

Simulation of Surge Pulse Generator and Applications in Automotive Immunity Testing

Andrei-Marius Silaghi, Aldo De Sabata
Dept. of Measurements and Optical Electronics
University Politehnica Timisoara
Timisoara, Romania
andrei.silaghi@upt.ro

Adrian Graur, Radu Fechet
Dept. of Computers, Automation and Electronics
University "Stefan cel Mare" Suceava
Suceava, Romania
adrian.graur@usv.ro

Abstract—A circuit simulation model for a combination wave generator used in Automotive immunity testing has been devised and is reported in this paper. The open circuit voltage and short circuit current outputs from the model have been validated by comparison with experimental data. A further validation has been accomplished by using the generator in a simulated immunity test on an Automotive product and comparing results with data from an actual immunity test performed in the laboratory. The main contribution of this paper is to provide a simulation tool that can be used in design and verification of Automotive products, to prove that they are according to IEC 61000 standard requirements.

Keywords—surge pulse; EMC simulation; PSpice; IEC 61000-4-5

I. INTRODUCTION

Electric fast transients occur as bursts on power supply lines caused by switching of inductive loads, fuse blows, switchings in the power grids, lightning etc. Since bursts on power lines may cause malfunctioning of electric and electronic equipment, immunity tests to surge pulses have been devised to be performed in EMC laboratories before products become available on the market. These tests must be repeated if products are subject to design modifications [1], [2].

Product design according to EMC requirements has become common practice in modern electric and electronic industry. EM circuit simulators can be used to find solutions to several EMC problems, thus assessing the impact of various design modification of the EUT (Equipment under test) [3]. This might be an economic alternative to running several full tests in semi-anechoic chambers. The penetration of electromagnetic simulation in solving surge pulse-related issues is well reflected in the engineering literature [4]-[7].

Transient over-voltages or surges, generated by various causes, frequently occur in mains voltage networks. Particularly energy-rich are the surges that result when a fuse blows. Such transients have pulse widths extending into the region of milliseconds. These transients containing very high energy could damage electronic equipment [4]. The cause of these high energy pulses being generated is the charging of the

network inductance as well as the stray inductance of the distribution transformers by the exponentially increasing short circuit current [4].

A filter design methodology was given in [5] to mitigate Bust pulses such as Electrical Fast Transients (EFT) and surges. The design was done keeping in mind the requirement to protect costly sensitive components in the circuit. Simulations have been done using CST to design a two-stage filter and have been validated in laboratory by experimenting with actual components in order to verify that the immunity requirements are met [5]. The simulation results of the filter performance matched the lab measurement of the actual two stage filter. Measurement result proved the design filter could mitigate EFT noise. The effect of component variation and how to evaluate the impact of the design of component variation was carried out.

The equivalent circuit modeling method is developed for the electromagnetic pulse (EMP) generators at the equipment-level immunity test. For the generators of EFT/burst, surge combination wave, and electrostatic discharge (ESD), equivalent circuits and components parameters are proposed in [6]. The equivalent circuit model of an ESD generator with double-exponential pulse output is presented and the components parameters are proposed. Finally, simulation results validate the proposed method and circuit models [6].

System efficient ESD design (SEED) is an effective method for simulating behavior of a system subject to electrostatic discharge (ESD). Based on this simulation method, the work [7] investigates transient behavior of a co-design protection circuit and failure of a hybrid-triggered power clamp under surge stress. Moreover, relevant measurements are reported for verifying the simulation results of the co-design protection circuit and failure analysis of the power clamp [7].

In this paper, a circuit simulation model for a combined wave generator is proposed in order to assist product initial design and late design EMC-related troubleshooting in Automotive industry. The considered type of generator is used in many immunity test setups. The validity of the model is demonstrated by comparing simulation results against data

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measured on an actual generator in the laboratory. Furthermore, a comparison of results of a simulated test and the real one is reported. Thus, this model can be further used with a variety of EUT's, to prove that they meet the requirements of the IEC 61000 standard.

This paper is structured as follows: Section II covers the automotive standard used for Surge Pulse Testing (IEC 61000-4-5). In the next section the calibration of the surge pulse generator in PSpice is presented. Firstly, the surge generator with 2 and 4 kV, short and open cases has been considered. Then, the impact of the coupling/decoupling networks for the above-mentioned cases has been assessed. In Section III the application of the tested generator model to an automotive device under test is discussed. Finally, comparison is made between measurement results in the EMC laboratory and numerical predictions.

II. IEC 61000-4-5 STANDARD

Part 5 of IEC 61000 relates to the immunity requirements, test methods, and range of recommended test levels for equipment with regard to unidirectional surges caused by over voltages from switching and lightning transient [2].

For example, the major mechanisms by which lightning produces surge voltages are the following:

- direct lightning stroke to an external (outdoor) circuit injecting high currents that produce voltages by either flowing through ground resistance or flowing through the impedance of the external circuit (including wires);
- indirect lightning stroke (i.e. a stroke between or within clouds or to nearby objects which produces electromagnetic fields) that induces voltages/currents on the conductors outside and/or inside a building;
- lightning ground current flow resulting from nearby direct-to-earth discharges coupling into the common ground paths of the grounding system of the installation [2].

Two types of combination wave generators are specified in the standard. Each has its own particular applications, depending on the type of port to be tested. The 10/700 μ s combination wave generator is used to test ports intended for connection to outdoor symmetrical communication lines. The 1,2/50 – 8/20 μ s combination wave generator is used in all other cases [2].

The voltage and current output waveforms defined in the standard must meet specifications at the point where they are to be applied to the EUT. Waveforms are specified as open-circuit voltage and short-circuit current and therefore must be measured without the EUT connected [2].

The 1,2/50 – 8/20 μ s combination generator is intended to generate a surge having: a double exponential pulse open-circuit voltage with front time of 1.2 μ s and duration of 50 μ s; a short-circuit current pulse front time of 8 μ s, a current duration of 20 μ s. The 30% undershoot specification applies only at the generator output [2].

A simplified circuit diagram of the generator is given in Fig. 1. The values for the different components R_{S1} , R_{S2} , R_m , L_r , and C_c are selected so that the generator delivers the required voltage surge at open-circuit conditions and current surge into a short-circuit [2].

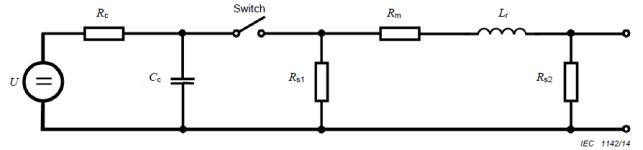


Fig. 1 Generator model [2]

The roles of the components from Fig. 1 are as follows: U =high-voltage source, R_c =charging resistor, C_c =energy storage capacitor, $R_{S1,2}$ =impulse duration shaping resistors, R_m =impedance matching resistor, L_r =rise time shaping inductor [2].

In Table 1, the relationship between peak open-circuit voltage and peak short-circuit current are presented.

Table 1 Relationship between peak open-circuit voltage and peak short-circuit current [2]

Open-circuit peak voltage $\pm 10\%$ generator output	Short-circuit peak current $\pm 10\%$ generator output
0.5 kV	0.25 kA
1.0 kV	0.5 kA
2.0 kV	1.0 kA
4.0 kV	2.0 kA

III. SURGE PULSE GENERATOR CALIBRATION IN PSPICE

The 1,2/50 – 8/20 μ s combination generator is calibrated in order to establish that its characteristics meet the requirements of the standard IEC 61000-4-5, previously described. We tested firstly only the surge generator with 2 and 4 kV, short and open cases. We turned then to the use of coupling/decoupling networks for the above-mentioned cases.

The schematic is built in PSpice, Fig. 2. The component values were optimized to obtain the desired waveform. These values are as follows: $U=4.3$ kV, $C_c=6.04 \mu$ F, $R_{S1}=25.1 \Omega$, $R_m=0.94 \Omega$, $L_r=10.4 \mu$ H. We started with the case of the generator model for Open case (placing a high load at the output - in this case $R_{S2}=19.8 \Omega$ was enough) and with the maximum voltage case: 4kV.

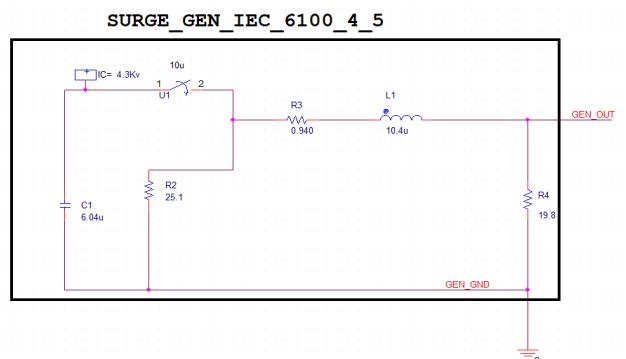


Fig. 2 Pulse generator model for Open (4kV)

In Fig. 3, the time variation of the voltage at the output is reported. This waveform respects the standard: the maximum amplitude is 4 kV, the duration is within 50 us \pm 20% and the front time is within 1.2 us \pm 30 %.

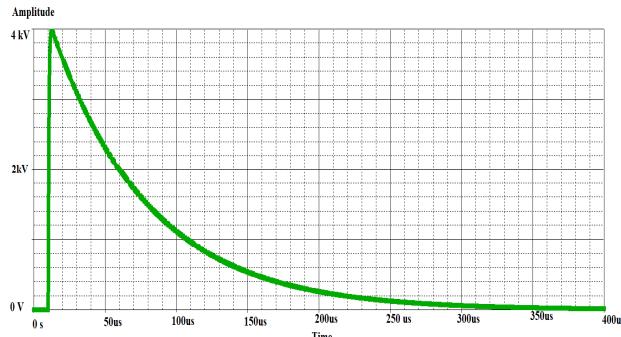


Fig. 3 Open (Voltage) for 4 kV case

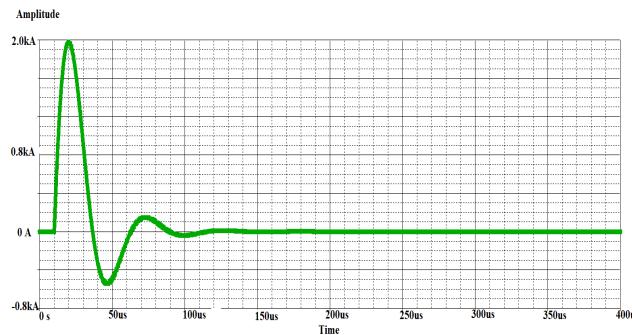


Fig. 4 Short (Current) for 4kV case

Afterwards, the schematic is built in PSpice with the case for Short (placing a very low load at the output- $R_{S2}=0.1 \Omega$). In Fig. 4 we can notice the result for the current at the output. This waveform respects the standard: the maximum amplitude is 2 kA, the duration is within 20 us \pm 20%, the front time is within 8us \pm 20 %.

Then, we connected the coupling/decoupling network (CDN) to the setup. Each CDN consists of a coupling network and a decoupling network. On the a.c. or d.c. power lines, the decoupling network provides relatively high impedance to the surge waveform but at the same time, allows current to flow to the EUT [2].

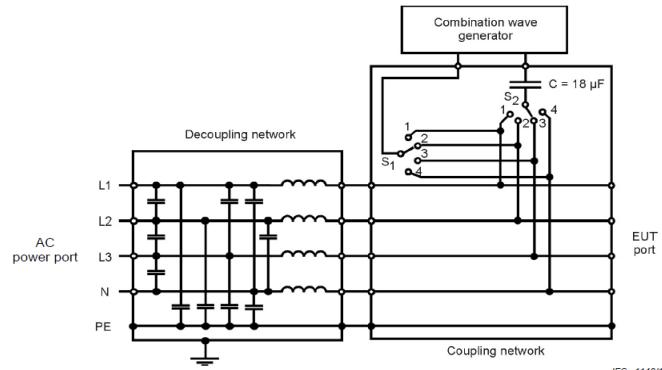


Fig. 5 CDN for three phases – line to line configuration [2]

In this way, the voltage waveform is developed at the output of the coupling/decoupling network and it is applied to

the EUT and the surge current is prevented from flowing into the a.c. or d.c. power supply. High voltage capacitors are used as coupling elements, sized to allow the full waves to be coupled to the EUT. There is no undershoot specification in the standard for the output of the coupling/decoupling network, [2].

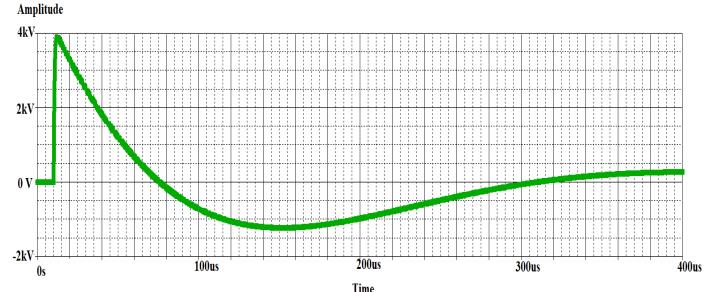


Fig. 6 Voltage (Open) for CDN with three phases

An example of a CDN for three phases, line to line configuration, is represented in Fig. 5. In Fig. 6 the voltage measured for the open case (CDN + surge pulse generator) is visible. It is again according to IEC 61000-4-5 Standard.

IV. PSPICE APPLICATION IN A PROJECT

A. Simulations

After the calibration presented in the previous section, the surge pulse generator has been applied to an automotive EUT. The EUT has been an on-board charger (OBC), which is used in an electric vehicle (EV) or hybrid electric vehicle (HEV) to charge the traction battery.

In Fig. 7 the schematic of the setup is reported, containing: surge pulse generator (having the schematic from Fig. 2), CDN (based on the schematic from Fig. 5), block of protection devices and the project EMC Filter. The surge generator was set at an amplitude of 4 kV, and to trigger at 25 ms. The generator has been connected at each phase (L1, L2, L3) at a time and neutral (N) or protective earth (PE) (in Fig. 7, only the connection between L1 and neutral is exemplified).

Initially, simulations without protection components (varistors and arrester) have been performed. The varistor is an electronic component that has a resistance depending on the applied voltage. In this case, a Metal Oxid Varistor (MOV) has been considered. The surge arrester is a device used to protect electrical equipment from over-voltage transients.

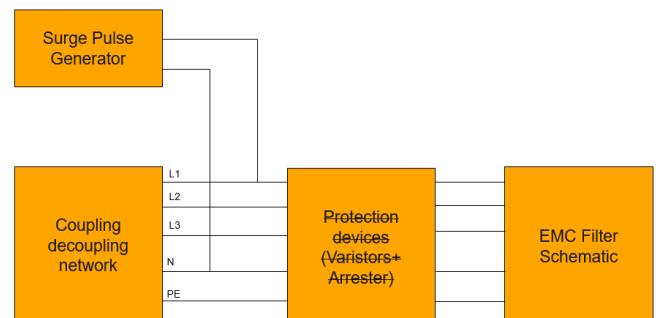


Fig. 7 Schematic with protection absent

In Fig. 8, the measured voltage between L1 and N, without protection components is represented. At the time of interest, the maximum amplitude has a value of 1.6 kV. Besides that time frame, the generator does not have any influence.

The results when protection components are present are reported in Fig. 9. The voltage at the time of interest is smaller than in the previous case. At 25 ms, the maximum amplitude is approx. 500 V.

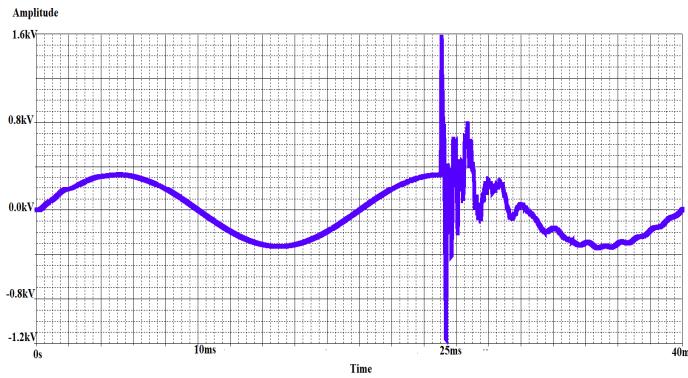


Fig. 8 No protection – results voltage for 4 kV

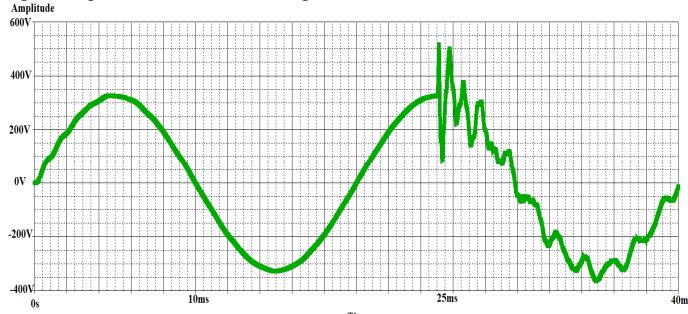


Fig. 9 With protection – results voltage for 4 kV

B. Measurements

In a next step, the simulation results have been compared to those obtained in the EMC laboratory by measuring the surge pulse. In Fig. 10, the measured voltage between L1 and N is reported (with protection components present in the circuit). By comparing Figs. 9 and 10, a good agreement between simulation and measurement results can be noticed. The differences in level and small differences in shape of the curves are motivated by the incomplete knowledge of the EUT impedance.

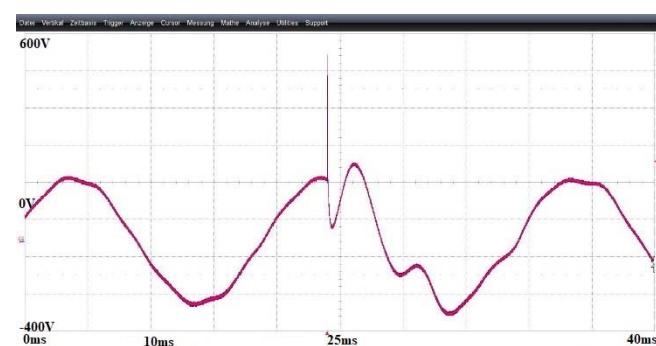


Fig. 10 EMC Laboratory test results

V. CONCLUSIONS

In this paper, the use of 2D analog simulation built for solving surge pulse immunity issues for an automotive on-board charger has been presented.

The Surge Pulse Standard: IEC 61000-4-5 has been briefly reviewed. A 2D model for the surge pulse generator has been devised and validated, relying on 2D simulation tool: PSpice.

After experimental validation of the model in laboratory, it has been applied to assess the behavior of an automotive product during surge pulse immunity test. Results of the 2D model have also been favorably compared to laboratory testing.

The proposed circuit model for the combination wave generator can be used in the future for simulating immunity test on various EUT's, and to demonstrate that the measurement results of the Automotive product are according to IEC 61000 standard.

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REFERENCES

- [1] A. Schwab, W. Kuerner, *Electromagnetic Compatibility*, AGIR 2003 (in Romanian translated from German)
- [2] IEC 61000-4-5 International Standard, Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test, 2017.
- [3] PSpice, Orcad, v.2019.
- [4] H. Kunz, T. Hilger, “EMC Testing with Milisecond Surge Pulses”, 1992 Regional Symposium on Electromagnetic Compatibility, 2-5 November 1992, Tel-Aviv (Israel), 1992.
- [5] A. Kamath, B. Nayak, “Common mode filter design for burst type pulses”, 2016 International Conference on ElectroMagnetic Interference & Compatibility (INCEMIC), 8-9 December 2016, Bangalore (India), 2016.
- [6] G. Luo, W. Zhang, S. Huang, L. Qi, H. Wang, H. Ma, J. Liu, “Equivalent Circuit Modeling of Electro-magnetic Pulse Generator for Typical Immunity Simulation”, 2017 International Symposium on Electromagnetic Compatibility - EMC EUROPE, 4-7 September 2017, Angers (France), 2017.
- [7] Y. Wang, Y. Wang, Y. Li, R. Huang, “Co-design Circuit Simulation to Investigate the Failure of Devices under Surge Stress”, 2019 Joint International Symposium on Electromagnetic Compatibility, Sapporo and Asia-Pacific International Symposium on Electromagnetic Compatibility (EMC Sapporo/APEMC), 3-7 June 2019, Sapporo (Japan), 2019.