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**Risk assessment of damages to
telecommunication sites due to lightning
discharges**

Recommendation ITU-T K.39



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Summary

Protective measures against a randomly occurring overvoltage phenomenon like lightning discharges have to a great extent been empirically based. Modern equipment has shown to be more prone to damages compared with older ones. Serious consequences in complexed communication systems may also occur in built-up areas, earlier classified as unexposed. The widespread use of radio stations with high antenna masts for wireless telecommunication has significantly increased the risk for damages due to direct lightning strikes to the site.

The need for protection should be based on a risk assessment considering the cost and importance of the system, the electromagnetic environment at the particular site and the probability of damages. The protection levels and the type of protective methods should also be chosen regarding the costs of installation and maintenance of protective devices.

An assessment of the probability of overvoltage occurrences and the sensitivity of the existing telecommunication installation shall give a possibility to attain a well-balanced protection of the whole system.

Protective measures to eliminate severe injuries to people during thunderstorms are especially important at exposed sites that are permanently or temporarily manned.

History

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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.

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Recommendation ITU-T K.39

Risk assessment of damages to telecommunication sites due to lightning discharges

1 Scope

This Recommendation comprises a method for the risk assessment of damages to equipment at telecommunication sites and personnel safety due to overvoltages and overcurrents caused by lightning discharges.

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.20] Recommendation ITU-T K.20 (2019), *Resistibility of telecommunication equipment installed in a telecommunication centre to overvoltages and overcurrents*.
- [ITU-T K.21] Recommendation ITU-T K.21 (2019), *Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents*.
- [ITU-T K.27] Recommendation ITU-T K.27 (2015), *Bonding configurations and earthing inside a telecommunication building*.
- [IEC 62305-1] IEC 62305-1:2010, *Protection against lightning – Part 1: General principles*.

3 Definitions

This Recommendation defines the following terms.

3.1 surge protective device (SPD): A device that is intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component.

3.2 subscriber line circuit (SLIC): A printed circuit board containing subscriber line functions and placed in an exchange at the interface to the external telecommunication lines.

4 Conventions

None.

5 General

Telecommunication centres and other information systems contain large amounts of electronic equipment sensitive to lightning discharges. Unprotected sites may be damaged by cloud to ground flashes at a distance of several kilometres. Interferences may even be caused by intracloud discharges.

The risk of damages depends on a number of factors, among which the following are the more important:

- type of incoming services, especially power supply and telecommunication cables;

- size and shape of the building containing the equipment and the shielding effect of the building material;
- layout of the electronic system including the cable routing and the utilization of internal shields;
- protective measures, integrated in the building construction, inherent of the equipment or at the interface between external and internal cables.

Physical damages to telecommunication sites are dominated by hardware damages of the electronic equipment due to overvoltages and overcurrents on incoming lines. Direct lightning strikes to a building can cause extensive damages to the building itself in form of fire, explosion or other physical destruction. In such cases the installed equipment usually suffers severe losses.

Also software parts of the system may be destroyed or partly affected, e.g., erased memories and false or inhibited alarm signals.

However, the most severe consequential effect of a thunderstorm is often the loss of communication service that will lead to high costs for both the subscriber and the telecommunication operator.

6 Coupling mechanisms

Lightning transients will affect a telecommunication centre or similar systems by the following coupling mechanisms.

6.1 Resistive coupling

A lightning discharge to an object creates a potential rise that may reach several hundreds of kV at the point of impact with respect to the remote earth. In a telecommunication centre, the potential rise will generate currents that are distributed amongst metallic services like telecommunication and power supply cables bonded to the reference point of the system. Currents in cable shields cause overvoltages between the shield and the cable core proportional to the transfer impedance.

6.2 Magnetic coupling

Lightning currents in a conductor or in the lightning discharge channel create magnetic fields, which for a distance up to some hundred metres may be assumed to have the same time variation as the current. However, the magnetic field is often disturbed and attenuated by building materials or surrounding objects and therefore a more precise analysis may be necessary in some cases.

The magnetic field variations induce voltages and currents in the internal wiring and in the outdoor cable plant.

The distribution of lightning current parameters is given in [IEC 62305-1].

6.3 Electric coupling

Adjacent to the charge in the lower part of the lightning channel, a very high electric field arises. It can have an effect on rod antenna equipment. Inside a building the interference from the field may normally be neglected.

6.4 Electromagnetic coupling

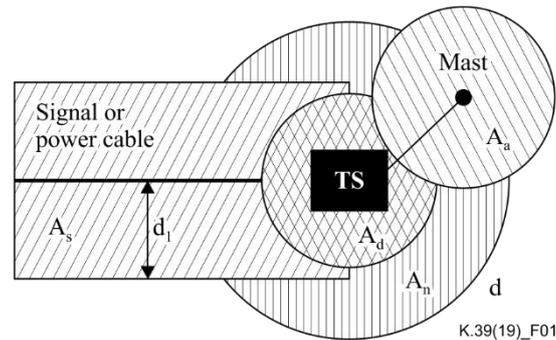
At large distances, electromagnetic fields from lightning discharges impress substantial overvoltages on an extended telecommunication network. This conducted interference appears at the equipment interface. Directly radiated fields will hardly damage any telecommunication equipment inside a building or cabinet.

7 Principles for the risk assessment

A risk assessment for damages in telecommunication centres should be performed in two steps: firstly, a basic assessment of the need of lightning protection for the object; secondly, the selection of protection methods and the energy withstanding of protection components, SPDs, on telecommunication and power supply services.

7.1 Frequency of damage, F

Risk areas should be defined for coupling mechanisms described above. Lightning discharges confined to these areas are assumed to damage the telecommunication building itself, TS, or at least the installed electronic equipment inside, see Figure 1.



- A_d Equivalent risk area for direct strikes to the building.
- A_n Risk area for discharges to ground nearby the building affecting the telecommunication centre by resistive and inductive coupling.
- A_s Risk area for incoming services (power supply, telecommunication cables, etc.).
- A_a Risk area for direct strikes to adjacent objects, e.g., antenna masts, with metallic connection to the telecommunication centre.

Figure 1 – Risk areas for lightning discharges

It should be noticed that different risk areas may cover each other, which should be considered when the total risk area is calculated.

Higher structures will, to a certain extent, shield lower nearby buildings or areas from direct lightning strikes. Direct strikes will normally cause more severe damages than indirect strikes.

Also the risk area A_s , for incoming cables, is assumed to have a higher priority than A_n for strikes to ground nearby the site to be protected.

The sum of the areas gives the total risk area for the site and corresponds to the average number of damages every year, F , at a normalized lightning intensity N_g of 1 flash to ground per km² and year. It is assumed here that the telecommunication equipment has a resistibility against lightning transients according to [ITU-T K.20], [ITU-T K.21] and [ITU-T K.22] and the power supply equipment to other international standards. The requirements shall comprise parameter values of the transients concerning maximum voltage, current, charge, steepness, specific energy, etc.

The risk areas are calculated on condition that the communication site is not provided with any particular protective measures or such protection that may be included as natural protective parts of the construction of the building or in the outside cable plant. In reality there are always some characteristics of the site that reduce the penetrating fields and currents. The likelihood that damage should occur is therefore significantly lower than in the theoretical case. Influences from inherent and additional protective measures are considered in clause 9 – "Estimation of probability factors p ".

Regarding the local lightning flash density, the number of yearly prospective number of damages, F , is expressed by the formula:

$$F \approx N_g(A_d p_d + A_n p_n + A_s p_s + A_a p_a)$$

where the different values of p depend on the existing or planned protective measures, which all decrease the probability of damages.

$$F \approx F_d + F_n + F_s + F_a$$

The four terms represent damages caused by direct strikes to the site, (d), nearby strikes to ground, (n), lightning discharges to or in the vicinity of incoming cables, (s), and direct discharges to adjacent objects, e.g., antenna towers, with metallic connection to the telecommunication site (a). In most cases the third term will dominate, but for large buildings or buildings with high antenna towers the influence from other terms may be substantial.

It is advantageous to keep the terms separated during the calculations in order to be able to identify the main reason of failures and to implement the most efficient protective methods.

Information about the lightning flash density can often be obtained from detailed keraunic maps. Otherwise the following approximate formula may be used:

$$N_g = 0.04 T_d^{1.25} \text{ per km}^2 \text{ and year,}$$

where T_d is the average number of thunderstorm days registered per year.

7.2 Risk of damage, R

The risk R that the telecommunication site will suffer serious damages can be estimated to:

$$R = (1 - e^{-F \cdot t}) \cdot \delta$$

which in most cases is simplified to:

$$R = F \cdot \delta = \sum F_i \cdot \delta_i$$

for $t = 1$ year and $F \ll 1$.

The factor δ is determined with respect to the prospective consequential damages in relation to the full hardware value of the equipment and to the effects of a total loss of service.

8 Calculation of risk areas

A computer program for analysing the risk of damages would allow the implementation of more complicated calculation methods. However, for manual estimations the calculations must be simplified in order to be useful for practical applications.

The equivalent risk area for direct lightning strikes to a structure A_d is defined as a plane area with the same lightning strike frequency as the structure of interest. In the simple case, the building is isolated from other tall structures and placed on a flat ground.

A_d is then an area bordered of a line, with the slope 1:3, drawn from the upper parts of the building, as shown in Figure 2, where

$$A_d = ab + 2(3ha) + 2(3hb) + \pi(3h)^2$$

This relation is valid for structures up to at least 60 m height.

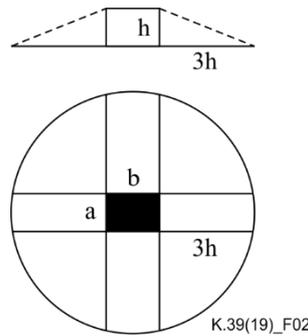


Figure 2 – Risk area A_d for direct lightning strikes to a structure

A_n is the risk area for the surrounding ground, where a lightning strike creates a potential rise that may influence the telecommunication centre. A_n is formed by a line at a distance d from the building minus the risk area for direct impacts, A_d . Where adjacent objects like high structures and incoming cables are present, the area A_n is further reduced, see Figure 1.

The distance d , in m, is directly related to the value of the soil resistivity, in Ω m, and has an assumed maximum value of 500 m.

Strikes may also induce transients directly in the interior installation of the building. However, the inductive coupling from lightning strikes within the area A_n can normally be disregarded due to the distance to and the limited size of the loops of wires inside the usually small building. The induction effect, caused by strikes within A_n , will mainly influence installations in large area buildings of low height, and not for longer distances than 50 m from the point of strike.

Also the influence from the resistive coupling may often be neglected, as a significant part of the risk area A_n is covered by the area A_s for incoming lines.

A_s is an area, within which lightning strikes generate substantial transients in extended cable networks connected to the telecommunication site of interest. For aerial cables the aggregate length and the height are relevant parameters. Although buried communication and power cables offer lower risk than overhead lines, direct lightning strikes in the vicinity of buried cables may cause substantial overvoltages, especially in high resistivity soils.

The maximum distance d_1 from the cable, at which the strikes are regarded, is influenced by the soil resistivity, in principle also for aerial cables. d_1 for the risk area of underground cables may, if soil resistivity values are available for all parts of the cable length, be assumed to follow the same relation to the resistivity as for A_n , but is here, for reasons of simplification, replaced by fixed values.

$A_s = 2d_1 \cdot L$, where L is the length of the cable.

d_1 for underground cables is assumed to be 250 m and for aerial networks 1000 m.

The risk areas for direct strikes to the network may be assumed to $A_{sd} = 6 hL$ for aerial cables, where h is the height above ground of the line, and $A_{sd} = 2L \sqrt{\rho}$ for underground cables, ρ being the soil resistivity.

Where telecommunication or low-voltage supply cable networks consist of both underground and aerial parts, the effective risk area may be replaced by $A_s = \sum L_i d_i$, L_i being the length of each line section and d_i the corresponding collection distance.

In some cases detailed information about the cable types may not be available or the network consists of a complexed mixture of cable types (shielded/unshielded, aerial/underground). The formulae, based on measurements summarized in Chapter 10 of the ITU Lightning Handbook, can then be used to estimate the yearly number of prospective damages per incoming telecommunication cable to an

unprotected site. It should be assumed that the equipment resists at least $V_p = 1 \text{ kV}$ or 1.5 kV in accordance with [ITU-T K.20] and [ITU-T K.21], respectively.

A_a is the area representing direct strikes to an adjacent object and calculated as A_d .

A lightning discharge to an adjacent radiocommunication antenna mast may bring a substantial part or even the majority of the current through the interior of the telecommunication site by the antenna cables. This current and the current in the nearby mast will create high magnetic field derivatives inside an unshielded building.

9 Estimation of probability factors p

Every factor p can be divided into one representing the natural protective characteristics of the installation (building material, aerial or underground network) and another depending on the specific protective measures provided at the building or cabinet interface and such installed in the internal and external network (surge protective devices, cable shields and isolation techniques).

The user of this Recommendation should be aware of the fact that many of the values of the probability factors in the tables below are only rough estimations, while others are based on calculations or longer field experiences. The accuracy of the risk assessment method is to a high degree dependent on the input data of these factors.

In many cases, where several measures are taken, the effective probability factor may be given by the product of the particular values:

$$p_{eff} = \prod p_i, (p_i \leq 1)$$

e.g., where an incoming cable is provided with both metallic shields and surge protective devices.

The probability for injuries of people is reduced by measures minimizing the current through parts of the human body. This is achieved by extensive bonding measures within the risk areas and by limiting the conductivity of the ground or floor surface. Insulation with high breakdown voltage of lightning current carrying parts of the installation may serve the same purpose.

Examples of values of probability factors are given in Tables 1 to 4.

Tables 1 and 2 represent the effect of inherent and specifically provided protective measures to mitigate the resistive and inductive coupling due to lightning strikes to telecommunication building, to an adjacent antenna mast or to the close surroundings of the site.

The effective probability is in these cases the product of the relevant p-factors in Tables 1 and 2.

Table 1 – Values of p for different building materials

Building materials	$P_d P_a P_n$
Non-screening (wood, bricks, concrete without steel reinforcement)	1
Steel reinforced concrete with a standard mesh size	0.1
Metal container	0.01

Table 2a – Values of p for specific protective measures on the building

Specific external protective measures of the building	$P_d P_{inj}$
No external or internal lightning protection	1
External lightning protection according to IEC 1024-1 with Application Guides	0.1

Table 2b – Values of p for specific protective measures inside the building

Separate protective measures internal to the building	P_d P_a P_n P_{inj}
Internal EMC measures according to [ITU-T K.27]	0.5
Application of internal installation techniques in [IEC 62305-1]	0.1

Table 3 represents the protective effect of measures taken on incoming or leaving telecommunication and power supply services, external to the building and at the building interface.

The protective effect of laying underground cables is already included in the calculation of the risk area A_s .

A multiplication of the p-factors in Table 3 for different types of protective measures will give the effective reduction of the risk of damages, e.g., $p_{\text{shielding}} \times p_{\text{SPD}}$.

Based on field experiences, it is assumed that the implementation of SPDs at the entrance of a telecommunication site will reduce the number of lightning damages on equipment by at least 90%.

To reach a higher order of efficiency a particular installation technique is required, especially where strong high frequency magnetic fields are present, e.g., due to direct strikes to communication masts. High demands on the performance of bonding are needed for cable shields and SPDs.

A coordination of SPD protection levels and equipment resistibility must also be assured.

The use of metal-free opto cable will eliminate the risk for damages to telecommunication equipment.

Table 3 – Values of p for protective measures on incoming cables

Protective measures against conducted lightning transients	P_s P_n
Unshielded external cables without SPDs	1
Shielded external communication cables with maximum transfer impedance 20 Ω /km ($f < 1$ MHz)	0.5
Shielded external communication cables with maximum transfer impedance 5 Ω /km ($f < 1$ MHz)	0.1
Shielded external communication cables with maximum transfer impedance 1 Ω /km ($f < 1$ MHz)	0.01
Isolation transformers at the low-voltage network interface, (breakdown voltage > 20 kV)	0.1
Standard SPDs at cable entrances and normal installation technique	0.1
Selected SPDs, good coordination with equipment resistibility, qualified installation technique	0.01
Metal-free opto cables	0

Note that all shields shall be continuous along the cable route and correctly bonded to the reference plane of the site. A special care shall be given to the bonding of antenna cable shields and waveguides to the reference of building plane or shield.

Protective measures according to Tables 2a and 2b will contribute to reduce the risk for severe injuries to people being present inside or close to the telecommunication building during a thunderstorm.

However, in case of a direct strike to the structure, high potential differences may still occur between conducting elements.

The risk for injuries due to step and touch voltages may be further reduced by surfaces with poor conductivity and high breakdown voltages. Such measures intend to limit or prevent dangerous lightning currents from passing through the human body. This is achieved by appropriate working procedures as well as bonding measures within the working area.

Table 4 gives estimated probability factors for different material.

Table 4 – Values of p for different surface layers to mitigate step and touch voltages

Type of surface of the ground or conductive parts carrying lightning currents	P_{inj}
Wet concrete, humus	10^{-2}
Dry concrete	10^{-3}
Asphalt, wood	10^{-5}
Insulation layer with material of high breakdown voltage (cable plastic jacket, etc.)	10^{-6}

To get the effective p-factor for injuries, the values in Table 4 shall be multiplied with relevant values in Tables 2a and 2b.

10 Consequential damage factor d

The weighting factor δ represents the consequential effects of damage due to a lightning strike direct or close to the telecom centre or its incoming lines. It represents the relation between the estimated annual damages to an unprotected site and the total value of the object to be protected.

The weighting factor δ may adopt different values depending on the type of damage.

Injuries to people

Personnel safety is a key issue for protection designers and installers. Safety risks to people may exist from dielectric breakdown or due to lightning surges during installation and maintenance of lines connected equipment.

δ should be given the value 1 in case of risk for severe injuries to people.

Loss of service

It is usually difficult to estimate the prospective loss of services to subscribers due to a lightning strike. As an example it is assumed that a telecommunication centre is always in full operation after 24 hours after damage. In a severe case the centre may be out of operation for this time period or even longer, e.g., due to a direct strike to a connected nearby antenna mast.

With this assumption $\delta = 24/8760 = 2.74 \times 10^{-3}$ per damage (8760 hours in a year). However, in the majority of cases the service losses are limited to only a part of the network and the consequence of damage is reduced according to n_x/n_{tot} , where n_x is the number of subscribers affected by the damage and n_{tot} is the total number of subscribers connected to the exchange or remote site.

Physical damages

Damages to hardware equipment in a telecommunication centre are rarely total, even when there is no protection provided. The damages are normally limited to parts close to the interface to the external network, e.g., SLIC circuits on the signal side or rectifiers on the power supply side. For hardware damages, a value of $\delta = 0.20$ may be representative. A higher value may be chosen for direct strikes to the cable network.

Direct strikes to the telecommunication building or adjacent objects, especially antenna masts, will cause more severe damages than those caused by surges on incoming lines.

A factor δ as high as 0.8 is quite realistic for such a site with no protection provided.

11 Acceptable risk levels, R_{accept}

The purpose of the protection measures is to reduce the number of damages and to limit the consequential effects of damage to a tolerable level. Where only economic damages have to be considered, the acceptable risk level is decided by the telecommunication operator.

When setting the acceptable risk level, the consequences of a degradation or loss of services for the subscribers should be a determining factor. It shall include direct expenses for service unavailability of equipment, computers and other information technology. A service interruption may also affect the business productivity and revenues. Emergency services may have high indirect expenses associated with loss of operations and should be paid high attention.

The decision of an appropriate risk level should also be based on costs for the protective measures compared with prospective physical damages, all referred to on a yearly basis.

The acceptable risk level regarding injuries to people should be assessed by safety authorities, (e.g., international or national bodies).

Acceptable risk levels, R_{accept} , should, with the exception of risk for injuries, be decided by the operator of the telecommunication network. Table 5 gives some representative values for hardware damages and service losses.

Table 5 – Representative values of R_{accept}

Type of damage	R_{accept}
Physical	10^{-3}
Loss of service	10^{-4}

Appendix I

Example – Risk assessment of damages to a telecommunication site with an adjacent antenna mast

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

Basic data

Building, size and material:	5 × 3 × 3 m, reinforced concrete.
Antenna tower, height h and distance from building:	80 m placed 4 m from the telecom building.
Total cable length and shielding:	Power cable 600 m, unshielded, underground. Telecom cables 1000 m, unshielded, overhead.
Soil resistivity:	High, estimated to at least 500 Ω m within the area considered.
Lightning flash density:	No measurements available. 24 thunderstorm days/year according to a keraunic map.

See Figure I.1.

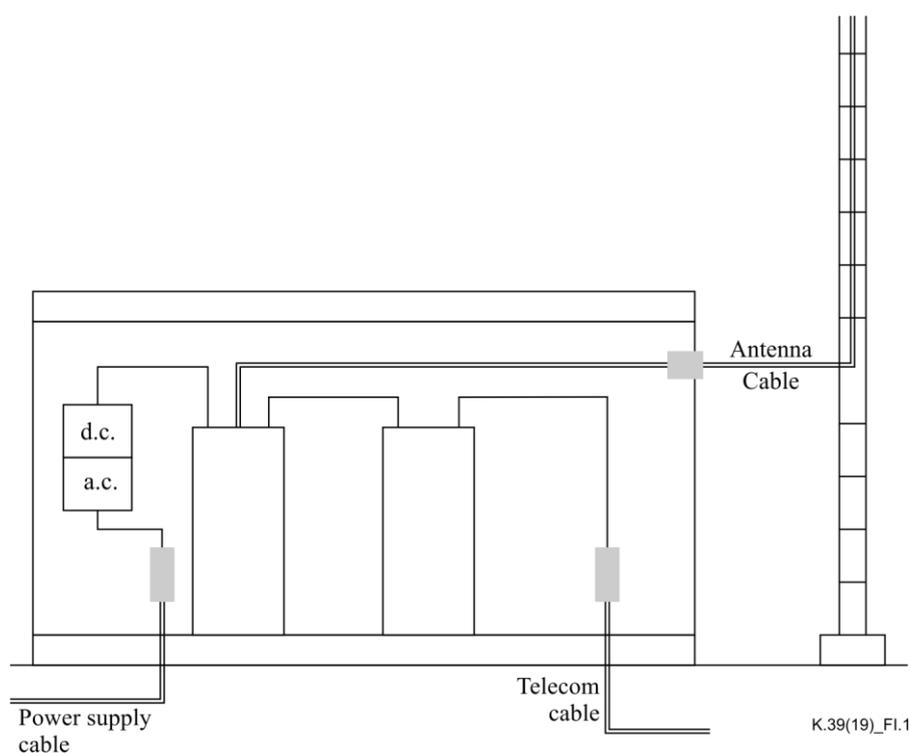


Figure I.1 – Example of a well-shielded telecommunication building with incoming cables

Calculation of risk areas, A

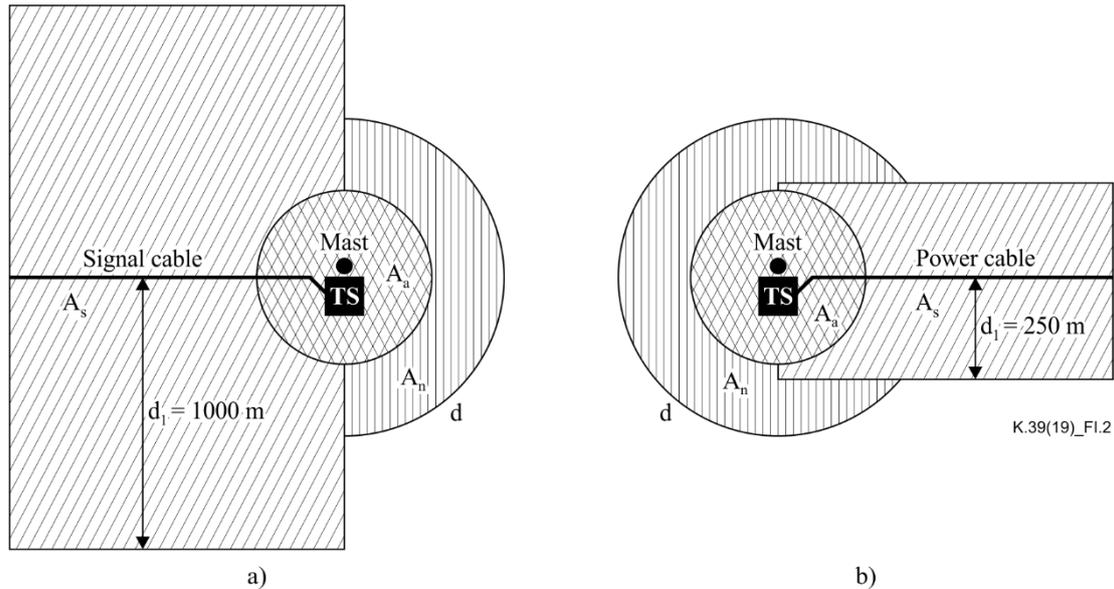


Figure I.2 – Risk areas for the telecommunication and power supply cases

According to Figure I.2 a) and b), the risk areas will have the following values:

$A_d \approx 0$ (covered by A_a)

$$A_a = \pi(3h)^2 = \pi(3 \times 80)^2 = 180\,956 \text{ m}^2 = 0.2 \text{ km}^2$$

$A_s = 2 \times d_{\text{Itele}} \times L_{\text{tele}} - A_a/2 = 2 \times 1000 \times 1000 - 90\,000 = 1.91 \times 10^6 \text{ m}^2 = 1.9 \text{ km}^2$ for the telecommunication cable

$A_s = 2 \times d_{\text{Ipower}} \times L_{\text{power}} - A_a/2 = 2 \times 250 \times 600 - 90\,000 = 0.21 \times 10^6 \text{ m}^2 = 0.2 \text{ km}^2$ for the power cable

The nominal risk area for nearby strikes, A_n , is reduced by the area already covered by A_a and by A_s for overhead telecommunication and underground power supply cables, respectively.

For the telecommunication cable case: $A_{n(\text{tele})} = \pi d^2/2 - A_a/2 = 0.3 \text{ km}^2$

For the power supply cable case: $A_{n(\text{power})} = \pi d^2/2 - A_a/2 + (\pi d^2/3 - \sqrt{3} d_1^2) = 0.5 \text{ km}^2$

where the terms within the brackets represent the area of a circle segment when $d = 2d_1$.

Calculation of expected number of damages, F

The flash density N_g is calculated by the formula $N_g = 0.04 \times T_d^{1.25} = 2.1$ per km^2 and year for $T_d = 24$.

The number of damages, F , depends on N_g , (A_d) , A_a , A_n , A_s and the different probability factors, p , selected from Tables 1 to 4.

With no protection measures, in addition to those given by shielding of the building construction and bonding of incoming antenna cable shields, the number of damages is:

$$F = N_g((A_{n(\text{tele})} + A_{n(\text{power})})p_n + (A_{s(\text{tele})} + A_{s(\text{power})})p_s + A_a p_a) = 2.1((0.3 + 0.5) \times 0.1 + (1.9 + 0.2) \times 1 + 0.2 \times 0.01) = 2.1(0.08 + 2.1 + 0.002) = 4.6 \text{ per year.}$$

The reinforced concrete of the building reduces F_n by a factor $p_n = 0.1$ and F_a is reduced by $p_a = 0.01$ due to the low shield transfer impedance of the antenna cables, which are assumed to have their shields well bonded to the reinforcement.

One damage on average more than four times every year will undoubtedly not be tolerable.

It is obviously more efficient to install additional protective measures on the incoming lines.

Surge protective devices on all telecommunication and the low-voltage power line will reduce the number of damages, F_n and F_s , by $p = 0.01$ if qualified installation methods are used.

With those measures the expected number of damages will be:

$F = 2.1(0.08 \times 10^{-2} + 2.1 \times 10^{-2} + 0.2 \times 10^{-2}) = 5.0 \times 10^{-2}$ damages per year corresponding to on average 1 damage in 20 years.

Calculation of risk levels, R

The risk for damages and loss of service is reduced according to the value of weighting factor δ .

It is assumed that the weighting factor for physical damages to the equipment is $\delta = 0.20$ except for direct strikes where $\delta = 0.8$. The risk for hardware damages is then:

$$R_{\text{damage}} = (F_n + F_s)\delta_{\text{dam1}} + F_a \cdot \delta_{\text{dam2}} = 2.1((0.08 \times 10^{-2} + 2.1 \times 10^{-2}) \times 0.2 + 0.2 \times 10^{-2} \times 0.8) = 0.92 \times 10^{-2} + 0.16 \times 10^{-2} = 1.1 \times 10^{-2}$$

The risk for loss of service is calculated in a similar way assuming the service interruption being e.g., 24 hours and $\delta = 24/8760 = 2.74 \times 10^{-3}$ (all lines affected).

$$R_{\text{loss}} = \sum F \cdot \delta = 5.0 \times 10^{-2} \times 2.74 \times 10^{-3} = 1.4 \times 10^{-4}$$

The risk for severe injuries to people, being present inside or near outside the site, may be further reduced by bonding and insulating measures. With an external earthing arrangement with meshed earthing network following [IEC62305-1] ($p = 0.1$) and the surface of the working area covered with asphalt, wood or equivalent material, ($p = 10^{-5}$), the risk is (assuming $\delta_{\text{injury}} = 1$).

$$R_{\text{injury}} = \sum F \cdot \delta = 5.0 \times 10^{-2} \times 0.1 \times 10^{-5} \times 1 = 5.0 \times 10^{-8}$$

If needed, additional measures may be implemented to further reduce the risk for physical damages, service losses or injuries to people.

Bibliography

- [b-ITU-T K.40] Recommendation ITU-T K.40 (2019), *Protection against lightning electromagnetic pulses in telecommunication centres*.
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