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A Case Study to Effective Protection of Sensitive Apparatus by Means of Voltage Limiting SPD

***Abstract**. The operations of digital apparatus in the information and telecommunication systems can be influenced by impulsive current of direct and nearby lightning flashes. The aim of the paper is to investigate the typical problems of selection and installation of voltage limiting SPDs, which can affect its effectiveness. In this contribution several results obtained by laboratory tests are presented. Special focus was addressed to ascertain the influence of circuit configuration where SPD is installed for the protection of sensitive apparatus against lightning overvoltages.*

***Streszczenie.** Praca urządzeń cyfrowych systemów informatycznych, telekomunikacyjnych może być zaburzona poprzez uderzenia pioruna bezpośrednio w strukturę, bądź w wyniku pośredniego oddziaływania prądu piorunowego. Celem pracy jest przybliżenie typowych problemów dotyczących wyboru poziomu ochrony SPD ograniczającego napięcie, poprzez przedstawienie wpływu wybranych elementów konfiguracji chronionego układu (**Badania efektywności ochrony czułych urządzeń zapewnianej przez urządzenia ograniczające przepięcia**)*

Keywords: Lightning protection, Surge Protective Device, SPD protection level.
Słowa kluczowe: Ochrona odgromowa, urządzenie ochrony przepięciowej, poziom ochrony.

Introduction

Lightning flashes to and near a structure and connected lines may have influence on electrical and electronic systems within such structure. Nowadays apparatus are more and more sensitive to electromagnetic disturbance. These not demands occurrences can be caused by whole or partial lightning current flowing to a structure, causing different shape overvoltages by resistive or inductive coupling [1]. To assure operation of these apparatus connected to power and signal lines, the surge protective devices (SPD) can be applied. Three types of SPD are available, namely switching, limiting or their combination, which can be dedicated for protection electronic and electrical systems. In accordance with IEC 62305-4 the basic criteria for selection an SPD depends on the point of installation and expected function. This procedure is based on the Lightning Protection Zones (LPZs) definition.

The aim of the paper is to investigate the typical problems of selection and installation of a voltage limiting SPD, which can affect its effectiveness. This type of SPD can be used e.g. for protection apparatus against induced overvoltages due to lightning flashes nearby the structure or connected lines or in LPZ 0_B where internal systems may be subjected to partial lightning surge currents [2]. For this investigation a real arrangement of an electric system within a structure has been considered (Fig.1) and the schematic electric circuit of such arrangement (Fig.2) has been reproduced in laboratory where several tests have been performed. Special focus was addressed to ascertain the influence of circuit configuration, especially bonding network for apparatus to be protected.

Case study under consideration

Overvoltages incoming to the circuit within a protected structure are reduce through the SPD according to their protection level U_P. However a value of voltage on the apparatus terminals U_L can be different from U_P [3, 4].

The considered arrangement in real situation and equivalent electric circuit analysed in laboratory are shown in Fig.1 and Fig.2 respectively. A sensitive apparatus (7) is installed in an upper floor within a steel reinforced concrete structure and bonded directly to the steel reinforcement in concrete (9) at the floor level and through the PE conductor (3) at equipotential bonding bar (5) of switch board. In the same figure is shown also the earth resistance (1); surge protective device (2); low voltage feeder (4); common inlet for different services (6) and bonding joint (8).

The schematic circuit in order to reproduce in laboratory the real arrangement is reported in Fig.2, where it is shown the impulse voltage generator *(G)*, the typical low-voltage limiting SPD, the conductors of length d leading the SPD and apparatus to be protected represented by high value of resistance *(R)*. It is assumed that the resistive part of the impedance of the considered bonding conductors is prevalent.

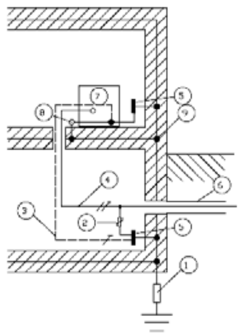

Fig.1. Real arrangement of electrical system in a structure:
1 – Earth resistance; 2 – Surge protective device (SPD); 3 – PE conductor; 4 – power line; 5 – equipotential bonding bar; 6 - Common inlet for different services; 7 – apparatus to be protected; 8 - bonding joint; 9 – steel reinforcement in concrete (with superimposed mesh conductors)

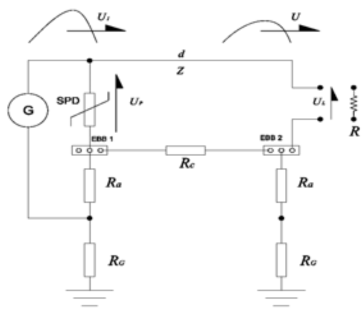

Fig.2. Schematic illustration of analysed arrangement in laboratory: G – impulse voltage generator; U_I – surge voltage; EBB – equipotential bonding bar; R_C – PE conductor resistance; R_a – resistance of conductors connecting EBB to earth resistance; R_G – earth resistance; SPD – surge protective device; U_P – voltage on the SPD terminals; d – line length; Z – surge impedance right by the line; U – overvoltage incoming through distant SPD; R – resistive load; U_L – voltage on the terminals of equipment to be protected

Laboratory setup

In laboratory tests the apparatus to be protected have been stressed by an impulse voltage generator. To this aim the HAEFELY recurrent surge generator type 48 has been used. This equipment has the possibility of generating a different forms of overvoltages selected by user. The peak value as well as times T_1 and T_2 generated impulses can be regulated. The voltage wave form 1,2/50 μs and 0,25/50 μs have been selected. The peak value of stressing impulse was fixed on 450 V in each case.

The typical voltage limiting SPDs with level of protection U_P = 40 V, copper wires with 0,14 mm^2 cross-section adapt to nominal voltage 150 V, high value of resistance R (open circuit) as a load have been used.

Analysed circuit has been connected to the local ground system of laboratory where the earth resistance R_G = 0,1 Ω.

The resistance of conductors connecting EBB to earth resistance was measured of the order of 0,2 Ω.

Voltages at SPD and at apparatus terminals were measured by a digital oscilloscope Yokogawa mod. 2022 with maximum samples rate 2,5 GS/s, frequency bandwidth 200 MHz and maximum record length 62.5 Mpoints.

The following voltages have been measured during the tests:

- U_P - voltage on the SPD terminals (CH1)
- U_L - voltage on the terminals of equipment to be protected (CH2)

Criteria for selection an SPD according to the standard

Voltage protection level of SPD used as a measure of protection suggested by standard IEC 62305–4 depends on:

- the characteristics of equipment to be protected especially on the impulse withstand voltage U_W
- the length of the SPD bonding conductors
- the length and routing of the circuit between the SPD and an apparatus to be protected

Moreover the standard insert the $U_{P/F}$ definition as the effective voltage protection level of SPD, where this value determines the protection level U_P (voltage on the SPD terminals) obtained when the discharge current flows added to the inductive voltage drop U_B of the connecting conductors in the SPD branch [2]; it follows: $U_{P/F} = U_P + U_B$

The standard IEC 62305-4 suggests that systems within a structure are protected if:

- they are energy coordinated with the upstream SPD
- one of the following three conditions is fulfilled:

a) when the circuit length between the SPD and the apparatus is negligible:

$$U_{P/F} \le U_W \qquad (1)$$

b) when the circuit length is not greater than ten meters:

$$U_{P/F} \le 0{,}8 \cdot U_W \qquad (2)$$

c) when the circuit length is more than ten meters:

$$U_{P/F} \le (U_W - U_I)/2 \qquad (3)$$

where U_I is the induced voltage on the circuit (loop) formed by SPD and load.

If it is assumed that the U_I = 0 V, and U_B = 0 V, U_P is the maximum voltage that can appear on the SPD terminals ($U_{P/F} = U_P$), so that the basic rules for selection an SPD can be presented by following equations:

a) when the circuit length between the SPD and the apparatus is negligible

$$U_P \le U_W \qquad (4)$$

b) when the circuit length is more than ten meters:

$$U_P \le U_W / 2 \qquad (5)$$

In accordance with IEC 62305 standard series, equations (4) and (5) can be applied if spatial shielding of the structure (or of the rooms) and/or line shielding (use of shielded cables or metallic cable ducts) are provided. In these cases the induced voltage on the circuit (loop) formed by SPD and load may be neglected.

Analyses of influence of circuit length between SPD and apparatus

First investigation has been performed to take into account the influence of the length of circuit between an SPD and apparatus to be protected on the values of voltage appearing on such apparatus. For this aim several laboratory tests have been performed with high value of resistance (R = 1 MΩ) as a load, assuming negligible the resistance of PE conductor (R_C = 0 Ω), circuit bounded in two points as shown Fig.2, different values of *d* ranging between 5 m and 30 m, and for the two selected stressing overvoltages. The results of tests are plotted in Fig.3.

It is to note that the appearing values of voltage on the apparatus terminals are increasing with distance d between SPD and apparatus [5, 6].

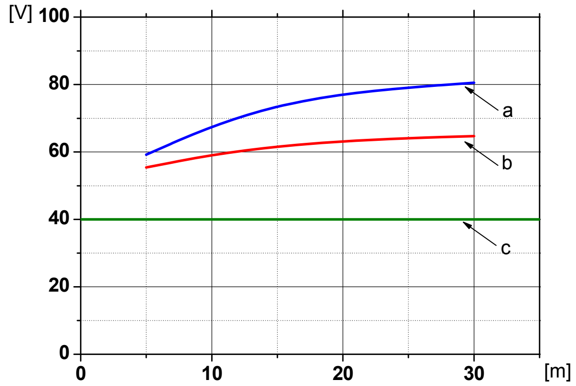

Fig.3. Voltages in analysed arrangement as a function of circuit length between the SPD and the apparatus to be protected a – voltage at apparatus to be protected represented by resistive load R = 1 MΩ, under influence of stressing overvoltage shape 0,25/50 μs; b – voltage at apparatus to be protected represented by resistive load R = 1 MΩ, under influence of stressing overvoltage shape 1,25/50 μs; c – nominal voltage protection level of SPD

Analyses of bonding condition for resistive load

As suggested in Fig.1 and sketched in Fig.2 the apparatus can be bonded by several points.

In the case under consideration the apparatus is connected to the switch board EBB by PE conductor and to the local EBB directly connected to the steel reinforcement of concrete.

In the following section the influence of bonding conditions in the case of open end circuit has been taken into account. Tests have been performed with different values of PE equivalent resistance R_c = 0 Ω, 100 Ω and 1 MΩ, with a fixed distance d = 30 m and with two types of stressing overvoltage 0,25/50 μs and 1,2/50 μs.

Fig.4 and 5 shows more critical case where stressing overvoltage has a 0,25/50 μs form.

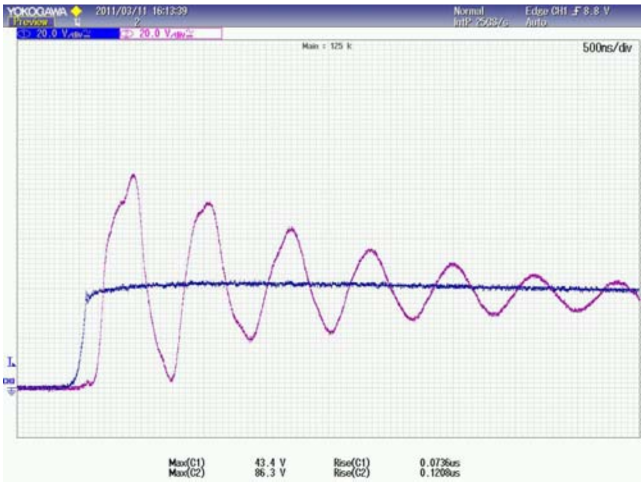

Fig.4. Oscillograms of voltage: CH1 voltage on the SPD terminals; CH2 voltage at equipment to be protected represented by resistive load R = 1 MΩ; Stressing impulse voltage wave shape 0,25/50 μs; R_C = 0 Ω; line length d = 30 m

Fig.5. Oscillograms of voltage: CH1 voltage on the SPD terminals; CH2 voltage at equipment to be protected represented by resistive load R = 1 MΩ; Stressing impulse voltage wave shape 0,25/50 μs; R_C = 1 MΩ; line length d = 30 m

Synthetic results of performed tests for open end circuit simulated by R = 1 MΩ are reported in Table 1 for different R_C values.

Table 1. Measured values of voltage on the SPD terminals and at equipment to be protected for R = 1 MΩ load condition and different R_C conditions

Wave shape T_1/T_2 [μs]	R_C = 0 Ω		R_C = 100 Ω		R_C = 1 MΩ	
	U_P [V]	U_L [V]	U_P [V]	U_L [V]	U_P [V]	U_L [V]
1,2/50	42,8	63,9	43,1	69,1	44,1	87,3
0,25/50	43,4	86,3	43,4	90,3	44,6	113,6

From obtained results it is possible to make the following comments:

- according to the best practice if PE conductor has negligible resistance (R_C = 0 Ω) the expected voltage at the apparatus is less or equal to the double of SPD protection level, according to the rise time of the incoming surge. It follows that equation (5) for the selection of an SPD seems to be adequate;
- if the PE conductor is bad connected (simulated by R_C = 100 Ω) or disconnected (R_C = 1 MΩ), the voltage at the apparatus terminals may exceed even 2 U_P as shown in Fig.5 and standard relation (5) is not on safety side.

Conclusions

In this paper bonding and loading conditions have been analysed in order to limit lightning surges by SPD for the protection of sensitive apparatus.

On the base of performed experimental tests the following conclusions could be formulated:

- where multi points bonding connection to earth are available for an apparatus within a structure is important that the PE conductor should have low impedance value in comparison with the other bonding connections;
- if such condition is accomplished the relations adopted by IEC standards for the selection of SPD are adequate;
- unfortunately a not correct designing by under sizing of the PE conductor cross section or a not good routing, may increase the risk of failure of apparatus and the condition suggested by the standard could be not on the safety side. In this case one possibility to reduce the voltage at the apparatus terminals is to adopt a coordinated SPD system where a second SPD should be installed immediately at the apparatus terminals.

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