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Currents on Electric Installations Inside of Buildings in Case of Lightning Equipotential Bonding at the Roof

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SUMMARY

The main objective of this paper is to evaluate the share of the lightning current, which flows on electric installations inside of buildings. The electrical conductors are equipotentially bonded to the external lightning protection system (LPS) at the roof level. A variety of wiring in typical buildings is analyzed using the computer code CONCEPT II. The transferred charge is the most important parameter for the selection of the surge protective devices (SPD). For a single conductor of an electrical line, the transferred charge is up to 0,6 C for buildings with metal façades. If the building is additionally equipped with a metal roof, the charge is reduced to less than 0,1 C. For (large) industrial buildings with steel reinforcement in the roof and in the ceilings, the charge is also very low, typically less than 0,1 C. In contrast, for houses without shielding elements such as metal façade, metal roof or reinforced concrete ceiling, the charge is relatively high, in the range of several coulombs. These results were obtained using copper or aluminum as materials for the external LPS. The use of normal steel increases the charge slightly. On the other hand, the use of stainless steel increases the charge to a higher extent due to the poor conductivity of stainless steel.

KEYWORDS

equipotential bonding, lightning current, lightning protection, surge protection device, separation distance

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1. INTRODUCTION

The lightning protection systems (LPS) consists of five components: (1) the air-termination system, (2) the down-conductor system, (3) the earth-termination system, (4) the lightning equipotential bonding, and (5) the electrical insulation. The air-termination system, the down-conductor system and the earth-termination system are components of the external LPS, whereas the lightning equipotential bonding and the electrical insulation are protective measures of the internal LPS. The functions of the external LPS are to intercept the lightning flash, to conduct the lightning current safely to earth and to disperse it into the ground [1].

In case of direct lightning strike, dangerous sparking may occur between the external LPS and metal installations inside the building. The function of the internal LPS is to prevent such dangerous sparking. This can be achieved either by lightning equipotential bonding or by electrical insulation of the external LPS, by keeping a separation distance between the external LPS and the conductive installations inside the building. The necessary separation distance depends on several parameters, as the height of the structure [2-7]. It is typically in the range of several tens of centimeters up to more than one meter. If it cannot be realized, the lightning equipotential bonding must be applied. In this case, a current share will flow from the external LPS along the connections into the building.

The aim of this work is to evaluate the maximum share of the lightning current, which flows on electric conductors of the low voltage installation network inside of buildings, in case of a lightning strike. Such investigations are usually based on models using electrical networks with lumped elements as capacitances, inductances, resistors and transmission lines (e.g. [8]). In the present work, the computer simulations involve the complete solution of the Maxwell's equations.

The equipotential bonding of energized lines, as the phase or live-line (L) and the neutral (N) of the low-voltage network, requires the use of SPD (surge protective device). The SPD has to withstand the current share flowing through it.

The present work evaluates the current share in case of lightning equipotential bonding at the roof.

The evaluations include the most relevant current parameters as the current peak, the maximum current steepness, the charge, and the specific energy. Among these parameters, the transferred charge is the most important parameter for the selection of the SPD. A variety of configurations of LPS and line routings are considered, in order to estimate the main electrical requirements for the SPD in a large range of possibilities.

2. COMPUTATIONAL APPROACH

The electromagnetic computations are carried out by the computer code "CONCEPT II", which has been developed during the last decades by the Hamburg University of Technology (TUHH) [9]. This computer code is based on the so-called Method of Moments (MOM). The computer code solves the full Maxwell equations in the frequency domain. Therefore, the time-domain solutions (transient quantities: currents, fields etc.) are obtained from the inverse Fourier transformation.

The skin effect is automatically taken into account by the software package.

The electrical structure of the buildings, including the attached lightning channel, is modeled by patches and wires according to the simulation conditions of CONCEPT II. In CONCEPT II ideal conducting triangular and rectangular patches are used advantageously for the simulation of voluminous electrical bodies. Thin cylindrical structures, as the lightning channel, are modeled by wires, which are subdivided into segments. The highest frequency considered is 10 MHz.

The ground is considered to be ideal conducting. It is represented by the method of electrical images. The fundamental assumptions of the computer code and the handling of the program package are described in [10].

The return stroke process is taken into account by the well-known transmission-line (TL) model [11]. In the frequency domain, this model uses a current source, where the phase velocity is given by the progress velocity of the return stroke. The inverse Fourier transformation gives a time-varying current wave starting from the point of strike and traveling along a straight wire with a constant return stroke velocity. In the simulations, the return stroke velocity chosen is 100 m/µs (see [12]).

The lightning current at the striking point (channel-base current of the TL-Model) is taken into account by the following Heidler function [13]:

$$i = \frac{I_{max}}{k} \cdot \frac{(t/\tau_1)^{10}}{1+(t/\tau_1)^{10}} \cdot e^{-t/\tau_2} \qquad (1)$$

The function is suggested in the standard IEC 62305-1 [1] for theoretical analysis. The parameters τ_1 and τ_2 are the front and the tail time constants, and k is a dimensionless constant for the correction of the peak value.

3. ASSUMPTIONS

The structures studied are all equipped with a lightning protection system (LPS) according to class III of IEC 62305-3 [2]. The currents of the positive and of the negative subsequent strokes are considered according to Lightning Protection Level (LPL) III of IEC 62305-1 [1]. Table 1 gives the parameters of the lightning currents according to eq. (1).

TABLE I
CURRENT PARAMETERS FOR EQUATION (1)

Type	I_{max} (kA)	k	τ_1 (µs)	τ_2 (µs)	Waveform (µs/µs)
Positive stroke	100	0,93	19,0	485	10/350
Subsequent stroke	25	0,993	0,454	143	0,25/100

For the air-termination system or the down-conductor system, it was considered copper, aluminum, steel and stainless-steel. The conductors of the air-termination system or the down-conductor system are represented as round wires with the diameter of 8 mm (cross-sectional area: 50 mm^2). For the materials considered, Table II contains the resistivity according to IEC 62305-1 [1].

TABLE II
RESISTIVITY OF THE CONSIDERED MATERIALS

Material	Copper	Aluminum	Steel	Stainless steel
ρ (Ωm)	$1,8 \cdot 10^{-9}$	$29 \cdot 10^{-9}$	$120 \cdot 10^{-9}$	$700 \cdot 10^{-9}$

For the electrical conductors (cables/wires) of the electric installation inside the building, only copper is considered. The following types of electrical installations are investigated:

- One-phase (L_1,N, PE) : 3 x 1,5 mm^2
- Three-phases (L_1, L_2, L_3, N, PE) : 5 x 2,5 mm^2
- Bonding connections (PA) : 1 x 16 mm^2
- Heating of the rain gutter : 2 x 1,5 mm^2
- Jalousie (L1,N,up,down) : 4 x 1,0 mm^2

The interspacing between the conductors of an individual electrical installation is considered 1 cm. A closer distance cannot be realized due to limitations of the computer code CONCEPT II. The insulating material of the electric conductors was ignored and the permittivity of air was taken into account.

The electrical conductors are usually connected to a bonding bar (on ground level) either directly or indirectly via SPD. In the simulations, a bonding bar is not used, because the electrical lines are bonded to a perfectly conducting ground. The SPD is substituted by metal connections due to the very low impedance in case of lightning strike. The equipotential bonding at the roof requires that the electrical lines (inside of the building) are connected to the conductors of the air-termination and down-conductor system via bonding connections. The bonding connections are considered with the cross-sectional area of 16 mm^2.

Other calculations revealed that these simplifications are of some influence. However, the worst case is covered, which is the intention of this paper.

4. EXAMINED STRUCTURES AND RESULTS

The following four basic structures (buildings) are used as models for the computer simulations:

- Detached house (single-family house) (Fig. 1)
- Unshielded apartment building (Fig. 2)
- Apartment building with metal façade (Fig. 3)
- Office building with reinforced concrete ceilings (Fig. 4)

During a lightning strike, a share of the current flows on each conductor of the electrical line. For covering the worst case, only the conductor with the highest current is taken into account. The following current parameters are examined:

- Current peak I_{max}
- Charge (absolute value) $Q = \int |i| \cdot dt$
- Specific energy $W/R = \int i^2 \cdot dt$
- Maximum current steepness di/dt_{max}

The current peak, the charge and the specific energy are determined by the current of the positive stroke. The maximum current steepness is determined by the current of the subsequent stroke. According to IEC 62305-1 [1], the average current steepness can be used alternatively to the maximum current steepness. In the following tables, the average current steepness is given. It is defined by the current slope (during the front) from the 10%-value to the 90%-value of the lightning current.

A. Detached house (single-family house)

For the detached house (single-family house) three different configurations are examined. They are presented in Fig. 1. Fig. 1a shows the first configuration. The striking point is considered at the middle of the roof. From there, an electrical line runs in 30 cm distance from the roof ridge towards the wall and from there in 1 m distance from the wall to ground.

Table III summarizes the maximum current parameters. Two arrangements are considered. The first arrangement is based on the one-phase line (3 x 1,5 mm^2), the second one on the three-phase line (5 x 2,5 mm^2). There is an overall trend towards higher current parameters with increasing resistivity of the material for the external LPS. Thus, the current parameters are smallest for the material copper and almost the same for aluminum. For these materials, the percentage current share is about 9 % ($I_{max} \approx$ 9 kA) for the one-phase line and about 7,5 % ($I_{max} \approx 7{,}5$ kA) for the three-phase line. Because steel has a somewhat lower conductivity, the current parameters are slightly higher. For stainless steel, especially the charge (Q) and the specific energy (W/R) are much higher due to the poor conductivity.

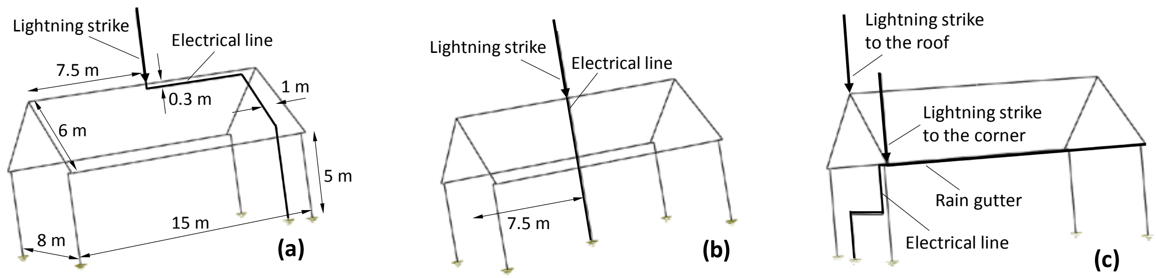

Fig. 1. Detached house (single family house) with the *(a) electrical line close to the roof and the wall, (b) electrical line straight down from the roof to ground,* and *(c) electric line for the heating of a rain gutter.*

The (average) current steepness (Δi/Δt) does not depend on the material, because the current distribution (during the fast current rise) is determined by the inductive and capacitive couplings, but not by the resistive behavior of the structure.

TABLE III
MAXIMUM CURRENT PARAMETERS FOR THE ELECTRICAL LINES CONSIDERING THE (FIRST) CONFIGURATION, SHOWN IN FIG.1A

Internal electric line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)	Δi/Δt (kA/µs)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	9,20	2,60	9,25	9,73
	Aluminum	9,19	2,46	9,41	9,76
	Steel	9,31	3,31	14,6	9,75
	Stainless steel	12,2	9,91	78,6	9,79
3 phases (L1, L2, L3, N, PE) 5 x 2,5 mm2	Copper	7,46	2,52	7,37	7,81
	Aluminum	7,47	2,36	7,66	7,86
	Steel	7,56	4,02	13,5	7,88
	Stainless steel	9,76	8,04	51,3	7,88

The current parameters are generally somewhat higher for the one-phase electrical installation compared to the 3-phase electrical installation. This is due to the fact, that in case of the one-phase electrical installation, the current is distributed to three conductors (L_1, N, PE), whereas the current is distributed to five conductors (L_1, L_2, L_3, N, PE) in case of the 3-phases electrical installation.

Fig. 1b shows the second configuration. Again, the striking point is at the middle of the roof. From there, an electrical line runs straight down to the perfectly conducting ground. Table IV summarizes the maximum current parameters for the electrical lines considering the one-phase installation (3 x 1,5 mm^2) and the three-phase installation (5 x 2,5 mm^2). Again, the maximum current steepness is not influenced by the material. This configuration represents the worst case with the highest current parameters. For copper, aluminum and steel, the percentage of current share is about 13 % for one-phase line and about 10 % for three-phase line. Again, the charge (Q) and the specific energy (W/R) are much higher for stainless steel.

TABLE IV
MAXIMUM CURRENT PARAMETERS FOR THE ELECTRICAL LINES CONSIDERING THE (SECOND) CONFIGURATION, SHOWN IN FIG. 1B

Internal electric line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)	Δi/Δt (kA/µs)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	12,9	4,36	22,0	13,9
	Aluminum	13,5	4,20	23,5	14,1
	Steel	13,1	5,28	34,4	13,9
	Stainless steel	15,6	12,14	123,4	13,9
3 phases (L_1, L_2, L_3, N, PE) 5 x 2,5 mm^2	Copper	9,97	3,39	14,8	10,6
	Aluminum	9,99	3,37	15,8	10,5
	Steel	10,1	5,48	25,3	10,5
	Stainless steel	11,7	8,80	65,5	10,6

Fig. 1c shows the third configuration with a rain gutter equipped with a heating. An electrical line with two conductors (2 x 1,5 mm^2) is used for the power supply of the heating. Table V summarizes the maximum current parameters. Again, the maximum current steepness is not influenced by the material of the external LPS. The current peak is about the same for the materials copper, aluminum and steel. Again, the charge and the specific energy are somewhat higher for steel and extremely higher for stainless steel.

In order to examine the influence of the location of the lightning channel, two different striking points are considered, one at the top of the roof and the other one at the corner. For the lightning strike at the corner, the current share is about double compared to the lightning strike at the roof.

TABLE V
MAXIMUM CURRENT PARAMETERS FOR THE ELECTRIC CONDUCTORS OF THE HEATING OF THE ROOF GUTTER, SHOWN IN FIG. 1C

Striking point	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)	Δi/Δt (kA/µs)
Lightning strike to the corner	Copper	9,73	2,7	10,3	9,85
	Aluminum	9,79	2,6	10,4	9,86
	Steel	9,91	2,8	14,6	9,86
	Stainless steel	12,95	10,0	84,2	9,85
Lightning strike to the roof	Copper	5,72	1,58	3,51	6,80
	Aluminum	5,73	1,52	3,56	6,90
	Steel	5,80	1,62	4,99	6,91
	Stainless steel	7,61	6,00	29,8	6,90

B. Unshielded apartment building

An unshielded apartment building is considered with the base area of 15 m x 30 m and the height of 15 m. The striking point is at the air termination conductor in the middle of the building. Three different configurations are examined, shown in Fig. 2. The configurations take into account an electrical line close to the striking point (Fig. 2a), an electrical line connected to the air-termination system (Fig. 2b), and an electric line connected to a downward conductor (Fig. 2c).

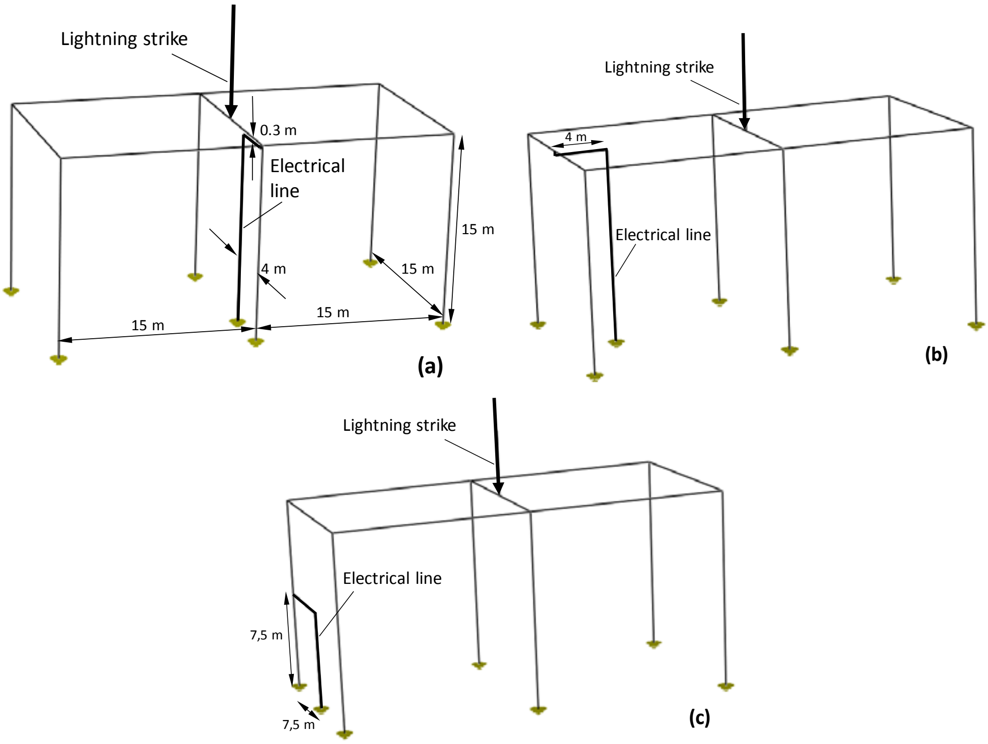

Fig. 2. Unshielded apartment building with (a) *the electrical line close to the striking point*, (b) *the electrical line connected to the air-termination system*, and (c) *the electric line connected to a downward conductor*.

Table VI summarizes the maximum current parameters for the configuration shown in Fig. 2a. The calculations revealed that this configuration represents the worst case with the highest current share. The current share is reduced to about one third for the other configurations (see Fig. 2b,c). Because the current parameters for copper and aluminum are almost identical, the material aluminum is ignored in Table VI.

TABLE VI
MAXIMUM CURRENT PARAMETERS FOR THE CURRENTS THROUGH THE ELECTRIC CONDUCTORS ACCORDING TO THE CONFIGURATION IN FIG. 2A.

Internal electric line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)	Δi/Δt (kA/µs)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	6,00	1,86	4,09	6,33
	Steel	6,07	1,86	5,53	6,16
	Stainless steel	7,13	5,87	27,80	6,35
4 conductors L_1,N,up,down 4 x 1,0 mm^2	Copper	5,02	1,32	2,07	5,38
	Steel	5,06	1,23	2,95	4,97
	Stainless steel	5,35	4,22	14,78	5,40
3 phases (L_1, L_2, L_3, N, PE) 5 x 2,5 mm^2	Copper	4,83	1,65	2,73	4,89
	Steel	4,54	1,22	2,51	4,88
	Stainless steel	4,83	3,71	11,40	4,90

Again, the one-phase and the 3-phase installations are investigated. In addition, the electrical line to a jalousie is considered. This electrical circuit consists of 4 conductors (4 x 1,0 mm^2). Two of them (L_1, N) are used for the power supply and the other two for the motor control (up, down). The current share is highest for the one-phase electric installation ($I_{max} \approx 6$ kA), reduced by about 20 % for the four-conductor installation to the jalousie and further reduced for the three-phase installation. The current parameters are about the same for copper and steel, but significantly higher for stainless steel.

C. Apartment building with metal façade

Now the apartment building is shielded by a metal façade. The metal façade is connected to ground by bonding connections with the length of 1 m. Two cases were examined:

- First case: The metal façade was connected to ground by bonding connections every 5 m.
- Second case: The metal façade was connected to ground by bonding connections every 15 m (see Fig. 3).

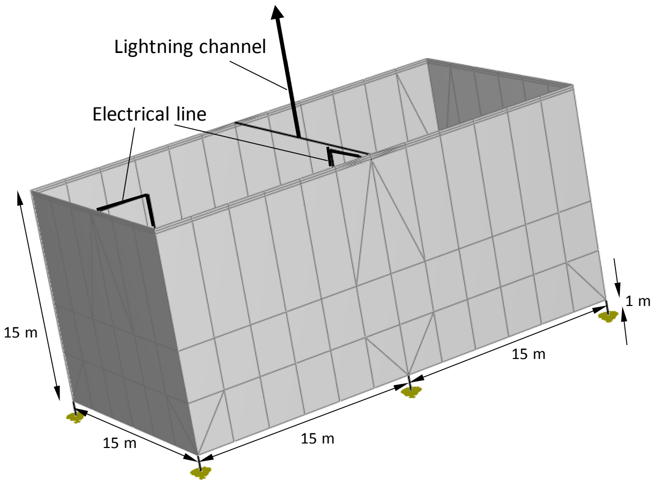

Fig. 3. Apartment building with metal façade and bonding connection to ground every 15 m.

For the internal electrical installations (inside the building), the same three configurations were used as for the unshielded apartment building. Also here, the electrical line routing according to Fig. 2a represents the worst case with the highest current share. For that case, Table VII summarizes the maximum current parameters considering bonding connections every 5 m. Because the results are almost the same for copper, aluminum and steel, the values for the materials aluminum and steel are not presented. Compared to the unshielded apartment building, the installation of metal façades reduces the current share by more than the factor of three. The current share is about 1,8 % ($I_{max} \approx$ 1,8 kA) for the one-phase circuit and to about 1,5 % ($I_{max} \approx$ 1,5 kA) for the four-conductor installation to the jalousie.

TABLE VII
MAXIMUM CURRENT PARAMETERS FOR THE APARTMENT BUILDING
WITH METAL FAÇADE AND BONDING CONNECTIONS TO GROUND EVERY 5 M.

Internal electric line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)	Δi/Δt (kA/µs)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	1,78	0,41	0,30	2,24
	Stainless steel	1,78	0,50	0,30	2,24
4 conductors (L_1, N, up, down) 4 x 1,0 mm^2	Copper	1,53	0,06	> 0,1	1,94
	Stainless steel	1,53	0,29	0,18	1,95

Table VIII contains the respective results for bonding connections every 15 m (case 2). Compared to case 1 (bonding connections every 5 m), the less use of bonding connections increases the current maximum (I_{max}), the charge (Q) and the specific energy (W/R) by roughly about 10 % to 40 %.

TABLE VIII
MAXIMUM CURRENT PARAMETERS FOR THE APARTMENT BUILDING
WITH METAL FAÇADE AND BONDING CONNECTIONS TO GROUND EVERY 15 M.

Internal electric line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	1,99	0,56	0,38
	Stainless steel	2,01	0,71	0,47
4 conductors (L_1, N, up, down) 4 x 1,0 mm^2	Copper	1,71	0,41	0,23
	Stainless steel	1,71	0,33	0,27

Finally, the apartment building is equipped by a metal roof (not shown here). The metal façade is connected to ground by bonding connections every 5 m. Table IX summarizes the maximum current parameters considering only the one-phase line (L_1, N, PE). The metal roof reduces the lightning parameter by at least the factor of three.

TABLE IX
MAXIMUM CURRENT PARAMETERS FOR BUILDING WITH METAL ROOF AND
METAL FAÇADE WITH BONDING CONNECTIONS TO GROUND EVERY 15 M.

Internal electric line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	0,52	0,08	0,01
	Stainless steel	0,52	0,19	0,03

D. Office building with reinforced concrete ceilings

Fig. 4a shows the simulation model of a three-story office building with reinforced concrete ceilings (roof) represented by ideal conducting plates. The pillars are substituted by steel bars having a cross-sectional area of 1000 mm^2.

Three different line routings and three different striking points are considered.

In Fig. 4b the roof is removed in order to have a look to the electrical lines. Again, the one-phase line and the 3-phase line are considered.

Table X summarizes the maximum current parameters considering the worst case for the combination of striking point and line routing. The currents through the conductors of the electrical lines are very low, typical in the range of several tens of amperes. The maximum current share is about 0,17 % (I_{max} ≈ 0,17 kA) for the one-phase line and about 0,14 % (I_{max} ≈ 0,14 kA) for the three-phase line (Table X). Now, the pillars (steel bar) are removed and substituted by round down conductors with the cross-sectional area of 50 mm^2. The materials copper, aluminum, steel and stainless steel are taken into account.

Table XI summarizes the maximum current parameters, again considering the worst case for the combination of striking point and line routing. Compared to Table X, the reduction of the cross-sectional area leads to higher current parameters

TABLE X

MAXIMUM CURRENT PARAMETERS FOR THE CURRENTS THROUGH THE ELECTRIC CONDUCTORS OF THE THREE ELECTRICAL LINES SHOWN IN FIG. 4.

Internal electric line	I_{max} (kA)	Q (C)	W/R (kJ/Ω)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	$168 \cdot 10^{-3}$	$45{,}8 \cdot 10^{-3}$	$2{,}62 \cdot 10^{-3}$
3 phases (L_1, L_2, L_3, N, PE) 5 x 2,5 mm^2	$139 \cdot 10^{-3}$	$80{,}5 \cdot 10^{-3}$	$3{,}49 \cdot 10^{-3}$

On the other hand, for the materials copper and aluminum the current share is still rather low, with about 0,25 % ($I_{max} \approx 0{,}25$ kA) for the one-phase circuit and about 0,21 % ($I_{max} \approx 0{,}21$ kA) for the three-phase circuit. The current parameter are slightly higher for steel and again much higher for stainless steel.

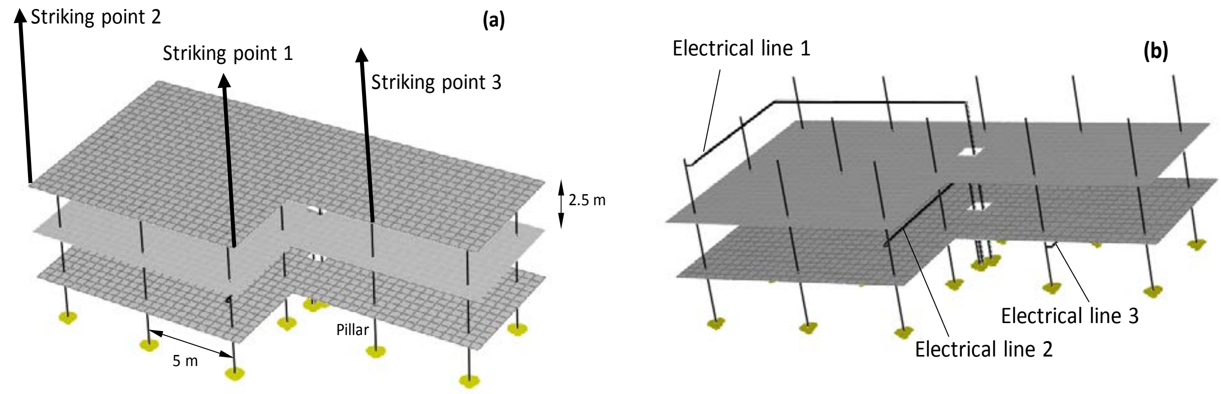

Fig. 4. - Office building with reinforced concrete ceilings (roof) represented by ideal conducting plates: (a) *Complete simulation model* and (b) *simulation model without roof*, showing the internal electrical lines.

TABLE XI

MAXIMUM CURRENT PARAMETERS FOR THE CURRENTS THROUGH THE ELECTRIC CONDUCTORS OF THE THREE ELECTRICAL LINES SHOWN IN FIG. 4.

Internal electrical line	Material of external LPS	I_{max} (kA)	Q (C)	W/R (kJ/Ω)
One-phase (L_1,N, PE) 3 x 1,5 mm^2	Copper	$252 \cdot 10^{-3}$	$69{,}4 \cdot 10^{-3}$	$7{,}93 \cdot 10^{-3}$
	Aluminum	$253 \cdot 10^{-3}$	$68{,}7 \cdot 10^{-3}$	$9{,}10 \cdot 10^{-3}$
	Steel	$266 \cdot 10^{-3}$	$235 \cdot 10^{-3}$	$38{,}0 \cdot 10^{-3}$
	Stainless steel	$1032 \cdot 10^{-3}$	$1058 \cdot 10^{-3}$	$827 \cdot 10^{-3}$
3 phases (L_1, L_2, L_3, N, PE) 5 x 2,5 mm^2	Copper	$208 \cdot 10^{-3}$	$73{,}9 \cdot 10^{-3}$	$7{,}36 \cdot 10^{-3}$
	Aluminum	$209 \cdot 10^{-3}$	$96{,}9 \cdot 10^{-3}$	$9{,}31 \cdot 10^{-3}$
	Steel	$226 \cdot 10^{-3}$	$363 \cdot 10^{-3}$	$54{,}4 \cdot 10^{-3}$
	Stainless steel	$1174 \cdot 10^{-3}$	$1528 \cdot 10^{-3}$	$1211 \cdot 10^{-3}$

5. DISCUSSION

For the different configurations, Table XII summarizes the overall maxima of the current share (I_{max}) and of the maximum charge (Q_{max}) based on the materials copper, aluminum and (normal) steel. The charge is the most important parameter that the SPD has to withstand.

According to the various requirements, the SPD are subdivided in different classes [14]. The highest SPD class is the class I, which is designed to withstand the threat of the total lightning current. In low power installation network, they are installed at the entrance into a building, which represents the transition from lightning protection zone LPZ 0 to LPZ 1.

The partial currents, which enter the LPZ 1, are reduced and the waveforms are changed due to the switching and limiting characteristics of the SPD of class I. The succeeding SPD, class II, has to withstand those currents. The SPD of class II uses normally varistors to limit the overvoltages. They are commonly tested with impulse currents with the wave shape 8/20 µs. A SPD of class II, which is specified for a maximum current of 40 kA (8/20 µs), can withstand a charge of about 1 C.

This type of SPD may be used for buildings (structures) equipped with metal shields such as metal façade, metal roof or reinforced concrete ceilings (see Table XII). For building without metal shield such as normal detached houses (single-family houses) or unshielded apartment buildings, the charge exceeds the value of 1 C. In this case, the use of SPD of class II is not recommended, and a SPD of class I is required.

TABLE XII

MAXIMUM CURRENT AND MAXIMUM CHARGE ON LINES INSIDE OF BUILDINGS.

Type of house and configuration	I_{max} (kA)	Q_{max} (C)
Single-family house	~ 12	~ 5
Un-shielded apartment building	~ 6	~ 2
Apartment building with metal façade and bonding connections to ground every 15 m	~ 2	~ 0,6
Apartment building with metal façade and bonding connections to ground every 5 m	~ 2	~ 0,5
Apartment building with metal façade and metal roof	~ 0,5	~ 0,1
3-storey building with reinforced concrete ceilings	~ 0,2	< 0,1

6. CONCLUSION

In case of direct lightning strike, dangerous sparking can be prevented by lightning equipotential bonding. In this case, a share of the lightning current flows on electric lines inside of the buildings. The SPD has to withstand that current share characterized by the current peak, the charge, the specific energy and the maximum current steepness.

The maximum current steepness does not depend on the material of the external LPS, because the current distribution (during the fast current rise) is determined by the inductive and capacitive couplings, but not by the resistive behavior of the structure. For the other current parameters (current peak, charge, specific energy) there is an overall trend towards higher values with increasing resistivity of the material for the external LPS.

If possible, the use of stainless steel should be avoided, because the current parameters are very high due to the poor resistivity of that material.

For the materials copper, aluminum and steel the SPD of class II may be used, if the building is equipped by metal shields, such as metal façade, metal roof or reinforced concrete ceilings. For unshielded buildings the use of SPD of class II is not recommended. In this case, SPD of class I is required.

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