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CALCULATION OF THE SEPARATION DISTANCE ACCORDING TO IEC 62305-3: 2006-10 – REMARKS FOR THE APPLICATION AND SIMPLIFIED METHODS

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Abstract - The international standard IEC 62305-3 [1], published in 2006, requires as an integral part of the lightning protection system (LPS) the consideration of a separation distance between the conductors of the LPS and metal and electrical installations inside the structure to be protected. IEC 62305-3 gives two different methods for this calculation: a standard, simplified approach and a more detailed approach, which differ especially regarding the treatment of the current sharing effect on the LPS conductors. Hence, different results for the separation distance are possible, leading to some discrepancies in the use of the standard.

The standard approach defined in the main part (Clause 6.3) and in Annex C of the standard in some cases may lead to a severe oversizing of the required separation distance. The detailed approach described in Annex E naturally gives more correct results. However, a calculation of the current sharing amongst all parts of the air-termination and down-conductor network is necessary, in many cases requiring the use of network analysis programs. In this paper simplified methods for the assessment of the current sharing are presented, which are easy to use as well as sufficiently adequate.

1 INTRODUCTION

The new standard IEC 62305-3:2006-10 [1] shows some remarkable changes regarding the calculation of the separation distance compared to previous versions. The method defined in the main part (Clause 6.3) and in Annex C of IEC 62305-3 may lead to a severe oversizing of the required separation distance, in some cases up to a factor of 2.5. Furthermore a more detailed approach is given in Annex E of IEC 62305-3. Unfortunately both methods may come to different results of the separation distance for the same case. And, this is based on the same standard without any further information about the backgrounds of both methods. This discrepancy results in a lot of discussions among LPS planers and installers and uncertainties in education and training of specialists.

This paper intends to answer some questions regarding the calculation of the separation distance. Solution methods are shown and some guidance for the practical application is given. This contains (1) a detailed description of the different methods according to IEC 62305-3; (2) recommendations, under which assumptions the application of Clause 6.3 together with Annex C is useful, and for which cases the method described in Annex E is preferred; (3) an accuracy test of the method of Annex E using a electromagnetic field computing code solving correctly the Maxwell equations; (4) a simplified method to assess the current sharing coefficients for a more practical application of Annex E.

2 STANDARD METHOD

The standard (or simplified) method according to IEC 62305-3:2006 [1] is largely identical to the method described in the preceding standards IEC 61024-1:1990 and ENV 61204-1:1995 [2, 3]. The separation distance between the air-terminations and the down-conductors on the one hand and the metal installations and electrical systems within the structure to be protected on the other hand is given by:

$$s = k_i \cdot \frac{k_c}{k_m} \cdot \ell \qquad (1)$$

where:

k_i depends on the selected class of the LPS,
k_c depends on the lightning current flowing in the down-conductors,
k_m depends on the electrical insulation material,
ℓ is the shortest length, along the air-termination or the down-conductor, from the point where the separation distance is to be considered, to the nearest equipotential bonding point.

The discrepancy of IEC 62305-3 to both preceding standards [2, 3] is that according to Clause 6.3 the length

ℓ is not only the vertical height, i.e. the length of the down-conductors, but the length along the air-terminations or the down-conductors (Fig. 1). However, the current sharing coefficient k_c according to Annex C (Eq. 2) gives as a worst-case the partial current, flowing in case of a lightning strike to the edge or corner of a LPS, in the nearest, directly connected down-conductor. But in case of a strike to the roof (Fig. 1) the partial currents are remarkably lower than suggested by the k_c-calculation according to Annex C, due to the multiple branching of the current along the path ℓ.

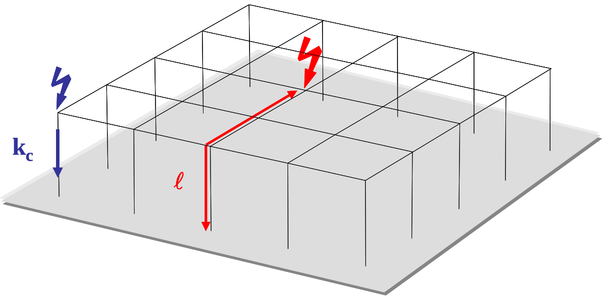


Fig. 1 - Conductor length ℓ according to IEC 62305-3 [1]

$$k_c = \frac{1}{2n} + 0{,}1 + 0{,}2 \times \sqrt[3]{\frac{c}{h}} \qquad (2)$$

Originally, the lightning strike to the edge or corner of a LPS was assumed to be a worst-case for the separation distance covering also strikes to other parts of the roof. The length ℓ naturally was only the length of the down-conductor (i.e. the height of the structure in Fig. 1). Therefore, for the application of the standard method given in IEC 62305-3, Clause 6.3 and Annex C it has to be considered:

- The lightning strike to edge or corner presents the worst-case and covers more or less all other parts of the roof conservatively. Condition for this is that the roof is protected with a mesh-type air-termination system according to the selected class of LPS.
- If air-termination rods or masts are used to protect roof installations, the additionally necessary separation distance can be simply added to the value which is valid for the whole roof.
- As the length ℓ, however, in contradiction to IEC 62305-3 only the length of the down-conductors should be used. This was already suggested in [2, 3]. In case of a ridge roof the entire length of the down-conductor to the ridge may be used.

If especially the last point is not taken into account, in many cases unrealistic and unnecessary high separation distances are calculated, which often can not be realized with “usual” means and measures.

3 DETAILED METHOD (NODE-POTENTIAL ANALYSIS)

IEC 62305-3, Annex E shows a more detailed method, which was not described in the previous standards [2, 3]. The required entire separation distance follows from the addition of individual partial values, which arise along the n lightning current carrying conductors (air-terminations and down-conductors). Due to current sharing different partial currents flow over the conductors:

$$s = \frac{k_i}{k_m} \cdot \left(k_{c1} \cdot \ell_1 + k_{c2} \cdot \ell_2 + \ldots + k_{cn} \cdot \ell_n \right) \quad (3)$$

An example for a large flat roof with a mesh-type air-termination system is given in Fig. 2.

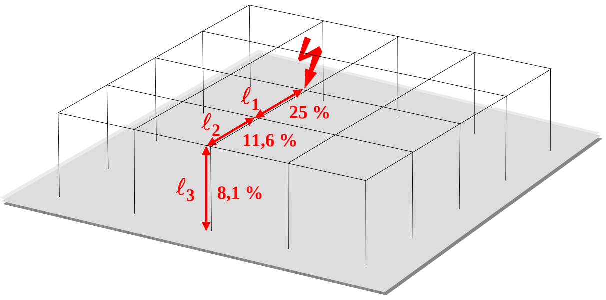


Fig. 2 - Current sharing for a large flat roof (length of all conductor section is 10 m)

It has to be mentioned, that the method given in Annex E simplifies the physical mechanism to a certain extent. The induced voltage in a loop as a result of the magnetic flux’ time derivative is represented as the longitudinal voltage along the current carrying impedances. The errors as a result of this simplification, however, are acceptable, as shown in chapter 4.

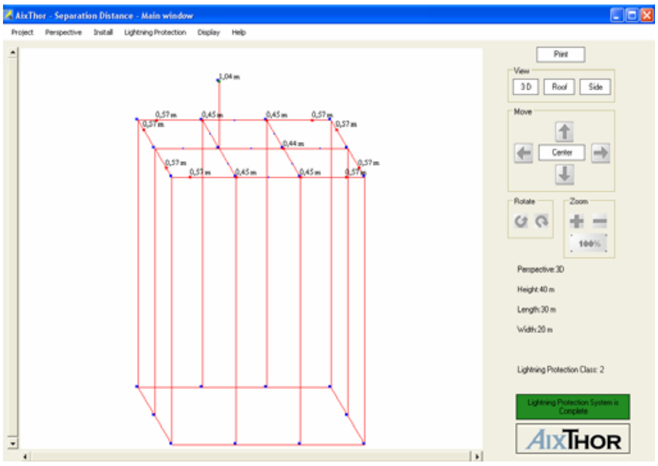
With this detailed method generally LPS of arbitrarily complex geometry can be simulated. This requires, however, the calculation of the individual values of the current sharing coefficients $k_{c\nu}$. This is possible using well-established methods of the network theory, e.g. the node-potential analysis. Here, for the calculation of the potentials of the individual nodes (φ_1, φ_2 ... φ_n), as the result of the lightning current I_1 injected at node 1, a matrix equation has to be solved:

$$\begin{bmatrix} A_{1,1} & A_{2,1} & \ldots & A_{n,1} \\ A_{1,2} & A_{2,2} & \ldots & A_{n,2} \\ \ldots & \ldots & \ldots & \ldots \\ A_{1,n} & A_{2,n} & \ldots & A_{n,n} \end{bmatrix} \bullet \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \ldots \\ \varphi_n \end{bmatrix} = \begin{bmatrix} -I_1 \\ 0 \\ \ldots \\ 0 \end{bmatrix} \quad (4)$$

After calculation of the inverse conductance matrix $[\mathrm{A}]^{-1}$ the node-potentials are given as:

$$[\varphi] = [A]^{-1} \cdot [I] \quad (5)$$

For this calculation also commercial network analysis programs may be used (e.g.. PSPICE, EMTP). Fig. 3 shows as an example a program especially developed for lightning protection application.



Perspective: 3D
Height: 40 m
Length: 30 m
Width: 20 m
Lightning Protection Class: 2

Fig. 3 - Calculation with a network analysis program

If the detailed method according to IEC 62305-3, Annex E is applied, the following has to be considered:

- As the worst-case the lightning strike has to be assumed usually at the position, where the separation distance should be calculated. For different positions on the roof, normally also different values for the separation distance occur.
- With this method air-termination rods and masts for the protection of roof installations can be easily taken into account.

4 REFERENCE CALCULATIONS USING THE MOM-SIMULATION PROGRAM CONCEPT II

To test the accuracy of the detailed method according to IEC 62305-3, Annex E, comparative calculations were performed using the computer code CONCEPT II. This code is based on the so-called Methods-of-Moments (MoM) and solves the Maxwell equations in the frequency domain. The current and voltage time wave-shapes then are obtained using an inverse Fourier-transformation. The basic principle and the application of CONCEPT II are described in [4, 5].

The reference calculations were performed for different structures representing typical building's dimensions [6]. We simulated structures with a base area of 20 m x 20 m and heights between 10 m and 60 m and a large flat structure with a base area of 60 m x 60 m and a height of only 10 m. The structures were protected with a LPS class II:

- mesh width of the air-terminations 10 m x 10 m,
- distance of the down-conductors 10 m,
- ring conductors every 10 m of height.

The lightning current was injected to the corner and to the center of the roof. The lightning current was fixed with i_{max} = 37.5 kA and T_1 = 250 ns according to Lightning Protection Level II [1]. For calculating the separation distance two loops were implemented. For the corner strike a 10 m wide loop was considered, running from the corner diagonally in direction to the structure's center and from there to the ground. For the center strike in the structure's center a vertical wire from roof to ground was used. These loops were terminated with a high-ohmic resistance (1 MΩ), to obtain the induced voltage in an approximately open loop. Finally from the voltages the required separation distance was determined using the voltage-time area criteria for air-gaps.

Table 1: Comparison of the results for the separation distance s based on calculations with the MoM simulation code CONCEPT II and according to IEC 62305-3, Annex E (assumptions: $k_i = 0.06$, $k_m = 1$)

Structure		Striking point	Separation distance s [cm]		Error %
Base area [m x m]	Height[m]		MoM	Annex E	
20m x 20m	10m	Corner	28.7	26	-9
		Center	23.1	24	4
20m x 20m	20m	Corner	43.6	36	-17
		Center	33.8	32	-5
20m x 20m	40m	Corner	65.3	52	-20
		Center	44.4	47	6
20m x 20m	60m	Corner	77.5	67	-14
		Center	52.1	62	19
60m x 60m	10m	Corner	28.2	26	-8
		Center	31.5	29	-8

The results are summarized in Table 1. The values obtained from the solution of the Maxwell equations via the Method-of-Moments and the values from a network analysis based on IEC 62305-3, Annex E differ only by a range of ± 20 %. Therefore, using the method of Annex E leads to acceptable results; the errors are clearly smaller than those of the standard method according to IEC 62305-3, Clause 6.3.

5 SIMPLIFIED METHODS TO ASSESS k_c

Methods for network analysis (Chapter 3) are often too complex for practical applications in the LPS planning process. Therefore, in the following two simple methods are presented, which can be applied by the practitioner after a short "training period". Both simple methods generally assume that between the lightning strike point and the earth-termination system multiple current sharing will occur. Due to this current sharing the partial currents will become smaller along the current path.

In case of wide-spreaded and/or high buildings the partial current may get smaller than the physically reasonable value of $1/n$ (n = entire number of down-conductors). This is due to the simplifications of both methods in case of a multiple application of the current sharing rules. Hence, it is necessary from this point on not to perform further current sharing and to calculate with a constant $k_{cv} = 1/n$ for the remaining conductor sections.

5.1 Current divider method

In this simple method the treatment of the current sharing points follows the current divider rule. The relation of the total current flowing into one branching point I_Σ to the partial current after the branching point I_{Part}, which has to be considered on the relevant conductor section, follows from the corresponding conductances:

$$\frac{I_{Part}}{I_\Sigma} = \frac{G_{Part}}{\sum\limits_V G_V} \qquad (6)$$

The application of this simple current divider rule implies that all partial currents after the branching point V end in an equipotential surface (see branching destination Z in Fig. 4). In case of the separation distance calculation this is finally the earth-termination system with earth potential. For the previous branching points the assumption of an equipotential surface is not valid, however. This is the simplification. Therefore, at all conductor sections leaving the branching point there is the same potential difference $\varphi_Z - \varphi_V$.

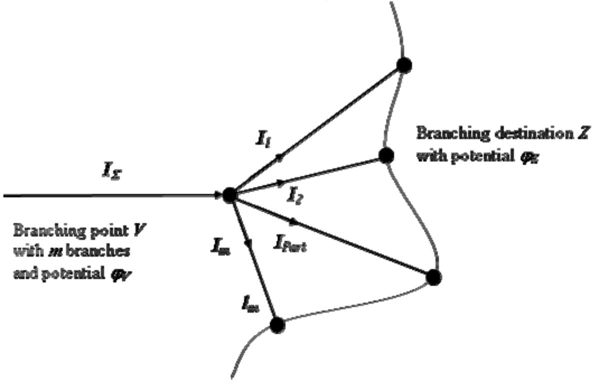


Fig. 4 - Current sharing at a branching point

Applying the next simplification, that only conductors of the same material and the same cross-sectional area are used, the conductances G_v are simply inversely proportional to the length ℓ of the conductor. The partial current I_{Part}, flowing in the considered conductor section, is described with the partial current coefficient k_V. Using the parameter length we get for each branching point:

$$k_V = \frac{I_{Part}}{I_\Sigma} = \frac{1}{\ell_{Part}} \cdot \frac{1}{\sum\limits_V \frac{1}{\ell_V}} \qquad (7)$$

The individual coefficients for k_c along the calculation path are the result of a weighting with the partial current coefficient k_V. For example, if the conductor section ℓ_1 ends in the branching point V1, for the consecutive conductor section ℓ_2 it follows:

$$k_{c2} = k_{c1} \cdot k_{V1} \qquad (8)$$

In case the path begins with a branching point V0 it is $k_{C1} = k_{V0}$.

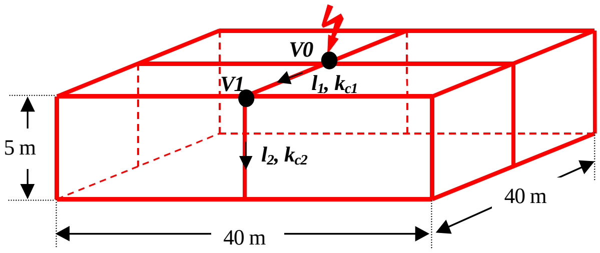


Fig: 5 - Example for the application of the current divider method

The procedure should be demonstrated with a calculation example (Fig. 5). The path begins with the branching point V0. Here 4 partial lightning currents exist on 4 conductor sections having the same length of 20 m. The length of the first path is ℓ_1 = 20 m. At the branching point V0 the coefficient k_{V0} is calculated:

$$k_{V0} = \frac{1}{\ell_1} \cdot \frac{1}{\sum\limits_{V0} \frac{1}{\ell_{V0}}} = \frac{1}{20} \cdot \frac{1}{4 \cdot \frac{1}{20}} = \frac{1}{4} = 0.25$$

$$k_{C1} = k_{V0} = 0.25$$

The path continues to a branching point V1. Here 3 partial currents flow on 2 conductor sections with 20 m length and one further considered conductor section with 5 m length to the earth-termination system. The calculation at the branching point V1 is:

$$k_{V1} = \frac{1}{\ell_2} \cdot \frac{1}{\sum\limits_1^3 \frac{1}{\ell_{V1}}} = \frac{1}{5} \cdot \frac{1}{2 \cdot \frac{1}{20} + \frac{1}{5}} = \frac{1}{5} \cdot \frac{1}{\frac{6}{20}} = \frac{2}{3} = 0.66$$

$$k_{C2} = k_{C1} \cdot k_{V1} = 0.25 \cdot 0.66 = 0.165$$

Finally, for a LPS class II (k_i = 0.06) and air as the isolating material (k_m = 1) the separation distance s is given by:

$$s = \frac{k_i}{k_m} \cdot (k_{c1} \cdot \ell_1 + k_{c2} \cdot \ell_2) =$$

$$= \frac{0.06}{1} \cdot (0.25 \cdot 20 \text{ m} + 0.165 \cdot 5 \text{ m}) = 0.35 \text{ m}$$

5.2 Two-stage calculation

If the result shall be more accurate, especially in case of unsymmetrical current sharing, the method described above can be expanded to 2 stages. If applicable, 2 cascaded branching stages until the branching destination Z (equipotential surface) are considered:

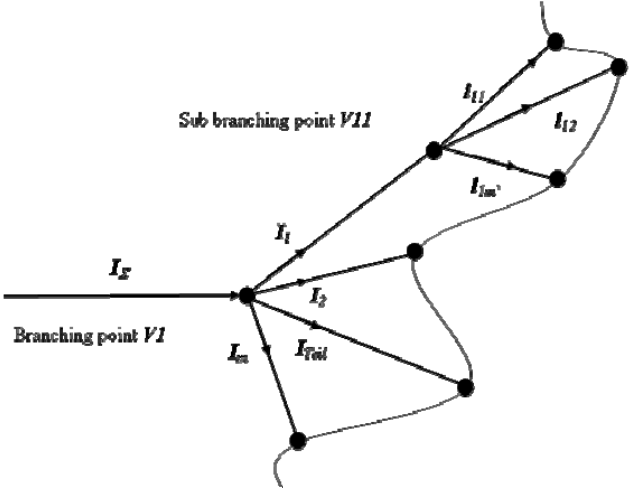


Fig. 6 - Current sharing for 2 cascaded branches

Fig. 6 as an example presents at the end of the first conductor section a sub-branching point V11. Because the branching destination Z is reached only after a longer current path, if the sub-branching point is considered, also the conductance of the relevant current path decreases. This is taken into account by using an (extended) fictitious length ℓ' for this current path. With that, the current divider rule gives for the relevant current path "1":

$$\ell_1{}' = \ell_1 + \frac{1}{\sum\limits_{V11} \frac{1}{\ell_{V11}}} \tag{9}$$

To achieve the optimum accuracy for the calculation, the method with the fictitious length must be used for all branches, where it is applicable. This is valid for all the cases, where the conductor section considered does not terminate at the end of the calculation path (earth-termination system, equipotential bonding point).

5.3 Empirical method

This method does not have a sound scientific basis. It was developed only by means of a larger number of examples. Again, it is assumed, that all conductors of the air-termination and the down-conductor system have identical cross-sections and are made of the same material. The method is based on the following rules:

- At the lightning strike point (or at the point, where the full lightning current is injected) the current is shared equally to all outgoing conductors.
- At all further branching points the current is divided by 2, independent on the number of the outgoing (continuing) conductors.
- If, due to multiple sharing, the partial current would be reduced below the value 1/n (n = total number of down-conductors), there is no further current sharing. For the remaining conductor sections the calculation is performed using the value $k_{cv} = 1/n$.

An application example for this method is presented in Fig. 7. At the lightning strike point „1“ the lightning current is shared to 4 conductors, so that:

$k_{c1} = 1/4 = 0.25$

At the next node (branching point "2)“ the current is divided by 2:

$k_{c2} = 1/2 \cdot 0.25 = 0.125$

At the following node (branching point „3“) a further reduction by a factor of 2 would occur:

$k_{c3} = 1/2 \cdot 0.125 = 0.0625$

This value, however, is less than the value 1/n = 1/8. Therefore, there is no more reduction, and it is:

$k_{c3} = 1/n = 1/8 = 0.125$

Again assuming the values k_i = 0.06 (LPS class II) and k_m = 1 (air), the separation distance s follows:

$$s = \frac{k_i}{k_m} \cdot (k_{c1} \cdot \ell_1 + k_{c2} \cdot \ell_2 + k_{c3} \cdot \ell_3)$$

$$= \frac{0.06}{1} \cdot (0.25 \cdot 10 \text{ m} + 0.125 \cdot 10 \text{ m} + 0.125 \cdot 10 \text{ m}) = 0.30 \text{ m}$$

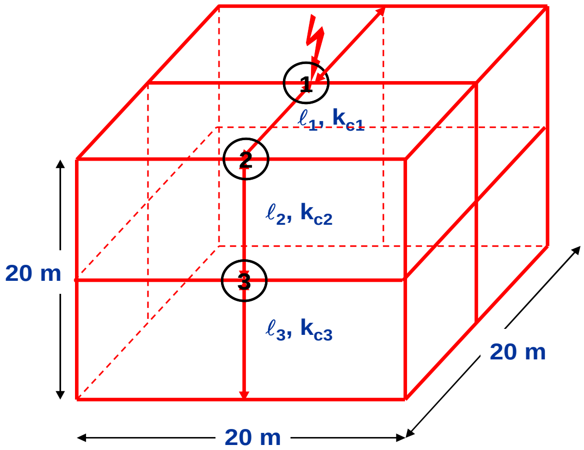


Fig. 7 - Example for the application of the empirical method

6 COMPARISON OF THE METHODS

To check and evaluate the simplified methods presented in chapter 5, the values for the separation distance s obtained with the different methods are compared with a calculation, which is based on an exact determination of the individual coefficients k_{cv} along the current path with the node-potential analysis. The examination is performed for the same structure configurations as defined in chapter 4 with a LPS class II ($k_i = 0.06$ and $k_m = 1$). The results for the corner strike are shown in Table 2 and for the center strike in Table 3.

Table 2: Comparison of the separation distance s for the detailed and for the simplified methods in case of a corner strike (Assumptions: $k_i = 0.06$, $k_m = 1$)

Structure		Separation distance s [cm]			
Area [m x m]	Height [m]	Node-potent. analysis	Current divider 1-stage	Current divider 2-stage	Empi-rical
20m x 20m	10m	26	20	24	20
20m x 20m	20m	36	28	28	30
20m x 20m	40m	52	45	45	45
20m x 20m	60m	67	60	60	60
60m x 60m	10m	26	20	24	20

Table 3: Comparison of the separation distance s for the detailed and for the simplified methods in case of a center strike (Assumptions: $k_i = 0.06$, $k_m = 1$)

Structure		Separation distance s [cm]			
Area [m x m]	Height [m]	Node-potent. analysis	Current divider 1-stage	Current divider 2-stage	Empi-rical
20m x 20m	10m	24	20	21	23
20m x 20m	20m	32	30	30	30
20m x 20m	40m	47	45	45	38
20m x 20m	60m	62	60	60	53
60m x 60m	10m	29	25	26	28

Table 4: Deviation in percent of the simplified methods compared to the detailed node-potential analysis

Deviation %	Current divider 1-stage	Current divider 2-stage	Empirical
Corner strike			
Maximum	-23	-22	-23
Average	-18	-12	-17
Center strike			
Maximum	-17	-13	-19
Average	-9	-7	-10

Table 4 finally gives a compilation of the maximum values and the mean values of the percentage deviations between the simplified methods and the exact calculation with the node-potential analysis for all structure configurations. In case of a corner strike the maximum deviations are less than 25 % and the mean values less than 20 %. For the center strike the maximum deviations are less than 20 % and the mean values less than 10 %. The 1-stage current divider method and the empirical method can be classified as approximately equal. The more elaborate 2-stage current divider method leads to only marginally better results.

7 CONCLUSION

The standard method according to IEC 62305-3, Clause 6.3 generally gives a separation distance valid for the entire roof. For that, the lightning strike to the corner or the edge of the LPS has to be considered as a worst-case. However, in contradiction to IEC 62305-3, as the value ℓ only the vertical length of the down-conductors should be used. Otherwise unrealistic and unnecessary high separation distances are the result.

More realistic values for the separation distances are obtained using the detailed method according to Annex E of IEC 62305-3. A comparison with a calculation using the computer code CONCEPT II solving the Maxwell equations shows, that the deviations are usually less than ± 20%. However, the method of Annex E requires the knowledge of the lightning current distribution in the external LPS. This usually calls for the use of network analysis programs.

A possible compromise are the simplified methods for the estimation of the current sharing coefficients k_{cv}. The methods presented in this paper lead to sufficiently correct results differing by less than 25 % from the exact calculations. Especially the so-called empirical method may serve as an easy-to-apply and adequately correct procedure for the LPS planning and installation practice.

8 REFERENCES

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