CUE2015-Applied Energy Symposium and Summit 2015: Low carbon cities and urban energy systems

Diagnosis method of radiated emission from battery management system for electric vehicle

Xinjie Gao\textsuperscript{a}, Donglin Su\textsuperscript{a}, Li Zhai\textsuperscript{b,*}, Xinyu Zhang\textsuperscript{b}

\textsuperscript{a}Beihang University, Xueyuan Street NO.37, Haidian District, Beijing 100083, China
\textsuperscript{b}Beijing Institute of Technology, Zhongguancun South Street NO.5, Haidian District, Beijing 100081, China

Abstract

Electromagnetic emission from EVs has an effect on board equipment and nearby vehicles in urban transportation. Moreover, the electromagnetic emission from BMS in EVs can exceed the CISPR 12 limits of radiated emission for EVs. The radiated electric fields average for an electric car (CISPR12) is measured in semi-anechoic chamber (SAC) at a distance of 10m to study the diagnosis method for EMI. An exclusion procedure for EMI from BMS is designed to determine the component responsible for emission peaks through far-field antenna testing for vehicle. BMS and instrument are responsible for the average radiated emission exceeded the limits for the testing EV. The near-field testing is used to diagnose the location of EMI. From measurements and analysis of EMI from clock, the clock oscillator is the key component responsible for narrowband emission, and power devices’ switching in DC-DC converter BMS is the key component responsible for broadband emission.

Keywords: diagnosis method, electromagnetic interference, radiated emission, battery management system (BMS), electric vehicle

Nomenclature

\begin{itemize}
  \item EVs \hspace{1cm} electric vehicles
\end{itemize}

* Corresponding author. Tel.: +86-135-2288-5040
E-mail address: zhaili26@bit.edu.cn
EMI  electromagnetic interference
VCU  vehicle controller
BMS  battery management system
MCU  motor controller
RMS  remote terminal
PWM  pulse width modulation

1. Introduction

The limits in CISPR12 for vehicle in urban transportation are designed to provide protection for broadcast receivers in the frequency range of 30MHz to 1000MHz when used in the residential environment [1]. From the CISPR12 measurement, much more emission in vertical polarization exceed the average limits at no motor in working condition, in which some high voltage system and low voltage system are in working condition, except electrical steering systems, electric vacuum booster system. Not only high voltage components such as MCU can generate EMI, but also low voltage components such as BMS, RMS, and instrument can generate electromagnetic emission to interference aboard equipment and to make radiated emission for EVs exceed the CISPR 12 limits [2]. Power devices’ switching in DC-DC converter of BMS can generate conducted and radiated emission [3]. The EMI at high-frequency content from PWM is due to the rise/fall time of the clock pulse of the oscillator in electric control system. It is a challenge to the design of BMS and other low voltage components. Diagnosis method is needed to propose to determine the component responsible for emission peaks exceeded the limits.

2. Construction of electric fields emission measurement

The radiated electric fields average for an electric car (CISPR12) in vertical polarization is measured in semi-anechoic chamber at a distance of 10m, as shown in Fig.1. The vertical emissions of both sides exceed the CISPR 12 limit at A, B, C, and D area shown in Fig.2.

The peak at A is broadband emission at 110.8 MHz. The peak at B occurs at 196 MHz. The peaks at C occur at 576 MHz, 600 MHz, and 624 MHz. The peaks at D occur at 720 MHz, 768 MHz, 816 MHz, and 864 MHz. The narrowband emissions at 600MHz exceed the CISPR12limit by 10dB.

3. Diagnostic procedure

From Fig.1, the vehicle’s electronic systems shall be in normal operation mode with the vehicle stationary “READY” state, and the motor drive system could not be in working operation at N state. The low voltage active open electric equipment consisting of double flashing lights, wipers, radio and fan should be switched by the driver for testing. In addition, electric units such as vehicle controller (VCU), battery management system (BMS), and instrumentation should be all in working condition. The high voltage electrical equipment comprising of motor controller (MCU), DC/DC converters, PTC, electric air conditioning compressor controller and batteries are supplied and enabled by low voltage control.
An exclusion method is used to determine the component responsible for emission peak through far-field testing for vehicle. First of all, the active open electrical components are closed one by one. However the radiated emissions testing results was not significantly different. Then the possibility of the active open electrical components responsible for emission peaks are excluded and restored to normal operation.

Secondly, an investigation is made for the high voltage electric components except for high-powered batteries. The MCU’s low voltage connector is disconnected, and the vehicle cannot be “READY”. However the emission peak cannot be mitigation. Next, the low voltage control connectors are disconnected from the other high voltage electric components one by one. However the emission peak still cannot be mitigated. The high voltage electric components except for battery power may not lead to radiated emission exceeded the limits and restored to normal operation.

Next, check the orientation of EMI from low-voltage electrical components including VCU, BMS, instrumentation, and RMS, etc. in "invisible work". When the connector of RMS is removed, the measurement results are unchanged. After the instrument connector is disconnected, the peak at B point (196MHz) in Figure 2 is removed, as shown in Fig.4. It can be indicated that the instrument are responsible for the peak at 196MHz. However the peak at A, C, and D could not be removed.

Finally, the fuse of power supply for BMS is removed to disconnect the input power of internal DC-DC converter of BMS. The testing results are shown in Figure 4. The emission peaks at A, C, and D area disappear. The emission peak at A point disappears due to no power supplied to BMS. However narrowband emissions at E area still exist at 111.65 MHz, 127.6 MHz and 143.55 MHz. The clock oscillator and other high frequency electronic components in BMS are responsible for the emission peaks at C and D area. We can conclude that BMS and instrument are responsible for the average radiated
emission exceeded the limits. However there are three peaks at E area shown in Fig.4, which is potential to exceed the limits.

![Graph showing emission measurements without instrument](image1)

**Fig. 3. Emission measurements without instrument**

![Graph showing emission measurements without the fuse of BMS](image2)

**Fig. 4. Emission measurements without the fuse of BMS**

**4. Diagnosis method of key interference frequency**

The CISPR 12 radiated emission measurements for vehicle is a far field testing, from which the problematic frequencies can be obtained. However it is hard to determine the exact location of EMI from the components by antennas. The near-field testing can be used to find the location of EMI.

A spectrum analyzer and a near-field scanning probe can be used to test near electric field or magnetic field to diagnose EMI from the instrument shown in Fig.5.

The fundamental frequency of the scanning is 28 MHz shown in Fig.6, which is the frequency of the clock oscillator. The problematic frequency 196 MHz at B point is 7th harmonics of 28 MHz.

![Near-field scanning test for instrument](image3)

**Fig. 5. Near-field scanning test for instrument**
We use the near-field method to scan the cable connector of BMS installed in vehicle chassis. The fundamental frequency of the scanning is 24 MHz, which is the frequency of the clock oscillator of electric control unit for BMS. The limits are exceeded at 576 MHz, 600 MHz, and 624 MHz, 720 MHz, 768 MHz, 816 MHz, and 864 MHz due to the fundamental frequency 24 MHz.

From Fig. 4, the frequency difference between two peaks at E area is 15.95 MHz due to the frequency of the clock oscillator of electric unit for fan, shown in Fig. 7. The emission peaks at E area are removed after the cable connector of fan is disconnected.

5. Analysis of EMI from clock

Clock waveform is represented as periodic trapezoid-shaped pulses. The key parameters that contribute to the high-frequency spectral content of the waveform are the rise and fall times $\tau_r, \tau_f$ of the pulse [4]. A continuous envelope of clock waveforms is given as

$$\text{Envelope} = 2A \frac{\tau}{T} \left| \frac{\sin(\pi \tau f)}{\pi \tau f} \right| \left| \frac{\sin(\pi \tau_f f)}{\pi \tau_f f} \right|$$

(1)

Where $T$ is the period of the waveform, $A \tau/T$ is dc term or level. $\pi \tau f = m \pi, m = 1, 2, 3, ...$, From (1), the bounds for this spectrum is expressed as

$$20 \log_{10}(\text{envelope}) = 20 \log_{10}(2A \frac{\tau}{T}) + 20 \log_{10}\left(\frac{\sin(\pi \tau f)}{\pi \tau f}\right)$$

$$+ 20 \log_{10}\left(\frac{\sin(\pi \tau_f f)}{\pi \tau_f f}\right)$$

(2)

From (2), the first breakpoint in the spectral bound is related to the pulse width $1/\pi \tau$. And the second breakpoint is due to $1/\pi \tau$. Then the high-frequency content is due primarily to the rise or fall time of the pulse which causes the product’s inability to meet the requirements on radiated emissions. The low-frequency content is due to pulse width and $A \tau/T$ and $1/\pi \tau$. 
The narrowband emission peaks at B, C, D, and E area exceed the CISPR 12 limits due to the rise and fall time of the clock pulse of electric control system in BMS, instrument and fan. The broadband emission peaks at A is due to the pulse width of the pulse of PWM signals generated from DC-DC in power supply of BMS.

6. Conclusion

An exclusion procedure for EMI from BMS is designed to determine the component responsible for emission peaks through far-field antenna testing and near-field scanning for vehicle. From measurements and analysis of EMI from clock, the clock oscillator is the key component responsible for narrowband emission, and power devices’ switching in DC-DC converter of BMS is the key component responsible for broadband emission.

Acknowledgements

This work was supported by the National Natural Science Foundation of China for financially supporting this project (51475045).

References


Biography

Li Zhai has been an Associate Professor in Beijing Institute of Technology since 2009. From 2013 to 2014, she was a Visitor Scholar with the EMC Laboratory, Missouri University of Science and Technology. Her research interests include EMC/EMI of power electronics in EVs, and electrical machine control.