

International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

K.111

(11/2015)

SERIES K: PROTECTION AGAINST INTERFERENCE

**Protection of surrounding structures of
telecommunication towers against lightning**

Recommendation ITU-T K.111

ITU-T



Recommendation ITU-T K.111

Protection of surrounding structures of telecommunication towers against lightning

Summary

Recommendation ITU-T K.111 considers the protection of structures in the area surrounding telecommunication towers (including masts and poles) against damage and injury derived from direct lightning flashes to the towers. The assessment and protection measures intend to reduce the possible risk derived from the erection of towers, but not to improve the overall lightning protection for every surrounding structure.

This Recommendation considers towers whose height is less than 100 m from ground level, which rarely meets the initiation condition of upward flashes, so that the presence of the tower does not significantly influence the incidence of lightning flashes.

Based on the analyses of sources of damage for an individual surrounding structure referring to IEC 62305-2, the risk components mostly include the possible influence in the close vicinity of a tower due to earth potential rise (EPR) and the transferred transients through common power feeds. For the former risk component, the hazard resulting from the occurrence of sparking and the injury to living beings are under consideration. For the latter, a series of exemption criteria and the corresponding protection (mitigation) measures are recommended. The requirements detailing the implementation of protection measures are also introduced.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K.111	2015-11-29	5	11.1002/1000/12668

Keywords

Earth potential rise, lightning protection, surrounding structures, telecommunication tower, transferred surge.

* To access the Recommendation, type the URL <http://handle.itu.int/> in the address field of your web browser, followed by the Recommendation's unique ID. For example, <http://handle.itu.int/11.1002/1000/11830-en>.

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Recommendation ITU-T K.111

Protection of surrounding structures of telecommunication towers against lightning

1 Scope

This Recommendation considers the protection of structures in the neighbourhood of telecommunication towers (including masts and poles) against damage and injury derived from direct lightning flashes to the towers. These protection measures intend to reduce the possible risk derived from the erection of towers, but not to improve the overall lightning protection for every surrounding structure. The systemic protection for these structures should refer to the IEC 62305-x series.

This Recommendation only considers towers whose heights are less than 100 m from ground level. Towers higher than 100 m or those situated on mountain ridges or high hills are not considered in this Recommendation.

The lightning protection of telecommunication sites attached to the tower, such as a radio base station (RBS) and a dedicated telecommunication building, is not included in this Recommendation. To this aim, the user should refer to the corresponding Recommendations, such as [b-ITU-T K.27], [b-ITU-T K.35], [b-ITU-T K.56] and [b-ITU-T K.97].

The lightning protection of service lines, such as power lines and telecommunication lines, is not included in this Recommendation. The information about telecommunication lines is given in [b-ITU-T K.46] and [b-ITU-T K.47].

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.39] Recommendation ITU-T K.39 (1996), *Risk assessment of damages to telecommunication sites due to lightning discharges.*
- [ITU-T K.66] Recommendation ITU-T K.66 (2011), *Protection of customer premises from overvoltage.*
- [IEC 62305-1] IEC 62305-1 (2010), *Protection against lightning – Part 1: General principles.*
- [IEC 62305-2] IEC 62305-2 (2010), *Protection against lightning – Part 2: Risk management.*
- [IEC 62305-3] IEC 62305-3 (2010), *Protection against lightning – Part 3: Physical damage to structures and life hazard.*
- [IEC 62305-4] IEC 62305-4 (2010), *Protection against lightning – Part 4: Electrical and electronic systems within structures.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 conventional earthing impedance [IEC 62305-1]: Ratio of the peak values of the earth-termination voltage and the earth-termination current which, in general, do not occur simultaneously.

3.1.2 coordinated SPD system [IEC 62305-1]: SPDs properly selected, coordinated and installed to form a system intended to reduce failures of electrical and electronic systems.

3.1.3 dangerous event [IEC 62305-2]: Lightning flash to or near the structure to be protected, or to or near a line connected to the structure to be protected that may cause damage.

3.1.4 downward flash [IEC 62305-1]: Lightning flash initiated by a downward leader from cloud to earth.

NOTE – A downward flash consists of a first impulse, which can be followed by subsequent impulses. One or more impulses may be followed by a long stroke.

3.1.5 lightning protection level (LPL) [IEC 62305-1]: Number related to a set of lightning current parameters values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning.

NOTE – Lightning protection level is used to design protection measures according to the relevant set of lightning current parameters.

3.1.6 radio base station [b-ITU-T K.56]: Installation intended to provide access to the telecommunication system by means of radio waves.

3.1.7 surge protective device (SPD) [IEC 62305-1]: Device intended to limit transient overvoltages and divert surge currents; contains at least one non-linear component.

3.1.8 upward flash [IEC 62305-1]: Lightning flash initiated by an upward leader from an earthed structure to cloud.

NOTE – An upward flash consists of a first long stroke with or without multiple superimposed impulses. One or more impulses may be followed by a long stroke.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 common power feed: A low voltage distribution system which makes the powered buildings and installations interconnected through the same low voltage line.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

EPR	Earth Potential Rise
LPL	Lightning Protection Level
LPS	Lightning Protection System
LV	Low Voltage
MV	Medium Voltage
RBS	Radio Base Station
SPD	Surge Protective Device

5 Conventions

None.

6 Reference configuration

Figure 1 shows the typical layout scenario consisting of the telecommunication tower and the affected surrounding structures (area) in the neighbourhood. In this figure, the possibly affected items are divided into two parts according to the corresponding risk components introduced in Annex A. These two parts can be classified as tower vicinity and local community and are defined as follows:

- **tower vicinity:** Includes the close vicinity around the tower within a limited distance from the edge of the telecommunication site. In this area, the current density and the voltage gradient is much larger than that of the far vicinity. There is the possible risk of injury to living beings by electric shock due to step and touch voltages and/or the hazard resulting from the occurrence of sparking between the tower and the metal parts of adjacent structures.
- **local community:** Includes the premises and installations connected with the telecommunication site through common low voltage (LV) power feeds, which suffer the influence of transferred surge from the interconnected LV power lines. If the telecommunication site is supplied by a dedicated transformer, the influence of transferred surge through medium voltage (MV) power lines can be negligible.

NOTE 1 – The earth-termination system of the tower shall comply with [IEC 62305-3] and [b-ITU-T K.56].

NOTE 2 – There may be other interconnected lines, such as telecommunication lines, and their influence is under study.

NOTE 3 – If the tower is erected on a rented building, the overall risk re-assessment and protection are needed for the rented building according to the IEC 62305-x series.

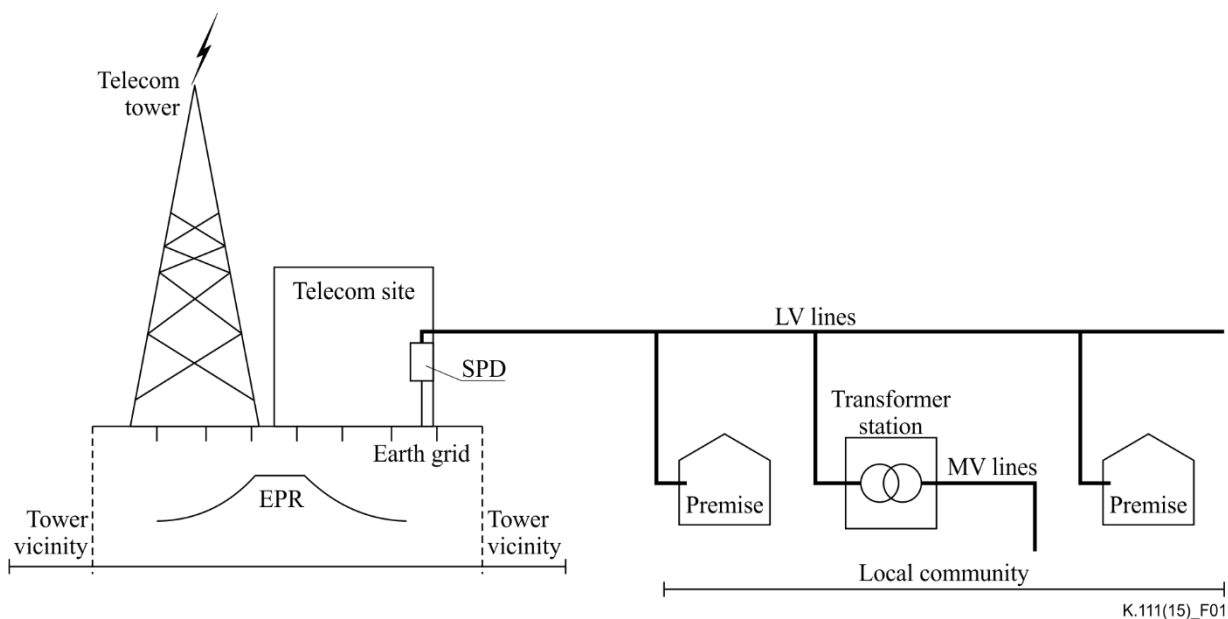


Figure 1 – Reference configuration

7 Protection of tower vicinity

7.1 Need of protection

The risk assessment shall be performed in order to determine a lightning protection level (LPL) for the determination of safety distances and the design of protection measures.

For the particular application, this Recommendation presents a simplified approach for the evaluation of the protection need based on [IEC 62305-2]. In this approach, the protection needs can be evaluated by considering the frequency of damage (F), as described in [ITU-T K.39].

$$F = N_D \cdot P_{dis} \quad (1)$$

where:

N_D is the number of direct flashes to the tower per year

P_{dis} is the protection factor of the safety distance.

When the frequency of damage is greater than the tolerable value ($F > F_T$), then protection measures are necessary. The tolerable frequency of damage value should be defined by the owner of the tower or the authority having jurisdiction according to the hazard level resulting from the occurrence of sparking. For example, $F_T = 0.05$ means that, on average, 1 damage in 20 years (1/20) is acceptable.

NOTE 1 – Each surrounding structure in the close vicinity of the tower may have different tolerable values.

NOTE 2 – In some countries, the relative authority having jurisdiction may specify the safe separation between the dangerous structures (e.g., gas station, explosive storage building) and the tower directly.

The expected number of direct flashes to the tower per annum (N_D) can be evaluated by:

$$N_D = N_G \times \pi \times (3H)^2 \times C_D \times 10^{-6} \quad (2)$$

where:

N_G is the lightning ground flash density (1/km² × year)

H is the height of the tower (m)

C_D is the location factor of the tower considering the relative height of the tower with respect to the surrounding objects or the ground within a distance of $3 \times H$ from the tower (see Table 1).

Table 1 – Structure location factor C_D

Relative location	C_D
Tower surrounded by higher objects	0.25
Tower surrounded by objects of the same height or shorter	0.5
Isolated tower: no other high objects in the vicinity	1
Isolated tower on a hilltop or a knoll	2

Under the most severe conditions, the required maximum protection factor (P_{dis}') can be given by the ratio between the tolerable (F_T) and expected number of direct flashes to the tower (N_D), which is shown by Equation 3:

$$P_{dis}' = F_T / N_D \quad (3)$$

The LPL to be considered in the protection design can be determined by the comparison of P_{dis}' and P_{dis} as shown in Table 2. The value of P_{dis} corresponding to the selected LPL cannot be greater than the P_{dis}' value calculated by Equation 3. For example, for a value $P_{dis}' = 0.03$, the LPL II is at least needed. The lightning parameters associated with LPL are given in Table 3 of clause 7.2.

Table 2 – Lightning protection level as function of P_{dis}

LPL	I	II	III-IV
P_{dis}	0.01	0.02	0.05
NOTE 1 – If $P_{dis}' < 0.01$ in very severe conditions, one or more protection measures shown in clause 7.3 should be adopted to ensure safety. NOTE 2 – If $P_{dis}' > 1$, no protection is needed.			

7.2 The assessment of the safety distance

The earth electrodes of the tower should have sufficient separation from existing buried metal parts of structures, cables and metal pipes in the earth to avoid the occurrence of dangerous sparking. From an engineering perspective, this separation is permitted to be relatively rough and conservative. The buried safety distance (S_d) can be assessed by Equation 4. In addition, there are some cases in which the metal protrudent parts of structures or cables are close to the tower body or down-conductor. The aerial safety distance (S_k) for these cases can be assessed by Equation 5. Figure 2 provides an illustration of these safety distances. The information about the determination of parameters for the assessment is given in Annex B.

$$S_d = (I_{LPL} \cdot Z) / E_{soil} \quad (4)$$

$$S_k = (I_{LPL} \cdot Z + h \cdot L \cdot di/dt) / E_{air} \quad (5)$$

Where:

S_d is the buried safety distance between the earth electrode of the tower and the affected metal objects. In this equation, the peak current of the first positive impulse is considered as I_{LPL} , according to the selected LPL

S_k is the aerial safety distance between the tower body or down-conductors and the affected metal objects. It is the largest value calculated by the lightning parameters (I_{LPL} and di/dt) of the first positive impulse, the first negative impulse, and subsequent impulse according to the selected LPL

I_{LPL} is the peak current relevant to the LPL to be considered, which is shown in Table B.1

di/dt is the average steepness relevant to the LPL to be considered, which is shown in Table B.1

E_{air} is the breakdown electric field strength of air. The reference value is 600 kV/m

E_{soil} is the breakdown electric field strength of soil. The reference values for types of soil are shown in Table B.2. Where the characteristics of soil are unknown, the average value of E_{soil} can be chosen as 500 kV/m [b-Zeng].

Z is the conventional earthing impedance of the earth-termination system of the tower. The reference values for typical earthing systems, which comply with [IEC 62305-3], are given in Table B.3

L is the inductance of the tower body. The reference average values of typical towers are given in Table B.4

h is the relevant height, in metres (see Figure 2).

NOTE 1 – It is assumed in the above formula that the earth-termination systems are relatively small so that the voltage drop on the earthing electrodes can be ignored. If this is not the case, more complex equations need to be used.

NOTE 2 – The lightning protection system (LPS) of the tower is seen as an isolated system and the total lightning current is assumed to disperse into the earth-termination system of the tower.

NOTE 3 – If there is other higher insulation material on the surface of these objects or in the interval, the safety distance would be diminished according to the performance of the insulation material.

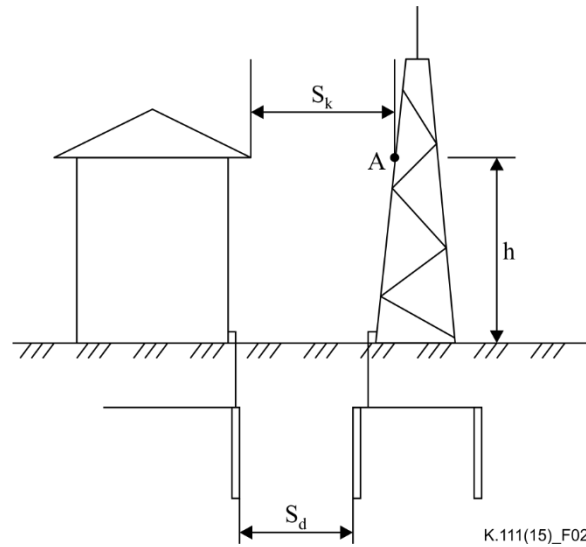


Figure 2 – Buried and aerial safety distance illustration

7.3 Protection measures

If the separation of the existing or planned configuration is less than the safety distance determined in clause 7.2, one or more of the following four protection measures should be adopted according to field conditions.

1) Expanding the separation

If there is sufficient space available, the separation between the earth electrode of the tower and affected objects should be as great as possible. It is beneficial to try to locate the tower on the opposite side of the earth-termination system. The direction and length of additional horizontal electrodes should be carefully considered in order to not violate the safety distance.

2) Enhancing the insulation of the affected object

If the affected object does not intend to act as an important part of LPS (e.g., pipes, decorative components) or other uncovered elements, an insulation cover (e.g., asphalt, plastics pipe) can be used to enhance the insulation of the affected object. The adequacy of insulation should be confirmed according to the nature of the cover and the actual separation.

3) Adding a segregation layer

For conditions with high ground resistivity or a difficult safe layout, a segregation layer made of insulating material (e.g., asphalt-concrete, asphalt) can be inserted into the soil between the earth electrodes of the tower and the affected objects. Figure 3 shows an illustration regarding this segregation layer.

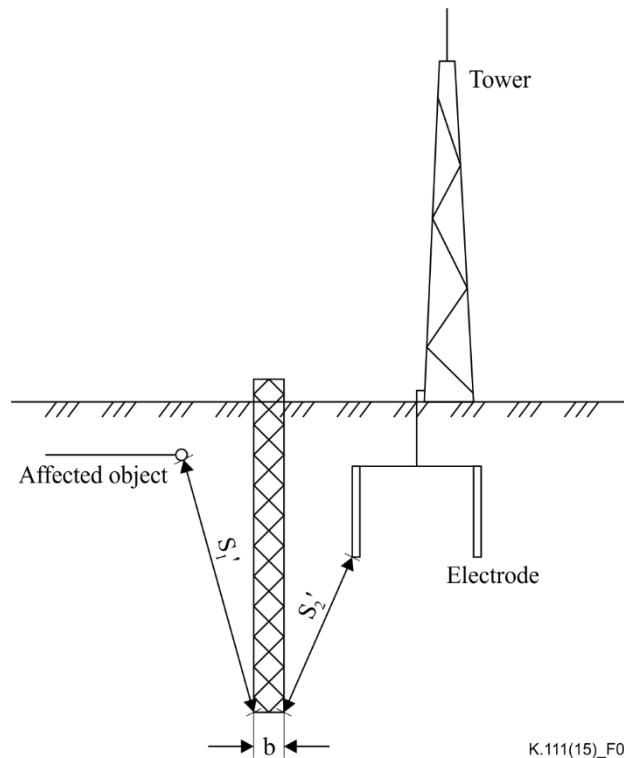


Figure 3 – Segregation layer to increase the separation distance through the soil

The breakdown electric field strength of asphalt-concrete is approximately 1500 kV/m. The thickness (b) of an asphalt-concrete segregation layer can be determined by Equation 6.

$$b = (I_{LPL} \cdot Z - S \cdot E_{soil}) / (1500 - E_{soil}) \quad (6)$$

Where:

b is the thickness of the asphalt-concrete segregation layer

S is the actual distance between the earth electrodes of the tower and the affected object.

The depth and width of the segregation layer should also meet the requirement of Equation 7.

$$S_1 + S_2 + b \geq S_d \quad (7)$$

Where:

S_1 is the minimum distance between the edge of the segregation layer and the affected object

S_2 is the minimum distance between the edge of segregation layer and the earth electrodes of the tower.

A similar method could be used for the aerial separation, provided that the insulation material has adequate insulating properties.

4) Equipotential bonding

If the affected structure is isolated and not dangerous, equipotential bonding between the electrodes of the tower and the affected parts can be carried out. The efficiency of the connecting materials and the LPS (including external and internal LPS) of the affected structure should be confirmed according to [IEC 62305-3]. Occasionally, for as yet unknown reasons, this measure must be adopted. In this case, the affected structure would be considered as part of the tower system and the expansion of the influence zone of the latter,

due to interconnected electrodes, should be considered. The relevant information is provided in clause 8.

NOTE – Other protection measures for cables can refer to [ITU-T K.47].

7.4 Protection measures against injury to living beings due to touch and step voltages

For more detailed information refer to [IEC 62305-3].

8 Protection of local community with common power feed

8.1 Need of protection

The risk from transferred surges through common power feed is related by many uncertain factors; this has been introduced in clause A.3. The hazard level resulting from this risk also varies over a very wide range. The efficiency of the existing protection measures in these affected structures are difficult to assess; this it is impossible to execute a precise assessment for this risk component.

In order to avoid the excessive workload and waste of investment derived from the protection of every telecommunication tower, it is recommended that the owner of the tower or the authority having jurisdiction on this subject set up a series of exemption criteria. When the telecommunication tower satisfies the exemption criteria, the risk can be considered as negligible.

A typical example of an exemption criteria is shown in the following. If one of the following two rules is fulfilled, the risk from transferred surges through common power feed does not need to be considered.

1) Exemption rule 1

The telecommunication site is served by a dedicated transformer.

NOTE – The lightning protection for a dedicated transformer itself shall conform with the requirements of [b-ITU-T K.110].

2) Exemption rule 2

The expected number of lightning flashes to the tower (N_D), that is calculated by Equation 2, is used for this exemption. If N_D is less than the reference values in Table 3, which depends on the criticalness of the surrounding structures, the site can be exempt from additional lightning protection measures.

Table 3 – Reference values for exemption based on the expected number of lightning flashes to the tower (N_D)

Criticalness of surrounding structures	Reference N_D value for exemption	Example
High	0.01	Hospital, Explosive materials
Medium	0.05	Schools
Low	0.1	Residential area

NOTE – The criticalness of the surrounding structures shall be selected according to the most important structure or the structure with the most severe prospective hazard.

3) Exemption rule 3

The occurrence rates of dangerous events derived from direct strokes on the LV lines and connected structures (S_3) for the LV system can also be used for an exemption criterion. These rates shall be computed for two conditions: (i) considering the presence of the tower (S_{3T}) and (ii) disregarding the presence of the tower (S_3). If the ratio between S_{3T} and S_3 is lower than 1.5, then the installation of

the tower does not significantly increase the risk associated with lightning surges conducted by the LV lines, and the influence of the tower could be ignored.

The collection areas under the above conditions could be used for the assessment of S_3 and S_{3T} . When the structures are sparse and small (e.g., rural environment), only the collection area of LV lines could be considered. When the structures are crowded (e.g., urban environment), only the collection area of the structures could be considered.

NOTE – Annex A of [IEC 62305-2] shall be used for the information about the occurrence rate of dangerous events.

8.2 Protection measures

When a telecommunication tower cannot satisfy the exemption criteria, the following three protection measures should be considered according to field conditions and economic analysis.

1) Adopting dedicated transformer for telecommunication site

It is proposed to use a dedicated transformer to power the base station, which gives a nearly-total prevention of lightning surge transferring to the nearby local community. This measure is the most effective method, especially for the cases where there are many power-sharing structures and most of the structures cannot be fitted with adequate protection.

2) Reassessment and retrofitting for the affected structures

When there are only a few structures with common feeds, the reassessment and retrofitting for these existing structures is also a possibility. In some cases, some important or sensitive structures could be selected separately for assessment and protection. The risk assessment and protection requirements should comply with the IEC 62305-x series and [ITU-T K.66].

3) Applicable mitigation measures

The protection measures may be very difficult to implement in some cases, due to heavy investment or workload, or due to field conditions. For example, some radio base stations (RBSs) are far away from MV lines and the cost of extending the MV line to these stations, in order to install a dedicated transformer, could be unacceptable to the telecommunication operator. In these cases, some mitigation measures can be adopted to decrease the amplitude of the transferred surges, which can reduce the hazard to a low level. These measures are described as follows:

- Reducing earthing resistance (or impedance) of the tower
The earthing resistance (or impedance) of the tower is not of prime importance for lightning protection. However, as introduced in clause A.3, this resistance (or impedance) has an important influence on the surges transferred from the telecommunication site to the local community. In order to reduce these outgoing surges, the earthing resistance (or impedance) shall be as low as possible.
- Adopting shield measures for incoming LV cables of the telecommunication site
Adopting effective shield measures for incoming LV cables of the telecommunication site can remove part of the lightning current from service cables and decrease the amplitude of the transferred current on the live conductors. It is beneficial to relieve the stress of the connected apparatus and surge protective devices (SPDs).

A common shielding technique is to install the cable inside a buried steel pipe or to lay bare conductors (wires) following the LV cables from the earthing system of the tower. The shielding conductors and cables are placed close together in order to reduce the potential difference between them. This measure is expected to carry a larger share of the current, compared to cable shields. The length of the pipe or shielding conductors is to be chosen in such a way that the potential difference developed between the cables and the far-end of the pipe or shielding conductor does not breakdown the cable insulation. In general, the length is recommended to be longer than 50 m. If needed, SPD

should be installed at the junction point between the buried cable and overhead lines, in order to prevent the breakdown of the cable insulation.

9 Implementation of protection measures

The lightning protection of surrounding structures of telecommunication towers is more complex than the protection of a single premise or of the telecommunication site. In most cases, the affected premises and installations are already in place when a telecommunication tower is planned to be erected. The following two aspects should be considered during the life of the tower:

1) Construction stage

- It is important to conduct a field survey to identify the possible affected objects and gather the information about existing conditions;
- The tower designer should try to select a reasonable location to maintain a safe distance as far as possible from vulnerable structures such as: gas stations, explosive storage, hospitals and the areas accessible to the public;
- If protection is needed, the designer should try to select the most convenient protection measures, with a minimum disturbance to other inhabitants. For example, when there are many structures with common power feed and most of the structures cannot be provided with adequate protection, a dedicated transformer shall be selected to power the RBS;
- In cases where the risk cannot be reduced to a tolerable level, some ultimate measures should be adopted, such as relocation or adding cell stations to decrease the height of the tower.

2) Operating stage

- Some artificial measures could be considered, such as adding warning notices and segregation fences;
- Attention should be given to the new construction of surrounding installations close to the dangerous area;
- Any inhabitant installation, e.g., TV antennas or metal lines, is prohibited to hang on to or be connected to the tower and should be frequently inspected by maintainers;
- Sufficient technical explanations should be provided to the public. Occasionally, dialog between the tower owner and surrounding community is necessary in order to avoid unjustified fears.

Annex A

Influence on the lightning risk of the surrounding structures due to the presence of a tower

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

A.1 Possible lightning risk components derived from erection of a tower

For the owner of a tower (e.g., telecommunication operator), the items of most concern are the identification of lightning risk components due to the erection of the tower and the adoption of corresponding protection measures to reduce the risk components to a safe level.

The erection of towers may influence the sources of damage due to lightning for surrounding structures. On the one hand, the height of the tower and the occurrence of a connecting leader from the top of the tower increase the effective collecting area for downward lighting and hence the tower acts as an efficient LPS, protecting the surrounding area from direct lighting strokes. On the other hand, the presence of a tower increases the number of lightning-current pulses that may be applied to a given structure, which may lead to the following sources of accidents:

- earth potential rise (EPR);
- transfer of transients through common power feeds;
- induced effects on wiring systems.

As shown in Appendix I, when the tower height is less than 100 m, the lightning ground flash density (N_G) in the area where the tower is situated can be considered as unchanged as compared with that of flat ground. For a given surrounding structure, according to the assessment methods introduced in Annex A of [IEC 62305-2], the influence on the sources of damage is analysed as follows:

1) S_1 (flashes to a structure)

The occurrence rate of dangerous events about S_1 for the structures in the close vicinity may be decreased due to the protection of towers. However, the occurrence rate of dangerous sparking from a tower may be increased, depending on the separation and the prospective hazard level. Additional information is provided in clause A.2 and clause 7.

2) S_2 (flashes near a structure) and S_4 (flashes near a line)

The occurrence rate of dangerous events about S_2 and S_4 , which are related with the induced effects on wiring systems, is independent of the tower height. In other words, for a given surrounding structure, the influence of erection of towers on S_2 and S_4 can be ignored.

3) S_3 (flashes to a line and to another structure to which a line is connected)

Strictly speaking, the occurrence rate of dangerous events about S_3 should consider not only the total length of the LV line, but also the height and the extension of all the structures served by the same LV system, see [b-Mirra] and [b-IEC TR 62066]. If the telecommunication site belongs to the same LV system and the erection of a tower increases the occurrence rate of dangerous events for this LV system significantly, the influence of the tower should be considered. On the opposite side, if the tower is just one more structure joining the LV system (i.e., it does not increase S_3 significantly), its influence should be ignored.

On the basis of these considerations, the possible risk components derived from the erection of a tower include:

- possible influence on the close vicinity of the tower due to EPR, such as injury to living beings by electric shock due to step and touch voltages, the insulation breakdown between

the tower and the adjacent installations (e.g., reinforcing foundation of building, metal pipes and lines);

- possible influence of transferred transients through common power feeds, which would lead to a partial lightning current flowing to the local community.

Note that the corresponding protection measures intend to reduce the possible risk derived from the erection of towers, but not to improve the overall lightning protection for every surrounding structure. The systemic protection for these structures should refer to the IEC 62305-x series.

Moreover, a misconception about the causes of damage to the surrounding structures should be clarified. In many countries, public complaints about lightning-related events such as property damages and injuries have increased in the region, after the erection of a telecommunication tower. In addition to the influence mechanisms described above, it is important to be aware that these surrounding structures may not have the basic LPSs according to the relevant international or national standards.

A.2 Risk from EPR on the close vicinity of a tower

When lightning hits a tower, the high lightning current flows into the earth-termination system where the tower is placed, and the earth potential will rise with respect to remote earth. This potential in the area will then decrease monotonically with the distance and depth. The potential decrease can be described according to Figure A.1. Based on a simple approach, the EPR at the lightning-striking point is equal to the maximum lightning current times the impedance of the earth-termination system, and the EPR at a given point is inversely proportional to the distance from the lightning strike point. If the earth impedance increases, the affected region by the EPR will also increase.

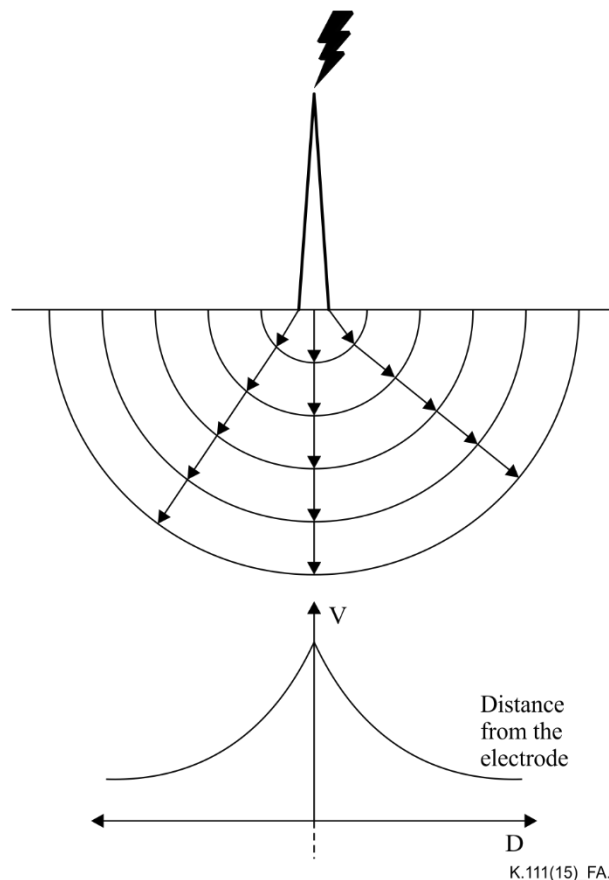


Figure A.1 – Distribution of the EPR due to lightning striking a tower

In the far region from the tower, the overvoltages are mainly due to inductive coupling. But in the close vicinity of the tower earthing system, the current density and the voltage gradient attain very high values, which may result in dangerous sparking to nearby metal structures. Field experiments on a group of vertical electrodes have also shown this phenomenon. When the current density $\delta \geq 0.05 \text{ A/cm}^2$ and soil resistivity $\rho \geq 2000 \text{ }\Omega\cdot\text{m}$, intensive sparking can be observed. When $\delta \geq 0.5 \text{ A/cm}^2$ and $\rho \leq 200 \text{ }\Omega\cdot\text{m}$ for normal soil condition, ground surface sparking has appeared from the electrodes, see [b-Zeng]. In actual circumstances, the adjacent structures are often connected to other structures through metallic lines, which lead to a very low equivalent resistance. As a result, a larger part of the lightning current will flow in this direction, which may enhance the sparking and the stress on the entrance interface of this structure. The amount of transient energy transferred to other connected structures will also be considerably high. Figure A.2 illustrates this phenomenon. At the same time, this dangerous sparking may give rise to physical damage and injury to living beings, as well as to catastrophic consequences to buildings with risk of explosion. In any case, this dangerous sparking should be prevented, as much as possible.

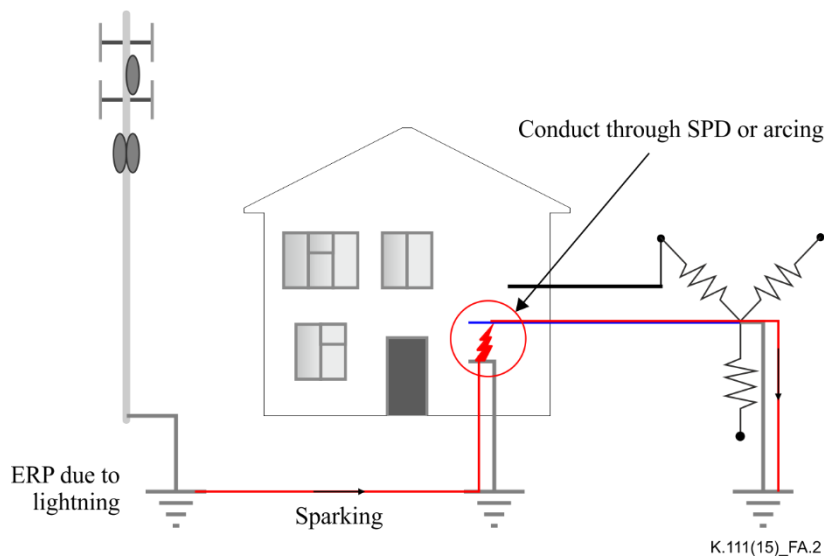


Figure A.2 – Influence on current dispersion due to an adjacent structure

Even if the electric fields are not sufficiently high enough to generate sparking, the current flow close to the ground surface may also give rise to step potential hazards when human beings and animals stand on the ground.

Because the distribution of EPR is related to the amplitude and shape of the lightning current, characteristics of the earthing grid, soil resistivity, soil dielectric constant and other factors, it is very difficult to carry out a precise calculation. However, from an engineering perspective, it is necessary to regulate sufficient separation (safety distance) from these existing metallic parts of structures, cables and metal pipes in the earth to avoid the occurrence of dangerous sparking. This separation is permitted to be relatively rough and conservative. At the same time, the LPSs of towers should make special provisions for protection against dangerous step voltages or touch voltages in the vicinity of the earth-termination networks, if they are installed in areas accessible to the public.

A.3 Risk from transferred surge through common power feed

Telecommunication towers and the equipment building of an RBS are not isolated systems. Usually, many cables, including power cables, enter the building from the local community network. A typical scenario is shown in Figure A.3. When the tower is hit by a lightning flash, the earth potential at the tower and associated RBS may be extremely high compared with that in the ground of the interconnected metallic system supplying the nearby structures. The high potential difference drives large surge currents via service cables to the local community, where it gets distributed to these

structures. Consequently, for a given flash density in the area, the presence of a tower, although reducing the probability of direct flashes to smaller buildings in its vicinity, enhances the probability of conducted overvoltages.

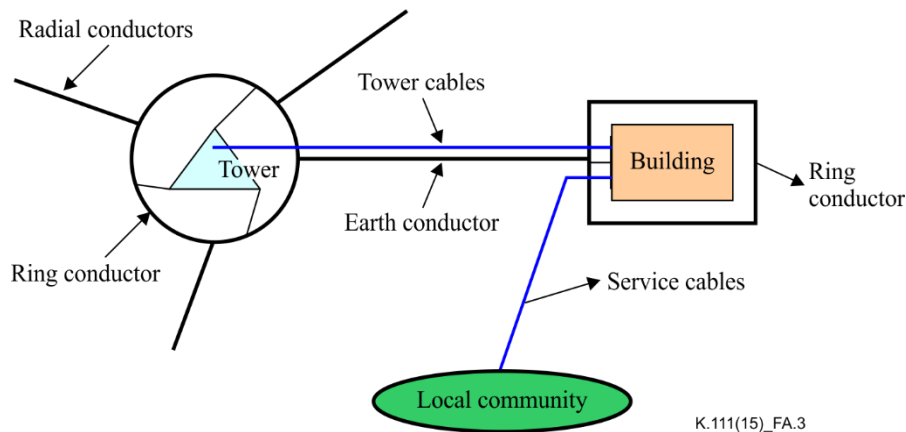


Figure A.3 – Typical configuration including local community

In an actual situation, the LV power distribution system is the most critical common dispersion route. The surrounding premises and installations sharing a mutual transformer with the tower site can all be affected. The transferred overvoltage and partial lightning current along the LV distribution lines will stress all of the connected apparatus and SPDs in the interconnected structures. At first glance, the most threatening situation would be the overvoltages between conductors and local earth applied to the power equipment. In addition, these transferred overvoltages may lead to overvoltages between the power system and the communications system connected to the same equipment. Field investigations have revealed that this coupling path is also the common damage mechanism.

Depending on the division of the lightning current, the configuration of the LV distribution system, earthing practices and the presence or absence of SPDs, the transferred overvoltage can be large or moderate. Because all the above factors vary over a wide range according to the general practice of the utility, as well as local configurations, it is impossible to present a quantitative calculation for all types of systems.

The division of the lightning current is mostly determined by the ratio of the resistances between the tower and local community, as described in [b-IEC 61643-12], [b-IEC TR 62066]. As a result, the worse the earthing condition of the tower or the higher the density of the mutual feeding buildings in an area, the greater the portion of the lightning current that would flow out of the telecommunication site through the incoming LV power cable.

NOTE – The above current division is suitable for 10/350 μ s as defined in [IEC 62305-1]. In the initial phase of lightning current, the current division is determined by the ratio of the inductances. In the tail, where the current time-derivative is low, the division is determined by the ratio of the resistances. For cases where the waveform is much shorter than 10/350 μ s, the current division cannot be simply assessed by considering only the resistances.

Different practices of earthing the neutral are found in different countries, so that some difference can be expected in the way the lightning current will disperse among the available paths. As a result, the transferred overvoltages will also be different, according to the actual configuration of the LV distribution system. For example, in a TN-C system, because the phase-to-earth voltage is much less attenuated than the neutral-to-earth voltage due to the multiple earthing connections of the neutral conductor, a significant phase-to-neutral voltage builds up as the distance from the BS increases. This is why the damage may be more severe when the structure is far from the tower in some actual incidents.

However, if the telecommunication site is served by a dedicated transformer, the flow of lightning current through the MV power system should have negligible consequences to the local community. Figure A.4 shows two typical configurations with dedicated transformers. In the left-hand side the transformer is installed outside the building and connected to the RBS (Telecom site) through an external LV cable, while in the right-hand side the transformer is installed inside the building that contains the telecommunication equipment (RBS).

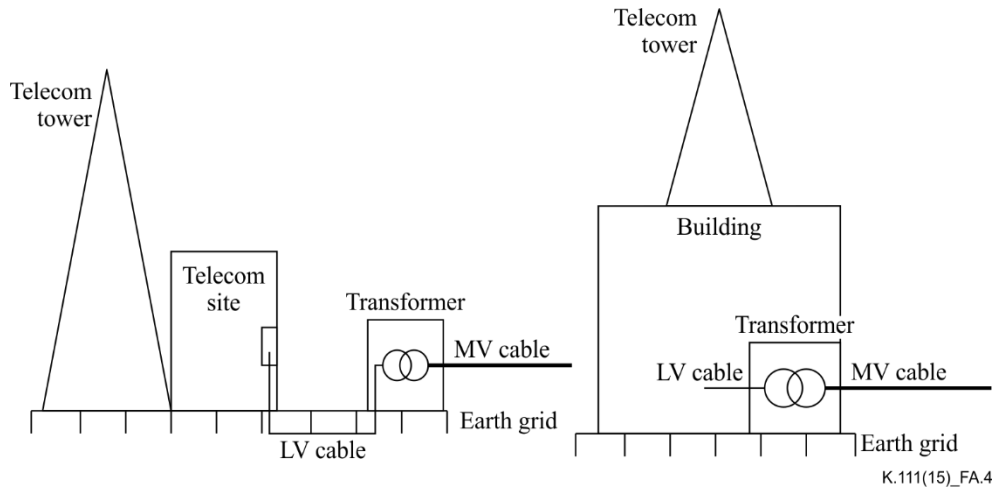


Figure A.4 – Two typical configurations with dedicated transformers

Annex B

Determination of parameters for the assessment of safety distance

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

B.1 Lightning parameters according to LPL

The corresponding lightning parameters related to LPL are given by [IEC 62305-1]. Table B.1 shows some lightning stroke parameters associated with each LPL.

Table B.1 – Lightning parameters according to LPL from [IEC 62305-1]

Parameter	Unit	LPL		
		I	II	III – IV
Maximum peak current of first positive impulse (10/350 μ s)	kA	200	150	100
Maximum peak current of first negative impulse (1/200 μ s)	kA	100	75	50
Maximum peak current of subsequent impulse (0.25/100 μ s)	kA	50	37.5	25
Average steepness of first positive impulse (di/dt)	kA/ μ s	20	15	10
Average steepness of first negative impulse (di/dt)	kA/ μ s	100	75	50
Average steepness of subsequent impulse (di/dt)	kA/ μ s	200	150	100

B.2 Reference values of E_{soil}

The reference value of the breakdown electric field strength (E_{soil}) of soil under different types of soil and soil resistivity are shown in Table B.2.

Table B.2 – The referring value of E_{soil} under different soil property and resistivity [b-Huai]

Soil property	Soil resistivity ($\Omega \cdot m$)	E_{soil} (kV/cm)
clay	2700	16
	1000	14.4
	250	8.4
	160	9
	140	10.4
	120	8.2
	70	7.4
humus	1050	4.2
	550	7.2
	350	5.8
	90	9.2
	35	9.6
	22	4.5
sandy soil	45~3400	12.8~13.8

B.3 Reference values of typical earthing impedance

The referring values for typical earthing systems, which comply with [IEC 62305-3], are given in Table B.3. Other available methods defined in national regulations are also permitted.

Table B.3 – Conventional earthing impedance values Z according to [IEC 62305-3], for different soil resistivities

Soil resistivity ($\Omega \cdot m$)	Conventional earthing impedance (Z) related to the type of LPS (Ω)		
	I	II	III – IV
≤ 100	4	4	4
200	6	6	6
500	10	10	10
1000	10	15	20
2000	10	15	40
3000	10	15	60

NOTE 1 – Values reported in this table refer to the conventional earthing impedance of a buried conductor under impulse condition (10/350 μs).

NOTE 2 – Earthing system complying with clause 5.4 of [IEC 62305-3].

B.4 Reference values of tower inductance

The reference average values of the inductance (L) of the tower body for different types of towers are given in Table B.4. These values are intended to be used in order to determine the safety distances according to this Recommendation (see clause 7.2).

Table B.4 – The referring average values L of the inductance of tower body [b-Huai]

Tower type	The referring average value ($\mu H \cdot m$)
Tubular tower	0.84
Tubular tower with stay wires	0.42
Three-leg tower	0.70
Three-leg tower with stay wires	0.35
Four-leg tower	0.50

Appendix I

Influence of the tower on the ground flash density

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

For a tall structure, there may be two basic types of flashes of concern:

- downward flashes initiated by a downward leader from cloud to earth;
- upward flashes initiated by an upward leader from an earthed structure to cloud.

Most downward flashes occur in flat territory, and to lower structures, whereas for exposed and/or higher structures upward flashes become dominant. The relative information about possible components of these two categories is given by [IEC 62305-1].

I.1 Downward flash

The most common form of downward flash is a multiple-stroke negative flash. The negatively charged leader, initiated after a preliminary discharge in the cloud, descends towards the ground in a stepped manner from the thundercloud. This stepped leader is highly branched (tortuous) due to randomly distributed space charge between the cloud and the earth. When this stepped leader propagates towards the ground, the field at the ground or grounded objects gradually increases. When the field reaches a critical value on the ground or grounded structures, upward leaders originate from them and propagate towards the tip of the descending stepped leader. The inception of the upward leaders from the tip of the structures is largely dependent on the level of field enhancement at the structure tips, predominantly governed by the structure geometry (heights and radii), the proximity of other structures, the background electric field due to the cloud, and the descending stepped leader charge. A strike is established when one of the upward leaders succeeds in establishing a contact with a descending stepped leader. At this junction, an intensive current wave, termed as return stroke, travels upward. It is this phase that is most hazardous because of the associated large transient currents and field changes. As the charge on the leader will be neutralized by the return stroke current wave, it is possible to relate the peak amplitude of the return stroke current with the charge on the leader.

Upward leaders from tall towers, in response to descending stepped leaders, ensure that lightning strikes the tower rather than the nearby ground. This is the same principle as the lightning rod in LPS of buildings. In principle, a tall tower on flat ground tends to attract the lightning flashes that would have struck the nearby ground.

I.2 Upward flash

The situation may be different when towers are placed on high hills or if the tower is extremely tall. The background electric field on the top of a hill under a thundercloud is high and when a tower is placed on that hill, the tower enhances the field even more. In such cases, the electrical discharges, happening inside the cloud or the cloud charges, may cause the launching of an upward leader from the tower, even without a downward moving leader at the beginning. If this upward leader travels all the way to the cloud and initiates a cloud-to-ground lightning to the tower, it results in an upward flash. This lightning flash would not have happened if the tower was not present. Therefore, in such cases, it is possible to say that the presence of the tower causes an increase in the number of lightning strikes to that area.

The initiating condition of upward flashes is related to ambient field on the ground due to the cloud and to the structure height. It is valid to speak in terms of ambient ground field because of the uncertainty that exists in knowing the position of the cloud and the cloud potential itself. In rocket-triggered lightning it has been observed that the ground electric field at the time of triggering a flash by the rocket is between 5 and 15 kV/m, and very rarely it exceeds 15 kV/m, see [b-Theethayi]. From the analysis of measurements and theoretical considerations, see [b-Theethayi], [b-Chandimal], the

tower height corresponding to a critical ambient ground field of 15 kV/m is approximately 100 m on flat ground. Thus, it is suggested that towers on level ground with heights below about 100 m on flat ground do not normally experience upward flashes. It should be pointed out that a tower shorter than 100 m can also initiate upward lighting if it is situated on a mountain ridge or high hill.

In general, as far as a downward lightning is concerned, the tower is acting like a huge lightning rod with a large protective area, and does not really increase the number of downward lightning flashes. It is the upward flashes that increase the lightning incidence to the tower and therefore, it can be inferred that towers less than 100 m high, on flat ground, do not increase the incidence of lightning.

In practical engineering, the circumstance of telecommunication towers placed in residential neighbourhoods rarely meet the initiation condition of upward flashes. Hence, it is highly unlikely that the occurrence of lightning strikes per year for the defined area increases due to the existence of the tower. This means that the lightning ground flash density (N_G) has not been changed due to the presence of the tower.

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