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Protection of telecommunication lines using metallic conductors against direct lightning discharges

ITU-T Recommendation K.47

(Formerly CCITT Recommendation)

ITU-T Recommendation K.47

Protection of telecommunication lines using metallic conductors against direct lightning discharges

Summary

This Recommendation gives a procedure for the protection of telecommunication lines using metallic conductors against direct lightning discharges to the line itself or to structures that the line enters. The protection procedure is related to the exposure of the line to direct lightning discharges and includes the selection of cable characteristics/installation, bonding/earthing of the cable shield, use of shield wires, installation of surge protective devices (SPD) and route redundancy.

Source

ITU-T Recommendation K.47 was prepared by ITU-T Study Group 5 (2001-2004) and approved under the WTSA Resolution 1 procedure on 8 December 2000.

FOREWORD

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NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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Protection of telecommunication lines using metallic conductors against direct lightning discharges

1 Scope

The scope of this Recommendation is the protection of telecommunication lines using metallic conductors against direct lightning discharges to the line itself or to the structures that the line enters. When applying this Recommendation, the user shall first apply the procedures intended to protect the line against lightning induced surges, as described in reference [1].

The lines targeted by this Recommendation are those that, due to being exposed to direct lightning discharges and/or to provide service that requires a high reliability, deserve a specific design from the protection point of view. For these lines, this Recommendation provides a procedure in order to evaluate the expected risk of damages (R_p) due to direct lightning discharges. If this value is higher than the tolerable risk of damages (R_t), then additional protection procedures shall be applied in the telecommunication line in order to reduce R_p.

Lines made from the following types of cables are covered by this Recommendation:

– symmetric cable: cable with a metallic sheath and a core made of one or many metallic symmetric copper pairs, with or without a plastic covering and/or a supporting wire;

– coaxial cable: cable with metallic inner and outer conductors separated by a dielectric, with or without a plastic covering and/or a supporting wire.

The protection procedures for lines made of optical fibre cables are given in reference [2].

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

[1] ITU-T K.46 (2000), *Protection of telecommunication lines using metallic symmetric conductors against lightning induced surges*.

[2] ITU-T K.25 (2000), *Protection of optical fibre cables*.

[3] ITU-T K.12 (2000), *Characteristics of gas discharge tubes for the protection of telecommunication installations*.

[4] IEC 61663-2, *Lightning protection – Telecommunication lines – Part 2: Lines using metallic conductors*.

3 Definitions

This Recommendation defines the following terms:

3.1 expected risk of damages (R_p): Expected annual loss of service to the telecommunication line due to direct lightning discharges.

3.2 tolerable risk of damages (R_t): Maximum level of risk of damages not requiring additional protective measures.

3.3 expected loss per damage (δ): Relative amount of expected service loss per damage caused by direct lightning discharge to a telecommunication line.

3.4 frequency of damages (F_p): Average annual number of service interruptions in a telecommunication line caused by direct lightning discharges.

3.5 striking distance (D): Distance from the line that, when multiplied by 2, by the line length (L) and the ground flash density (N_g) gives the number of lightning strokes per year that reaches the line.

3.6 failure current (I_a): Minimum peak value of the lightning current that causes damage in a telecommunication line.

3.7 sheath breakdown current (I_s): Minimum current flowing in the metallic sheath which causes breakdown voltages between metallic elements in the cable core and the metallic sheath, thus leading to damage.

3.8 test current (I_t): Minimum current injected by arc in the cable sheath that causes a primary failure due to thermal or mechanical effects.

3.9 breakdown voltage (U_b): Impulse breakdown voltage between metallic components in the core and the metallic sheath of a telecommunication cable.

3.10 keraunic level (T_d): Number of days per year in which thunder is heard in a given location.

3.11 damage correction factor (K_d): Factor which allows a conservative evaluation of the frequency of damages.

3.12 protection factor (K_p): Factor taking into account the effect of protection procedures.

4 Reference configuration

In order to evaluate the risk of damage (R_p) for a line, it may have to be segmented in the way that each section has the same characteristics regarding to:

- type of cable installation (aerial, buried);
- keraunic level;
- average soil resistivity;
- type of cable;
- type of environment (urban, suburban, rural).

It is also important to identify the exposed structures that the line or its branches enter. The value of R_p has to be evaluated for each section, and the value for the line is the sum of section values, including the values corresponding to discharges to the structures that the line enters. The Figure 1 shows an example of a line with different types of environment and cable installation. For this line, the value of R_p shall be calculated for the exposed sections and structure.

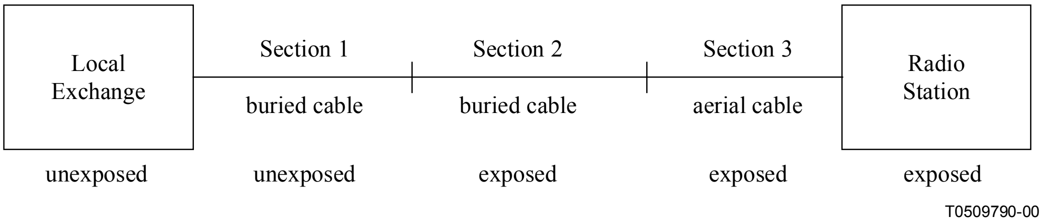

Figure 1/K.47 – Reference configuration (example)

5 Expected risk of damages

5.1 General

The procedures for lightning protection of a telecommunication line depend on the expected risk of damages (R_p) and its tolerable risk of damages (R_t). The expected risk of damages (R_p) is given by the following equation:

$$R_p = F_{pa}\ \delta_a + F_{pb}\ \delta_b + F_{ps}\ \delta_s \tag{1}$$

where:

- F_{pa} is the frequency of damages due to direct lightning discharges to aerial cables;
- F_{pb} is the frequency of damages due to direct lightning discharges to buried cables;
- F_{ps} is the frequency of damages due to direct lightning discharges to structures that the cable enters;
- δ_a is the expected loss per damage due to direct lightning discharges to aerial cables;
- δ_b is the expected loss per damage due to direct lightning discharges to buries cables;
- δ_s is the expected loss per damage due to direct lightning discharges to structures that the cable enters.

The values of δ_a, δ_b and δ_s shall be determined by the network operator or the owner of the installation. If this determination cannot be carried out, representative values are proposed in Appendix II. The maximum value of tolerable risk of damage (R_t) requested by this Recommendation is $R_t = 10^{-3}$.

If the expected risk of damages is higher than the tolerable risk of damages ($R_p > R_t$), then additional protective measures are necessary in order to reduce F_p. A procedure for the evaluation of F_p is presented in the following subclauses.

5.2 Frequency of damages for cables

The frequency of damages for aerial and buried cables (F_{pa} and F_{pb}) can be calculated by the following equations:

$$F_{pa} = 2N_g\ L\ D\ p(I_a)K_e 10^{-3} \quad \text{[damages/year]} \tag{2}$$

$$F_{pb} = 2N_g\ L\ D\ p(I_a)K_e K_d 10^{-3} \quad \text{[damages/year]} \tag{3}$$

where:

L	line length [km]
$p(I_a)$	current probability factor (see 5.4.2)
K_e	environmental factor (see 5.4.3)
N_g	lightning ground flash density [$km^{-2}.year^{-1}$] (see 5.4.1)
D	striking distance [m] (see 5.4.4)
I_a	failure current [kA] (see clause 6)
K_d	damage correction factor (see 5.4.5)

5.3 Frequency of damages for structures that the cable enters

The lightning current of a direct stroke to an exposed structure flows into the grounding system of the structure and into the metallic services entering the structure. Therefore, a part of the lightning current enters the cable connection and the cable sheath of the telecommunication cable. This current can cause damages to the telecommunication cable. The frequency of damages for structures (F_{ps}) can be estimated by using the following equation:

$$F_{ps} = N_g \cdot A_d \cdot p(I_a) \tag{4}$$

where:

A_d is the collection area for direct lightning strikes to the structure. For a structure apart from other tall structures, on flat ground and up to 60 m height, A_d can be calculated by Equation (5):

$$A_d = \left(a.b + 6h.a + 6h.b + 9\pi\ h^2\right)10^{-6}\ \left[\mathrm{km}^2\right] \tag{5}$$

a = length [m]

b = width [m]

h = height [m]

5.4 Parameters for the evaluation of the frequency of damages

5.4.1 Lightning ground flash density (N_g)

Lightning ground flash density (N_g) is the average number of lightning discharges to ground per square kilometre per year. In some countries the N_g is directly measured by means of lightning detection systems, so that this information is available with relative accuracy. In a case where there is no data on N_g, it can be estimated by the following equation:

$$N_g = 0.04\ T_d^{1.25}\ \left[\mathrm{km}^{-2}.\mathrm{year}^{-1}\right] \tag{6}$$

In Equation (6), T_d is the keraunic level. Values of T_d are usually available in the form of isokeraunic maps.

5.4.2 Current probability factor (p(i))

The current probability factor is the cumulative probability distribution of lightning (p(i)), as given by Equation (7):

$$p(i) = 10^{-2} e^{(a-bi)}\ \text{ for } i \ge 0 \tag{7}$$

where:

i	lightning peak current [kA]		
a =	4.605 and	b = 0.0117	for $i \leq 20$ kA
a =	5.063 and	b = 0.0346	for $i > 20$ kA

5.4.3 Environmental factor (K_e)

When telecommunication lines are installed in urban areas, they are usually protected against direct lightning discharges due to the shielding provided by the buildings. Therefore, in order to take into account this shielding effect, the environmental factor (K_e) is defined as:

– $K_e = 0$ for an unexposed area;

– $K_e = 1$ for an exposed area.

The network operator or the owner of the installation shall evaluate the environmental factor value (K_e) for the line section under consideration. In order to help in this evaluation, this Recommendation suggests that urban area shall be considered as unexposed environment and rural area as exposed environment. An experimental method to evaluate K_e is given in ITU-T K.46 [1].

5.4.4 Striking distance (D)

a) **Buried cable**

The striking distance for buried cables is calculated as a function of earth resistivity, as follows:

$$D = 0.482(\rho)^{1/2} \quad \text{for } \rho \leq 100\ \Omega.m \tag{8}$$

$$D = 2.91 + 0.191(\rho)^{1/2} \quad \text{for } 100\ \Omega.m < \rho < 1000\,\Omega.m$$

$$D = 0.283(\rho)^{1/2} \quad \text{for } \rho \geq 1000\ \Omega.m$$

b) **Aerial cables**

For aerial cables the striking distance is given by the following equation:

$$D = 3H\,[m] \tag{9}$$

where:

H line height [m], which shall be between 4 m to 15 m

5.4.5 Damage correction factor (K_d)

The following values of the damage correction factor shall be considered:

$K_d = 2.5$ for buried unshielded cable;

$K_d = 1.0$ for buried shielded cable.

6 Determination of failure current (I_a)

6.1 Lightning discharges to cables

For unshielded cables, the failure current is considered to be zero, as long as every direct lightning discharge to the cable will produce a damage. For shielded cables, the failure current (I_a) is the lower value among the following values:

– the test current (I_t);

– twice the sheath breakdown current (I_s), evaluated with the procedure given in Annex A.

For typical telecommunication cables with lead sheath, the value of the test current is 40 kA, while for typical telecommunication cables with aluminium sheath this value is 20 kA. If there is any evidence that these values are not applicable for a given cable design, the tests described in Appendix I shall be used for the evaluation of the test current.

6.2 Lightning discharges to structures where the cable enters

For strikes to structures where the cable enters, the failure current (I_a) is given by:

$$I_a = 2 n I_s \qquad (10)$$

where:

n number of metallic services entering the structure (telecommunications, electrical power, water)

I_s sheath breakdown current evaluated as follows:

– for unshielded cables, $I_s = 0$;

– for shielded cables, I_s is calculated with the procedure given in Annex A;

NOTE – To consider $I_s = 0$ for unshielded cables is a simplification (on the safe side) with respect to the IEC 61663-2 [4].

7 Protection procedures

The metallic elements of the telecommunication cable shall be continuous along the length of the line, which means that they shall be connected across all splices, regenerators, etc. The metallic elements shall be bonded (either directly or through SPD) to the equipotential bonding bar at the ends of the cable.

While evaluating the frequency of primary failures (F_p), it is important to identify the line segments that are more representative of the value of F_p and concentrate the protection efforts on them. The use of protective procedures reduces the frequency of damage by the protection factor (K_p), as follows:

$$F'_p = F_p \cdot K_p \qquad (11)$$

where:

F'_p is the frequency of damage after the application of the protective procedure;

F_p is the frequency of damage before the application of the protective procedure.

Many protective procedures will reduce the frequency of damage by increasing the failure current. In this case, the protection factor is given by:

$$K_p = \exp[b_1(I_a - I'_a)] \qquad \text{for } I_a \text{ and } I'_a \le 20\,kA \tag{12}$$

$$K_p = \exp[b_2(I_a - I'_a)] \qquad \text{for } I_a \text{ and } I'_a > 20\,kA$$

$$K_p = \exp[(a_2 - a_1) + (b_1\, I_a - b_2\, I'_a)] \qquad \text{for } I_a \le 20\,kA \text{ and } I'_a > 20\,kA$$

where:

I'_a failure current after the application of the protective procedure;

I_a failure current before the application of the protective procedure;

a_1 = 4.605;

a_2 = 5.063;

b_1 = 0.0117;

b_2 = 0.0346.

7.1 Selection of the environment

When designing a telecommunication line, it's possible to select the cable route in order to reduce its exposure to lightning. Considering a rural line in flat ground as a reference, the following protection factors can be obtained by the selection of the cable route:

– K_p = 0.25 for an aerial line surrounded by structures of the same or greater height (power lines, trees, etc);

– K_p = 0.50 for aerial lines surrounded by smaller structures;

– K_p = 2.0 for a line on a hilltop or a knoll.

NOTE – In the IEC 61663-2 [4] the influence of nearby structures and hills on the frequency of direct lightning discharges to telecommunication lines is represented by the Environmental Coefficient (Ce).

7.2 Choice of the cable

7.2.1 Dielectric optical fibre cable

A dielectric optical fibre cable is not directly struck by lightning. Therefore, its use provides a protection factor K_p = 0.

7.2.2 Cable with high sheath breakdown current

If the failure current (I_a) is determined by the sheath breakdown current (I_s), it is possible to obtain a cable with a higher I_s by:

– increasing the sheath breakdown voltage by selecting plastic insulation instead of paper or improving the insulation at the splices, for example;

– reducing the sheath resistance by using a thicker metallic sheath, for example.

For the protection against direct lightning discharges to the telecommunication line, the sheath breakdown current shall not be increased above the test current.

The protection factor due to the increase in the failure current is given by Equation (12).

7.2.3 Cable with high sheath breakdown voltage

If the failure current (I_a) is determined by the test current (I_t), it is possible to obtain a cable with a higher I_t by:

– using a sheath with high mechanical strength (for example, iron);

– using a thicker metallic sheath.

For the protection against direct lightning discharges to the telecommunication line, the test current shall not be increased above the sheath breakdown current.

The protection factor due to the increase in the failure current is given by Equation (12).

7.3 Buried or aerial installation

Aerial cables are more exposed to lightning discharges than buried cables. For soil resistivities between 100 and 1000 Ω.m and a line height of 5 metres, an aerial line will receive between 3 to 1.7 times more lightning discharges than a buried one. However, the value of the failure current for a buried installation may be higher or lower than the value for an aerial installation, depending on the cable characteristics. It shall also be considered that damages in buried cables take more time to repair than in aerial cables, which means that the relative amount of losses per damage may offset a reduction in the expected frequency of damage due to burying the cable. Therefore, the decision to bury the cable in order to protect it against direct lightning discharges has to take into account the specific characteristics of the cable. This can be done by calculating and comparing the risk of damage (R_p) for aerial and buried installation, using the procedures of this Recommendation.

7.4 Use of surge protective devices (SPD)

Surge protective devices (SPD) can be installed at the point where the cable enters a structure exposed to direct lightning discharges, in order to reduce it's frequency of damages (F_{ps}). The SPD shall comply with ITU-T K.12 [3] and be connected between the conductors of the cable and the equipotential bonding bar (EBB) of the structure. If the cable is shielded, its shield shall be bonded to the EBB. If the cable is unshielded, it shall be installed inside a metallic duct buried in the soil, which shall be bonded to the EBB.

The length of the buried shielded section (shielded cable or unshielded cable inside a metallic duct) extending from the structure is given by:

$$2.5\rho^{1/2} \leq L_p \leq 8\rho^{1/2} \tag{13}$$

where ρ is the earth resistivity, in Ω.m.

NOTE – A higher length leads to more conservative protection.

At a distance L_p from the structure, another set of SPD shall be installed between the conductors and the cable sheath (or metallic duct).

The installation of SPD as described in this sub-clause will increase the sheath breakdown current. The new I_s value is given by:

$$I_s = 8 \cdot S_c \cdot \left(m + \frac{R_c}{R} \right) \tag{14}$$

where:

m is number of conductors of the cable;

S_c is the cross-section area of the conductor [mm^2];

R_c is the conductor resistance per unit length [Ω/km];

R is the sheath (or metallic duct) resistance per unit length (Ω/km).

The protection factor due to the increase in I_s is given by Equations (10) and (12).

7.5 Shielding

In order to limit the current entering the cable sheath it is possible to install shield wires in parallel with the cable, so that the current is shared among the cable and the shield wires. The shield wires increase the value of the failure current (I_a) and, therefore, reduces the frequency of damages. The new value of failure current (I'_a) is given by:

$$I'_a = \frac{I_a}{\eta} \tag{15}$$

Where η is the shielding factor. The protection factor (K_d) obtained by the use of shield wires is given by Equations (15) and (12).

Values of shielding factors for different arrangements of shield wires are given in ITU-T K.25 [2]. Approximated values for the protection factor, accordingly with IEC 61663-2 [4], are:

– K_p = 0.6 for one shield wire

– K_p = 0.4 for two shield wires

– K_p = 0.01 for a steel tube

7.6 Route redundancy

In order to improve the system reliability, one possibility is to install two lines so that the probability that both being subjected to primary failures simultaneously is very small. By adequately selecting the separation between the lines, it is possible to prevent the same lightning discharge from damaging both lines. A minimum separation of 30 m and 50 m for soil resistivities 100 Ω.m and 1000 Ω.m, respectively, is sufficient for buried cables or aerial cables. If the lines are separated so that the probability of a given lightning discharge reaching both lines is negligible, it is still possible to have damages in both lines during a short time interval, so that the maintenance crew is not liable to repair the first line that failed before the second fails. This situation may occur during the same thunderstorm and will determine the frequency of damages for the redundant routes.

ANNEX A

Evaluation of the sheath breakdown current

The procedure of this annex applies to cables with one metallic sheath. For typical telecommunication cables, the following values of breakdown voltage are considered:

– cables with paper insulation: U_b = 1.5 kV

– cables with plastic insulation: U_b = 5 kV

If there is any evidence that these values are not applicable for a given cable design, the tests described in Appendix I shall be used for the evaluation of the breakdown voltage.

A.1 Buried cable

The sheath breakdown current (I_s) of the cable with metallic sheath, with or without an insulating protective covering, may be estimated with the following equation:

$$I_s = \frac{U_b}{K \cdot R \cdot \rho^{1/2}} \qquad [kA] \tag{A-1}$$

where:

- K = 8 is the waveshape factor for lightning current $[(m/\Omega)^{0.5}]$)
- R is the sheath resistance per unit length [Ω/km]
- U_b is the breakdown voltage of the cable [V]
- ρ is the soil resistivity [Ω.m]

A.2 Aerial cable

The sheath breakdown current (I_s) is calculated by the following equation:

$$I_s = \frac{U_b}{K \cdot R \cdot \rho_e^{1/2}} \tag{A-2}$$

ρ_e is the effective earth resistivity in Ω.m, which is defined as:

$$\rho_e = \frac{\pi \cdot d \cdot R_g}{\ln\left(2 \cdot \frac{H}{a}\right)} \tag{A-3}$$

where:

- d is the spacing between earthing points, in metres (d is assumed to be short, so that reflections occur long before the crest voltage or current is reached)
- H is the height of the cable in metres
- a is the radius of the cable in metres
- R_g is the resistance of the earthing points in Ω.

APPENDIX I

Tests for the evaluation of surge resistibility of cables

It shall be observed that these tests are intended to evaluate the lightning resistibility of metallic cables and are not applicable for the qualification of a cable design. Under the cable manufacturer's responsibility, the test results on one type of cable can be used for another cable with similar characteristics from the construction point of view.

The breakdown voltage test shall be performed with an impulse generator that produces an open circuit voltage with a double exponential 1.2/50 µs waveform. The current generator for the test for surge current resistibility of cables is under study. The following current waveforms, measured with the test sample in place, are suggested:

– double exponential waveform with a rise time of 10 µs and a time to half value of 350 µs;

– damped oscillatory waveform with a maximum time-to-peak value of 15 µs and a maximum frequency of 30 kHz; the time to half value of its waveform envelope shall be between 40 µs and 70 µs.

I.1 Breakdown voltage (U_b)

A cable sample 5 metres in length shall be used for the test. The conducting components inside the cable core shall be electrically connected together to form one terminal. Another terminal is made by the metallic sheath isolated from the other conducting elements. The sheath termination shall be treated in order to reproduce, as closely as possible, the conditions of a real installation. A surge voltage generator shall be placed between the two terminals. The test voltage is measured during the test. Following the application of voltages in ascending amplitudes, the test identifies a threshold value of surge voltage (U_b) which causes a breakdown.

I.2 Test current (I_t) for buried cable

A cable sample of 1 m in length shall be immersed in wet sand contained in a non-conducting rigid box having a minimum length of 0.75 m in all inside linear dimensions. The box shall have two holes in the bottom for water drainage, approximately 25 mm in diameter. The sand shall be 20-40 mesh silica sand, and shall be fully saturated for a maximum time interval of 8 hours and drained for at least five minutes before tests. The cable sample shall be placed in the test box and the wet sand tamped around it. The moisture content of the sand in the more critical sand volume shall be 15% by weight. A discharge electrode shall be located near the centre of the test box, at a distance of 26 ± 1 mm from the sample. All conducting components at the cable end shall be electrically connected together to form one terminal and a current generator shall be placed between this terminal and the discharge electrode. In order to let the test current flow through the sample, any insulation covering the outer metallic sheath shall be opened with a small slit or hole with a 1 mm diameter tool facing the discharge electrode. If the voltage of the test generator cannot break down the air-gap, a thin wire shall connect the discharge electrode with the metallic sheath. Following the application of discharge currents in ascending amplitudes, the sample is tested for continuity of the metallic elements and insulation resistance between them. The test identifies a threshold value of surge current which causes primary failure. This value is the test current (I_t).

I.3 Test current (I_t) for aerial cable

A cable sample 1 metre in length shall be in tension according to the manufacturer's specifications. A discharge electrode shall be located near the sample at a distance of 26 ± 1 mm. All conducting components in the cable shall be electrically connected together to form one terminal and a current generator shall be placed between this terminal and the discharge electrode. In order to let the test current flow through the sample, any insulation covering the outer metallic sheath shall be opened with a small slit or hole with a 1 mm diameter tool facing the discharge electrode. If the voltage of the test generator cannot break down the air-gap, a thin wire shall connect the discharge electrode with the metallic sheath. Following the application of discharge currents in ascending amplitudes, the sample is tested for continuity of the metallic elements and insulation resistance between them. The test identifies a threshold value of surge current which causes damage. This value is the test current (I_t).

APPENDIX II

Expected loss per damage (δ)

The damage caused by lightning to a telecommunication installation may produce unacceptable loss of service. In this case, the decision whether or not to provide protective measures should be taken by a comparison of the expected risk of damages (R_p) of the installation with the value of the tolerable risk of damages (R_t). The value of R_p is calculated by Equation (1), based on the relative amount of the expected loss per damage.

The following values of expected loss per damage are proposed (based on IEC 61663-2 [4]):

$\delta_a = 2.1\ 10^{-3}$ (due to direct lightning to aerial lines)

$\delta_b = 3.1\ 10^{-3}$ (due to direct lightning to buried lines)

$\delta_s = 3.1\ 10^{-3}$ (due to direct lightning to structures)

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