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SERIES K: PROTECTION AGAINST INTERFERENCE

Protection of telecommunication lines against direct lightning flashes

Recommendation ITU-T K.47

ITU-T

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Summary

Recommendation ITU-T K.47 gives a procedure in order to protect telecommunication lines using metallic components (symmetric pair, coaxial or optical fibre cables) against direct lightning flashes to the line itself or to structures that the line enters.

The procedure is based on the representation of the line by a sequence of sections and the evaluation of the annual number of damages due to direct flashes for each section and for the structures connected to the line. This number shall be multiplied by the relevant loss in order to obtain the risk of failure due to direct lightning flashes. The sum of the risk of each line section and also the risk associated with the structures connected to the line gives the total risk of the line.

The risk of damage due to direct lightning flashes can be used in the risk assessment of a larger system to which the telecommunication line is a part, according to IEC 62305-2. The calculated risk can also be used by the line owner (e.g., telecommunication operator) in order to evaluate the need of implementing additional protection measures on the line. In this case, the calculated risk (R_d) shall be compared with the tolerable risk due to direct flashes (R_{Td}), the latter calculated based on Recommendation ITU-T K.72. If the calculated risk is lower than the tolerable limit, the line is adequately protected. Otherwise, it is necessary to implement additional protection measures until the risk of damage is lower than or equal to the tolerable limit.

Several parts of this Recommendation make reference to the cable sheath breakdown current (I_s) and test current (I_t), so that the assessment of these parameters are given in Annex A and Annex B, respectively. The appendices are organized as follows: Appendix I provides some guidance for the evaluation of the expected loss per damage (L), and Appendix II presents a rationale for the protective effect of guard-wires.

History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T K.47	2000-12-08	5
2.0	ITU-T K.47	2008-04-13	5
3.0	ITU-T K.47	2012-05-29	5

Keywords

Direct flashes, direct lightning performance, guard-wire, lightning protection, risk assessment, sand-box test, sheath breakdown current.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Protection of telecommunication lines against direct lightning flashes

1 Scope

This Recommendation gives a procedure to protect telecommunication lines using metallic components against direct lightning flashes to the line itself or to the structures that the line enters. Lines made by the following types of cables are covered by this Recommendation.

– Symmetric cable: Cable with a core made of one or many metallic symmetric pairs, which may have a metallic sheath, and/or a plastic covering, and/or a supporting wire.

– Coaxial cable: Cable with metallic inner and outer conductors separated by a dielectric, which may have a plastic covering and/or a supporting wire.

– Optical fibre cable: Cable with optical fibres, which may also have metallic components such as an inner strength member and/or an outer metallic sheath.

Its calculation procedure allows the assessment of the expected annual number of damages (N_d) and the risk of damage due to direct lightning flashes (R_d). The risk of damage due to direct lightning flashes can be used in the risk assessment of a larger system to which the telecommunication line is a part, according to [IEC 62305-2]. The calculated risk can also be used by the line owner (e.g., telecommunication operator) in order to evaluate the need of implementing additional protection measures on the line. In this case, the calculated risk (R_d) shall be compared with the tolerable risk due to direct flashes (R_{Td}), the latter calculated based on [ITU-T K.72]. If the calculated risk is lower than the tolerable limit, the line is adequately protected. Otherwise, it is necessary to implement additional protection measures until the risk of damage is lower than or equal to the tolerable limit.

The protection against direct flashes for equipment connected to the line is not considered by this Recommendation and it should be evaluated using the risk assessment applied to the structure where the equipment is located (i.e., exchange, customer's building or remote site).

The protection of persons using telecommunication equipment inside a structure from dangerous situations caused by direct flashes (e.g., touch voltages) is outside the scope of this Recommendation and should be evaluated using the risk assessment applied to the relevant structure.

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. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.12] Recommendation ITU-T K.12 (2010), *Characteristics of gas discharge tubes for the protection of telecommunications installations*.

[ITU-T K.46] Recommendation ITU-T K.46 (2012), *Protection of telecommunication lines using metallic symmetric conductors against lightning-induced surges*.

[ITU-T K.72] Recommendation ITU-T K.72 (2011), *Protection of telecommunication lines using metallic conductors against lightning – Risk management*.

[IEC 62305-2] IEC 62305-2 (2010), *Protection against lightning – Part 2: Risk management*. <http://webstore.iec.ch/webstore/webstore.nsf/ArtNum_PK/45856?OpenDocument>

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 shielded cable [ITU-T K.46]: Group of one or more pairs of twisted wires balanced with respect to earth, assembled together and covered by a continuous metallic sheath.

3.1.2 unshielded cable [ITU-T K.46]: Group of one or more pairs of twisted wires balanced with respect to earth and assembled together without a metallic sheath.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

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

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

3.2.3 ground flash density (N_g): Average number of lightning flashes to earth per square kilometre per year.

3.2.4 guard-wire: Metallic wire buried above a cable in order to reduce physical damage due to direct lightning flashes to the cable.

3.2.5 lightning protective cable: Special cable with increased dielectric strength, whose metallic sheath is in continuous contact with the soil either directly or by the use of conducting plastic covering.

3.2.6 lightning protective cable duct: Cable duct of low resistivity in contact with the soil (for example, concrete with interconnected structural steel reinforcements or a metallic duct).

3.2.7 loss (L): Annual mean amount of loss (humans and goods) consequent to a specified type of damage due to a dangerous event, relative to the total value (humans and goods) of the object to be protected.

3.2.8 loss due to direct lightning flashes to the line (L_d): Annual mean amount of loss (service to the public and economic value) consequent of damage in a telecommunication line due to direct lightning flashes to the line, relative to the total value of the service.

3.2.9 loss due to direct lightning flashes to the structure (L_s): Annual mean amount of loss (service to the public and economic value) consequent of damage in a telecommunication line due to direct lightning flashes to a structure connected to the line, relative to the total value of the service.

3.2.10 number of damages due to flashes to the line (N_d): Expected annual number of damages in the telecommunication line due to direct lightning flashes to the line.

3.2.11 number of damages due to flashes to the structure (N_s): Expected annual number of damages in the telecommunication line due to lightning flashes to a structure connected to the line.

3.2.12 protection factor (K_p): Factor that quantifies the capacity of a line to receive a direct flash without suffering damage. It usually takes into account the effect of protective measures.

3.2.13 risk (R): Value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the object to be protected.

3.2.14 risk of damage from direct flashes (R_d): Risk component related to failure of lines and connected equipment caused by direct lightning flashes to the line or to the structure connected to the line.

3.2.15 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.

3.2.16 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 direct flashes per year that hit the line.

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

3.2.18 tolerable risk of damages (R_T): Maximum value of risk of damages not requiring additional protective measures.

3.2.19 tolerable risk due to direct flashes (RTd): Maximum value of risk that can be tolerated for the line due to direct lightning flashes to the line or to a structure connected to the line.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

GDT Gas Discharge Tube

OGW Overhead Ground Wire

SPD Surge Protective Device

5 Reference configuration

In order to evaluate the risk of line damage (R_d), the line may have to be segmented in such a way that each section has the same characteristics regarding the type of cable installation (aerial or buried), ground-flash density, average soil resistivity, type of cable, and environment (urban, suburban or rural).

It is also important to identify the structures that the line or its branches enter. The value of R_d 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. Figure 1 shows an example of a line with different types of cable installation. The risk of damage shall be evaluated for all transmission media of a cable (twisted pair or coaxial), regardless of whether they are being used for a service or kept as spare.

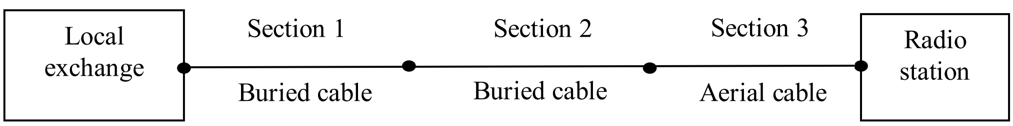


Figure 1 – Reference configuration (example)

6 Line performance for direct flashes

6.1 Annual number of damages

The annual number of line damages due to direct flashes to the line section i is given by:

$$N_d\,(i) = N_g\;\; A_d\,(i)\;\; K_p\,(i) \qquad (1)$$

where:

N_g is the ground flash density;

$A_d\,(i)$ is the collection area for direct flashes to the line section i;

$K_p\,(i)$ is the protection factor related to section i;

NOTE 1 – If the value of the ground flash density is not available, it can be assessed from the number of days with thunderstorms per year (T_d), as $N_g = 0.1\; T_d$.

The annual number of line damages due to direct flashes to the structure j connected to the line is:

$$N_s\,(j) = N_g\;\; A_s\,(j)\;\; K_p\,(j) \qquad (2)$$

where:

$A_s\,(j)$ is the collection area for direct flashes to the structure j;

$K_p\,(j)$ is the protection factor related to the line interface with the structure j;

The annual number of line damages (N_d) for the entire line is:

$$N_d = \sum_{i=1}^{m} N_d(i) + \sum_{j=1}^{2} N_s(j) \qquad (3)$$

where m is the number of line sections.

NOTE 2 – In Equation 3 it is assumed that the line is connected to two structures, as shown in Figure 1. However, the case where line branches are connected to other structures can be considered in this equation by replacing the limit 2 by the number of structures.

6.2 Risk of damage

The risk of line damage due to direct flashes to the line section i is given by:

$$R_d\,(i) = N_d\,(i)\;\; L_d\,(i) \qquad (4)$$

where $L_d\,(i)$ is the loss due to direct lightning flashes to section i.

The risk of line damage due to direct flashes to the structure j connected to the line is:

$$R_d\,(j) = N_s\,(j)\;\; L_s\,(j) \qquad (5)$$

where $L_s\,(j)$ is the loss due to line damage from direct flashes to structure j. Therefore, the risk of damages (R_d) for the entire line is:

$$R_d = \sum_{i=1}^{m} N_d(i)\,L_d(i) + \sum_{j=1}^{2} N_s(j)\,L_s(j) \qquad (6)$$

The values of L_d and L_s shall be determined by the network operator or the owner of the installation. Appendix I provides a procedure for this assessment and also suggests some representative values.

6.3 Tolerable risk

The protective measures contained in this Recommendation are intended to reduce telecommunication line susceptibility to direct lightning flashes and, consequently, to reduce its number of damages N_d and its risk R_d. The need of protection and the evaluation of its effectiveness shall be assessed by the procedure contained in this Recommendation.

According to [ITU-T K.72], the tolerable risk of damage due to direct flashes to a telecommunication line (R_{Td}) is given by the difference between the total tolerable risk (R_T) and the risk of damage due to indirect flashes (R'_Z):

$$R_{Td} = R_T - R'_Z \qquad (7)$$

If the risk of damage due to direct flashes is lower than or equal to the tolerable risk for direct flashes ($R_d \leq R_{Td}$), then no additional protective measure is needed. Otherwise, additional protective measures shall be applied until the tolerable condition is achieved ($R_d \leq R_{Td}$). The detailed procedure for this risk assessment is described in [ITU-T K.72] and the procedure for the evaluation of R'_Z is given in [ITU-T K.46].

NOTE – When the determination of R_{Td} is uncertain or difficult, this Recommendation suggests adopting $R_{Td} = 2 \times 10^{-4}$ as a reference value. Combined with the typical consequential loss values suggested in Appendix I ($L_{da} = 2 \times 10^{-3}$ and $L_{db} = 3 \times 10^{-3}$), it leads to an upper limit for N_d equal to 0.1 for aerial lines and 0.067 for buried lines, which corresponds to one line damage due to direct flashes at each ten and fifteen year intervals for aerial and buried lines, respectively. This suggested value shall be revised by the user based on service requirements and field experience.

7 Collection area

7.1 Aerial cable

The collection area for aerial cables (A_{da}) is given by:

$$A_{da} = 6 \times 10^{-6} \left[L - 3\left(H_1 + H_2\right)\right] h\, C_e \tag{8}$$

where:

- L is the line section length in metres;
- H_1 is the height of the structure at one end of the line section (if any), in metres;
- H_2 is the height of the structure at the other end of the line section (if any), in metres;
- h is the line height, in metres;
- C_e is the environmental factor (see Table 1).

7.2 Buried cable

The collection area for buried cables (A_{db}) is given by:

$$A_{db} = 2 \times 10^{-6} \left[L - 3\left(H_1 + H_2\right)\right] D\, C_e \tag{9}$$

where:

D is the striking distance, in metres, which depends on the earth resistivity (ρ):

$$\begin{aligned} D &= 0.482(\rho)^{1/2} && \text{for } \rho \leq 100\ \Omega m \\ D &= 2.91 + 0.191(\rho)^{1/2} && \text{for } 100\ \Omega m < \rho < 1000\,\Omega m \\ D &= 0.283(\rho)^{1/2} && \text{for } \rho \geq 1000\ \Omega m \end{aligned} \tag{10}$$

7.3 Structure connected to the cable

The current of a direct flash to a structure flows into the earthing system of the structure and into the metallic services connected to the structure. Therefore, part of the lightning current enters into the telecommunication cable and may damage it. The collection area (A_s) for an isolated structure on flat ground is the area defined by the intersection between the ground surface and a straight line with 1/3 slope, which passes from the upper parts of the structure (touching it there) and rotating around it. The determination of the value of A_s may be performed graphically or mathematically. For an isolated rectangular structure on flat ground, A_s is given by:

$$A_s = (a\,b + 6\,H\,a + 6\,H\,b + 9\,\pi\,H^2)10^{-6}\ [km^2] \tag{11}$$

where:

a = structure length, in metres;

b = structure width, in metres;

H = structure height, in metres.

Table 1 – Environmental factor (C_e)

Environment	C_e
Lines installed on a hill in rural area[a)]	2
Rural	1
Suburban	0.5
Urban	0.1
Urban with tall buildings[b)]	0.01

a) Experience shows that telecommunication lines installed on a hill in rural area are more likely to be subjected to a direct strike than lines installed on flat ground. Lines installed along a ridge in a rural area are a particular problem.

b) Buildings higher than 20 m.

8 Protection factor

A telecommunication line has the capacity of receiving a direct flash without being damaged, which depends on the magnitude of the lightning stroke current. This capacity is quantified by the protection factor (K_p), which is defined for a line section as the ratio between the number of damages due to direct flashes to the section and the number of flashes that strikes the section. Similarly, the protection factor can also be defined for a structure connected to the line.

From its definition, the protection factor (K_p) is a number between 0 and 1. The value $K_p = 0$ means that the line section or structure can withstand any flash without damage, while $K_p = 1$ means that every flash will cause a damage. The proper selection of the telecommunication cable and/or the application of specific protective measures reduces the protection factor, as will be described in the following clauses.

The protection factor depends on the minimum stroke current that causes a damage in the line (failure current) and also on the probability distribution of the stroke currents:

$$K_p = p\,(I_a) \tag{12}$$

I_a is the failure current, in kA (see Annex A);

$p\,(I_a)$ is the stroke current probability factor:

$$p(I_a) = 10^{-2} \exp\left(a - b\,I_a\right) \qquad \text{for } I_a \geq 0 \tag{13}$$

where:

$a = 4.605$ and $b = 0.0117$ for $I_a \leq 20$ kA

$a = 5.063$ and $b = 0.0346$ for $I_a > 20$ kA

The failure current (I_a) is the minimum peak value of the lightning current that causes damage in a telecommunication line. If I_a is too small, then $K_p = p\,(I_a) \approx 1$ and every direct flash to the line causes a damage. Figure 2 shows the protection factor as a function of the failure current.

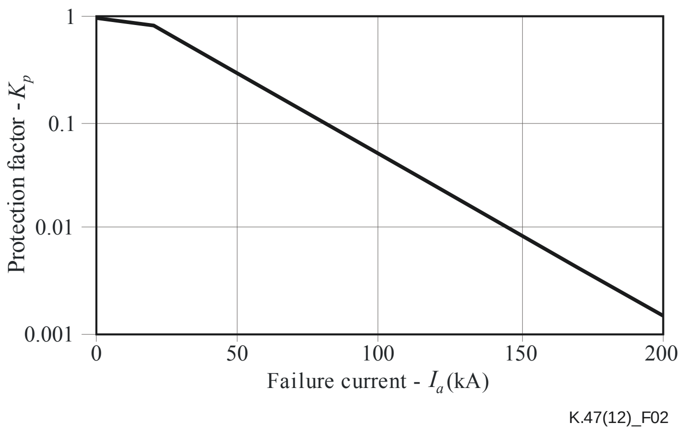


Figure 2 – Protection factor (K_p) as function of the failure current (I_a)

9 Protection factor of cables

The ability of a telecommunication cable to withstand a direct lightning flash depends on the cable characteristics and type of installation. Before a new telecommunication line is installed in a lightning-prone area, it is possible to select a cable and an installation procedure that provides a low protection factor against direct flashes. Some guidelines are described in this clause.

9.1 Requirements for cable installation

In order to provide protection against direct flashes, 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 an SPD) to the equipotential bonding bar at the ends of the cable (i.e., at the entrance of structures).

NOTE 1 – In some specific cases it may be allowed to provide insulating joints in optical fibre cables with metallic components, provided that the insulation is properly dimensioned.

Some examples of metallic elements of a telecommunication cable are:

– aluminium or lead outer sheath used as electromagnetic shield or moisture barrier;
– steel outer armouring of metallic or fibre optical cables;
– copper conductors of symmetric twisted pairs, used for signal transmission;
– outer and inner conductors of coaxial cable;
– steel strength member of optical cables;
– steel supporting strand of aerial cables.

NOTE 2 – The metallic elements of a telecommunication cable shall be regularly earthed along the line and the earthing connection shall have a low earthing resistance. See [ITU-T K.46] for details regarding earthing resistance and separation between earthing points.

9.2 Optical fibre cable

A dielectric optical fibre cable is not directly struck by lightning, as there is no metallic elements to conduct the lightning current. Therefore, the use of such cable is an effective method of avoiding a lightning strike and provides a zero protection factor:

$$K_p = 0 \tag{14}$$

However, in some situations it is useful to have an optical fibre cable with an external metallic sheath (armour), which may have the function of mechanical protection, moisture barrier or cable localization. In this case, the failure current is determined by the test current ($I_a = I_t$), which can be assessed from Annex B. Table 2 shows some typical values of withstand current (I_w) for this type of cable, with the corresponding protection factor values calculated assuming that $I_w \approx I_a$.

NOTE – If besides the outer metallic sheath, the optical fibre cable has also metallic components in its core, then its failure current shall be assessed from clause 9.3.

Table 2 – Typical withstand current and protection factor for armoured optical fibre cables[a)]

Class	I_w	K_p
I	105 kA	0.04
II	80 kA	0.10
III	55 kA	0.24
a) These values are related to direct flashes to cables; for flashes to a structure connected to an armoured optical fibre cable, $K_p \approx 0$.		

9.3 Cables with internal conductors

This clause deals with telecommunication cables that have metallic elements in its core, such as shielded or unshielded symmetric pair cables and coaxial cables. Tables 3 and 4 summarize a method for assessing the failure current and protection factor for this type of cable, for flashes to cables and flashes to structures connected to cables, respectively.

Table 3 – Failure current (*Ia*) and protection factor (K_p) for cables with internal conductors (flashes to cables)

<table>
<tr><th colspan="3">Type of cable</th><th>I_a</th><th>K_p</th></tr>
<tr><td colspan="3">Unshielded</td><td>0</td><td>1</td></tr>
<tr><td rowspan="3">Shielded</td><td colspan="2">Aerial</td><td>0[a)]</td><td>1</td></tr>
<tr><td rowspan="2">Buried</td><td>$2 I_s \leq I_t$</td><td>$2 I_s$</td><td rowspan="2">Equation 12</td></tr>
<tr><td>$2 I_s > I_t$</td><td>I_t</td></tr>
<tr><td colspan="5">a) Shielded aerial cables usually have a negligible I_a value.</td></tr>
</table>

NOTE – Regular telecommunication cables with small number of pairs have a relatively low sheath breakdown current (see Annex A), so that assuming an inherent protection factor $K_p = 1$ for these cables and relying on the protective measures described in clause 10 for the protection factor is a simplified safe-side strategy to assess the line performance from direct flashes.

Table 4 – Failure current (I_a) and protection factor (K_p) for cables with internal conductors (flashes to structures connected to cables)

Type of cable	I_a	K_p
Unshielded cable	0	1
Shielded cable	$2\,n\,I_s$[a)]	Equation 12
a) n is the number of services connected to the structure.		

The assessment of the sheath breakdown current (I_S) and of the failure current (I_t) are described in Annexes A and B, respectively, where the cable parameters are considered.

10 Protective measures applied to the line

This clause provides some protective measures to be applied to a telecommunication line in order to protect it against direct flashes. The corresponding protection factors (K_p) shall be used in order to reduce the annual number of line damages (N_d) calculated according to Equation 1.

While evaluating the annual number of line damages (N_d) and the risk of line damage (R_d), it is important to identify the line sections that contribute more to the total risk and to apply the protective measures on them.

10.1 To bury an aerial cable

Aerial cables are usually more exposed to direct flashes than buried cables, so that burying an aerial cable reduces the number of direct flashes. However, it shall be considered that damages in buried cables take more time to repair than in aerial cables, which means that the increase of the relative amount of loss per damage may offset the reduction in the expected number of damages due to burying the cable. Therefore, the decision to bury a cable in order to protect it against direct flashes has to take into account the specific characteristics of the line.

Considering that the failure currents of typical aerial and buried lines are small, the protection factor obtained by burying a line section can be calculated from the corresponding collection areas given in clause 7. Some representative values of this calculation are shown in Table 5.

Table 5 – Protection factor from burying an aerial cable

Earth resistivity (Ωm)	50	100	200	400	1000	2000
Protection factor	0.19	0.27	0.31	0.37	0.50	0.70

10.2 Guard-wire on buried cable

The installation of a guard-wire above a buried cable may intercept the lightning strike and, depending on the magnitude of the stroke current, prevent the cable from being struck. Even if the cable is struck together with the guard-wire, the latter may still provide some protection by carrying part of the stroke current. This clause describes the guard-wire installation and provides means to assess its protection factor.

NOTE – Experience shows that a significant number of buried cable service interruptions are due to excavation; a guard-wire may act as a warning to workers and prevent cable damage.

10.2.1 Requirements for guard-wire installation

In order to intercept the stroke current, the guard-wire shall be installed above the cable. In general, the guard-wire shall be installed at an intermediate depth between the cable and the earth surface. For instance, if the cable to be protected is installed at 0.7 m below the earth surface, the guard-wire shall be installed at about 0.35 m depth. Figure 3 shows a diagram of guard-wire and cable installation.

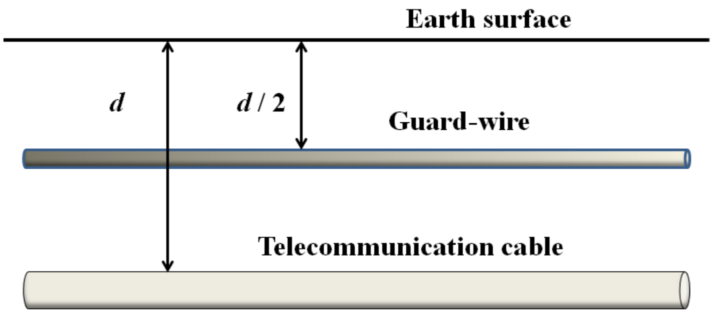


Figure 3 – Typical guard-wire installation

The guard-wire material shall be selected taking into account several characteristics, such as:

– high electrical conductivity;

– resistance against corrosion;

– high melting temperature;

– high mechanical strength;

– low cost.

Several metallic materials could be considered for a guard-wire, and a compromise among its characteristics shall be reached. Some examples are: copper-clad steel, hot-dip galvanized steel, stainless steel and copper.

In general, the guard-wire shall not be bonded to the cable metallic sheath, so that it can perform its function of diverting the stroke current from the cable. An exception to this rule shall be made in the case where the cable is equipped with SPDs along its route (see clause 10.4), when the guard-wire should be bonded to the equipotential bonding bar of the protected joints.

10.2.2 Assessment of guard-wire protection factor

The peak value of the lightning current up to which the guard-wire prevents the cable from being struck is the failure current (I_a) for this protection measure, and it is given by the approximate expression (in kA):

$$I_a = \frac{2\ U_b}{\sqrt{\rho\ r_{gw}}} \tag{15}$$

where:

U_b is the impulse breakdown voltage of the outer cable sheath, in kV;

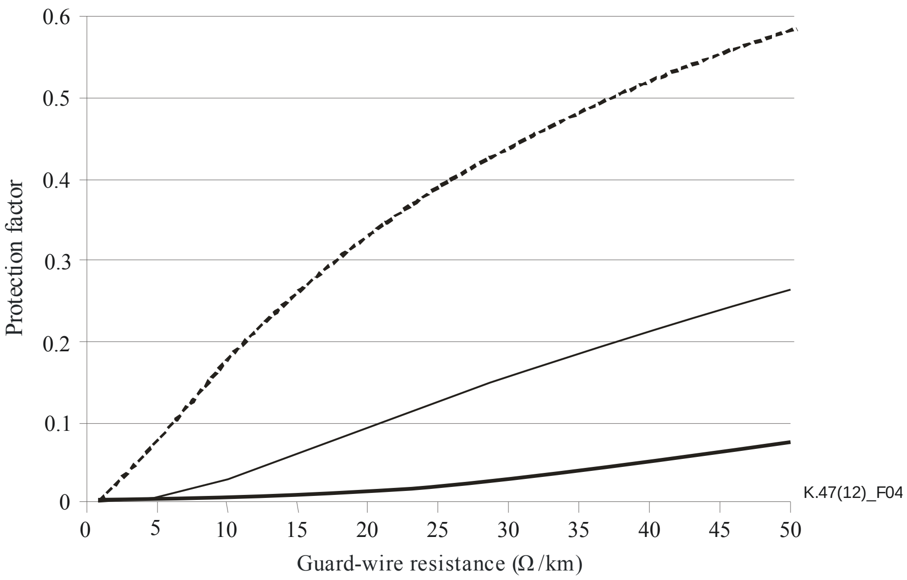
r_{gw} is the intrinsic resistance of the guard-wire, in Ω/m;

ρ is the earth resistivity, in Ωm.

NOTE 1 – This equation is based on a simplified model whose results agree with the experimental data available (see Appendix II).

NOTE 2 – Telecommunication cables with high-density polyethylene outer jackets usually have values of U_b around 100 kV.

The protection factor (K_p) is given by Equations 15 and 12, which allows the construction of the curves shown in Figure 4. These curves show the protection factor as a function of the guard-wire resistance, for different values of earth resistivity and considering the cable impulse breakdown voltage U_b = 100 kV. It can be seen that a guard-wire can provide low values of protection factor, particularly for soils that conduct electricity well.



NOTE – U_b = 100 kV; bold line: ρ = 100 Ωm; thin line: ρ = 300 Ωm; dashed line: ρ = 1000 Ωm.

Figure 4 – Protection factor (K_p) provided by a guard-wire for different earth resistivities

10.3 Overhead ground wire on aerial cable

The installation of an overhead ground wire (OGW) above an aerial cable may intercept the lightning flash and, depending on the magnitude of the stroke current, prevent the cable from being struck. This clause describes the OGW installation and provides means to assess its protection factor.

In order to divert the stroke current to earth, the OGW shall be connected to earth at short intervals. This can be accomplished by connecting the OGW to the poles, in cases where the latter are conducting (e.g., metallic poles or concrete poles with steel reinforcement). For non-conducting poles (e.g., wood), a down-conductor and an earthing electrode shall be installed at each pole.

The insulation between the cable and the pole is usually provided by the cable plastic outer cover, and it can be enhanced by installing insulators between the cable and the pole. Special care shall be taken at the splices, in order to preserve the cable insulation.

NOTE – The steel strand often used to support an aerial telecommunication cable shall not be considered as an OGW, because its close proximity to the cable is likely to cause the melting of the cable plastic cover at the striking point and thus eliminating its insulation.

The peak value of the lightning current up to which the guard-wire prevents the cable from being struck is the failure current (I_a) for this protection measure, and it is given by the approximate expression (in kA):

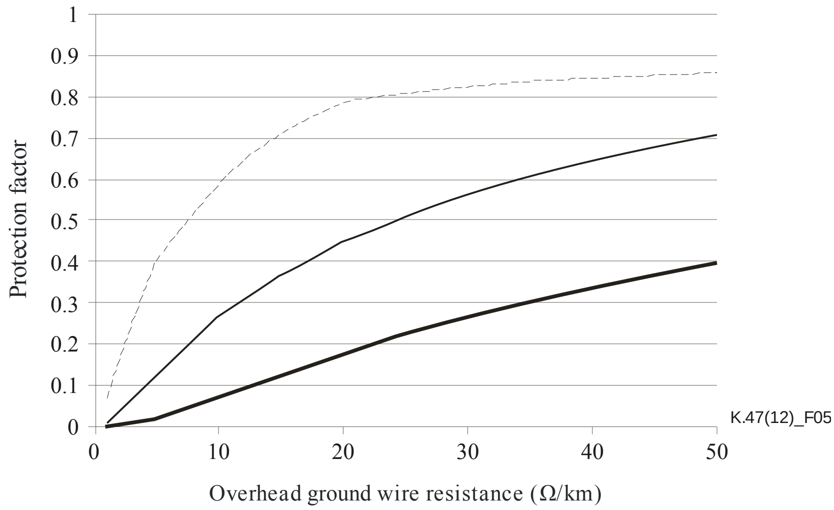
$$I_a = \frac{2\ U_b}{\sqrt{R_t\ l_t\ r_{ogw}}} \qquad (16)$$

where:

- U_b is the impulse breakdown voltage between the cable and the pole, in kV;
- r_{ogw} is the intrinsic resistance of the OGW, in Ω/m;
- R_t is the resistance of the earthing connections, in Ωm;
- l_t is the average distance between the OGW earthing connections, in metres.

The protection factor (K_p) is given by Equations 16 and 12, which allows the construction of the curves shown in Figure 5. These curves show the protection factor as a function of the guard-wire resistance, for different values of earthing resistance and considering the spacing between earthing points l_t = 50 m and cable impulse breakdown voltage U_b = 100 kV.

A comparison with the values provided by a buried guard-wire shows that an OGW is much less effective in protecting the telecommunication cable than a guard-wire. In fact, the installation of an OGW is usually restricted due to economic reasons, and should be applied only to particularly exposed line sections that cannot be protected by other means.



NOTE – U_b = 100 kV; l_t = 50 m; bold line: R_t = 10 Ω; thin line: R_t = 30 Ω; dashed line: R_t = 100 Ω.

Figure 5 – Protection factor (K_p) provided by an OGW for different earth resistances

10.4 Installation of SPDs along the line

The installation of surge protective devices (SPDs) in splices regularly spaced along the line is an effective means of reducing the cable damage due to breakdown of the insulation between the inner conductors and the outer metallic sheath (shield). With the use of this protective measure, the failure current of the cable may be determined by its test current:

$$I_a = I_t \tag{17}$$

In order to be effective, the SPDs shall be installed between each active internal conductor (e.g., each symmetric metallic pair) and the cable metallic sheath, which shall be connected to an earthing system. The SPDs recommended for this application are the gas discharge tubes (GDTs) complying with [ITU-T K.12]. Non-active internal conductors (e.g., steel strength member), if any, shall be directly bonded to the cable metallic sheath.

NOTE – As the test current for unshielded cables is zero (I_t = 0), this protective measure shall not be applied to unshielded cables.

The maximum distance between two consecutive protected splices (l_p) for a buried cable is given by the following approximate expression (in km):

$$l_p = \frac{Z\,U_w}{R_s\,U_b} \tag{18}$$

where:

- U_w is the withstand voltage between the cable inner conductors and its shield, in kV;
- U_b is the breakdown voltage of the cable outer plastic sheath, in kV;
- Z is the common-mode surge impedance of the cable;
- R_s is the shield resistance per unit length, in Ω/km.

NOTE – The application of this procedure to aerial cables is under study.

Telecommunication cables with high-density polyethylene outer jackets usually have values of U_b around 100 kV, and common-mode surge impedance of buried cables (Z) is about 100 Ω. Typical values of U_w for symmetric pair cables are given in Table A.1.

11 Protective measures applied to the line-structure interface

This clause provides some protective measures to be applied at the interface between a structure and a telecommunication line connected to it, in order to protect the line against direct flashes to the structure. The corresponding protection factors shall be used in order to reduce the annual number of line damages calculated according to Equation 2.

When evaluating the annual number of line damages (N_d) and the risk of line damage (R_d), it is important to identify whether flashes to the connected structures are significant contributors to the total risk and, if so, to apply the protective measures on them.

11.1 Tubular shield

To shield the telecommunication cable where it leaves the structure is an effective means of reducing the number of line failures due to flashes to the structure. This shielding shall be applied to a short line section and it is very effective when provided by a tubular shield, as indicated by one of the alternatives:

– using a lightning protective cable;

– installing a regular cable inside a steel pipe.

Lightning protective cable is a special cable designed to have high failure current. It has high dielectric strength between its internal conductors and a good conducting metallic sheath. The outer metallic sheath is in continuous contact with the soil either directly or by the use of conducting plastic covering. The inner conductors of the lightning protective cable shall be terminated by SPDs at both ends, as shown in Figure 6.

A tubular shielding may also be provided by installing a regular cable inside a steel pipe, which is in direct contact with the soil. The steel pipe shall be protected against corrosion, e.g., by using hot-dip galvanized steel. The minimum cross-section area of the steel tube shall be 50 mm^2. For bends (for example, entrances into buildings), the steel pipe may be adapted to flexible metallic conduits connected by welding or flanges.

The shielding conductor of the protective measure (i.e., the steel tube or the outer metallic sheath of the lightning protective cable) shall be connected to the equipotential bonding bar (EBB) of the structure. This connection can be made directly or through SPDs, as shown in Figure 6, for the lightning protective cable.

In order to get the full benefit from the protective measure, its length (L_p) shall be equal to or greater than the effective length (L_e) of a horizontal earth electrode given by:

$$L_e = 2.5\,\sqrt{\rho} \qquad (19)$$

where ρ is the soil resistivity, in Ωm, and L_e is in metres.

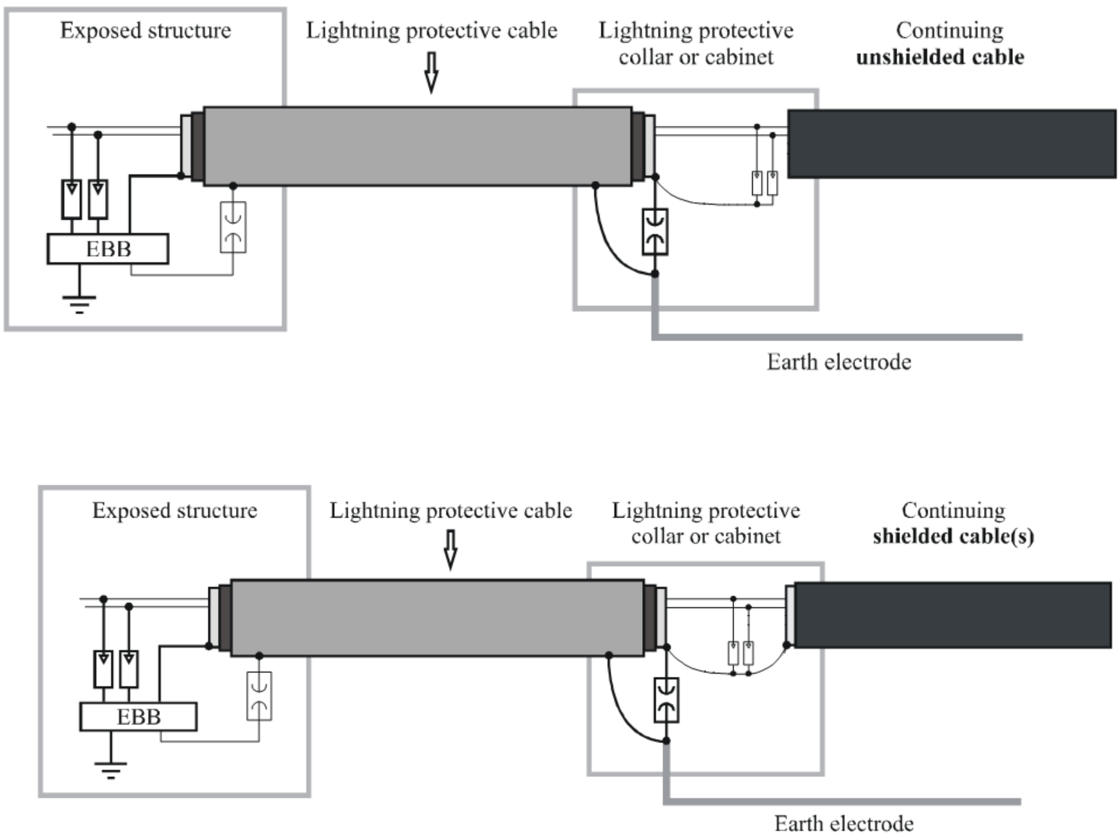
The protection factors for tubular shields can be assessed from their failure current, considering that:

$$I_a = 2\,n\,I_s \qquad (20)$$

where n is the number of metallic services connected to the structure and I_s can be calculated according to Annex A, where the steel tube could be conservatively considered as being in parallel with the cable metallic sheath. Typical protection factor values are given in Table 6.

Table 6 – Typical protection factor values for tubular shields

Protection measure	K_p
Lightning protective cable	0.02
Steel tube	0.01



NOTE – Above: continuing unshielded cable; below: shielded continuing cable.

Figure 6 – Lightning protective cable installed in a telecommunication line entering an exposed structure

11.2 Shielding by parallel conductors

Another way of shielding the telecommunication cable where it leaves the structure is installing parallel conductors in contact with the soil. This shielding shall be applied to a short line section and it can be accomplished by one of the alternatives:

– installing a regular cable inside a lightning protective cable duct;

– installing shielding wires in parallel with the cable.

The lightning protective cable duct is made of concrete with continuous and interconnected structural steel reinforcements. This cable duct shall have at least four steel bars in parallel along its entire length and the duct shall be in direct contact with the soil.

The shielding wires shall be made of bare wire of reasonable size buried along the telecommunication cable. Preferable conductors for this application are hot-dip galvanized steel or copper-clad steel. In the case where more than one conductor is used, they shall be disposed symmetrically around the cable.

The shielding conductor(s) of the protective measure (i.e., the shielding wire(s) or the steel bars of the lightning protective cable duct) shall be connected to the equipotential bonding bar (EBB) of the structure. The minimum total cross section area of the shielding conductors shall be 50 mm^2.

In order to get the full benefit from the protective measure, its length (L_p) shall be equal to or greater than the effective length (L_e) of a horizontal earth electrode given by Equation 19.

The parallel conductors carry part of the stroke current and thus increase the cable failure current, which is given by:

$$I_a = \frac{2\,n\,I_s}{\eta} \tag{21}$$

where η is the shielding factor provided by the protective measure. Typical values of shielding factors provided by the use of parallel conductors, as well as for a lightning protective cable duct, are shown in Table 7. The protection factor is calculated by Equation 12.

Table 7 – Typical shielding factor values (η) for parallel conductors

Protection measure		η
No protective measure		1
Number of parallel conductors	1	0.6
	2	0.4
	3	0.3
Lightning protective cable duct		0.2

11.3 Use of SPDs at structure entrance

Surge protective devices (SPDs) can be installed at the point where the cable enters a structure exposed to direct lightning discharges in order to reduce the annual number of line damages (N_d). The SPD shall comply with [ITU-T K.12] 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. The installation of an SPD as described in this clause increases the failure current (I_a) and, consequently, reduces the protection factor (K_p).

When SPDs are installed at the entrance of the cable into a structure, the failure current due to direct flashes may be evaluated by the approximate expressions given in Table 8. In this table, it is assumed that the installation of SPDs in unshielded cables is not effective to protect against direct flashes to the structure because the common-mode voltage is likely to break down the cable-to-earth insulation when the cable leaves the structure.

Table 8 – Effect of SPDs at structure entrance

Type of cable	I_a	K_p
Unshielded cable[a)]	0	1
Shielded cable without SPDs	$2\,n\,I_s$[b)]	Equation 12
Shielded cable with SPDs	$4\,n\,I_s$[b)]	Equation 12

a) This protective measure effect on unshielded cables is under study and a safe-side approach is assumed.

b) I_s is given in Annex A and n is the number of services connected to the structure.

Lower protection factors may be achieved by installing SPDs on shielded cables at the structure entrance and along the line. For assessing the spacing between SPDs along the line, refer to clause 10.4. The resulting failure current (in kA) can be assessed by the cable current carrying capacity:

$$I_a = 16\, n \left(S_s + m S_c \right) \tag{22}$$

where:

- n is the number of services connected to the structure;
- S_s is the cross-section area of the cable shield (in mm^2);
- S_c is the cross-section area of the cable conductor (in mm^2);
- m is the number of conductors in the cable.

NOTE – The effect of this protective measure on unshielded cables is under study.

Annex A

Evaluation of the sheath breakdown current (I_s)

(This annex forms an integral part of this Recommendation.)

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

$$I_s = \frac{10^3 U_w}{K R \rho^{1/2}} \tag{A.1}$$

where:

K is the waveshape factor for lightning current, $K = 8$ (m/Ω) $^{1/2}$;

R is the sheath resistance per unit length, in Ω/km (for cable with sheath and armouring, R is given by the parallel association between the sheath and the armouring resistance values per unit length);

U_w is the breakdown voltage between the cable metallic sheath and the core, in kV;

ρ is the soil resistivity, in Ω.m.

Typical impulse withstand voltage for symmetric pair cables are given in Table A.1.

Table A.2 shows representative values of sheath breakdown current for different values of sheath resistance and earth resistivity, considering a plastic insulation according to Table A.1.

Table A.1 – Typical values of impulse withstand voltage for symmetric pair cables

Type of insulation	Withstand voltage (U_w)
Paper	1.5 kV
Plastic	5 kV

Table A.2 – Representative values of sheath breakdown current of cables (in kA)

Cable type[a)]		Earth resistivity		
No. of pairs	Shield resistance (Ω/km)	100 Ωm	400 Ωm	1000 Ωm
400	1	62	31	20
100	2	31	16	10
50	3	21	10	7
20	4	16	8	5
[a)] Aluminium sheath 0.2 mm thick, 0.40 mm conductor diameter, and plastic insulation.				

Annex B

Evaluation of the test current (I_t)

(This annex forms an integral part of this Recommendation.)

This annex describes a test procedure in order to evaluate the susceptibility of a telecommunication cable from a direct lightning flash. The test is intended to reproduce the mechanical and thermal stresses acting upon the cable at the striking point. As it is performed in a box full of sand, it is also known as the "sand-box" test.

Although the 10/350 current waveshape is recommended to simulate a direct flash, several manufacturers quote their cables (especially optical fibre cables) as tested by a 15/70 waveshape. Therefore, until more information on test results is available, both waveshapes can be used by the methodology described here, in order to produce I_t values to be used in the context of this Recommendation. The referred waveshapes are defined as:

– 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.

NOTE 1 – The test report must state the waveshape used to obtain the test data.

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, and some holes in the bottom for water drainage.

The sand shall be 20-40 mesh silica sand, which shall be fully saturated during about 8 hours and drained at least five minutes before the test.

The cable sample shall be placed in the test box, and a metallic rod shall be located near the centre of the test box, perpendicular to the cable sample, and having its tip at a distance of 26 ± 1 mm from the sample. Figure B.1 shows a diagram of the test set up.

In order to let the test current flow through the cable sample, any insulation covering its outer metallic sheath shall be removed. If the voltage of the test generator cannot break down the 26 mm gap through the wet sand, a thin wire shall connect the discharge electrode with the metallic sheath.

NOTE 2 – This thin wire may have 0.4 mm diameter and it should vaporize at the inception of the test current. Therefore, it is not likely to affect the test results.

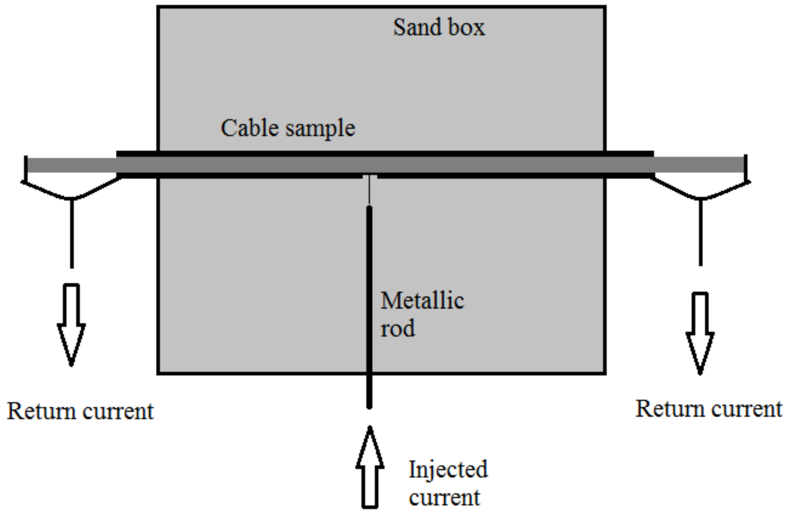


Figure B.1 – Diagram of the test set up

Wet sand shall be tamped around the cable sample and the rod. The moisture content of the sand in the more critical sand volume (i.e., around the rod tip) shall be 15% by weight. In this process, care shall be taken in order to not dislodge the thin wire (if any).

All conducting components at both cable ends shall be electrically connected together to form one terminal and a current generator shall be connected between this terminal and the rod electrode (see Figure B.1).

Following the application of discharge currents in ascending amplitudes, the sample is tested for the basic parameters that affect its transmission characteristics, such as:

– attenuation of optical fibres;
– continuity of twisted pairs or coaxial cables;
– insulation resistance of twisted pairs or coaxial cables.

The test identifies a threshold value of surge current that causes a failure and this value is the test current (I_t) of the sample. Reference peak values of currents to be used in the test are shown in Table B.1 and representative values for regular telecommunication cables are shown in Table B.2.

NOTE 3 – Before applying the impulsive current in a cable sample, it may be convenient to use a dummy sample (e.g., a steel tube) to calibrate the test set up.

Table B.1 – Reference current values for I_t assessment

Class	I_t
I	105 kA
II	80 kA
III	55 kA
IV	20 kA

Table B.2 – Representative values of I_t for symmetric telecommunication cables

Type of cable shield	I_t
Aluminium 0.2 mm thick	20 kA
Corrugated steel armour 0.15 mm thick	55 kA

Figure B.2 shows an example of an armoured optical fibre cable before and after the application of 55 kA peak current with the damped oscillatory waveform specified above. Although the sample was crushed, the fibres passed the tests for attenuation.

Figure B.2 – Armoured optical fibre cable before and after the 55 kA sand-box test

Appendix I

Expected loss per damage (*L*)

(This appendix does not form an integral part of this Recommendation.)

The damage caused by lightning flash 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 due to direct flashes (R_d) of the installation with the value of the tolerable risk of damages due to direct flashes (R_{Td}). The value of R_d is calculated by Equation 6, based on the relative amount of the expected loss per damage.

The values of the expected loss per damage L can be determined in terms of relative amount of possible loss from the approximate relationship:

$$L = \frac{n_p \times t}{n_t \times 8760} \qquad \text{(I.1)}$$

where:

- n_p is the mean number of users not served;
- n_t is the total number of users served;
- t is the annual period of loss of service (in hours).

The following values of expected loss per damage, for use when the determination of n_p, n_t and t is uncertain or difficult, are proposed:

$L_{da} = 2\times10^{-3}$ (due to direct flashes to aerial lines);

$L_{db} = 3\times10^{-3}$ (due to direct flashes to buried lines);

$L_s = 2\times10^{-3}$ (due to direct flashes to structures).

Appendix II

Rationale for the protective effect of guard-wires

(This appendix does not form an integral part of this Recommendation.)

A common protection practice against direct flashes to buried cables is the installation of a guard-wire above the cable. The assessment of the protective effect of guard-wires has been largely influenced by the work carried out by [b-Sunde], which neglects the effect of the cable insulating cover. However, results from [b-Ungar] showed that cable insulation is an important aspect to be considered when assessing a buried cable's susceptibility to direct flashes, although the author did not provide an alternative model to guard-wire behaviour.

Despite the high time-derivative of the stroke current, recent studies show that the current distribution in the earth close to the striking point is dominated by conductive effects rather than inductive ([b-Barbosa 1], [b-Barbosa 2], [b-Cooray]). The assumption of the prevailing conducting phenomenon in the close-region supports, to some extent, the development of a simplified model to represent the guard-wire behaviour. Results from this model are in line with experimental data available from experiments with rocket-triggered lightning ([b-Barbosa 3]), as presented here.

When a lightning flash strikes the earth surface near a telecommunication cable protected by a bare guard-wire, it is assumed that the flash connects first to the guard-wire and that it carries the bulk of the current. Due to the high current density at the guard-wire surface, it is likely that the earth around it will ionize. This ionization is modelled as an increase in the effective diameter of the guard-wire. This ionized region is more pronounced in the close vicinity of the striking point, so it is assumed that, in this region, the earth around the cable will attain a potential close to the guard-wire potential. As the metallic cable sheath will tend to attain the potential of a remote region, the voltage across its insulating cover will be given by the resistive voltage developed along the guard-wire.

NOTE – It is important to highlight that a current propagating in a perfectly-conducting bare guard-wire does not induce any current in a parallel cable, due to the cancelling effects of inductive and conductive coupling. Therefore, only the resistive voltage drop generates a stress on the cable insulation.

The resistive voltage developed along the guard-wire can be assessed modelling the guard-wire as a chain of series and shunt resistances, as shown in Figure II.1. It is easy to show that the equivalent resistance of this circuit is given by:

$$R_{eq} = \sqrt{R_s\ R_p} \tag{II.1}$$

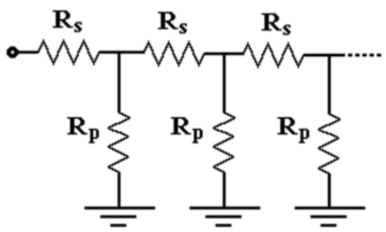


Figure II.1 – Resistive model for the guard-wire

Considering a small length Δx of the guard-wire, the resistances are:

$$R_s = \Delta\, x\ r_{gw} \tag{II.2}$$

$$R_p = \frac{\rho}{\pi \, \Delta x}\left[\ln\left(2\sqrt{\frac{L_e}{d}} \right) - 1 \right] \tag{II.3}$$

where:

- r_{gw} is the guard-wire resistance per unit length;
- ρ is the earth resistivity;
- d is the guard-wire effective diameter;
- p is the guard-wire depth;
- L_e is the guard-wire effective length.

The guard-wire effective length represents the portion of the guard-wire that carries the bulk of the current into the earth, as given by Equation 19. Similarly, the effective diameter of the guard-wire takes into account the apparent increase in the guard-wire diameter due to the ionization of the nearby soil. The exact evaluation of L_e and d is not very relevant due to the low sensitivity of the logarithmic function in Equation II.3, i.e., significant variations in these parameters lead to small variations in R_p. Therefore, it is assumed the representative values $d = 0.1$ m and $L_e = 90$ m, which leads to:

$$R_p \approx \frac{\rho}{\Delta x} \tag{II.4}$$

Inserting Equations II.2 and II.4 into Equation II.1 leads to:

$$R_{eq} = \sqrt{\rho \, r_{gw}} \tag{II.5}$$

The voltage applied to the cable insulation is therefore:

$$U = \frac{I_{gw}}{2}\sqrt{\rho \, r_{gw}} \tag{II.6}$$

where the current I_{gw} is the flash current injected in the guard-wire and the factor 2 means that this current is split into the two guard-wire branches. If U_b is the impulse breakdown voltage of the cable plastic cover, then the flash current needed to reach U_b is:

$$I_{gw} = \frac{2\,U_b}{\sqrt{\rho \, r_{gw}}} \tag{II.7}$$

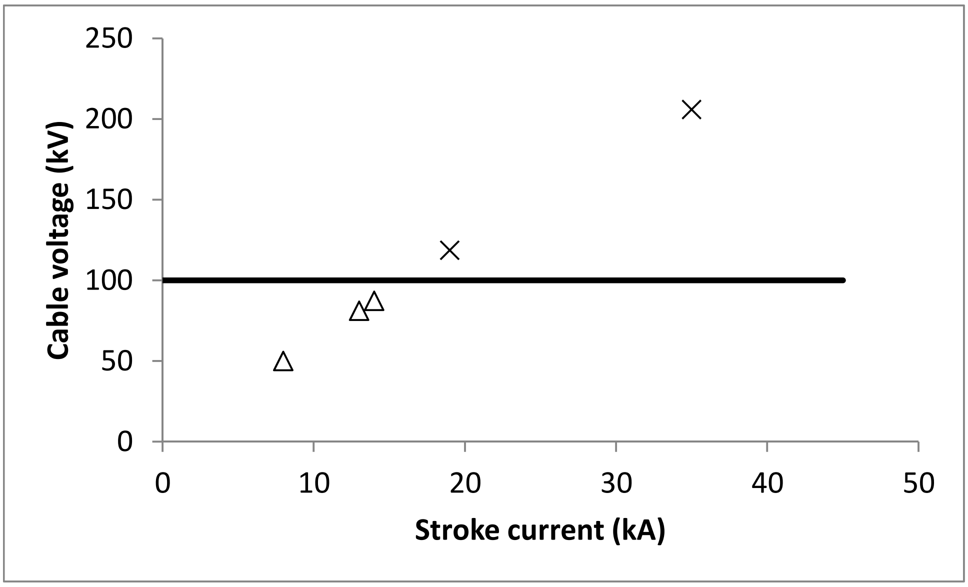
Equation II.7 provides the maximum current up to which the guard-wire intercepts the flash current and prevents the cable from being struck.

A test of Equation II.7 can be done by comparing its prevision with results from experiments with rocket-triggered lightning, as reported in [b-Barbosa 3]. In these experiments, lightning flashes were triggered just above a buried telecommunication cable protected by a guard-wire, at the middle of a 1 km section. The total lightning stroke current was measured at the rocket platform and the cable and guard-wire currents were measured in an instrumented station placed at 85 m from the striking point. By analysing the guard-wire and the cable currents, it was possible to determine whether a given flash injected current in the cable metallic sheath.

The guard-wire used in the test site was a stainless steel wire having 2.5 mm diameter and $r_{gw} = 160$ Ω/km. The earth resistivity measured near the striking area was about 1000 Ωm. The telecommunication cable was a shielded cable having 30 pairs of 0.64 mm covered by an aluminium sheath (3.9 Ω/km) and a plastic cover. The cable and the guard-wire were installed at depths of 0.70 m and 0.40 m, respectively.

Results of this experiment, as reported in [b-Barbosa 3], are shown in Figure II.2. Five return strokes are represented in this figure, where the corresponding voltages across the cable insulation was calculated using Equation II.7 and based on the measured current peak values. The triangles represent the strokes that did not inject current in the cable shield, while the crosses represent the strokes that led to breakdown of the cable insulation and injected current in its shield.

The bold horizontal line in Figure II.2 represents the nominal impulse withstand voltage of the cable outer cover. It is clear from this figure that Equation II.7 provides results that agree with the experiments.



NOTE – Δ: strokes that did not break down the cable insulation; ×: strokes that did break down the cable insulation.

Figure II.2 – Cable voltage produced by stroke current according to Equation II.7

These five strokes were contained in the same flash, and they followed the sequence shown in Table II.1. This was a fortunate flash for this experiment, as the peak currents in ascending amplitudes allowed the assessment of the current interval that caused the breakdown of the cable insulation.

Table II.1 – Peak values of the measured return stroke currents

Stroke	1st	2nd	3rd	4th	5th
Peak current	13 kA	14 kA	8 kA	19 kA	35 kA

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