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Influence of different factors on coordination of two cascaded SPDs

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ABSTRACT

Surge protective devices (SPDs) are the essential devices for the protection of low-voltage electrical equipment against in-rushing surges. This article presents numerical analysis of surge protection for electrical equipment with two cascaded SPDs; one at the service entrance of a building, and another at the equipment or in the socket. Coordination of these two cascaded SPDs is discussed by considering various influential factors. The influence of impulse waveforms on the coordination is the main issue addressed. It is found that the selection of SPD parameters might need the consideration of the impulse waveform of concern. Other factors such as separation distance are also discussed. Finally, this article also presents a case study on the cascaded SPD coordination when one ZnO varistor is substituted with a Class I spark-gap SPD.

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1. Introduction

Electrical equipment for commercial and domestic use generally is equipped with voltage dependent resistors (VDRs or varistors) at its input circuit for limiting overvoltage. However, compared with normal surge protective devices (SPDs), this kind of built-in varistors have a low energy absorption capability, and may be thermally damaged under high-voltage surges [1]. Thus additional SPDs are usually installed at the switchboards or the entrance of power lines to protect equipment against surges. By integrating resistors available at the electrical equipment, surge protection with cascaded SPDs is formulated in the distribution circuit.

In order to effectively protect electrical equipment, the cascaded SPDs should be coordinated with each other to ensure them undertaking the impulses safely. In this paper, we discussed numerically the coordination of cascaded SPDs with different parameters when impulse waveforms (1.2/50–8/20 μs mixed impulse waves, 0.5 μs–100 kHz oscillatory waves and 10/1000 μs long impulse) are considered. Note that the distance between an SPD and an appliance is one of the important parameters affecting the protection performance [1–7]. Thus, the influence of connecting wire length on the coordination of cascaded SPDs and other possible factors such as loads, SPD capacity are also discussed.

According to IEC 61643-1, the spark-gap SPDs, commonly used for the protection against lightning surge, are defined as Class I SPD [8]. In this article, a case study is presented on the coordination of cascaded SPDs, one of which is substituted with a Class I spark-gap SPD. This article is an extended version of our article in 32nd International Conference on Lightning Protection [9].

2. Models and impulse waveforms applied in analysis

2.1. Analysis model

The coordination of two cascaded SPDs in the practical scenario of electrical equipment protection is addressed numerically in this article (the simulation is conducted on PSCAD). One SPD is installed in the distribution panel at the entrance of a building, while another SPD is added inside the equipment or in the socket. Note that a low-voltage distribution system in building is earthed at both the supply side and at the consumer side. These two earthing terminals are normally connected each other to form a TN-C-S earthing arrangement. The TN-C-S system is then selected for the coordination analysis in this article. Its basic wiring diagram is shown in Fig. 1.

The distribution line to which SPDs are connected is made by single-core non-armored PVC cables. The diameter of their conductive cores is 1.6 mm. The thickness of their insulation layers is 0.66 mm and the relative dielectric constant is 4.55. For each line to which appliances is connected, the live wire, neutral wire, and protective ground wire are placed in juxtaposition, and the distance between adjacent wires is 3 mm. The line is buried 50 mm below

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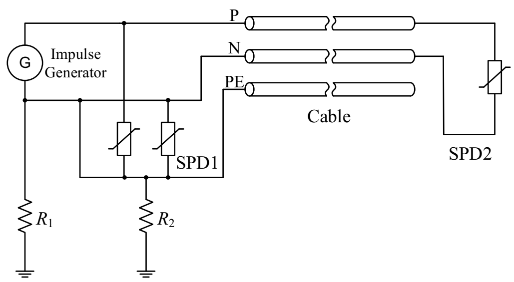

Fig. 1. Model of a TN-C-S system with cascaded SPDs.

Table 1
ZnO varistors applied in the analysis.

Type	Diameter (mm)	Max permitted ac voltage (V)	Capacity (kA) (8/20 μs)	Max. clamping voltage (V)
V275LA40A	20	275	6.5	710
V320LA40B	20	320	6.5	810
V660LA100B	20	660	6.5	1650

the ground and represented with a frequency dependent model [6] in the simulation. The grounding resistance of the live and neutral wires (R1) is 10 Ω, and the grounding resistance of the protection ground wire (R2) is 4 Ω. The cascaded SPDs are connected in parallel between the live wire and the protection ground wire.

Three different ZnO varistors are selected for the coordination of two cascaded SPDs. Table 1 shows the general information of these three samples. Their U-I properties are given in Fig. 2.

2.2. Impulse waveforms applied in the analysis

Three impulse waveforms are adopted in the analysis, that is, a 1.2/50–8/20 μs combination wave, a 0.5 μs–100 kHz ring wave, and a 10/1000 μs long impulse wave [10].

In the lightning impulse tests of low-voltage equipment, the combination wave is used to simulate lightning surge voltage and current wave experienced on the equipment. A combination wave generator is required to generate a 1.2/50 μs impulse voltage wave in an open circuit, and to an 8/20 μs impulse current wave [2,11] in a short circuit. According to the ANSI/IEEE Std.C62.41.1 [12] and the ANSI/IEEE Std. C62.41.2 [10], the 10 kV/5 kA combination wave is used for the coordination study.

The 0.5 μs–100 kHz oscillatory waveform is used to simulate the transient voltage observed at a LV circuit away from the service entrance. It has a virtual front time of 0.5 μs, and a damped oscillation with a frequency of 100 kHz (attenuation coefficient is 0.6). The 0.5 μs–100 Hz oscillatory waveform can be described mathematically [13]:

$$V(t) = \begin{cases} BV_{P}y(1+\eta y) & (0 \le t \le 2.5\mu s) \\ BV_{P}y & (t > 2.5\mu s) \end{cases} \quad (1)$$
$$y(t) = A[1-\exp(-t/\tau_1)]\exp(-t/\tau_2)\cos\omega_0 t$$

where, $\tau_1 = 0.4791\,\mu s$, $\tau_2 = 9.7881\,\mu s$, $\omega = 2\pi 10^5/s$, $A = 1.590$, $B = 0.6025$, $\eta = 0.523$.

Normally, the ratio of open circuit impulse voltage and short circuit impulse current is 12 Ω when calculating overvoltage level type B as described in ANSI/IEEE Std. C62.41.2 [10], the ratio of open circuit impulse voltage and short circuit impulse current is 30 Ω when calculating overvoltage level type A. The amplitude of 0.5 μs–100 kHz oscillation wave varies with the protected equipment. At the type A and type B overvoltage level, the lowest oscillating impulse wave adopted in the experiment is 2 kV, and the highest is 6 kV, however, the highest is always favorable in regard to the most severe circumstance; as for overvoltage level type C, since it's at the entrance of a building, there's no specific regulation for the oscillating wave applied in the experiment [14]. For worst-case analysis, the 6 kV ring wave is applied in the simulation. For evaluating surge protection under switching transients, a 10/1000 μs long impulse waveform is applied to analyze the case with the huge impulse energy.

2.3. Load

The load connected to the distribution line was not considered in the analysis. The load might be influential in the discussion of SPD coordination, as it will disperse a part of the current. For example, when both SPDs are V275LA40A, the currents through SPD1 and SPD2 are 3.6 and 2.0 kA, when a 5 Ω load is added the currents through SPD1 and SPD2 are 3.5 and 1.8 kA. Simulation is conducted to investigate the possible effect of the connected load on the SPD coordination.

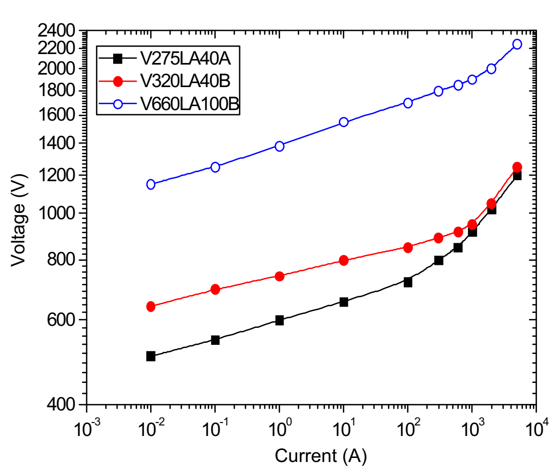

Fig. 2. U-I curves of three ZnO varistors used in the analysis.

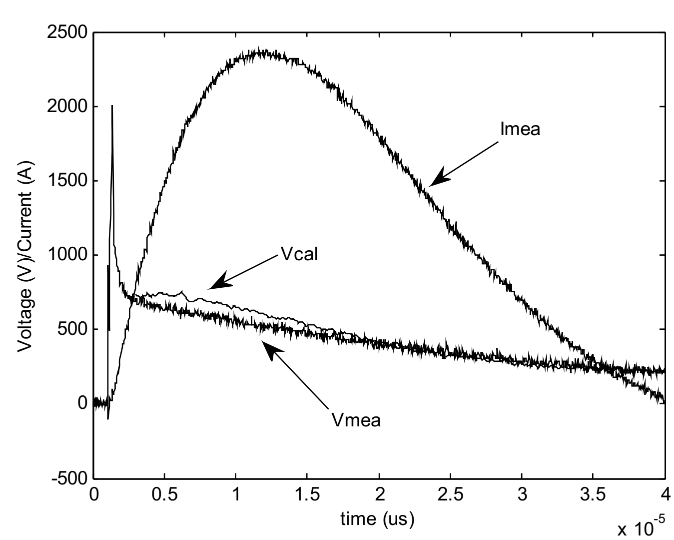

Fig. 3. Comparison between measured and calculated voltage and current waveforms of the Class I SPD with spark-gap under 6 kV 8/20 μs impulse voltage waveform (I_{mea} = Measured current, V_{mea} = Measured voltage, V_{cal} = Calculated voltage).

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