Andrzej SOWA

Bialystok University of Technology, Faculty of Electrical Engineering

Lightning currents in low-voltage power systems

***Abstract**: Correctness estimation of lightning protection solutions require definition of lightning current distribution in conductive installations entering the structure during direct strike to lightning protection system of this structure. It concerns particularly this part of lightning current, which flows in electric installation. Information about this current gives the possibility to estimate the levels of overvoltages on the equipment's ports and appropriate choose of surge protective devices. The calculations of this current in low-voltage power systems connected to different types of structures calculations were performed based on the circuit theory approach.*

Streszczenie.** Poprawny dobór rozwiązań ochrony odgromowej wymaga posiadania informacji o podziale prądu piorunowego w przewodzących instalacjach dochodzących do obiektu podczas bezpośredniego wyładowania w urządzenie piorunochronne. Szczególnie istotne jest określenie prądów udarowych występujących w instalacji elektrycznej. Wykorzystując metody obwodowe wyznaczono prądy wpływające do przewodów instalacji elektrycznych kilku różnych typów obiektów budowlanych **(Prądy piorunowe w instalacji elektrycznej).

Keywords: surge protective device, lightning current, lightning protection, low-voltage power system
Słowa kluczowe: urządzenia ograniczające przepięcia, ochrona odgromowa, instalacja elektryczna

Introduction

During direct lightning strike to external lightning protection system (LPS) of structure the surge current flows on air-termination and down conductors into the earth and generate high potential which might lead to dangerous sparking between installations inside the structures.

To avoid such sparks all metal installations, low-voltage power system and date links at the entrance of the structure must be integrated into the equipotential bounding. In case of low-voltage power system LVPS, the protection against potential differences requires the surge protective devices SPD type 1. The arrangement of SPD should be places and montage in such manner, that their limited overvoltages to the levels which are required for low-voltage installation and for supply ports of devices. From the application point of view, it is interesting to evaluate the maximal values and shapes of surge currents in individual SPD during direct lightning strike to the LPS of structures.

It was characteristic of the different analyses and measurements that these currents were a large part of total lightning current (Table 1).

Table 1. Lightning currents distribution during direct strike to LPS

Reference	Lightning current distribution *
Scenario suggested by IEC [1]	50% I_{ML} in the LPS ground, 25% I_{ML} in LVPS ground, 25% I_{ML} in conductors of LVPS
Scenario presented in IEC standards [2, 3]	50% I_{ML} in the LPS ground, 50% I_{ML} in conductors of LVPS
Triggering-lightning experiments in 1997 [4]	The peak value of current entering the conductors of LVPS was over 80% I_{ML}.
Triggering-lightning experiments in 2004 [4]	Simple LPS with 2 grounding rods and additional rod for LVPS. Currents in LVPS varied from 16% do 28% I_{ML}.
Triggering-lightning experiments in 2005 [4]	LPS with 4 grounding rods and additional rod for LVPS. Currents in LVPS varied from 51% do 72% I_{ML}.
Calculation results [5]	LPS wit 4 grounding rods. Currents in LVPS varied from 46% do 56% I_{ML}.

*- in the absence of the other metallic services entering the building such as metal gas or water pipes,
I_{ML} – maximal value of lightning current

In this paper, the great attention has been paid to develop suitable models for evaluating the lightning current distribution within the conductors of LVPS and especially the stress of individual SPD.

Models description

In paper only the low-voltage side of distribution system has been considered. Analyses were done for the LVPS with one stage protection systems - the arrangements with voltage-switching SPDs type 1 inside the structure.

In theoretical consideration the model of SPD was realized on the base of switch with additional resistor, when the switch is closed. The spark-over voltages of SPDs were 1500 V and 2500 V.

Furthermore the impedances, such as inductances and resistances of the SPDs connections also are included.

The LVPS was connected to the distribution transformer located outside the structure. The earthing impedance of the transformer is represented by L3 I R3 [6].

The basic of LVPS has been converted into equivalent circuit diagram presented in Fig.1.

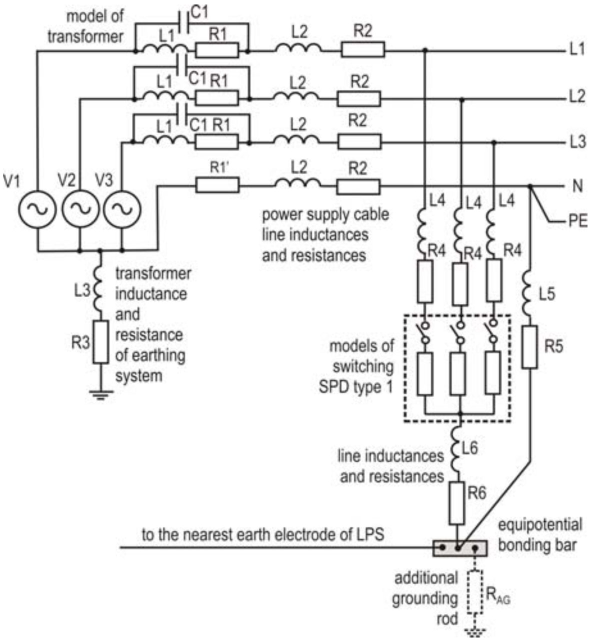

Fig.1. Circuit diagram for LPS with switching SPD type 1

In analysis the surge currents 100 kA and 150 kA (peak values) and shape 10/350µs were used for simulation the first lightning strokes.

This lightning current was described by typical equation [7]:

$$i(t) = \frac{I_{ML}}{\eta} \cdot \frac{(t/\tau_1)^{10}}{1+(t/\tau_1)^{10}} \cdot e^{-\frac{t}{\tau_2}} \quad (1)$$

where: I_{ML} = peak values of current (100 kA or 150 kA), η = 0,930, τ_1 = 19 μs, τ_2 = 485 μs, t -time.

Calculations were realized for LPS model of the trade hall with dimensions 48 m x 12 m x 12 m (case A). Down conductors were connected to simple earth electrodes type A with resistance R_G = 6,4 Ω (Fig. 2).

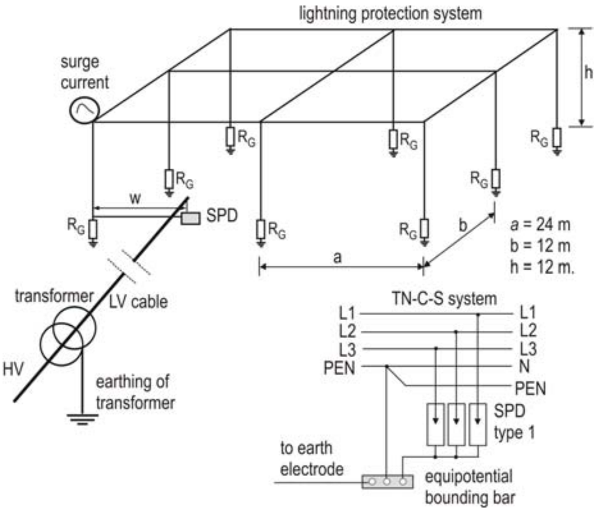

Fig.2. Model of LPS and LVPS used in calculation (case A)

Additionally, the calculations were realized for LPS of 2 types of structures and the following conditions were considered:

Case B - office building (Fig. 3)
- lightning protection level II,
- base equal 20 m x 40 m and height h = 20 m,
- the mesh side of the air-termination system on the roof was 10 m x 10 m, and the distance between down conductors 10 m,
- conductors of LPS with radius 4 mm,
- surge currents were injected to the corners of LPS,
- earth termination system type A with earth electrode resistance R_G = 10 Ω.

Case C - residential building (Fig. 3)
- lightning protection level IV,
- base 10 m x 20 m and maximal high 10 m,
- four down conductors at each edge of the structure,
- conductors of LPS with radius 4 mm,
- earth termination system type A with earth electrode resistance R_G = 21 Ω.

Calculation results

Theoretical calculations of lightning current distribution are based on the simple circuit theory approach. In models, the conductive elements of LPS have been represented with an equivalent π model taking into account resistance and self-inductance, the inductance coupling with another segments and capacitance to the ground.

In the proposed models the influence of current in lightning channel between striking point and cloud were not considered. In calculation The Electromagnetic Transient Program EMTP [8] was used.

Examples of computed currents (case A) that flow to the earthing system of transformer through the PEN and phases conductors are shown in figure 4.

Case B

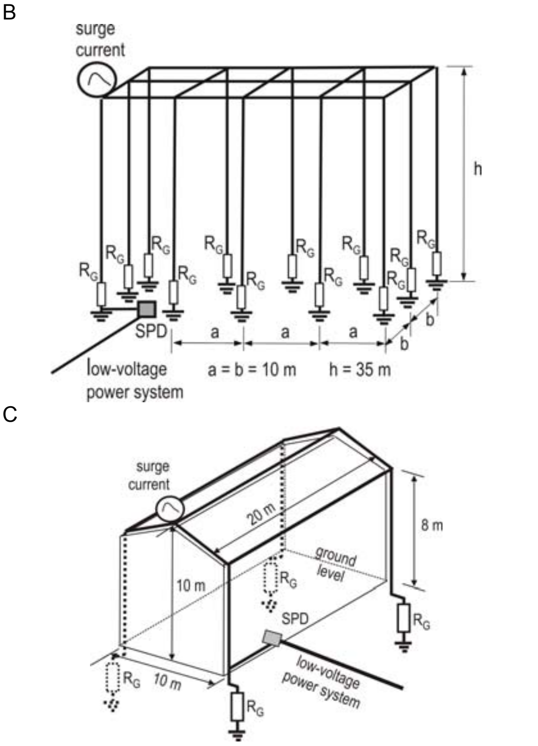

Fig.3. Diagram of lightning protection systems (case B and C)

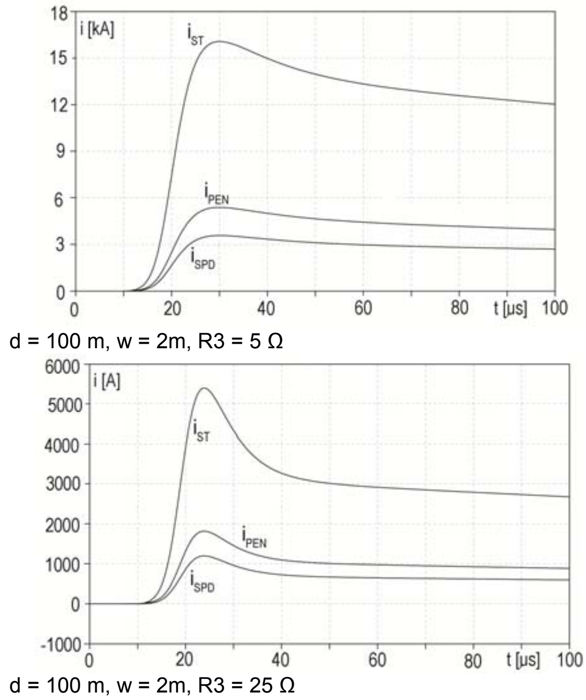

Fig.4. Calculated waveforms for currents in SPD (i_{SPD}), PEN conductor (i_{PEN}) and in earthing system of transformer (i_{ST})

The overall division of lightning current is influenced by many factors. In calculations the following were considered:
- resistance R3 in range from 1 Ω to 20 Ω (Fig. 5 and 7).
- distance d between transformer and SPDs from 10 m to 300 m (Fig. 6),

A reduction of the partials lightning currents in SPDs and PEN conductor can be achieved if the LVPS bounding bar is connected to additional grounding rod R_{AG}. In calculations the values of R_{AG} were the same like R_G in LPS.

a)

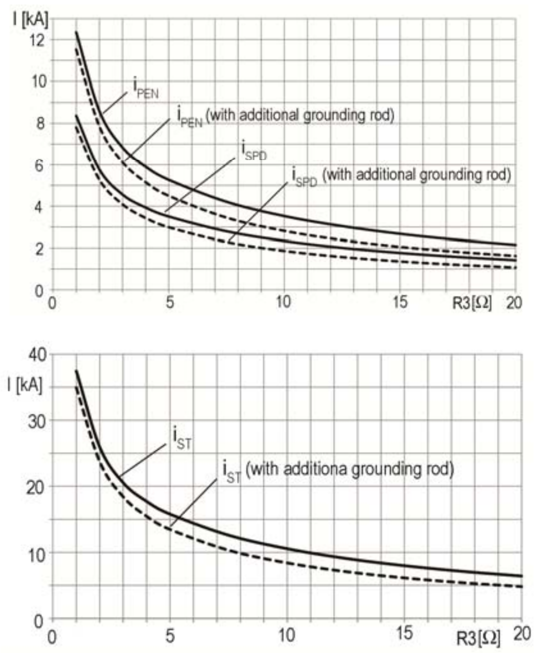

Fig.5. Maximal values of currents with increasing values of transformer grounding system (case A, d = 100 m, w = 2m), a) currents in SPD and in PEN conductors, b) total current in LVPS

Changes in surge current distribution caused by additional grounding rods are presented in Fig. 5.

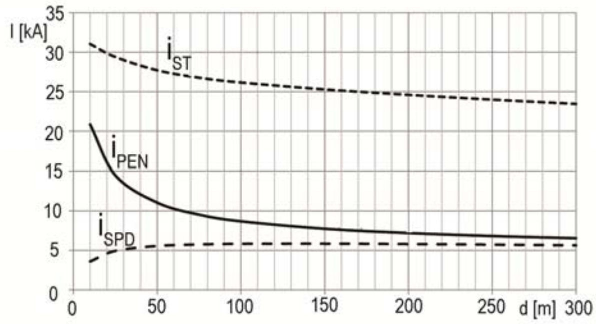

Fig.6. Maximal values of currents in conductors of LVPS (case A, w = 2m) with increasing distance d between SPD and transformer

In order to comparison the effect of LPS on current distributions in conductors of LVPS calculations were realized with the same conditions in analyzed structures (values of R_G, R3 = 5 Ω, distances d = 100 m and w = 5 m). Some results are presented in table 2.

Table 2. Maximal values of currents in conductors of LVPS

Structure	R_G	I_{SPD}*	I_{PEN}*	I_{ST}*
Trade hall	50 Ω	12%	18%	54%
	100 Ω	15,6%	23,5%	70,5%
Office building	50 Ω	9,4%	14%	42,4%
	100 Ω	13,3%	19,8	59,7%
Residential building	50 Ω	15,7%	23,5%	70,6%
	100 Ω	18,5%	27,6%	83%
* - values in percentages are obtained by comparing the peak values of currents in conductors with current introducing to LPS				

Conclusions

In this paper the results of numerical calculations of lightning currents in low-voltage power systems supplying different types of buildings during direct strikes to LPS were presented.

a)

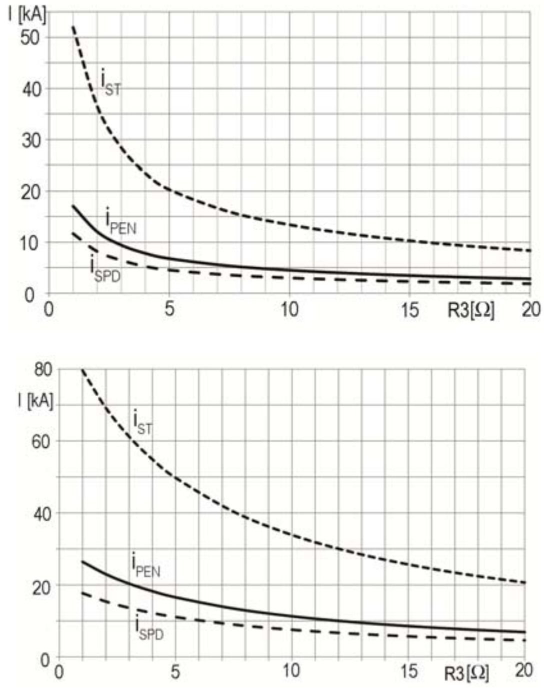

Fig.7. Maximal values of currents in conductors of LVPS with increasing values of transformer grounding system (d = 100 m, w = 5 m,, a) office building - case C, b) residential building - case C

The knowledge of these currents may be great importance for an accurate determination of adequate SPD system in low-voltage installations inside the structures, more accurately than it can be done using the procedures suggested by international standards.

Further studies will be performed to correct models of SPD, low-voltage installations and load inside the structures.

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***Autor**: dr hab. inż. Andrzej W. Sowa, prof. P.B., Politechnika Białostocka, Wydział Elektryczny, 15-351 Białystok, ul. Wiejska 45D, E-mail: Andrzej.sowa@ochrona.net.pl*