Solutions to the Inability to Start the Automotive Electronic Products during Surge Immunity Test

Shuai Hou[a*], Yan Fan[b], Dengyu Zhang[c]

China Automotive Research Institute New Energy Vehicle Inspection Center (Tianjin) Co., Ltd Tianjin, China

[a*]houshuai@catarc.ac.cn; [b]fanyan@catarc.ac.cn; [c]zhangdengyu@catarc.ac.cn

Abstract. During the surge (impact) immunity test of automotive electronic products, the presence of the decoupling inductor within the coupled decoupling network system renders self-oscillations, resonance, or high voltage drop in the testing system, ultimately resulting in the failure of equipment under test (EUT) in normal operation. Moreover, the increasing application of high-frequency nonlinear components in electric vehicles leads to more frequent occurrence of this situation. In response to this challenge, this research proposes several solutions, investigating the practicability and applicability of these methods. Briefly, this study has certain guiding significance for the implementation of the surge immunity test, a common electromagnetic compatibility test item.

Keywords: Resonance; Decoupling Inductor; Surge Immunity Test

1 Introduction

Surge immunity test stands as a fairly common test item within the field of electromagnetic compatibility tests, which is based on the IEC 61000-4-5:2017 [1]. Specifically, this test aims to simulate the unipolar surge phenomenon induced by switching as well as lightning transient overvoltage. Presently, the application of high-frequency nonlinear components in a plurality of automotive electronic components leads to the surge phenomenon in the switching process of components. Concurrently, new energy vehicles are vulnerable to lightning during outdoor charging. Hence, an increasing number of automotive electronic products are required to accept this test. During the surge immunity test for this kind of product, numerous test systems appear resonance phenomena or self-oscillations of products after the test equipment is connected to the products, ultimately leading to the failure of equipment under test (EUT) in normal operation. In this regard, this research systematically expounds the common solutions to this problem, which has certain guiding significance for the related detection industry and the lightning performance evaluation of automobile electronic components [2].

The informative Appendix I of the IEC 61000-4-5:2017 furnishes relevant expla-

G. Zhao et al. (eds.), *Proceedings of the 2024 7th International Symposium on Traffic Transportation and Civil Architecture (ISTTCA 2024)*, Advances in Engineering Research 241,
https://doi.org/10.2991/978-94-6463-514-0_43

nations, especially for system resonance or self-oscillations of EUT. The foregoing phenomena can be primarily attributed to the existence of the decoupling inductor [3], which renders the steep rise and fall of voltage and current during PWM chopping, which is beyond the allowable voltage or current range of EUT. Ultimately, the protection mechanism triggered by the product makes the product fail to work normally. Briefly, a fundamental reason lies in the insufficient purity of the loop current of the whole test system. With the connection of surge immunity test equipment, the novel circuit topology formed with the decoupling inductor makes EUT present an excessively high dynamic voltage-current conversion rate during the switching process, thereby resulting in unnecessary self-oscillations. In cases where the self-oscillation phenomenon exceeds the threshold set by the product, the EUT self-protection will eventually lead to the failure of the equipment in normal operation.

A higher switching frequency of switching elements, coupled with a larger working current, causes an increasing number of products to fail in normal operation and even start up due to system resonance or self-oscillations. Regarding the current automotive electronic components, except for pure power supplies such as high-voltage battery packs and low-voltage batteries that do not need pulse-width modulation (PWM), other direct current (DC) supply products are exposed to the phenomenon that the products fail to work normally or cannot work under the specified load during the surge test process. Overall, products with similar phenomena encompass high/low voltage positive-temperature-coefficient (PTC) automobile heaters, DC/DC converters, power distribution units (PDUs), fuel pumps, etc.

2 Reasons for the Inability to Start the Samples

Concerning a passive one-port network including capacitors, inductors, and resistors, its ports may be capacitive, inductive, and resistive. In the case that the voltage U at the circuit port is in phase with the current I, the circuit presents resistivity, which is described as resonance. Hence, such a circuit is called a resonance circuit. Resonance circuits can be divided into parallel resonance and series resonance as per their topology structures. The resonance outlined in this research refers to series resonance in particular. Figure 1 depicts the structure of the waveform-generating device of the composite wave signal generator employed in the surge immunity test.

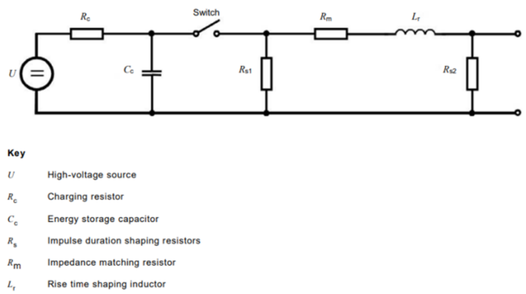

Fig. 1. Simplified circuit diagram of the combination wave generator

The equation used to describe the structural block diagram of the whole test system is given by:

$$Z = R + j\omega L + (-j\frac{1}{\omega C}) = R + j\ (\omega L - \frac{1}{\omega C}) \tag{1}$$

In the case of $\omega L = \frac{1}{\omega C}$, in which resonance occurs, the test system presents the minimum impedance and the maximum current. When the current value exceeds the maximum allowable current of the product, the product reports that the current is over-current and therefore stops working.

In the above Equation (1), L represents the sum of the decoupling inductor and the equivalent inductance of the signal generator. As a general rule, the decoupling inductor presents a larger value than the equivalent inductance of the generator. Therefore, to avoid the resonance phenomenon, it is imperative to seek solutions from the perspective of decoupling inductors first, as illustrated in Figure 2.

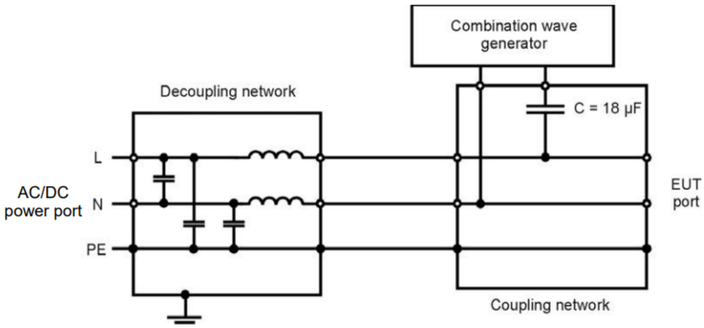

Fig. 2. Coupling network and decoupling networkfor capacitive coupling on a.c./d.c. lines line-to-line coupling

3 Solutions

Combining with the existing standard data and test experience, this research systematically analyzes the causes of this phenomenon, proposing targeted solutions for different situations. Meanwhile, this research comprehensively compares diverse methods, thereby providing methodological support for the testing of this kind of product to some extent.

Currently, the solutions to this kind of problem can be summarized as follows.

3.1 Changing the Circuit Structure of the Test System [4]

Electromagnetic Clamp Decoupling Method.

As depicted in Figure 3, the power supply bypasses the decoupling circuit part of the coupling decoupling network and is then directly connected to the product end, thereby sheathing the electromagnetic clamp as a decoupling element on the power supply end to protect the power supply. Furthermore, the composite wave signal generator provides an interference signal, which is directly injected into EUT. In this method, it is necessary to ensure that the interference signal can be injected into the EUT, provided that the electromagnetic clamp can filter out the surge signal with a specific bandwidth, thus protecting the power supply from the interference of the surge signal. Hence, on the one hand, the internal resistance of EUT shall be kept within a small enough range compared with that of power supply, so that surge signals can be injected into EUT. The electromagnetic clamp, on the other hand, should possess enough filtering function to filter out such surge broadband signals at tens of kHz as much as possible. Notably, this method is recommended.

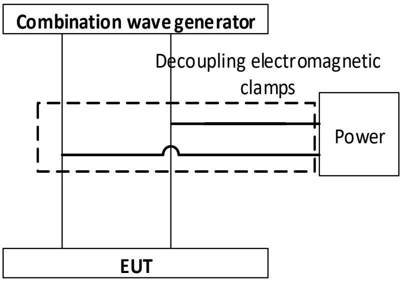

Fig. 3. Connection Diagram of Decoupling by Electromagnetic Clamp

Adding Additional Circuits at the Power Supply End.

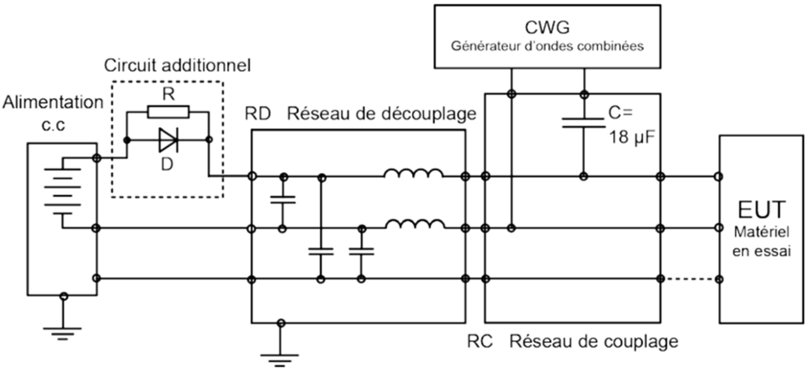

Fig. 4. Example of Preventing Resonance of Test System by Additional Circuits

This research adds a circuit device as shown in Figure 4, whose primary function is to suppress or eliminate self-oscillations. This circuit is mainly the parallel connection of diode and resistor (quoted from Appendix I of IEC 61000-4-5:2017), which can achieve resonance with the decoupling inductor element of the surge immunity test system by adjusting the resistance value as well as the equivalent capacitance value shown when the matched diode current flow is selected. In other terms, it is capable of eliminating nonlinear elements, thus realizing the elimination of self-oscillations. Notably, this method will not affect various index parameters of the test pulse. Thus, this method is recommended.

Changing the Length of the Power Supply Line.

Decreasing or increasing the cable length of the power supply line is helpful in changing the circuit structure, thereby destroying resonance. During the specific design process, the corresponding estimation can be implemented as per the additional increase of 1 μH inductance by extending 1 meter line [5]. Despite the simplicity and feasibility of this method, it exhibits relatively sub-optimal effects. Accordingly, this method is not recommended.

3.2 Modifying Parameters of Test Equipment

The modification of test equipment parameters can be realized by changing the parameters of the decoupling inductor within the coupling decoupling network. IEC 61000-4-5:2017 does not specify the value of the decoupling inductor within the coupling decoupling network. Consequently, modifying the inductance value of the decoupling inductor can change the circuit structure. Presently, some suppliers have introduced decoupling inductor values of coupling decoupling networks with different supply currents, which can be adjusted and selected (see Appendix H of IEC 61000-4-5:2017 for details). Hence, this method is recommended.

The size of the decoupling inductor should be selected by the manufacturer of the coupling decoupling network so that the voltage drop generated on the coupling decoupling network does not exceed 10% of the input voltage of the coupling decoupling network at the rated current, provided that the inductance value should not exceed 1.5 mH. For coupling decoupling networks with a rated current greater than 16 A, it is typically imperative to reduce the value of the decoupling inductor to prevent unexpected voltage drop. In this case, the peak voltage and duration of the open-circuit voltage waveform measured when the load is not connected can be changed within the tolerance range outlined in Table 1. EUT showcases low impedance under the test condition of a large current, which leads to the surge equipment approaching a short circuit. Consequently, the current waveform acts as the dominant waveform for the coupling decoupling network with a large current. Given this, the voltage regulation can be broadened to the tolerance range. Theoretically, a higher decoupling inductor value usually produces a larger voltage ripple, which makes the product more likely to fail to work. Accordingly, it is imperative to select a decoupling inductor with a smaller inductance value as far as possible on the premise of ensuring that the peak voltage and duration of the open-circuit voltage waveform are within the specified tolerance range.

In cases where the input current is greater than 200 A, the decoupling inductor value of the coupling [6] decoupling network is illustrated in Table 1, which is quoted from Appendix H of IEC 61000-4-5:2017.

Table 1. Relationship between the EUT Working Current and Recommended Decoupling Inductor Value

EUT working current value	Recommended decoupling inductor value
200 A < rated current ≤ 400 A	200 μH < L ≤ 100 μH
400 A < rated current ≤ 800 A	100 μH < L ≤ 50 μH
800 A < rated current ≤ 1600 A	50 μH < L ≤ 25 μH

Additionally, another simple method is to connect the negative power supply line directly to the product end by bypassing the coupling decoupling network during the surge test aimed at testing the DC line-to-line coupling position. In this case, the decoupling inductor value is reduced to half of the original value while maintaining the original decoupling effect [7].

3.3 Changing the Protection Voltage/Current Range of EUT

With the customer's permission, the manufacturer can change the voltage and current thresholds of products through software to ensure their stable operation, so that EUT will not report errors or automatically stop due to excessive voltage or current fluctuations beyond the rated working range of products during the process of self-oscillations. This method is recommended.

3.4 Selecting a Relatively Pure Power Supply[8]

Both the self-oscillation circuit and the resonance circuit generate unexpected induced voltage after encountering nonlinear components due to AC components in the power supply, which in turn leads to the failure of the product in normal operation. By contrast, pure direct current can remain stable even under the action of nonlinear components.

In summary, the various methods mentioned above present their respective advantages and disadvantages. Hence, engineers should flexibly select one or more methods as per the characteristics of products and test equipment in the field test process, intending to achieve the assessment of surge immunity of EUT without the interference of surge signals.

3.5 Providing a Higher Supply Voltage at the Input Port of the Coupling Decoupling Network

Simultaneously, increasing the voltage at the input port of the coupling decoupling network can be employed to offset the voltage drop induced by the decoupling inductor, thereby ensuring that the voltage at the input end of the sample is within the rated power supply range.

4 Conclusions

Surge immunity test serves as a common immunity test item within the electromagnetic compatibility testing industry. The majority of AC-powered products, coupled with numerous DC-powered automotive electronic products, need to undergo such tests. Moreover, most of these test items are implemented as per the IEC 61000-4-5:2017. Nevertheless, this standard can solely furnish a universal testing method. Regarding some specific products, such as products with high starting current or products with high requirements for power purity, it is imperative to introduce certain methods to supplement and improve them. Particularly, field test requires engineers to take appropriate measures according to product characteristics to achieve EUT testing.

References

1. IEC 61000-4-5:2017 Electromagnetic Compatibility (EMC) - Part 4-5: Testing and Measurement Techniques - Surge Immunity Test [S].
2. Kumar, K.J.; Kumar, R.S. Surge Immunity Protection in AC LED Street Lights. In Proceedings of the IEEE International Conference for Innovation in Technology (INOCON), Bangluru, India, 6 – 8 November 2020:1-4.
3. Wang J. G., Zhou M., & Liu Y., et al. Coupling and Decoupling Network (CDN) for Lightning Surge Immunity Test [J]. *High Voltage Engineering, 33*(11): 84-87.
4. Zhang Z. Q. Application of Isolation Transformer in Surge Immunity Test on Power Lines [J]. *Low Voltage Apparatus, 2010*(24): 58-61.
5. Yao X. L., Chen J. L., & Sun W. Study on Decouple Network Used for Surge Discharge Test [J]. *High Voltage Engineering, 2004, 30*(7): 7-11.
6. Hu D. L., Liu G. Q., & Pan Y., et al. Comparative Analysis of New and Old Standards for Electromagnetic Compatibility Surge Immunity Test [J]. *Quality Supervision, 259*: 16-18.
7. Yao X. L., Chen J. L., & Sun W. Study on Decouple Network Used for Surge Discharge Test [J]. *High Voltage Engineering, 30*(7): 7-9.
8. Garcia, J.; Saeed, S.; Quintana, P.; Cardesin, J.; Georgious, R.; Dalla Costa, M.A.; Camponogara, D. Optimization of a Series Converter for Low-Frequency Ripple Cancellation of an LED Driver. Electronics 2019, 8, 664.