Research on Coupling Measurement Method of Inverter in High Voltage Electric Drive System

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***Abstract*—Instead of combustion engine, electric drive becomes the main power source for pure electric and hybrid vehicles. For one thing, it's eco-friendly and economical. For another, it introduces nonnegligible electromagnetic interference that threaten the electromagnetic compatibility of the system. One way it affects is high-low coupling, where electromagnetic interference transfers from high voltage components to low voltage components by means of conduction and radiation. In R&D stage, high-low coupling attenuation need to be considered and evaluated. After system integration, measurement of high-low coupling need to be performed. In this paper, mechanism of high-low coupling is studied. Test method at both R&D stage and system integration stage is introduced. It will help engineers find the weak point of the system and provides suggestion for optimization.**

Keywords—high voltage electric drive system; high and low voltage coupling; inverter; coupling attenuation

I. INTRODUCTION

With the development and maturity of electric drive technology, the number of pure electric vehicles (PEV) and hybrid electric vehicles (HEV) has increased steadily. Unlike traditional vehicles, PEV and HEV take high-voltage (HV) electric drive system as their main power. In addition to traditional low-voltage (LV) electronic devices, various HV components and systems are integrated as well. As a result, electromagnetic interference (EMI) in PEV and HEV is much higher than that of traditional vehicles [1]. And EMI coupling between HV and LV systems is complex, which may affect safety critical equipment, such as the control system, communication networks and navigation devices. Therefore, for PEV and HEV, electromagnetic compatibility (EMC) becomes a challenging issue.

II. EMI OF INVERTER IN HV SYSTEM

As the main power source of electric vehicles, HV electric drive system mainly consists of HV battery pack, inverter, motor and interconnecting cables [2], as shown in Fig.1. HV battery provides higher-level DC voltage. Main circuit of inverter is a three-phase bridge, which converts DC input of battery pack into three-phase AC output. Cables include DC cables that connect battery and inverter, as well as AC cables that connect inverter and motor. Shielding cables are commonly used due to high voltage. Due to its high efficiency, three-phase permanent magnet synchronous motor is usually used in EV. The whole HV electric drive system realizes various working status for vehicle [3], including starting up, uphill, normal driving, downhill, deceleration, et al.

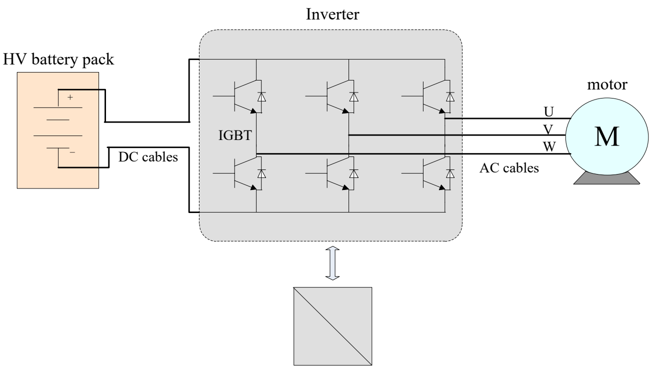

Figure1. Structure of HV electric drive system

HV electric drive system is also one major EMI source of electric vehicle. For battery, in order to get a balance between efficiency and power, different voltage levels are used including 270V, 360V, 560V and 700V. For some models, voltage level can be as high as 1000V to meet the requirements of high-power load. Compared with the traditional 12V, 24V, 48V LV power supply, the introduction of HV power supply will produce more severe EMI issue.

Inverter consists of drive circuit and main power circuit [4], which usually use pulse width modulation (PWM) to control the fast on and off of the semiconductor insulated gate bipolar transistor (IGBT) to achieve power conversion. As shown in Fig.2 and Fig.3.

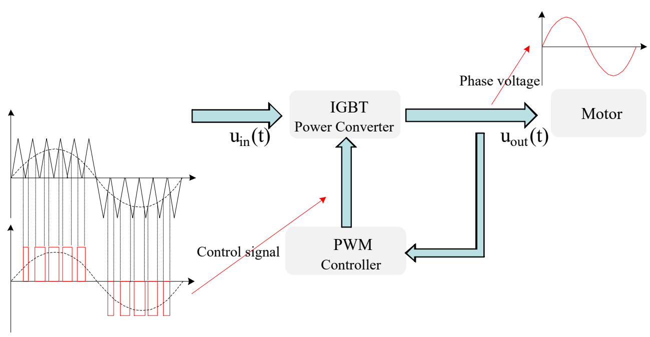

Figure2. Schematic of PWM control signal generation

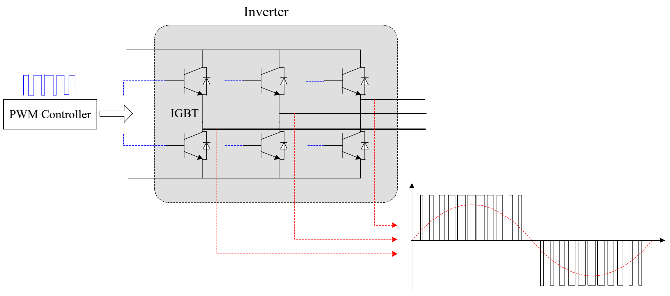

Figure3. Basic schematic of IGBT power conversion

Wherein, the three-phase input of motor is phase voltage waveform that DC/AC inverter desires to output, and as the signal wave of PWM modulation for inverter drive circuit, PWM with carrier (generally a triangular wave) to obtain rectangular wave of the IGBT gate, which can control the on and off of IGBT: high level corresponds to the IGBT's on, and low-level off.

The voltage between the collector and emitter of the IGBT corresponds to voltage of battery, which is as high as several hundred volts. While switching frequency of IGBT can reach hundreds of nanoseconds, thus when inverter works normally, the fast switching of IGBT can form very sharp pulses with high amplitude, then EMI introduced can be characteristic of wide band and large energy, so that inverter is main EMI source of system.

III. HV-LV COUPLING OF INVERTER

As main EMI source of HV electric drive system, inverter has both IGBT power circuit and LV control circuit incorporated inside. HV and LV parts are separated from each other with compartment. However, since IGBT need LV signals to drive, cable connection between them are necessary. And in order to ensure the control function, no filtering measures can be taken to avoid the signal distortion. Therefore, the wiring harness becomes a HV-LV coupling path inside inverter, which will not only carry conduction emission, but also radiation emission. In addition, ground connection can also cause HV-LV coupling. As shown below.

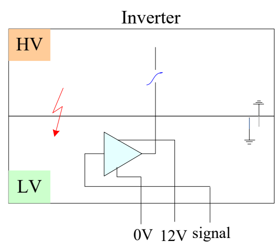

Figure4. HV-LV coupling of inverter

The HV-LV coupling of inverter affects normal operation of their own control circuits, signal lines, sensors, et al, which can also couple to other electronic devices located in the same vehicle, such as radio communication, navigation, and control devices, affecting their normal operation.

The coupling attenuation (CA) design of inverter must be tested and evaluated during the product Research and Development (R&D) phase, then verified under normal conditions to ensure sufficient decoupling coefficient to make LV parts meet limits specified by standard, such as Class 5 in CISPR25 [5].

IV. HV-LV COUPLING ATTENUATION MEASUREMENT OF INVERTER AT R&D STAGE

In HV electric drive system, inverter produces EMI as high as 120-160 dBμV for different voltage levels. Therefore, HV-LV coupling test and evaluation at product R&D stage can effectively avoid EMI exceeding for the entire system.

A. Test Ideas

The inverter may not work properly during the R&D phase. In this case, the standard test method with normal operation in CISPR25 can't be used. Therefore, we can use signal generator and power amplifier to simulate the interference signal generated by HV inverter, measure impact on LV parts with conducted emission test specified in CISPR25, thereby evaluate CA.

Based on the empirical value of EMI generated by inverter, combined with the output power of the power amplifier (100W or 200W) and easy to calculation, this paper chooses 120dBμV (1V) as the calibration signal level.

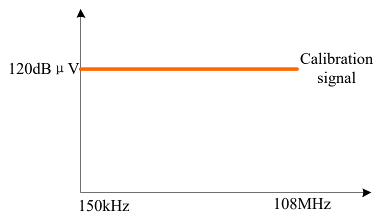

Figure5. Level of calibration signal

B. Test Procedures

1) Calibration

Perform signal calibration as shown below. The signal generator produces an RF signal, which is amplified by power amplifier and applied to power line between HV artificial network (AN) and inverter through a current injection probe. The RF terminal of HV AN is connected to test receiver through RF cable. Adjust the signal generator level to make receiver's voltage 120dBμV and record the calibration curve.

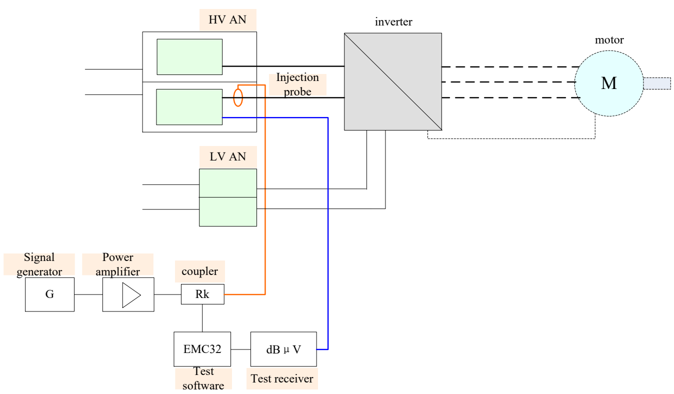

Figure6. Calibration

2) HV AN ambient noise test

Disconnect the receiver from the RF terminal within the HV AN. To completely disconnect, terminate metal caps on both RF cable and RF terminal. The signal generator and power amplifier are output at a test level calibrated in 1).

This step means to test the ambient noise in HV AN. If noise except ambient is detected, the inter-line coupling between the injected and the test cable can be one reason. It is recommended to install ferrite rings on the parallel placed RF cables to eliminate the effect of line coupling on test results.

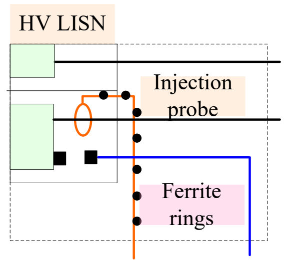

Figure7. HV AN ambient noise test

3) LV ambient noise test without injection

Conduct connection as shown below. Stop signal output from signal generator. Then measure LV ambient noise under condition of no injection with conducted emission (CE) test-voltage method.

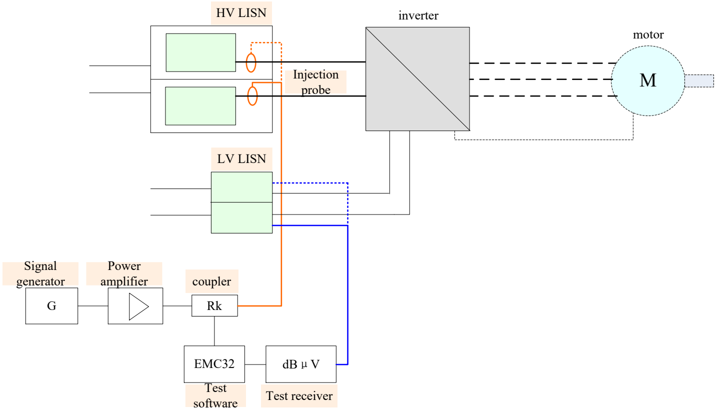

Figure8. LV ambient noise test

4) LV emission test with injection

Conduct connection as shown in Fig. 8. Signal generator and power amplifier output signals with test level calibrated in 1). Measure LV emission, which is HV-LV coupling curve.

C. Coupling Attenuation Assessment

Subtract the LV noise (coupling curve) measured in B from calibration curve, which can get the HV-LV CA curve.

In order to evaluate the HV-LV CA design of inverter at R&D stage, it can be compared with the CA curve specified in Appendix I of CISPR25. As shown below.

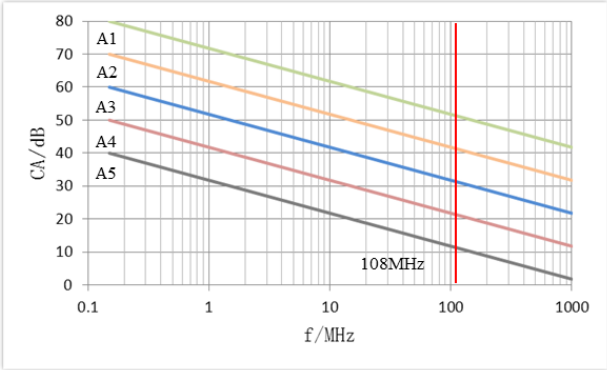

Figure9. Coupling attenuation coefficient (above 108MHz for reference only)

The decoupling between HV and LV should be at least A5 level. And the larger coupling attenuation, the better decoupling design between HV and LV.

V. HV-LV COUPLING ATTENUATION VERIFICATION

After the preliminary evaluation of HV-LV CA design for inverter at R&D stage, it should be verified under the normal working condition as well.

The HV-LV CA verification method is given in Appendix I of new CISPR25. Basic principle is to calibrate with limit of HV component, inject the calibrated signal into the inverter, then decide whether emission on the LV side satisfy standard requirements. If yes, HV-LV coupling attenuation design meets requirement, vice versa.

A. Test signal calibration

The calibration setup is shown below. The injected signal is calibrated at the HV AN port, which is HV limit specified in standard. The inverter is not supplied during calibration. Measure output level at the RF port of HV AN, and shielded HV AN output port terminated with 50Ω.

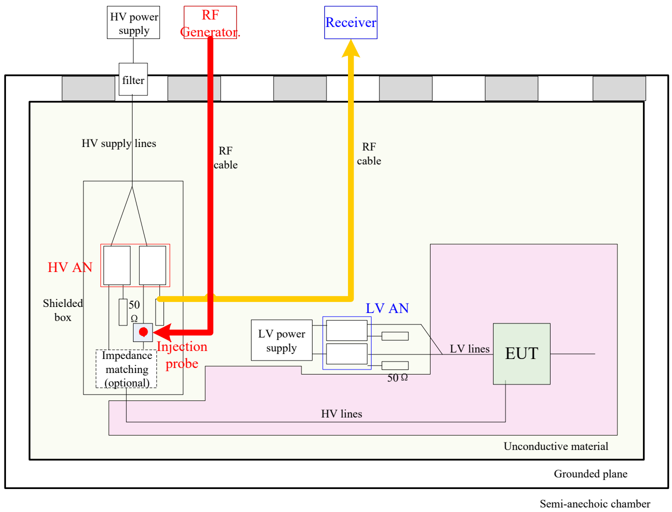

Figure10. RF calibration schematic

B. *LV noise test under different working conditions*

When the calibration signal is injected, measure the emission curve on the LV side as shown below. Measurements were made on LV+ and LV- ports respectively. Make record of emission curves. Since inverter can realize various working states, LV noise measurements should be conducted under every working mode separately.

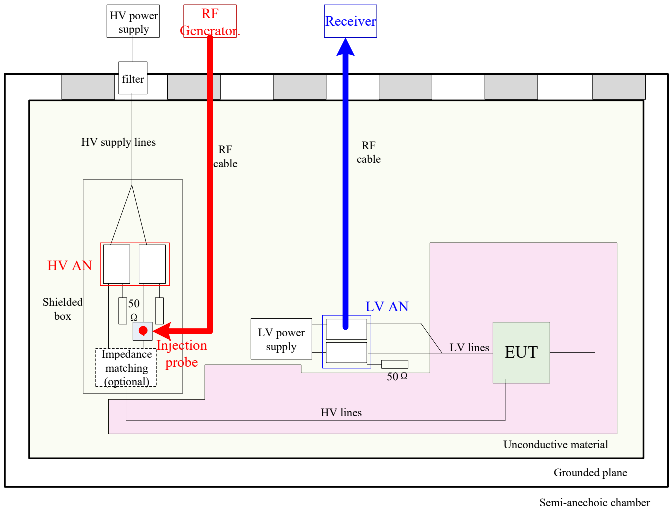

Figure11. Coupling test schematic

C. *Verification and Analysis of Coupling Attenuation*

When injecting the HV limit signal, judge LV emission curves according to the LV limit lines of CISPR25. If the LV emission is lower than the limit line, the HV-LV CA requirement is met, otherwise not.

Below are CE results measured with HV injection for LV+ and LV- ports of one inverter in HV electric drive system with motor speed 1000rpm, torque 100N • m, using an EMC test bench.

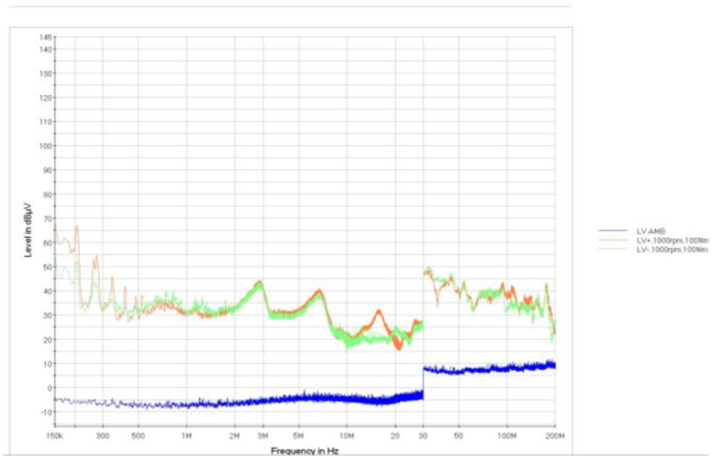

Figure12. CE results of LV ports with HV injection under one dynamic status

Comparing with limits of Class 3 specified in CISPR25, as shown below, it can be seen that, both results don't exceed limit lines. Then CA design can be thought to pass.

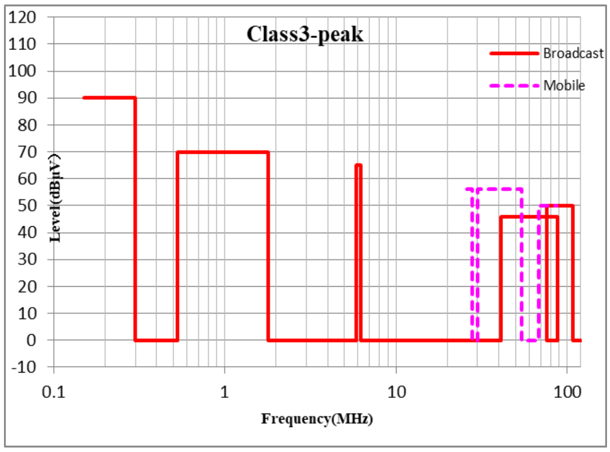

Figure13. LV limits of Class 3 in CISPR25

VI. Conclusions

This paper studies mechanism of EMI in inverter, analyzes HV-LV coupling path and evaluates influence to other components. In order to verify EMC of the system, detailed method of testing high-low coupling is proposed for two stages, product R&D stage and product integration stage, instead of one final standard verification. Finally, one example is given to indicate one method of CA evaluation.

Continuous research will be conducted in the follow-up work, and the test method be continuously improved to form a complete one supported with sufficient data.

References

[1] Zhou Yukui, Qi Linjian, Li Gaolin, Lian Yubo, "Test method for coupling attenuation of HV components in electric vehicles," J. Safety and Electromagnetic Compatibility, 2014.4, pp.16-18.

[2] Sun Hong, "Research on conducted electromagnetic interference of electric vehicle motor drive system,"D. Chongqing University, 2012.

[3] Peng Hemeng, "Research on electromagnetic interference prediction model of electric vehicle motor drive system." D. Chongqing University, 2015.

[4] Firuz Zare, "EMC and modern power electronic systems,"J. IEEE EMC Symposium,2008.

[5] CISPR25 "Vehicles, boats and internal combustion engines-Limits and methods of measurement for the protection of on-board receivers,"S.2016.