Evaluation of Transient Overvoltages at Terminations in Low-voltage Installations

Magno A. de Menezes, Camila A. Dias,
Murilo P. Franco, Ronaldo K. Moreira, Rose M. Batalha
Programa de Pós-Graduação em Eng[a]. Elétrica
Pontifícia Universidade Católica de Minas Gerais
Minas Gerais, Brazil
batalha@pucminas.br

Juliano F. Mologni
Electronic Design Automation Department
ESSS – Engineering Simulation & Scientific Software
São Paulo, Brazil
juliano.mologni@esss.com.br

Abstract — Surge protection devices (SPD) are widely used in low-voltage (LV) power systems in order to damp the possible transient surges that can occur at the terminals of electrical and electronic equipment. According to the standard IEC 62305-4, if the length between the SPD and the equipment is electrically long, there may be an overvoltage of up to twice the SPD protective voltage level due to the reflection effect. There are works in scientific literature claiming that the surge in these same circumstances, could reach up to three times the SPD protective voltage level, which in turn can cause greater interference, failure or total equipment loss. This paper investigates the maximum impulse voltage that can appear on the terminals of the equipment. A TN-S single phase circuit is modeled powering loads in an open circuit (high impedance) condition, through different routes of a three-story building. The simulations are made with the commercial softwares ANSYS HFSS® and PSpice®. A new measurement scheme is proposed in the simulations for interpretation and analysis of transients in the internal lines. The results show that IEC 62305-4 recommendations are suitable for surge protection projects.

Keywords - IEC 62305-4. Low-Power Systems. Transient Overvoltages. SPD. Surge Protection Devices.

I. INTRODUCTION

The surges are considered transient energy signals that produce electromagnetic interference due to a temporary voltage increase. They may be caused by switching power supplies, computer processors, spectral components of lightning, among others [1]. Low-voltage systems are intolerant to these surges that often exceed the maximum voltage supported by the equipment. High-intensity transient signals, such as those caused by lightning, can cause partial or permanent collapse of the hardware or temporary failures in the system [2]. To avoid such damage and disruption, it is required to implement an effective lightning protection design that necessarily takes into account the surge protective measures [3].

Surge protection devices (SPD) are widely used in low-voltage (LV) power systems, in accordance with national and international standards [4]. These devices protect the equipment if it is ensured that the impulse withstand voltage at the equipment terminals is greater than the surge overvoltage between the conductors normally energized and ground. Effective protective voltage is obtained by adding the SPD protection voltage, specified for a given nominal discharge current, with the inductive voltage between the SPD´s connection conductors and the grounding system [5]. Therefore, the selection of a SPD not only depends on its parameters, but also on the characteristics of the line, the circuit downstream of the SPD [6-8] and the characteristics of the SPD's grounding connection conductors. Normally, power networks are complex, with a wide range of loads and conductors interconnected by distinct physical routes, making it difficult to predict the transient response in installations [9,10].

The IEC 62305-4 standard foresees that if the circuit length between the SPD and the equipment is too long, the propagation of the surge may cause the reflection phenomenon. In a worst case scenario, which is an open circuit at the equipment's terminals, there may be an increased voltage of up to twice the value of the effective voltage. In [11], the authors question the protective recommendations set by this standard, once they obtain results showing that the voltage on the equipment terminals can actually reach three times that value.

The objective of this paper is to investigate the maximum impulse voltage that can appear at the equipment's terminals. With this purpose, a TN-S single phase circuit feeding three loads in open circuit (high impedance) condition is simulated. The phase conductor is excited by an impulsive signal and the effect of wavefront time in induced voltages at equipment terminals is observed. Results are obtained from two commercial software ANSYS HFSS® and PSpice®, and compared with those obtained in [11]. It is also proposed, through simulation, another method of measurement which contributes in the interpretation and analysis of transients in the structure's internal lines.

II. DEVELOPMENT AND COMPUTACIONAL MODELING

The simulation model consists of a single phase TN-S system, composed of the conductive phase L, the neutral conductor N and the protective earth conductor PE, feeding high impedance loads in open circuit in a three-story building.

The horizontal distance from the source to the load is 18.5m and vertically it is 1m above the ground, plus 3m up until the first floor and another 3m until the second floor. The interspacing between L, N and PE conductor is of 0.01 m. It was considered all cables with a cross-section of 6 mm^2.

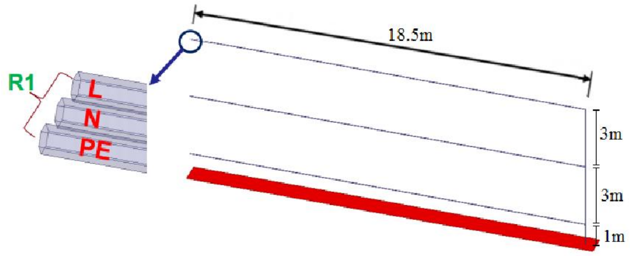
The surge applied through SPD in the phase L is shown in (1).

$$u(t)=\begin{cases} u_{\max}\cdot\dfrac{t}{t_f}, & 0\le t\le t_f \\ u_{\max}, & t>t_f \end{cases} \qquad (1)$$

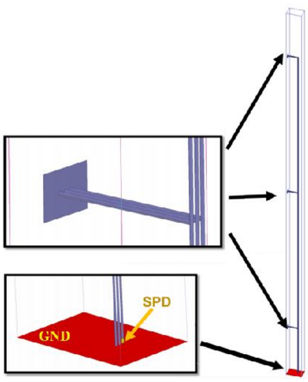
Where u_{max} is the peak value and t_f is the signal rise time. In this work it was considered the amplitude of 1pu and rise times from 0.01µs to 1µs.

The simulations were carried out by commercial software's PSpice® and ANSYS HFSS® in conjunction with ANSYS Designer® software.

In ANSYS HFSS®, due to cable length, deembeding technique was used where only a part of the model is simulated and the other results are numerically extrapolated. Figure 1(a) depicts the complete model, showing which are the lines, named phase (L), neutral (N) and protective earth (PE) and the insertion points of the resistance R1. In Fig.1(b), it is seen the model when deembeding is applied, highlighting the wave port, the SPD and the infinite ground plane.



(a)



(b)

Fig.1 (a) - Complete model structure using ANSYS HFSS®;

(b) - Model used with deembeding considerations.

The model was simulated from 0Hz to 110MHz to cover the spectrum required for representing the signal ramp applied to the conductor L through the SPD.

Because the intention is to check the transient behavior in line termination, after generating the electromagnetic model in ANSYS HFSS® , it is necessary to integrate ANSYS Designer® software to allocate the excitation and measurement elements.The integration of the magnetic circuit model with the electrical circuit is shown in Fig.2. The designation R1 shown in Fig.1 (a) is used to emphasize where the resistor R1, encircled in Fig.2, is inserted in the electromagnetic simulation. Voltmeters VL_PE_x, as shown in Fig.2, measure the load transient voltage at each simulated floor.

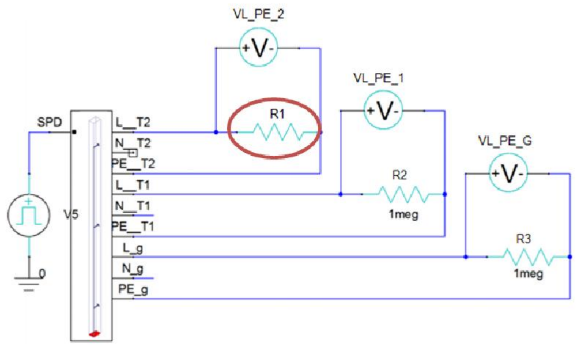


Fig. 2 - Electromagnetic model using ANSYS Designer® for pulse measurement in the differential mode.

In addition to the previously presented measurement configuration, this article also proposes another way of arranging the measurement elements. For this, the electromagnetic model was kept unchanged and part of the circuit in ANSYS Designer® was adapted as shown in Fig.3.

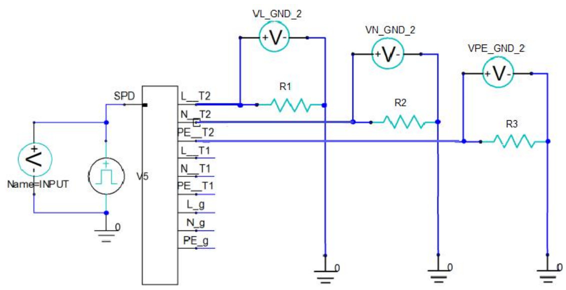


Fig. 3 - Adapted circuit to measure common mode surge with ANSYS Designer®.

The circuit presented in Fig.3 was designed in order to measure the differential voltage individually in the line terminations in relation to the infinite ground plane. This new simulation arrangement, proposed in this work, makes it possible to analyze the contribution of each line to the maximum peak voltage when measured in differential mode. In Fig.4, it is shown the equivalent measurement points in the electromagnetic environment.

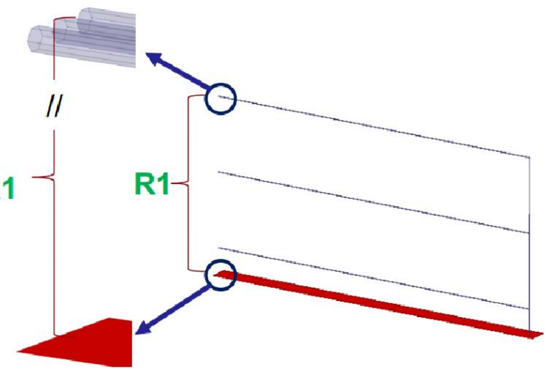


Fig. 4 – Equivalent measurement points using ANSYS HFSS®.

A similar approach was used in PSpice®, with the necessary adjustments to its operating mode. PSpice® T3coupledX block was used, simulating a trefoil cable, consisting of the conductor phase L, neutral N and protective earth PE, taking into account cable lengths and their own inductances and capacitances as well as mutual calculated for a cross section of 6mm^2 [12]. A signal ramp was injected in the phase L according to (1), with the amplitude of 1pu and rise time of 0.01µs and 1µs. Figure 5 shows a schematic mounted in the PSpice® environment.

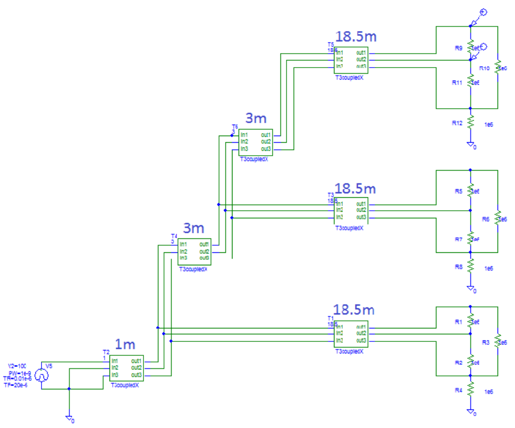


Fig.5 - Designed circuit in PSpice® simulation environment.

III. Results and Discussions

Figure 6 shows the result of both software referring to the disturbance voltage on the second floor for the proposed configuration in Fig.2, where the rising time of the surge applied is 1µs.

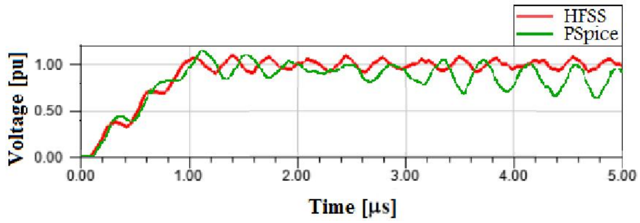


Fig.6 - Differential voltage on the 2nd floor, between the wire L and the PE wire (VL_PE_2) for a ramp of 1µs.

With the time of 1µs, the disturbance at the end of the line oscillates slightly around 1pu. However, applying a wavefront with a rise time of 0.01µs in the same configuration, leads to swings much more expressive, reaching maximum values greater than 3pu, as can be seen in Fig. 7.

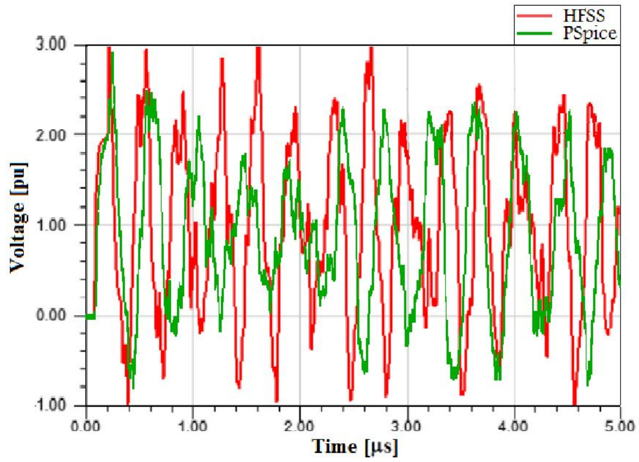


Fig.7 - Differential voltage on the second floor, between the wire L and the protective earth conductor (VL_PE_2) for a ramp 0.01µs.

The analysis of Figs. 5 and 6 reveals that the results obtained by ANSYS HFSS® and PSpice® are in good agreement with each other and with those obtained in [11]. In the initial 0.6µs of the simulation, the similarity among the results is more representative, but the consistency of the results is maintained during the entire 5µs of simulation.

In order to verify the voltage's behavior at the end of the supply lines, in an open circuit condition or high impedance (resistors 1MΩ), at all levels, a sweep of the rise time of the surge applied to phase line L was made. This rise time varied from 0.01µs to 1µs, with a step of 16.5ns, an equivalent of 61 steps. Upon these conditions, it is possible to simulate the maximum peak voltage on each floor, for each rise time of the ramp of the applied surge. The simulated behavior is shown in Fig.8.

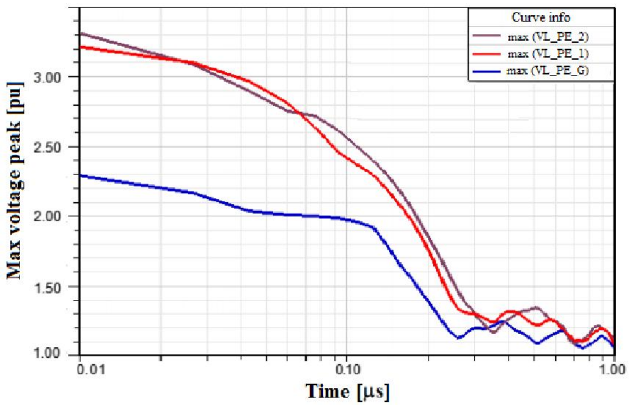


Fig. 8 – Voltage VL_PE in the three floors for the variation of the rise time of the surge from 0.01µs to 1µs, simulated in ANSYS HFSS®.

It is observed, from Fig.8, that the overvoltages in the VL_PE lines's terminations in all floors have a tendency to reduce their maximum peak value, as the applied surge rise time is increased.

The proposed configuration in Fig.3 allows to evaluate separately the surge effect at each line in the second floor. In order to investigate the behavior of the disturbance, for which the maximum peak voltage is obtained, the ramp rise time of 0.01µs was applied. The results are shown in Fig.9.

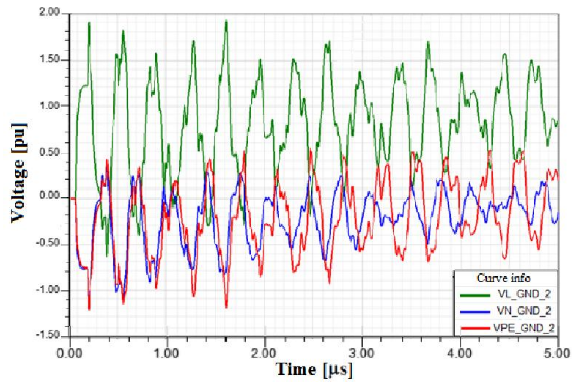


Fig.9 - Voltage in the terminations of each conductor cable in the second floor referring to the infinite GND, for a rise time of 0.01µs, simulated in ANSYS HFSS®.

Fig.9 shows that a value of 3pu is obtained by the sum of the induced surge in line L with the counter-phase signal induced in the PE line. It is possible to note that in none of the two lines separately the voltage amplitude exceeds 2pu, as is expected for reflections of pulses in transmission lines. However the sum of counter-phase causes the resultant voltage to reach values above 2pu.

ANSYS HFSS® is a simulator for electromagnetic phenomena and it enables the evaluation of the behavior of electromagnetic fields. Through the analysis of the proposed model, the observer was positioned in the simulation environment side of the structure in order to be able to see the electric field behavior E (V/m) simultaneously on the three floors. As this behavior is dynamic, it is necessary to determine the time elapsed of the simulation to capture the desired image. Thus, Fig.10 shows the result for the analysis of a time elapsed of 0.05µs after the injection of the ramp pulse.

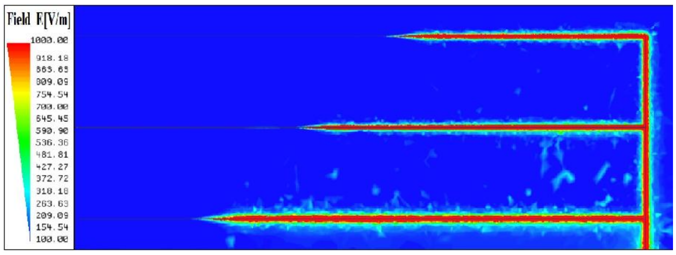


Fig.10 - Electric field generated in the structure of the cable in the three floors, due the surge of 0.05µs

IV. Conclusion

The fastest rise time assumed by IEC 62305-4 for a typical lightning is 0.25µs (subsequent strokes). Since, in both simulations of this work, the differential surge simulated with rise times higher than 0.25µs do not exceeded 2pu, it is considered that the approach established by the IEC 62305-4 standard is adequate, for design purposes of protection systems against transients arising from lightning.

Through Figs. 5 and 6 it is possible to see that the two software present good converging results, given the same conditions, and these results are in agreement with [11].

The new measurement structure proposed in this article combined with the results shown in Fig.9, displays the voltage disturbance generated in common mode at the terminal of each conductor on the second floor. This approach helps to interpret the results obtained, since for the simulations performed only in the differential mode it is not possible to identify each conductor contribution to the total overvoltage.

References

[1] D. Paul. Low-voltage power system surge overvoltage protection. IEEE Transactions on Industry Applications, 37(1):223–229, Jan 2001.

[2] E. Pannila and M. Edirisinghe. Transients in low voltage power systems (lvps) in Sri Lanka under modern domestic environment. In Information and Automation for Sustainability (ICIAfS), 2014 7th International Conference on, pages 1–6, Dec 2014.

[3] G. B. Lo Piparo, T. Kisielewicz, C. Mazzetti, and A. Rousseau. Procedure for selection of the spd system according to the probability of damage. In Environment and Electrical Engineering (EEEIC), 2015 IEEE 15th International Conference on, pages 1055–1060, June 2015.

[4] C. Long, W. j. Zhou, L. Wang, S. j. Lao, J. h. Yu, L. Qiu, andX. Yi. A new portable test system for surge protective device (spd). In Electromagnetic Compatibility (APEMC), 2010 Asia-Pacific Symposium on, pages 1554–1557, April 2010.

[5] Protection Against Lightning—Part 4: Electrical and Electronic Systems Within Structures, IEC 62305-4 IEC Standard, Geneva, 2010.

[6] J. He. Discussions on factors influencing the effective protection distance of spd to loads. In Electromagnetic Compatibility (APEMC), 2015 Asia-Pacific Symposium on, pages 420–423, May 2015.

[7] S. Wang and J. He. Discussion on worst distance between spd and protected device. IEEE Transactions on Electromagnetic Compatibility,53(4):1081–1083, Nov 2011.

[8] J. He, Z. Yuan, S. Wang, J. Hu, S. Chen, and R. Zeng. Effective protection distances of low-voltage spd with different voltage protection levels. IEEE Transactions on Power Delivery, 25(1):187–195, Jan 2010.

[9] T. Kisielewicz, G.B. Lo Piparo, F. Fiamingo, C. Mazzetti, B. Kuca, andZ. Flisowski. Factors affecting selection, installation and coordination of surge protective devices for low voltage systems. Electric Power Systems Research, 113:220 – 227, 2014.

[10] I.A. Metwally, F. Heidler. Influence of Line Routing and Terminations on Transient Overvoltages in LV Power Installations. Proceedings, 18th Int. Zurich Symposium on EMC, Munich 2007.

[11] A. Metwally and F. H. Heidler. Enhancement of the spd residualvoltage at apparatus terminals in low-voltage power systems. IEEE Transactions on Power Delivery, 22(4):2207–2213, Oct 2007.

[12] C. R. Paul, Introduction to Electromagnetic Compatibility. Hoboken NJ, EUA: John Wiley and Sons, Inc., 2006.