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Investigation of Cable Length Influence on EMI Spectrum in a WBG-Based Drive System

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***Abstract*— Despite the advantages of a wide band gap (WBG)-based motor drive system, the electromagnetic interface (EMI) caused by WBG devices is a critical issue which should be taken care of. This paper investigates the influences of cable length on electromagnetic interface (EMI) in a WBG-based drive system. This study shows its importance to adopt the actual length of cable installed in the drive system in order to make the test results more representative of real system level operation condition. Analysis is obtained on the EMI noise generated in a WBG-based drive system influenced from different cable length. This study is investigated based on the comparison of frequency response of common mode (CM) and differential mode (DM) impedance and the EMI spectrum. The CM and DM impedances influences in CM noise and overvoltage across output terminal impacts DM noise spectrum. The experiments results are given for the 250V DC input converter with 60 Hz, 105V and 4A Line to Line AC rms output with R-L load in a three-phase drive system with no cable, using 1- and 6-meter cables between converter and the load.**

Keywords—EMI, common mode, differential mode, WBG-based drive

I. Introduction

Due to outstanding performance of wide band gap (WBG) devices such as higher switching speed and less loss, it can increase the power density in drive systems [1, 2]. Therefore, development of WBG-based drive system has become a gained momentum, recently. Such a drive system and cable impedance create a complex combination of resonances and antiresonances. See Fig. 1 as the schematic for a motor drive system. WBG power electronics induces higher dV/dt and di/dt into the system, which can excite the resonance network with higher amplitude [3], [4] and [5].

It is recommended to adopt the actual length of the cables installed in a drive system in order to make the test results more representative of real system-level operation conditions [6] and [7]. As an important consequence of this observation, it is shown in this paper that conducted EMI is largely affected by the specific cabling length and characteristics.

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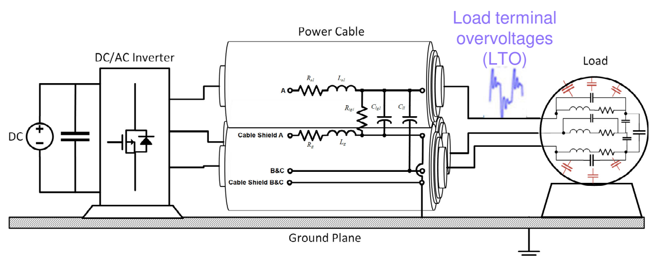

Fig. 1. Cable connected drive system schematic.

In [8, 9], the effects of separately shielded cables and cables with a total shield for three phases on the emission is studied. The separately shielded cables achieve worse results. In [9], the cabling impact in radiation emission is shown coupled from conducted emission. Although many factors affect far-field electromagnetic radiation, multiple studies have indicated that the common mode (CM) current on the cables is the main cause of the electromagnetic radiation in 30-300 MHZ band [10]. However, the influence of cable length is not analyzed to give guidelines in CM and differential mode (DM) noise spectrum through the CM and DM impedance study.

In this paper, the CM and DM EMI spectrum is studied for the WBG-based drive system with the three different cases of no cable, 1 and 6 m cables connecting the DC/AC converter to the R-L load. This study shows that only by the CM and DM impedance responses an overview of the possible peaks in EMI spectrum can gained.

- The lower frequency EMI level (lower than 1 MHz in this paper) increases using longer cable.
- The longer cable causes higher amplitude and lower frequency peaks in DM spectrum influenced by the load terminal overvoltages (LTO).
- The LTO also influences the CM noise spectrum.
- The long cable decouples the load CM parasitics from CM path.

II. EMI Measurement Experimental Setup

The EMI measurement experimental test is set up following the MIL-461-G standard [11] which is shown in Fig. 2. The Rigol DSA815 spectrum analyzer, LI3100 LISNs, split phase DC/AC converter [12], 6m cable and R-L load are

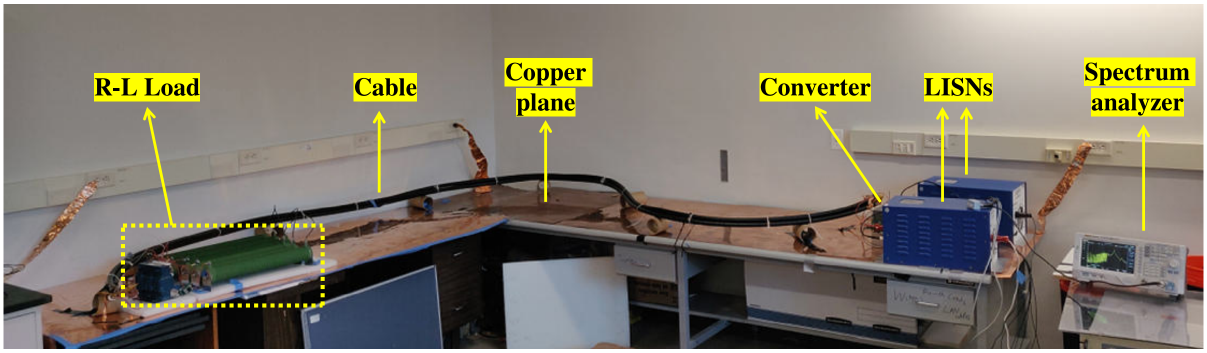

Fig. 2. EMI measurement experimental setup using 6m cable.

used in this practical test. The same platform is also set up for two case studies with 1m cable and no cable connecting the inverter to the load. The three cases under study in this paper are operated under the same 250V DC input voltage, with 60 Hz, 105V and 4A Line to Line AC rms out with load of $20\ \Omega/ph$ and $2.5\ mH/ph$.

III. Cable Length Influence on EMI Spectrum

Fig. 3 compares the DM and CM noise spectrum in three cases for different cabling length: no cable connecting the 2L inverter directly to the load, using 1 and 6 m cables. It can be seen from Fig. 3 (a) that the CM noise is higher in amplitude for lower frequencies (lower than1 MHz in this paper which changes for different cable length and characteristics), using 6m cable, 1m cable and no cable, respectively. However, in higher frequencies, the noise peaks are higher for the no cable configuration. The low frequency spectrum is also higher for the longer length cable in DM spectrum. It is shown that the HF peak is in higher amplitude and lower frequency for the case study with longer cable.

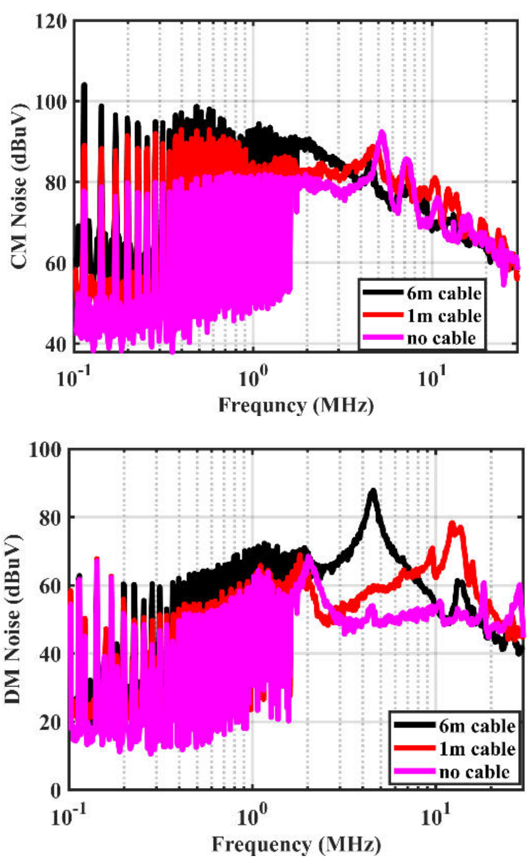

Fig. 3. Noise spectrum for the drive system with no cable, 1 and 6 meter cable (a) CM (b) DM

To investigate the cable length influence in the CM and DM spectrum, they are superimposed with the measured CM and DM impedances [13-15] of the drive system. Both CM and DM impedances influence the CM noise spectrum. From Fig. 4 (a), (c) and (e), it can be seen that the CM impedance impacts the CM spectrum. In Fig. 4 (c), for the case study using 1 m cable, it can be seen that the CM impedance has a small change in frequency range compared to the no cable case study in Fig. 4 (a). However, as it can be seen from Fig. 4 (e) using 6 m cable, the CM impedance peak has moved to the lower frequencies, and it is representing a different resonance network. This indicates that the longer cable decouples the load higher frequency CM parasitics. Also, it can be seen from Fig. 4 (a), (c) and (e) that the DM impedance also shows its influence on CM noise spectrum. This is because the voltage across parasitic capacitors in CM path of the drive system are derived by the DM impedance in the system. So, the DM impedance characteristic also comes into the CM spectrum.

The DM noise spectrums are superimposed with DM impedance of the three case studies, in this paper. It is shown in Fig. 4 (b), (d) and (f) that the DM impedance impacts the DM spectrum. Fig (5) shows LTO waveforms for the three case studies at output terminal on square wave voltage under the same experimental conditions. As shown in Fig, 5 (a), the LTO amplitude is 280, 350 and 460 V for the case studies of no cable, 1 m and 6 m cables, respectively. Also, the LTO frequency is 33 MHz, 12 MHz and 4.2 MHz, respectively. It should be highlighted that the higher amplitude and lower frequency of the LTO shown in Fig. 4 (b), (d) and (f) at 33, 12 and 4.2 MHz verify the LTO impact on the DM spectrum.

IV. Conclusions and Future Work

In this paper the cable length influence is studied on EMI spectrum through the DM and CM impedance response of the system in a WBG based drive system. The study shows that the DM and CM impedances influence the CM noise and LTO

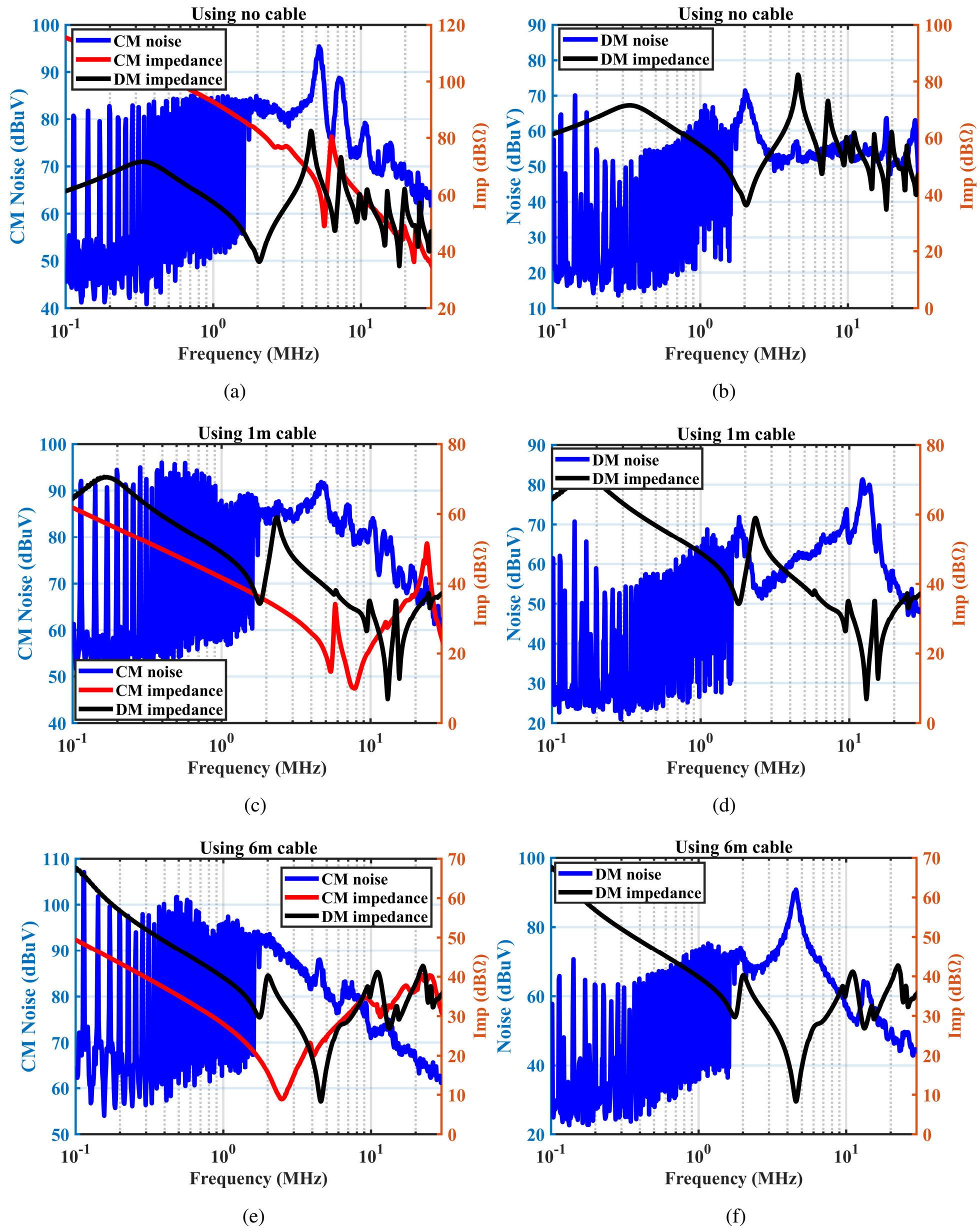

Fig. 4. Cabling influence in EMI noise (a) CM noise- no cable (b) DM noise- no cable (c) CM noise- using 1m cable (d) DM noise- using 1m cable (e) CM noise- using 6m cable (f) DM noise- using 6m cable.

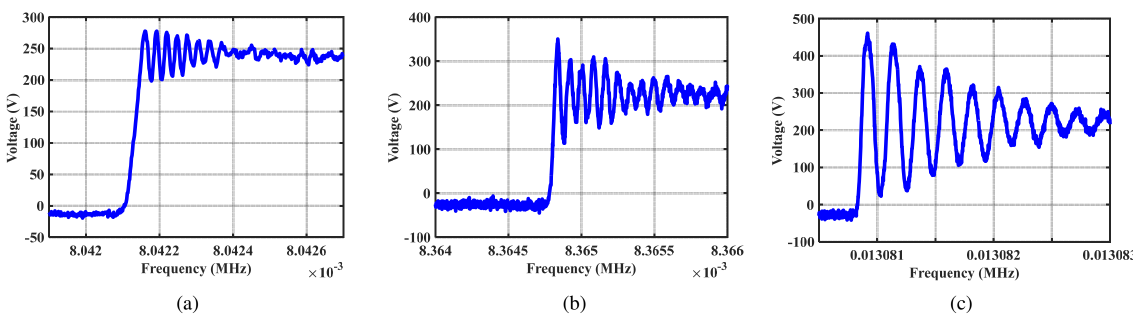

Fig. 5. Time domain output Line to Line square wave voltage zoomed in for the case study (a) no cable (b) 1m cable (c) 6 m cable

impacts in DM noise. It is shown that the noise amplitude increases for both CM and DM noise using longer cable in lower frequency ranges. However, longer cable decouples the higher frequency load parasitics from the CM noise path. This would be beneficial in decoupling the radiation emissions at higher frequencies. The higher amplitude and lower frequency impact of LTO using longer cable should be considered as filtering is more challenging for the lower frequency peaks [16]. Furthermore, the HF peaks in CM and DM noise spectrum due to the cabling influence is necessary to be considered in filtering design as the actual length of the cable in the application. Because, the filters do not act as an ideal filter and their filtering in HF ranges may diminish [15]. On the other hand, even though the system insulation is enough strength under the LTO caused by long cable, it still may need to filter out the LTO overvoltages if they exceed the EMI standards for the application.

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