IMPACT OF ELECTROMAGNETIC INTERFERENCE FROM POWER INVERTER DRIVE SYSTEM ON BATTERIES IN ELECTRIC VEHICLE

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Abstract

EMI is a major challenge to design of high power drive system in EVs due to large dv/dt and di/dt outputs of power devices in power inverter and/or converter, which can generate conducted DM and CM current through parasitics to interfere key components such as batteries and drive motors, low voltage system in EVs and nearby vehicles. The impact of conducted EMI from the inverter of ac motor on lithium batteries in EVs is present in paper. DM and CM current paths flowing to batteries are analyzed through the modeled equivalent circuits. A SPICE model of the power drive system and a test platform are built to verify the impact of EMI from the power drive system on the lithium-ion batteries. The results show that the batteries voltage fluctuation range without filter due to DM and CM current is higher than that with filter.

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Keywords: electromagnetic interference, power inverter system, batteries, Electric vehicle

Nomenclature

EVs electric vehicles
EMI electromagnetic interference

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1. Introduction

In recent years, EVs are developed to solve some problems of energy crisis and air pollution in urban transport field. However, the safety of EVs’ batteries increasingly threaten the passenger's life. Large dv/dt and di/dt outputs of power devices in power inverter and/or converter can generate conducted and/or radiated emissions through parasitics to interfere key components such as batteries and drive motors, low voltage system in EVs and nearby vehicles, and even destroy them. EMI is a major challenge to design of high power drive system. Impact of EMI from the inverter on motor and low voltage components have been studied in previous research [1-3]. However fewer studies on impaction of EMI on batteries are proposed in EVs.

CM current and DM current generated from the inverter could flow into batteries through ac cables, dc cables, and chassis, and affect the performance such as voltage, current SOC, heat, and life of the batteries. This paper focuses on the impact of conducted EMI from the power inverter of ac motor on lithium batteries in EVs through CM current and DM current. In order to protect the lithium-ion batteries, a filter is added to decrease the CM current and DM current.

2. Construction of the power inverter system

AC motors are widely used in EVs due to high energy density and high efficiency, the electric drive system of which is mainly composed of batteries, dc cables, power inverter, ac cables, and ac motor, as shown in Fig.1.

3. Analysis of DM current path and CM current path

The fast switching of IGBTs module in power inverter can produce the high value of dv/dt and di/dt, which will form DM and CM current flowing to batteries in EVs and result in voltage fluctuation and heat
3.1. DM current path

DM current could be mainly generated by parasitic parameters between the dc cables connection with the batteries in EVs. DM current in low frequency will flow through the ac cables, the motor winding, the dc cables and the batteries, as shown in Fig.2. From Fig.2, the impedance of the motor winding will increase with increasing frequency of DM current, therefore DM current will flow through C1 and C4, the dc cables and the batteries due to the decreasing the impedance of C1 and C4 at one bridge leg in the inverter. Equivalent circuits of DM current path at low-frequency and high-frequency are present to study the DM conducted emission transmitting to the batteries for the topology symmetry of the IGBTs module and the complexity of three bridges working at the same time, as shown in Fig.3.

EMI source is placed at the node of bridge leg output and equivalent to a trapezoidal wave voltage source due to PWM control. The EMI from the power inverter system are mainly dominated by the rise and down time of the trapezoidal wave. The DM current can be expressed as

$$I_{dm1} = \frac{E}{Z_{dm1}} \quad (1)$$
\[ Z_{dm1} = j\omega (L_{cable_u} + L_{cable_+} + L_{cable_v}) + \frac{1}{j\omega C_b} + \frac{Z_1 \ast Z_2}{Z_1 + Z_2} \]  

\[ Z_1 = j\omega (L_{m3} + L_{cable_v}) + \frac{1}{j\omega C_6} \]  

\[ Z_2 = j\omega (L_{m2} + L_{cable_w}) + \frac{1}{j\omega C_4} \]  

\[ I_{dm2} = \frac{E}{j\omega (L_{cable_u} + L_{cable_-} + L_{cable_v}) + \frac{1}{j\omega \left( C_2 + \frac{1}{C_b} + \frac{1}{C_1} \right)}} \]  

3.2. CM Current Path

CM current could be mainly generated by parasitic parameters between the power inverter system and chassis in EVs and increase the radiated emission of the AC cables. One CM current path will flow through the capacitance between IGBTs and heat sink into the chassis and back into the batteries through the capacitance between plates of the batteries and the chassis, as shown in Fig.4. From Fig.4, Another CM current path will flow through the capacitance between the motor winding and shell connection with chassis and back into the batteries. Equivalent circuits of two CM current paths are present to study the CM conducted emission transmitting to the batteries, as shown in Fig.6.
The DM current can be expressed as

\[
I_{cm1} = \frac{E}{j\omega C_m} + \frac{Z_3 + Z_4}{Z_3 \ast Z_4}
\]

(6)

\[
I_{cm2} = \frac{E}{j\omega C_p} + \frac{Z_3 + Z_4}{Z_3 \ast Z_4}
\]

(7)

\[
Z_3 = \frac{1}{j\omega C_{g1}} + \frac{1}{j\omega C_1} + j\omega L_{cable+}
\]

(8)

\[
Z_4 = \frac{1}{j\omega C_{g2}} + \frac{1}{j\omega C_4} + j\omega L_{cable-}
\]

(9)

4. Modeling and simulation

4.1. Lithium batteries second order RC model

The lithium batteries are modeled as a second-order RC circuit considered the dynamic and static characteristic of the batteries to simulate charge and discharge behavior, as shown in Fig. 6 and table 1.

![Fig. 6. Second order RC model of lithium batteries](image)

Table 1. Parameters of battery

<table>
<thead>
<tr>
<th>Items</th>
<th>Values</th>
<th>Items</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{Bat}</td>
<td>700V</td>
<td>R_{bat}</td>
<td>0.3Ohm</td>
</tr>
<tr>
<td>C_{DL}</td>
<td>0.6F</td>
<td>C_{Diff}</td>
<td>0.1F</td>
</tr>
<tr>
<td>R_{DL}</td>
<td>0.00167Ohm</td>
<td>R_{Diff}</td>
<td>0.001Ohm</td>
</tr>
</tbody>
</table>

A SPICE model of the power inverter system for real-time simulation is built in the CST designer to analysis the impact of DM and CM current by IGBT switching on the batteries, as shown in Fig.9. Parameters of parasitic circuit elements in the model were determined by actually measurements made with a vector network analyzer (VNA) and a TDR.
5. Experiment and verification

To verify the impact of EMI from the electric drive system on the lithium-ion batteries, a measurement platform was built as shown in Fig.9. The output voltage of lithium batteries is about 700 V. A 40 KW permanent magnet synchronous motor is controlled by space vector PWM.
From Fig.10, it can be seen that the DC output voltage of batteries fluctuate with IGBT switching dominated by DM current and CM current. The battery voltage fluctuation range without filter is about 14.32% and higher than that with filter, which is within 1.32%.

### 6. Conclusions

DM and CM current paths flowing to batteries are analyzed through the modeled equivalent circuits. A SPICE model of the power drive system and a test platform are built to verify the impact of EMI from the power drive system on the lithium-ion batteries. The results show that the batteries voltage fluctuation range without filter due to DM and CM current is higher than that with filter. Battery life will be reduced due to thermal reason caused by the increasing internal resistance with high frequency EMI.

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### 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.