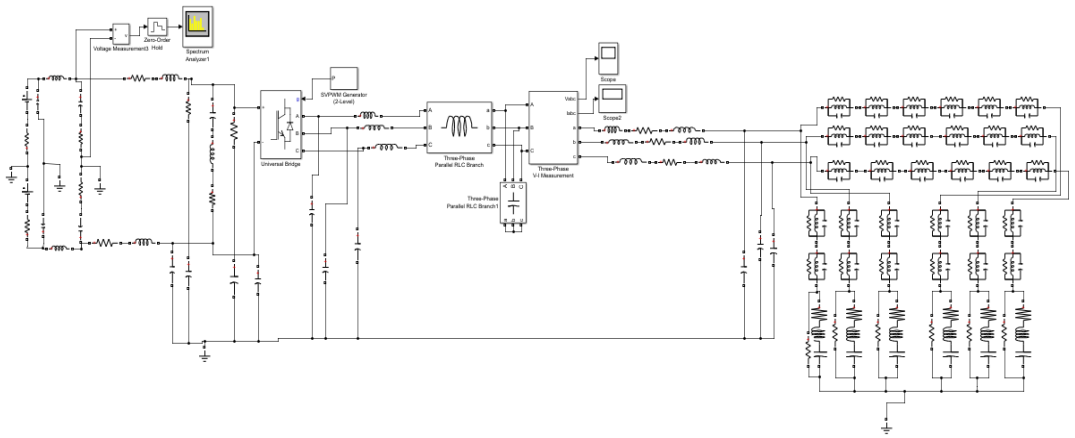

Fig. 4. Simulink – Electric Drive System (EDS) operated under SVPWM with filter.

IV. Result and Discussion

In this work, conducted emission spectrum generated by the EDS in EV were analyzed. The conducted emission spectrum before and after filtering were analyzed to test the electromagnetic compatibility. For analysis of influence by the inverter control algorithm on the electromagnetic emission suppression, the total harmonic distortion of the inverter due to two different inverter control algorithm were examined.

In this work, a three level SPWM control algorithm and two level SVPWM were implemented for the analysis purpose. In general, SVPWM is found to be superior inverter control algorithm for the purpose of electromagnetic compatibility. However, with increase in the PWM level, emission suppression can be efficient and the outcome of the same were explored. Fig. 5, depicts the conducted emission spectrum after adding filter.

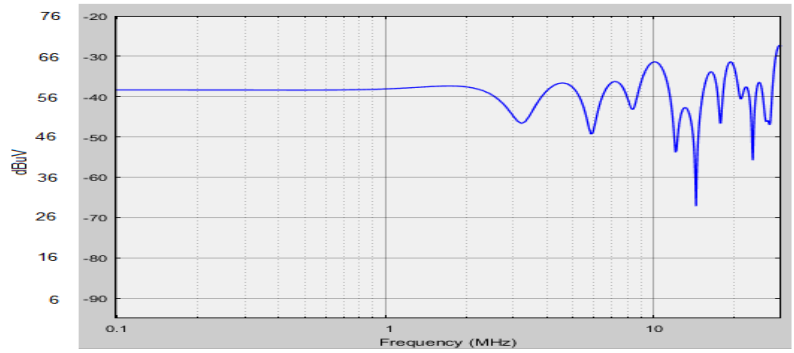

Fig. 5. Conducted emission spectrum.

The conducted electromagnetic emission generated by the EDS in EV according to the measured conducted emission spectrum requires suppression of it. Further, application of the filter reduce the conducted emission generated by the EDS. The total harmonic distortion (THD) of the two inverter control algorithm were explored.

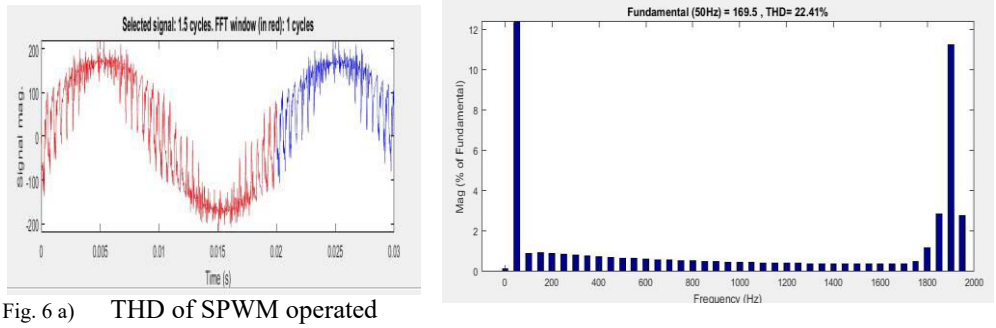

Fig. 6 a) THD of SPWM operated inverter output voltage.

Fig. 6 a) and b) depicts the THD of SPWM operated inverter output voltage and current respectively. Similarly, Fig. 7 a) and b) depicts the THD of SPWM operated inverter output voltage and current respectively.

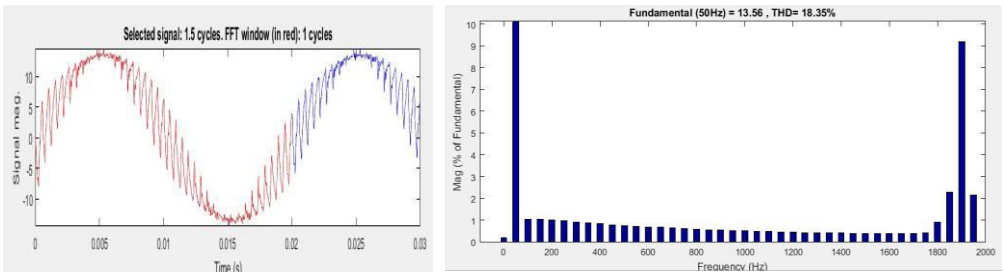

Fig. 6 b) THD of SPWM operated inverter output current.

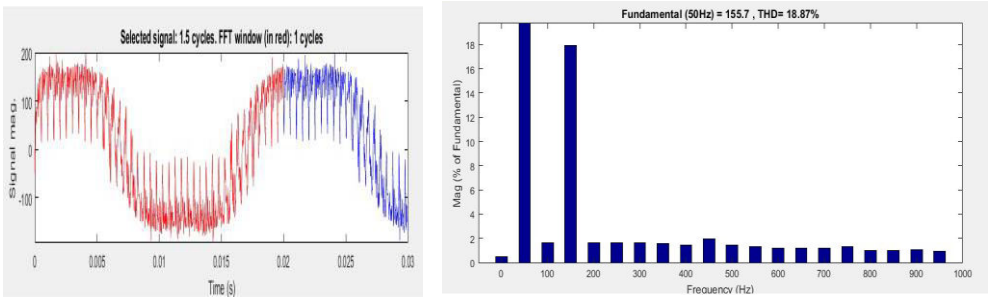

Fig. 7 a) THD of SVPWM operated inverter output voltage.

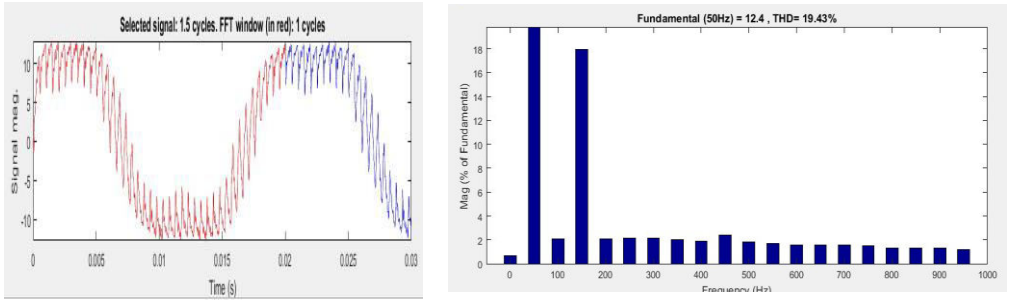

Fig. 7 b) THD of SVPWM operated inverter output current.

The SVPWM inverter control algorithm is superior compared to SPWM control algorithm. However, comparable resultant output is obtained since, three level for SPWM and 2 level for SVPWM were implemented. Therefore, as per requirement either we can increase the level of PWM technique or use efficient control algorithm in order to reduce the distortion.

V. CONCLUSION

Vehicle is an indispensable part of human existence in the present world. But the harmful effect of fuel vehicles towards the climate requires immediate recovery. At this situation, the arrival of electric vehicle helps in controlling the pollution due to the fuel vehicles. However, the presence of high power electric and electronic systems within the EV produce electromagnetic interference (EMI). This in turn, requires to meet the electromagnetic emission standards for safe and proper operation of the EV. This work models and analyzes the conducted electromagnetic emission by the EDS in the EV and the results direct the need for the suppression. This is followed by the application of filter to the EDS, which helps in the reduction of the conducted emission. Further, the efficiency of suppression is influenced by the inverter control algorithm used. In this work, outcome of two different inverter control algorithm were explored.

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