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Stress to surge protective devices system due to direct flashes to low voltage lines

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ABSTRACT

In the present paper practical recommendations for selection of a surge protective devices (SPD) system with aim to protect electronic and electrical apparatus within a structure against overvoltages coming from the low-voltage power lines are highlighted. The investigation is performed with two standardized lightning currents, namely 200 kA wave shape 10/350 μs for first positive stroke and 50 kA wave shape 0.25/100 μs for subsequent stroke of negative flashes. The analyses are performed by computer simulations at the referring typical basic arrangement consisting of ten poles overhead line terminated on one side by HV/LV transformer and on other side by apparatus to be protected. The results are obtained by means of commercial transient software EMTP-RV. This work is executed in the frame of discussion on recommendation of IEC/EN 62305 [1] for the selection of coordinated SPD system.

1. Introduction

The electronic and electrical apparatus within modern structures, namely civil buildings or industrial plants, are sensitive to electromagnetic disturbances. Theirs failure can be caused by different sources of damage [1–4]. The IEC standard [5] recommends surge protective devices (SPD) as typical protection measure. It is a relative economic and efficient measure which can assure the normal operation of apparatus to be protected. The protection system efficiency depends on various factors, namely proper selection of SPD and installations conditions [6,7]. In practice proper selection of SPD is related to the choice of the discharge current (I_{imp} or I_n) and of the protection level (U_p) taking into account the rated impulse level (U_w) of the apparatus to be protected. The installation conditions are mainly related to the length of connecting leads of SPD as well as of the circuit wire to the apparatus to be protected [8–13].

Aim of the present paper is to give practical recommendations for the SPD selection in case of lightning flashes to the line (source of damage S3 according to IEC standard [1]). In previous contributions [14–16] the problem of selection and installation of SPD in the case of direct lightning flash to a structure, (source of damage S1) has been analyzed. The investigation has been performed by means of computer simulations with models similar to the real circuits tested in the high voltage laboratory of University of Rome "La Sapienza" and Warsaw University of Technology. Similar approach is followed in the present paper focusing on apparatus protection against source of damage S3 by means of SPD. The results are presented and proper conclusions are given. Moreover comments and comparison with the IEC/ EN 62305-4 standard requirements are presented.

2. Case study under consideration

The analyzed system is shown in Fig. 1. Low voltage supply overhead line with two conductors consists of TN system defined by [9] is considered as basic arrangement. The overhead line is terminated by the HV/LV transformer and apparatus to be protected. The distance between poles is assumed as 50 m. The poles are 6 m high and grounded by a conventional earthing impedance Z_p in the range of 10–50 Ω. The impulse insulation level of the line is 15 kV.

The simulations are performed with two standardized lightning current, namely 200 kA wave shape 10/350 μs for first positive stroke and 50 kA wave shape 0.25/100 μs for subsequent stroke of negative flashes. These current values are defined by the standard for lightning protection level I (LPL I) [1]. The wave shape 10/350 μs is responsible for the highest values of charge transferred to SPD and then affects the SPD dimensioning in terms of discharge

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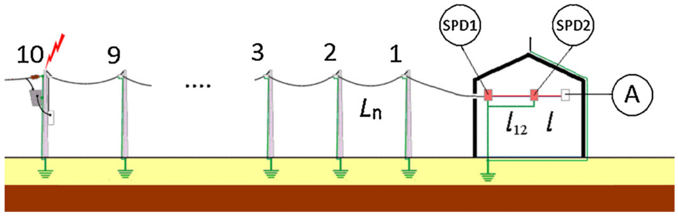

Fig. 1. Schematic representation of system analysed where: A—apparatus to be protected; SPD1—panel board with usptream SPD installed; SPD2—panel board with downstream SPD installed; 1-2-3-. . .-9-10—number of poles stricken by lightning current; L_n—overhead line span length; l_{12}—length of circuit between SPD1 and SPD2; l—length of circuit between SPD2 and apparatus to be protected.

current (I_{imp} or I_n). The parameters of I_{imp} or I_n are relevant to SPD class I tests and SPD class II tests, respectively, according to the IEC 61643-11 standard [8]. The wave shape 0.25/100 μs, due to high value of current steepness, is responsible for highest voltage drop on connection leads of SPD and for the reflection in the circuit between apparatus and the closest upstream SPD and then affects the SPD dimensioning in terms of protection level (U_p) [17–19]. The lightning current striking the line is represented by Heidler function [14–16]. The investigation includes both switching and limiting SPD types simulated to achieve proper characteristic voltage–ampere (U–I) and voltage–time (U–t) according to previous methodology presented in [20]. For this investigation, laboratory tests have been performed and further coherent models have been prepared. The SPDs used have similar values of U_p in the range of 1.5 kV. The supply line is represented by a typical lossy-line model taking into account traveling wave effects and current reflection [21–24]. The poles of overhead line and earthing arrangement are simulated according to the practice including their transient behavior [24–28]. The transient characteristics of HV/LV transformer are taken from [29,30].

This system is used to investigate the influence of lightning current distribution in a LV line directly struck by lightning (stricken pole) on the peak value and shape of the current flowing through the SPD installed at the entrance point of the structure to be protected, which affect its protective performances. It should be also put into evidence that due to high value of current amplitude and steepness flashover at some points of the line occurs and it has been considered in the model.

In this paper only common mode overvoltages are considered. For the present analysis a commercial transient program (EMTP-RV) is used.

Three types of SPD system are considered, namely:

(1) SPD S/L system, consisting of only one SPD, switching (S) or limiting (L) type;
(2) SPD SL system, consisting of SPD1 switching type and a downstream SPD2 limiting type;
(3) SPD LL system, consisting of SPD1 limiting type and a downstream SPD2 limiting type.

3. Investigation on current and charge

3.1. Upstream SPD (SPD1)

This investigation is carried out with reference to first positive strokes (wave shape 10/350 μs), which is responsible for the highest values of charge transferred to SPD and then affects the SPD dimensioning in terms of discharge current (I_{imp} or I_n), where I_{imp} is the rated current (10/350 μs wave shape) for class I test SPD and I_n is the nominal current (8/20 μs wave shape) for class II test SPD.

The typical waveform of the current I_{SPD1} flowing through the SPD1 installed at entrance point of the line into the structure to be protected in case of first, fifth and tenth pole struck by lightning is shown in Fig. 2 for positive stroke and in Fig. 3 for subsequent stroke of negative flash. The current I_{SPD1} flowing through the SPD1 and the associated charge Q_{SPD1} depend on the stricken pole and on its conventional earthing impedance; moreover while the current I_{SPD1} flowing through the SPD1 does not depend on SPD system type, charge Q_{SPD1} is affected by the installed type of SPD1 (switching or limiting).

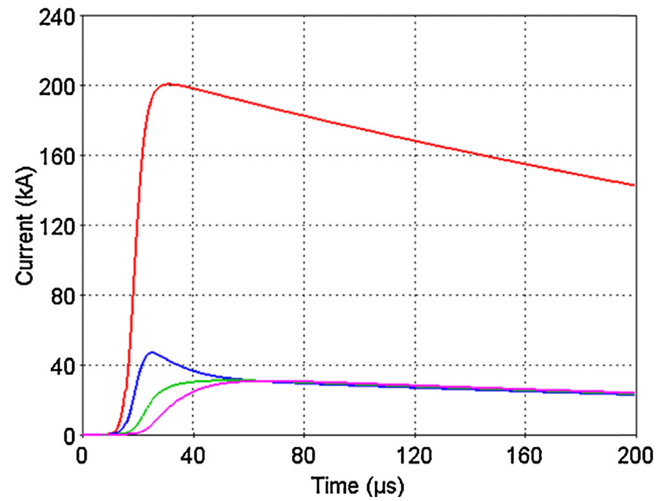

Fig. 2. Expected wave shape of current flowing through the SPD1 switching type installed at entrance point of the line into the structure to be protected in case of pole stricken n.1 (I_{SPD1}), n.5 (I_{SPD1}) and n.10 (I_{SPD1}) for positive stroke 200 kA (I).

In Fig. 4 the ratio I_{SPD1}/I of current I_{SPD1} and the lightning current I is shown as a function of stricken pole. It is worth noting that the value of ratio I_{SPD1}/I significantly decreases as the distance of stricken pole from SPD1 increases, but after 5 pole stricken these values have quasi constant character. Highest values of the ratio I_{SPD1}/I are related to the highest values of pole conventional earthing impedance Z_p.

It is to be noted that the ratio of current I_{SPD1} flowing through the SPD1 and the lightning current I does not depend on lightning current wave shape.

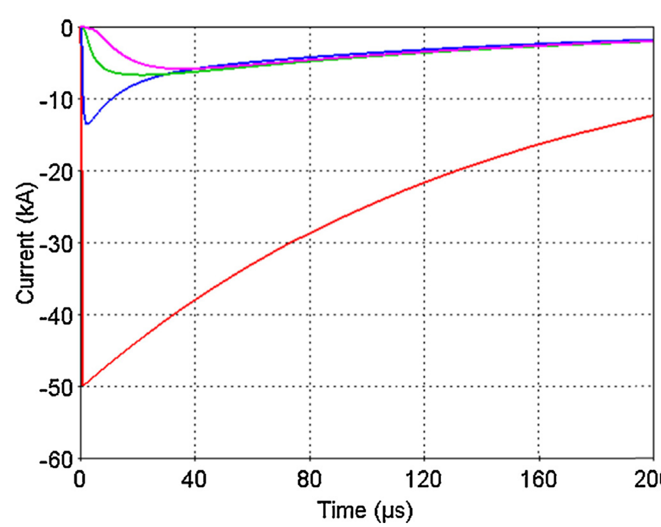

Fig. 3. Expected wave shape of current flowing through the SPD1 switching type installed at entrance point of the line into the structure to be protected in case of pole stricken n.1 (I_{SPD1}), n.5 (I_{SPD1}) and n.10 (I_{SPD1}) for subsequent stroke of negative flashes 50 kA (I).