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PART I

Series K Recommendations

PROTECTION AGAINST INTERFERENCE

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PROTECTION AGAINST INTERFERENCE

Recommendation K.1

CONNECTION TO EARTH OF AN AUDIO-FREQUENCY TELEPHONE LINE IN CABLE

(New Delhi, 1960)

Introduction

The present state of technique is such that cables can now be so manufactured that the capacitances of the various circuits at audio-frequencies, with respect to the sheath, are very exactly balanced.

This balance of the capacitances is adequate in the case of circuits having no unbalanced connections to earth.

On the other hand, every connection to earth, even with apparent balance, is likely to involve the inductance and resistance unbalances of each of the circuits to which such an earth connection is made.

The dielectric strength between the conductors of a cable is appreciably less than that between the conductors and the sheath and, consequently, the connection to earth of some of these conductors would create a danger of breakdown of the dielectric separating the conductors when the cable is subjected to severe induction.

When a loaded cable is subjected to a high induced electromotive force, the presence of connections to earth would permit a flow of current the value of which could, in some cases, exceed the limit for avoiding deterioration of the magnetic properties of loading coils

For these reasons, the CCITT makes the following unanimous recommendations:

No earth connection should be made at any point whatsoever on an audio-frequency circuit, unless all the line windings of the transformers are permanently connected to the sheath by low resistance connections at one or both ends of the cable.

As a general rule, it is desirable not to make any earth connection at any point whatsoever on an installation (telephone or telegraph) connected metallically to a long-distance line in cable.

However, if, for special reasons, an earth connection must be made to an installation directly connected to audio-frequency circuits, the following precautions should be taken:

a) The earth connection must be made in such a manner as not to affect the balance of the circuits with respect to earth and with respect to the neighbouring circuits.

b) The breakdown voltage of all the other conductors of the cable, with respect to the conductors of the circuit connected to earth, must be appreciably greater than the highest voltage which, owing to induction from neighbouring electricity lines, could exist between these conductors and those of the circuit connected to earth.

See the CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988 (see also Recommendation K.26).

c) When the installation connected to the cable is a telegraph installation, it is also necessary to conform to CCTT Recommendations concerning the conditions for coexistence of telephony and telegraphy (Series H Recommendations).

Recommendation K.2

PROTECTION OF REPEATER POWER-FEEDING SYSTEMS AGAINST INTERFERENCE FROM NEIGHBOURING ELECTRICITY LINES

(New Delhi, 1960)

To avoid interference to the power feeding of repeaters , either by magnetic induction from a neighbouring electricity line or as the result of resistance coupling with a neighbouring electricity line, the CCITT recommends that, whenever possible, the repeater power-feeding system should be so arranged that the circuit in which the power-feeding currents circulate (including the units connected to it) remains balanced with respect to the sheath and to earth.

Recommendation K.3

INTERFERENCE CAUSED BY AUDIO-FREQUENCY SIGNALS INJECTED INTO A POWER DISTRIBUTION NETWORK

(New Delhi, 1960)

In the event of the use by electricity authorities of audio-frequency signals injected into the power distribution network for the operation of remote control systems , such signals may cause interference to neighbouring telecommunication lines.

Calculation of such interference may be carried out, using the formulae in the *Directives* , and finding the values of the equivalent disturbing voltages and currents for these audio-frequency signals.

Recommendation K.4

DISTURBANCE TO SIGNALLING

(Geneva, 1964)

In order to reduce interference to direct current signalling or to alternating current signalling at mains frequencies on telecommunication lines on open wires, in aerial or underground cables, or on composite lines, arising from neighbouring alternating or direct current electricity lines, the possibility should be examined of adopting one or more of the following methods in each case where such interference appears liable to be produced or where it has been observed to exist:

— development and use of telecommunication systems:

a) in which the balance to earth of the signalling circuit is maintained in all circumstances, even during switching operations (see [1]);

b) in which, besides being balanced, interference in such systems due to longitudinal currents arising from direct or indirect earth connections is avoided;

— choice of site for telephone exchange earths so that, as far as possible, they are, in particular, remote from electric traction lines and also from the earth electrodes of power systems;

— adoption of measures for reducing induced currents (use of telephone cables with a low screening factor , use of booster transformers in single-phase traction lines, etc.) to facilitate the use of existing signalling systems;

— use of neutralizing transformers or use of the active reduction system in telecommunication circuits to compensate currents produced by induced voltages;

— use of tuned circuits to provide a high impedance at the frequency of the interfering current.

Note — The *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* mention a limit of 60 V for the voltage induced into telecommunication lines. This limit of 60 V concerns only the safety of personnel and should not be taken to be a limit for the purpose of ensuring that there is no interference to signalling systems. In the case of unbalanced signalling systems, such interference may be caused by much lower voltages, as is mentioned in [2].

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , Vol. IX, ITU, Geneva, 1988.

[2] *Ibid* ., Vol. VI.

Recommendation K.5

JOINT USE OF POLES FOR ELECTRICITY DISTRIBUTION

AND FOR TELECOMMUNICATIONS

(Geneva, 1964)

Administrations that wish to adopt joint use of the same supports for open-wire or aerial cable telecommunication lines and for electricity lines are recommended, when national laws and regulations permit such an arrangement, to take the following general considerations into account:

1) There are economic and aesthetic advantages to be derived from the joint use of poles by Administrations and electricity authorities.

2) When suitable joint construction methods are used, there is, nevertheless, some increased likelihood of danger by comparison with ordinary construction methods, both to staff working on the telecommunication line and to the telecommunication installation connected thereto. Special training of personnel working on such lines is highly desirable and especially when the electricity line is a high-voltage line.

3) The rules given in the *Directives* in connection with danger, disturbance, and staff safety should be complied with (see [1]).

4) Special formal agreements are desirable between the Administration and the electricity authority in the case of joint use of poles in order to define responsibilities.

5) If joint use is applied on short sections (of the order of 1 km), in most cases a few simple precautions may be enough to ensure that disturbances due to electric and magnetic induction are tolerable.

Reference

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , Vol. II, ITU, Geneva, 1988.

Recommendation K.6

PRECAUTIONS AT CROSSINGS

(Geneva, 1964)

Introduction

Crossings between overhead telecommunication lines and electricity lines present dangers for persons and for equipment.

A number of arrangements have been made by the responsible authorities in various countries, resulting in national regulations. These regulations are sometimes rather inconsistent and the effectiveness of the arrangements made varies somewhat.

Bearing in mind the stage now reached in technique and the experience gained in the various countries, it now seems possible for the CCITT to issue a Recommendation advocating the arrangements which seem to be the most effective, on the basis of which countries might draw up or revise their national regulations.

It is therefore recommended that, when an overhead telecommunication line has to cross an electricity line, either of two methods may be used: namely, to route the overhead telecommunication line in an underground cable at the crossing, or to leave it overhead.

1 Line routed underground

This method is not always to be recommended because if a conductor of the electricity line breaks, the underground cable may be in a region where the ground potential is high. This situation is dangerous if the cable has a bare metallic sheath ; the higher the voltage of the power line, the shorter the length of the cable section, and the higher the resistivity of the soil, the greater is the danger. This dangerous situation also arises whenever an earth fault occurs on a pylon near the cable.

If circumstances require the overhead line to be routed in a cable, special precautions will have to be taken at the crossing, for example:

— the use of an insulating covering around the metal sheath of the cable;

— the use of a cable with an all-plastic sheath.

2 Line left overhead

The method whereby the power line is separated from the telecommunication line by a guard-wire or a cradle cannot generally be recommended.

In any case, regardless of the circumstances, a minimum vertical distance has to be kept between telecommunication conductors, in conformity with national regulations.

There are, moreover a number of arrangements that could be introduced to reduce the danger:

2.1 *Use of a common support* at the crossing-point, provided the insulators used for the telecommunication line have, if necessary, a high breakdown voltage.

2.2 *Insulation of the conductors* , preferably the telecommunication conductors, provided that such insulation is properly adapted to the conditions existing.

2.3 *Reinforcement of the construction* of the power line where the crossing takes place, so as to minimize the risk of a break.

3 Circumstances in which the various arrangements in §§ 2.1, 2.2 and 2.3 above are applicable

The application of these methods depends primarily on the voltage of the power line. The voltage ranges to be taken into account are not related to the International Electrotechnical Commission (IEC) standardization, because of the special features of the problem raised.

3.1 *Systems using voltages of 600 V or less*

Arrangements to be as in § 2.1 and/or § 2.2.

3.2 *Systems using voltages of 60 kV or more*

(In particular the ‘‘high reliability’’ system referred to in [1].)

Arrangements to be as in § 2.3, if necessary.

3.3 *Intermediate voltage systems*

For the 600-V to 60-kV range, because of the variety of voltages, the mechanical characteristics of lines and the operating methods encountered, it is impossible to issue precise recommendations.

However, one or more of the arrangements described above might be applicable, although certain special cases call for thorough examination in close collaboration with the services concerned.

Reference

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , Vol. VI, ITU, Geneva, 1988.

Recommendation K.7

PROTECTION AGAINST ACOUSTIC SHOCK

(Geneva, 1964; modified at Malaga-Torremolinos, 1984)

In certain unfavourable circumstances, sudden transient voltages of exceptionally high instantaneous amplitude, of the order of 1 kV for example, may occur across a telephone set which is normally connected to a metal wire line, as a result of electromagnetic disturbances affecting the line.

If such voltages occur during a telephone call, they are liable to cause, through the earphone, such strong sound pressure as to endanger the human ear and the nervous system.

Such bursts are most likely to occur when lightning protectors are inserted in the two conductors of a telephone line and do not function simultaneously, so that a compensating current flows through the telephone. The CCITT therefore recommends the use, particularly on lines equipped with vacuum lightning protectors, of protection devices against acoustic shock arising from inadmissibly high induced voltages (see Chapter I/6 of the *Directives* , page 16).

Such devices consist, for example, of two rectifiers, in parallel and with opposite polarities, or of other semiconductor components connected directly in parallel to the telephone receiver.

For telephone sets of more recent design, sudden voltage bursts liable to occur in the receiver may be eliminated by ensuring that the electrical circuits between the access to the line where dangerous voltages originate and the earphone itself have suitable characteristics.

It is also recommended that the proposed provisions should limit the aural discomfort which might be caused by abnormal electrical signals applied to subscriber systems as a result of erroneous operation or unwanted actuation of the equipments to which subscriber systems are connected.

The provisions adopted to provide protection against acoustic shock should:

— be compatible with the technical requirements applicable to the equipment;

— facilitate performance checks;

— not noticeably impair telephone transmission quality.

For this purpose, it is particularly recommended that:

1) with regard to specific devices, their dimensions should be such that they occupy a small space, so that they can be placed in the case of the subscriber’s or operator’s telephone receiver ;

2) the electrical characteristics should not show significant changes under the temperature and humidity conditions to which the device is subjected in service;

3) effectiveness should be checked in conformity with the provisions of CCITT Recommendation P.36.

Recommendation K.8

SEPARATION IN THE SOIL BETWEEN TELECOMMUNICATION CABLES AND EARTHING SYSTEM OF POWER FACILITIES

(Mar del Plata, 1968; modified at Melbourne, 1988)

Introduction

If a buried telecommunication cable without an insulating layer around the metal sheath is located in the vicinity of a high voltage earthing system, part of the earth potential rise (EPR) in the event of an earth fault in the high voltage system can transfer to the telecommunication system through resistive coupling.

According to CCITT and CIGRE documents [1-3], EPR from high voltage power installations is recognized as a source of dangerous disturbance to telecommunication systems and a hazard to service personnel.

It is possible to calculate EPR near power installations following the methods given in the *Directives* [1] (see Volumes II and III), and this is especially recommended for dealing with switchyard earthing systems.

The object of the present Recommendation is to give practical guidelines in determining safe distances between buried telecommunication cables and earthing systems of power facilities in the absence of local measurements or calculated values of EPR.

1 Scope

Earth fault in a power system causes earth currents which raise the earth potential where the fault current leaves and enters the earth. The magnitude and extension of the EPR depends on the fault current level, the earthing resistance , the soil resistivity and the layout of the earthing arrangement. The duration of an earth fault depends on the type of power network.

This Recommendation gives information about:

a) locations where EPR may occur;

b) duration of EPR in different types of power networks;

c) ‘‘ safe distance ´LP d) measures to be taken if the safe distance is not achieved.

2 General considerations

The minimum separation in soil to be recommended between an earthing system of a power installation and telecommunication cables depends on a number of factors:

— type of power network;

— fault current level;

— power earthing system;

— soil resistivity;

— local conditions.

3 Type of power network

Power networks are classified according to how the neutral point is connected to earth. The earthing system affects both the level and duration of the fault current, and hence the EPR.

3.1 *Networks with the neutral point earthed directly or through a low impedance*

CIGRE International Conference on Large High-Tension Electric Systems.

The level of an earth-fault current is high. A relay system will clear the fault in a short time.

3.2 *Networks with the neutral point earthed through an arc suppression coil*

The level of an earth-fault current is small, usually not exceeding 100 amperes for each coil. The duration of an earth fault is relatively short.

Such networks may be equipped with delayed tripping to clear permanent earth faults.

3.3 *Networks with the neutral point isolated from earth*

The level of an earth-fault current is normally low, but the fault duration might be very long. Networks of large extent may give rise to large capacitive fault currents.

If such networks are equipped with devices for automatic fault clearing, the fault duration is short to medium.

4 Locations where earth potential rise may occur

4.1 *Power stations and sub-stations*

Power stations and sub-stations are most likely to experience EPR. The size of the station, the number and construction of power lines attached to the station, and the earthing arrangement are factors influencing the level and station, and the earthing arrangement are factors influencing the level and zone of EPR. As given in reference [4] the layout and structure of the earthing arrangement depends on regulations, size, age, purpose and location. If the power lines entering the station are provided with earth wires , they will be connected to the earthing system in the station.

4.2 *Power line towers*

Power line towers with footing electrodes are subjected to EPR due to earth-fault current in the power system, and currents from lightning strikes normally be connected to the tower electrodes. The probability of high EPR decreases when a power line is equipped with earth wires.

5 Magnitude of earth potential rise

The magnitude of the EPR depends on the power system voltage, the power line construction, the fault current level and the earthing resistance.

6 Zone of earth potential rise

EPR is measured as the earth potential referred to a distant neutral earth. The zone of EPR, near an earthing system, varies from some tens to some thousands of metres, depending on soil resistivity, the layout of the earth electrode, and other local conditions. Further information is found in reference [5]. The zones of EPR in urban areas are small compared to what can be expected in rural areas. Only EPR zones having a potential higher than values given in reference [1] are considered as dangerous. Measurements and calculation of the EPR zones are made by the power distribution authorities.

7 Duration of earth potential rise

The duration of an earth fault and hence the EPR, depends on the type of power network.

7.1 *Networks with the neutral point earthed directly or through a low impedance*

The duration of an earth fault is generally less than 0.2-0.5 s.

7.2 *Networks with the neutral point earthed through an arc suppression coil*

The duration of an earth fault is normally less than 0.8 s, but may in some cases last for several seconds. Such networks may be equipped with delayed (a few seconds) tripping to clear permanent earth faults.

7.3 *Networks with an isolated neutral point*

The duration of an earth fault can be very long, and may last until another earth fault occurs.

If such networks are equipped with automatic fault-clearing devices, the fault duration may be as short as in § 7.1.

8 Minimum separation in soil between buried telecommunication cables and power earthing systems

The EPR near a high voltage earthing system can be estimated from calculations based on idealized earth electrodes and a homogeneous soil resistivity in the EPR zone. In practice it is not possible to make an exact calculation of the potential transferred from a high voltage earthing system to an adjacent telecommunication cable. However, by feeding a current into the high voltage earthing system from a sufficiently great distance, the voltage

between the cable sheath and an auxiliary electrode in the area of neutral potential can be measured. The result must be corrected proportionately to the actual earth-fault current. (On armoured cables the correction factor is not linear, but depends on the magnetic characteristic of the ferromagnetic cable screen.) In the absence of other experiments, local measurements or calculated values of EPR, the values in Table 1/K.8 for the minimum separation in soil between ‘‘ordinary’’ telecommunication cable with a metal sheath in direct contact with the soil and a high voltage power earthing system should be observed.

H.T. [T1.8]

TABLE 1/K.8

Separation in soil (in metres) between telecommunication cables and high voltage earthing systems beyond which no calculation nor measurement is necessary

Earth resistivity	Power network system with { directly earthed neutral		Location
Less than 50 ohm | (mu |	2 5	5 10	Urban Rural
50-500 ohm | (mu |	5 10	10 20	Urban Rural
500-5000 ohm | (mu |	10 20	50 100	Urban Rural
{	10 20	50 100-200 | ua)	Urban Rural

a) 200 metres in areas with extremely severe soil conditions, i.e. greater than 10 | 00 ohm | (mu | .

Note 1 — The values in the table normally refer to lines and installations which have a nominal voltage equal to or greater than 132 kV.

Note 2 — The hazards due to lightning strokes on electric plants are not covered and may require taking into considerating the methods of § 9 for high keraunic level areas.

Note 3 — In the case of tower earthing, much shorter distances can be used if the power lines include earth wires.

Note 4 — Hazards for people working on telecommunication lines inside the zone of EPR is not taken into consideration by these values; such hazards require additional measures or precautions.

Table 1/K.8 [T1.8], p.

9 Measures to be taken to avoid hazards from EPR

The primary method to avoid dangerous influence from EPR is to increase the distance between telecommunication cables and power earthing systems. If local conditions do not permit sufficient separation to avoid dangerous EPR, the telecommunication cables should be provided with insulation, for example by placing the cables in insulating plastic tubes.

When the magnitude of EPR is extremely high, or the zone of EPR is of very great extension, optical fibre cables or radio-relay systems may be used instead of metallic cables.

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electrified power and electrified railway lines* , Vols. II and III, ITU, Geneva, 1988.

[2] CCITT Study Group V — Contribution No. 61/1979.

[3] CIGRE No. 36-04/1970 — Ground potential rise and telecommunication lines.

[4] ELECTRA No. 71/1980 Station grounding — Safety and interference aspects.

[5] ELECTRA No. 60/1978 — Zone of influence of ground potential rise.

Recommendation K.9

PROTECTION OF TELECOMMUNICATION STAFF AND PLANT AGAINST A LARGE EARTH POTENTIAL DUE TO A NEIGHBOURING

ELECTRIC TRACTION LINE

(Mar del Plata, 1968)

1 General

From the technical standpoint the precautions taken on electrified railways to protect staff and plant may differ according to a number of factors, the chief of which are:

— ground resistivity ;

— electrical line equipment (track circuits) which, though necessary for railway safety installations, may prevent the systematic connection to rail of metal structures near the railway;

— the characteristics of the protective devices required which, with a.c. electric traction systems , may be to some extent affected by the presence (or absence) of booster-transformers ;

— the degree of insulation of the contact system, which may also affect the nature of the protective devices, particularly in the case of relatively low-voltage electric systems such as 1500 V d.c. lines;

— the means to be recommended for linking a metal structure to the rail in case of overvoltage without making a permanent connection (one method is to make the connection via a spark gap).

2 A.c. electric traction lines

It is recommended that neighbouring metal structures, for example all those within a certain distance from the line, be connected to rail, provided that there are no safety installations which make this impossible.

If the structures cannot be connected to rail, it is recommended that they be earthed to an earth electrode having a sufficiently low resistance.

3 D.c. electric traction lines

Protective measures should also take account of the need to avoid any risk of electrolytic corrosion connecting to rail only such metal structures as are sufficiently insulated from the ground or linking them via a spark gap or, in the case of metal structures carrying an adequately insulated contact system or lines with a sufficiently low service voltage, connecting neither to rail nor to earth.

4 Telecommunication cables

In new installations, it is recommended that cables near rails, at the entry to substations or over metal bridges should have an outer plastic covering, possibly of high dielectric strength , where it is necessary to prevent contact between the cables and such structures.

If, on the other hand, cables with metal sheaths already exist, a good solution, at least in the case of large railway stations, may be to connect the sheaths to rail.

5 Conditions to be fulfilled by PTT installations in the neighbourhood of electric traction lines

The following are the main precautions taken to protect such installations:

— placing them outside the danger zone;

— screening;

— substituting insulating components for metal components, in particular the sheaths or covering of cables or in the construction of repeater cabinets or boxes.

Note — The above recommendations are inspired solely by technical considerations which are to be carefully weighed up in each case. It goes without saying that every Administration must comply with the laws and regulations in force in its country.

Recommendation K.10

UNBALANCE ABOUT EARTH OF TELECOMMUNICATION INSTALLATIONS

(Mar del Plata, 1968; modified at Malaga-Torremolinos, 1984)

1 Unbalance about earth of telecommunication equipments

In the interests of maintaining an adequate balance of telecommunication equipments and of the lines connected to them, it is recommended that the minimum permissible value for the unbalance of telecommunication installations longitudinal conversion loss (LCL) should be 40 dB (from 300 to 600 Hz) and 46 dB (from 600 to 3400 Hz). This is a general minimum value and does not exclude the possibility of higher minimum values being quoted for particular requirements in other Recommendations of the CCITT

The test arrangement in Figure 1/K.10 should be used to measure the unbalance of telecommunications equipment.

Nomenclature, definition and measurement of unbalance are based on Recommendations G.117 and O.121.

See, in particular, Recommendation Q.45, and also the outcome of further studies under Question 13/V [1].

Figure 1/K.10 p.2

The specification $Z_{L1} = Z_1/4$, $Z_{L2} = Z_2/4$ should apply in the audiofrequency range. (See Recommendation Q.45 and Recommendation O.121, § 3.2.)

The following terms are specified:

— longitudinal conversion loss (LCL) (applicable for one- and two-port networks):

$$20 \log_{10} \left| \frac{E_{L1}}{V_{T1}} \right| \text{ dB}$$

— longitudinal conversion transfer loss (LCTL) (applicable for two-port networks only):

$$20 \log_{10} \left| \frac{E_{L1}}{V_{T2}} \right| \text{ dB}$$

2 Unbalance about earth of telecommunication lines

If a long line is tested, essentially the same test circuit and nomenclature should be used as given in Figure 1/K.10. However, both the longitudinal induction and unbalances are distributed along the line. Consequently, the longitudinal conversion losses and longitudinal conversion transfer losses are not only determined by the inherent parameters but also by the distribution of the wire to earth/sheath voltages. To obtain the effect of unbalance in practical cases, it is recommended that measurements be made both with the wire to sheath voltage of constant polarity (i.e. supply at end, see Table 1/K.10) and with the wire to sheath voltage changing in polarity at the midpoint (i.e. supply at the middle, see Table 2/K.10).

In Table 3/K.10, conclusions derived from those measurements are listed.

TABLE 1/K.10 (a traiter comme figure MEP), p.

TABLE 2/K.10 (a traiter comme figure MEP), p.

TABLE 3/K.10 (a traiter comme figure MEP), p.

ANNEX A

(to Recommendation K.10)

Example for calculating transverse voltages of a telecommunications line

A.1 *General*

The Contribution mentioned in reference [2] contains many calculated values regarding the relationship between the longitudinal voltage and its conversion into the transverse one. This annex is an extract of that Contribution. It gives background information about the application of measurement proposals for lines which are contained in Recommendation K.10.

The most important results are summarized in Table A-1/K.10. They relate to a symmetric pair composed of paper-insulated copper wires of 0.9 mm in diameter and stranded in star quads with an equivalent mutual capacitance of 34 nF/km. In the course of the calculation, only the capacitance unbalance has been simulated.

A.2 *Wire to sheath voltages*

The distribution of the wire to sheath (earth) voltages are basically determined by (see column 2 of Table A-1/K.10 where, for the sake of simplicity, it is assumed that the total voltage source in the longitudinal path is 100 V):

— the location of the longitudinal source (see column 1 in Table A-1/K.10), and

— the termination of the longitudinal path (see column 3 of Table A-1/K.10).

On the basis of schemes indicated in column 2 of Table A-1/K.10, the following tendencies are worth mentioning:

a) When the e.m.f. is applied at one of the terminals of the longitudinal path, the wire to sheath voltages tend to be uniform with the same polarity along the line. When switch S is closed, the voltages decrease (compare the solid line with broken ones in the 1st row and 2nd column).

b) When the e.m.f. is applied at an intermediate section of the line, e.g. concentrated in the middle or distributed uniformly, then the wire to earth voltages have the same magnitudes but opposite polarity on each half of the line (see the curves of broken line in the 2nd and 3rd rows). The symmetry of the distribution is disturbed if only one switch at the terminals is closed (see the solid lines in the 2nd and 3rd rows). The differences between voltage distributions arising from terminations of open/closed and closed/closed switch positions tend to decrease with the increase of both the length of line and frequency.

A.3 *Longitudinal conversion losses*

The longitudinal conversion losses and the longitudinal transfer losses (defined in Tables 1/K.10 and 2/K.10) are basically determined by:

— the distribution of wire to sheath voltages, see § A.2, and

— the magnitude and distribution of capacitance unbalance

Regarding the second aspect, three cases have been studied. These are indicated in Table A-1/K.10 as one-sided, perfectly equalized and equalized with additional unbalance. The one-sided uniform ΔC = 600 pF/km tends to simulate the worst case which in practice does not exist. The perfectly equalized line (with crossing at each 0.5 km) can also never be reached.

The magnitudes of longitudinal conversion losses can be explained by a consideration of the fact that high transverse voltages are generated as a result of capacitance unbalance if the location of an unbalance coincides with high wire to earth voltages. The unbalance of a subsequent section tends to amplify the transverse voltage if both the direction of the unbalance and polarity of the wire to earth voltage are the same as those of the previous section. However, if one of them is reversed, the resultant transverse voltages become lower.

In the case of a well equalized line, the magnitude of the longitudinal conversion losses is high and is largely independent of both the location of the e.m.f. and the position of the switches at the terminals (see column 5 in Table A-1/K.10).

If the conversion losses increase significantly in magnitude with the opening of switch S and depend on the direction of supply, then the presence of local unbalance may be expected (see column 6 of Table A-1/K.10).

The low values of longitudinal conversion losses (i.e. less than 60 dB) might be caused by a one-sided nature of the capacitance unbalance (see column 4 of Table A-1/K.10). This is the case for Recommendation K.10 where the testing method specified in § 2 may produce significantly higher values for longitudinal conversion losses than the actual values in real conditions of power induction. In this case, more realistic values can be obtained by the method given in Table 2/K.10.

Tableau A-1/K.10 (a traiter comme figure MEP), p.

The main unbalance on lines is the capacitance unbalance. However, occasionally, the resistive unbalance (series resistance, R) is important as well. As has been pointed out before, when switch S_2 is open, the effect of shunt unbalance (in case of line *C*) is emphasized. If the switch S_2 (or S_1 and S_2 indicated in Table 2/K.10) is opened and the conversion loss remains unchanged (or even decreases), it indicates that series unbalance may not be the primary cause of the line unbalance unbalances are dominant. It should be noted, that while the reason for having Z_L and S_2 is to allow the tester to distinguish between series and shunt unbalances of the line, the effectiveness of this feature depends on the shunt impedance of the line provided by the resultant earth capacitance of the line (e.g. length of line [3]).

References

[1] CCITT Question 13/V *Unbalance of telephone installations* .

[2] CCITT Contribution COM V-38, *Study of relation between unbalance and induced transverse voltages* , 1981-1984 (Hungarian Administration).

[3] IEEE Std 455 — 1976 *IEEE Standard test procedure for measuring longitudinal balance of telephone equipment operating in the voice band* . Published by IEEE, Inc., September 30, 1976.

Recommendation K.11

PRINCIPLES OF PROTECTION AGAINST OVERVOLTAGES | AND OVERCURRENTS

(Geneva, 1972; modified at Malaga-Torremolinos, 1984 and at Melbourne, 1988)

Introduction

Current CCITT documents recognize lightning and faults on nearby electrical installations as sources of dangerous disturbances in telecommunications lines, which may cause damage leading to interruptions in service and the need for repairs or even hazards to personnel.

The object of the present Recommendation is to set out principles which enable the frequency and seriousness of such disturbances to be limited to levels which take account of quality of service, operating costs and safety of personnel. These principles are applicable to all parts of a telecommunications system. More details on certain methods of protection and for certain parts of the system are given in the References and in the following Recommendations: K.5, K.6, K.9, K.12, K.15, K.16, K.17. Information about disturbing phenomena and protection techniques are given in [1] and [2] (see also Recommendation K.26).

This Recommendation deals principally with the local exchange, local loop plant and subscribers equipment, but its contents may have wider application.

Note — The disturbing phenomena, when they appear, are relatively rare or of very brief duration (usually of the order of a fraction of a second) and in framing the present Recommendation, consideration has not been given to methods of avoiding interruption of the functioning of equipment during an actual disturbance. The CCITT is pursuing the study of such methods.

1 General considerations

1.1 *Origin of dangerous overvoltages and overcurrents*

1.1.1 *Direct lightning strikes*

Such strikes may cause currents of some thousands of amperes to flow along wires or cables for some microseconds. Physical damage may occur and overvoltage surges of many kilovolts may apply stress to the dielectrics of line plant and terminal equipment.

1.1.2 *Lightning strikes nearby*

Lightning currents flowing from cloud to earth or cloud to cloud cause overvoltages in overhead or underground lines near to the strike. The area affected may be large in districts of high earth resistivity.

1.1.3 *Induction from fault currents in power lines including electric traction systems*

Earth faults in power systems cause large unbalanced currents to flow along the power line inducing overvoltages into adjacent telecommunications lines which follow a parallel course. The overvoltages may rise to several kilovolts and have durations of 200 to 1000 ms (occasionally even longer) according to the fault clearing system used on the power line.

1.1.4 *Contacts with power lines*

Contacts may occur between power and telecommunication lines when local disasters, e.g. storms, fires, cause damage to both types of plant or when the normal safeguards of separation and insulation are not followed. Overvoltages rarely exceed 240 V a.c., r.m.s. above earth in countries where this is the normal distribution voltage but may continue for an indefinite period until observed. Where higher distribution voltages, e.g. 2 kV, are used the power line protection arrangements usually ensure that the voltage is removed in a short time if a fault occurs. The overvoltage may cause excessive currents to flow along the line to the exchange earth causing damage to equipment and danger to staff.

1.1.5 *Rise of earth potential*

Earth faults in power systems cause currents in the soil which raise the potential in the neighbourhood of the fault and of the power supply earth electrode. (See also Recommendation K.9.) These earth potentials may affect telecommunication plant in two ways:

a) Telecommunication signalling systems may malfunction if the signalling earth electrode is in soil whose potential rises by as little as 5 V with respect to true earth. Such voltages may be caused by minor faults on the power system which may remain undetected for long periods.

b) Higher rises of earth potential can cause danger to staff working in the affected area or, in extreme cases, may be sufficient to break down the insulation of the telecommunications cable causing extensive damage.

1.2 *Methods of protection*

1.2.1 Some of the protective measures for lines which are described in § 2 have the effect of reducing overvoltages and over-currents at their source and so reduce the risk of damage to all parts of the system.

1.2.2 Other protective measures which may be applied to specific parts of the system as indicated in §§ 2, 3 and 4 fall broadly into 2 classes:

— the use of protective devices which prevent excessive energy from reaching vulnerable parts either by diverting it (for example, spark gaps) or by disconnecting the line (for example, fuses);

— the use of equipment with suitable dielectric strength, current carrying capacity and impedance so that it can withstand the conditions applied to it.

1.3 *Types of protective devices*

1.3.1 *Air-gap protectors with carbon or metallic electrodes*

Usually connected between each wire of a line and earth, they limit the voltage which can appear between their electrodes. They are inexpensive but their insulation resistance can fall appreciably after repeated operation and they may require frequent replacement.

1.3.2 *Gas discharge tubes*

Usually connected between each wire of a line and earth or as 3-electrode units between a pair and earth. Their performance may be specified to precise limits to meet system requirements. The protectors are compact and will operate frequently without attention.

Detailed requirements for gas discharge tubes appear in Recommendation K.12.

1.3.3 *Semi-conductor protective devices*

Used in a similar way to carbon electrode protectors or gas-discharge tubes, these will protect equipment from values of overvoltage as low as 1 V. They are precise and fast-acting, but may be damaged by excessive currents.

1.3.4 *Fuses*

These are connected in series with each wire of a line to disconnect when excessive current flows. Simple fuses have a uniform wire which melts. Slow-acting fuses have a uniform wire which melts quickly when a large current flows, and a spring-loaded fusible element which melts gradually and disconnects when lower currents flow for a prolonged time. High level currents of 2 A and prolonged currents of 250 mA are typical operating levels. Fuses should not sustain an arc after operation. Fuses do not give protection against lightning surges and in districts where such surges are common, fuses of a high rating (up to 20 A) may be necessary to avoid trouble from fuse failures. Such fuses may not give adequate protection against power line contacts. Fuses can also be a source of noise and disconnection faults.

1.3.5 *Heat coils*

Fitted in series with each wire of a line, heat coils either disconnect the line, earth it, or do both, with the earth extended to line. Heat coils have some fusible component and operate when currents of, typically, 500 mA flow for some 200 s.

1.3.6 *Self-restoring current-limiting devices*

Fuses and heat coils have the disadvantage that they permanently interrupt a circuit when operated and it is then necessary to replace them manually. Certain variable impedance devices are available which, when heated by overload currents, increase their electrical resistance to a very high value. The device will return to a normal low electrical resistance when the overload current is removed. Attention is drawn to the response time and voltage handling capabilities of these items.

1.4 *Residual effects*

The essential purpose of protective measures is to ensure that the major part of the electrical energy arising from a disturbance is not dissipated in a vulnerable part of the installation and does not reach personnel. However, no device exists which has characteristics for suppressing ideally all voltages or currents connected with disturbances, for the following reasons:

1.4.1 *Residual overvoltages*

Account should be taken of:

a) voltages which are unaffected by the protective device because they are below its operating level;

b) transients which pass before the device operates;

c) residuals which are sustained after the device operates;

d) transients produced by the operation of the device.

1.4.2 *Transverse voltages*

Protective devices on the two wires of a pair may not operate simultaneously and so a transverse pulse may be produced. Under certain conditions, particularly if the equipment to be protected has a low impedance, operation of one protective device may prevent the operation of the other one and a transverse voltage may remain as long as the longitudinal voltages are on the line.

1.4.3 *Effect on normal circuit operation — coordinated design*

Sufficient separation should be allowed between the operating voltage of the protective devices and the highest voltage occurring on the line during normal operation.

Likewise the normal characteristics (internal impedances) of the protective elements must be compatible with the normal functioning of the installations, which must take account of their possible presence.

1.4.4 *Modifying effects*

A protective device may safeguard one part of a line at the expense of another, e.g. if a main distribution frame (MDF) fuse operates due to a power line contact, the voltage on the line may rise to full power line voltage when the fuse disconnects the telecommunication's earth.

Likewise the operation of a protector may greatly reduce the equivalent internal impedance of a circuit relative to equipment connected to it, thus permitting the circulation of currents which may cause damage.

1.4.5 *Coordination of primary and secondary protection*

For the protection of sensitive equipment it is sometimes necessary to use more than one protective device, e.g. a fast-operating, low-current device such as a semiconductor and a slower-operating, high-current device such as a gas-discharge tube. In such cases steps must be taken to ensure that in the event of a sustained overvoltage, the low-current device does not prevent the operation of the high-current device since, if this happens, the smaller device may be damaged, or the interconnecting wiring may conduct excessive current.

1.4.6 *Temperature rise*

Protective components should be designed and positioned in such a way that the rise in temperature which occurs when they operate is unlikely to cause damage to property or danger to people.

1.4.7 *Circuit availability*

The circuit being protected may be temporarily or permanently put out of service when a protective device operates.

1.4.8 *Fault liability*

The use of protective devices may cause maintenance problems due to unreliability. They may also prevent some line and equipment testing procedures.

1.5 *Assessment of risk*

1.5.1 The performance of a telecommunications system with respect to overvoltages depends on:

— the environment, i.e. the magnitude and probability of overvoltages occurring in the line network associated with the system;

— the construction methods used in the line network, see § 2;

— the resistibility of equipment in the system to overvoltages;

— the provision of protective devices;

— the quality of the earth system provided for operation of the protective devices.

1.5.2 *The environment*

In assessing the environment, consideration should be given to the factors mentioned in § 1.1.

The severity of overvoltages due to lightning varies widely in different localities. A high keraunic level and a high soil resistivity increase the risk of direct and nearby lightning strokes and, since lightning is the cause of a large proportion of power system faults, induction and rise of earth potential effects are also increased. On the other hand buried metal plant such as water pipes, armoured cables, etc., screens telephone cables and greatly reduces overvoltages due to lightning or induction.

— In city centres and in regions of low keraunic activity experience shows that overvoltages rarely exceed the residual voltages of protective devices and such environments may be classified as ‘‘unexposed’’. Recommendations K.20 and K.21 specify the tests to be applied to equipment for use in unexposed environments without protection and these tests give an indication of the most severe environment which can be regarded as unexposed.

— All other environments are classified as ‘‘exposed’’ but this, of course, covers a wide range of conditions including exceptionally exposed situations where a satisfactory service can only be achieved by the use of all available protective measures.

In the case of induced voltages and rise of earth potential the overvoltages can be calculated as indicted in [2] which also recommends the maximum values which may be permitted under various conditions.

1.5.3 *Fault records*

The risk of overvoltages and overcurrents can only be properly assessed in the light of experience. It is recommended that fault statistics be kept in a form which is convenient for that purpose. Faults due to overvoltages or overcurrents and faults due to failures of protective components should be separated from each other and from other component faults.

1.6 *Decision on protection*

1.6.1 In considering the degree to which a telecommunications network should withstand overvoltages, two classes of failure may be recognized:

— minor failures affecting only small parts of the system. These may be allowed to occur at a level acceptable to the Administration;

— major breakdowns, fires, exchange failures, etc., which must, so far as possible, be avoided completely.

Examples of conditions which may be permitted to cause minor failures but not major breakdowns are given in Recommendation K.20. It is desirable also that failure of a single protective device should not cause a major breakdown.

1.6.2 Particular attention should be given to overvoltage and overcurrent protection for new types of exchange or subscribers’ equipment to ensure that the benefits of its improved facilities are not lost due to unacceptable failures arising from exposure to overvoltages or overcurrents. Such equipment may be inherently sensitive to these conditions and damage or malfunction may affect large parts of a system.

1.6.3 It should be noted that over-protection, by the provision of unnecessary protective devices, is not only uneconomic but may actually worsen system performance since the devices themselves may have some liability to cause failures.

To avoid disturbances in telecommunication circuits caused by activated protective devices, the striking voltage values and the numbers of arrestors should be considered.

1.6.4 In the light of the above considerations and the assessment of risks in accordance with § 1.5, a decision should be made on the protection to be provided in all parts of the system. Account should be taken of commercial considerations such as the cost of protective measures, the cost of repairs, relations with customers and the probable frequency of faults due to overvoltage and overcurrent relative to the fault rate due to other causes.

The responsibility for making this decision and for ensuring the provision of any protective devices needed to coordinate lines and equipment should be clearly laid down.

It is necessary for manufacturers of equipment to know from the operating Administration the conditions the equipment will need to resist and for line engineers to know the resistibility of the equipment which will be connected to the lines. The line engineer should also define the constraints which equipment connected to the line will encounter, depending on the standards of line protection provided. Where parts of the network, such as subscribers’ apparatus, lines and switching centres may be under different ownership, this coordination may require formal procedures such as the production of local standards. Recommendations K.20 and K.21 give guidance for the preparation of these standards.

2 Protection of lines

2.1 *Protective measures external to the conductors themselves*

2.1.1 Telecommunication lines may be shielded from lightning to some extent by adjacent earthed metal structures, e.g. power lines or electric railway systems. Efficient metallic screens either in the form of cable sheaths, cable ducts or lightning guard wires, reduce the effects of lightning surges and power line induction. In areas with a high risk of lightning strikes special cables with multiple screens and high strength insulation are often used. Bonding all metal work gives useful protection.

2.1.2 Induction from power lines may be minimized by coordinating the construction practices for the power and telecommunication lines. The level of induction may be reduced at its source by the installation of earth wires and current limiters in the power system.

2.1.3 The likelihood of contacts occurring between power and telecommunications lines is reduced if agreed standards of construction, separation and insulation are followed. Economic considerations arise but it is often possible to benefit from jointly using trenches, poles and

ducts, providing suitable safe practices are adopted. (See Recommendations K.5 and K.6.) It is particularly important to avoid contacts with high voltage power lines by a high standard of construction since, if such contacts occur, it may be very difficult to avoid serious consequences.

2.2 *Special cables*

Special cables of high dielectric strength may be used where high overvoltages are likely to occur.

Standard plastic insulated and sheathed cables have a higher dielectric strength than paper insulated, lead-sheathed cables and are suitable for most situations where cables with extra thick insulation were formerly used. The use of cables with strengthened insulation may be justified in situations where there is exceptional proximity or length of parallelism to power lines, high rise of earth potential in the immediate neighbourhood of power stations or extreme exposure to lightning due to high keraunic level and low soil conductivity

Other examples of the use of special cables are:

— cables with metal sheaths which provide a good reduction factor to screen circuits within the cable;

— cables which carry circuits to exposed radio towers and which must be able to carry lightning discharge currents without damage;

— all-dielectric (i.e. non-metallic) optical fibre cables to effect isolation between conductive lengths of cable.

2.3 *Use of protective devices*

The use of protective devices may be desirable in the following circumstances:

2.3.1 They may be more economical than the special construction described in §§ 2.1 and 2.2. In this connection the cost of maintenance should not be overlooked since protective devices inevitably incur some maintenance expenditure whereas special cables, screening, etc., though initially expensive, usually incur no continuing costs.

2.3.2 Cables with extra thick insulation may themselves be undamaged by overvoltages or overcurrents but they can nevertheless conduct such conditions to other more vulnerable parts of the network. Extra protection is then required for the more vulnerable cables and is particularly important if these are large underground cables which are expensive to repair and affect service to many customers.

2.3.3 Induced overvoltages from power or traction line faults may still exceed levels permitted by the *Directives* even after all practicable avoidance measures have been followed.

2.4 *Installation of protective devices*

2.4.1 To protect conductor insulation it is beneficial to bond all metal sheaths, screens, etc., together, and to connect overvoltage protectors between the conductors and this bonded metal which should be connected to earth. This technique is particularly useful in districts of high soil resistivity as it avoids the need for expensive electrode systems for the protector earth connection.

2.4.2 Where protectors are used to reduce high voltages appearing in telecommunication lines due to induction from power line fault currents, they should be fitted to all wires at suitable intervals and at both ends of the affected length of line, or as near to this as practicable.

2.4.3 To protect underground cables against lightning surges protective devices may be placed at the points of connection to overhead lines. The protective devices fitted at the MDF and at subscribers' terminals reduce the risk of damage to lines but their main function is to protect components having lower dielectric strength than the cables. See Recommendations K.20 and K.21.

2.4.4 Connections for lines and earth to overvoltage protectors used against lightning should be as short as possible to minimize surge voltage levels between lines and the equipotential bond point.

2.5 *Planning of works*

The general considerations of §§ 1.5 and 1.6 apply to the protection of lines. To the greatest extent possible it is recommended that the protective measures applied to the line should be decided at the outset of a measures applied to the line should be decided at the outset of a project and should depend on the environment. It may be difficult and expensive to achieve a satisfactory standard of reliability from a line provided initially with insufficient protection.

2.6 *Recommended policy*

Where lines in a telecommunications network are exposed to frequent or severe disturbances from power line faults or lightning, the voltage of these lines relative to local earth potential should be limited either by connecting protective devices between the line conductors and earth or by using appropriate construction methods for the line.

3 Protection of exchange and transmission equipment

3.1 *Need for protection external to the equipment*

Operating organizations should take account of the possible need to fit protection external to the equipment, bearing in mind the following considerations:

3.1.1 A telecommunication line will give some protection to equipment under certain conditions, e.g.:

— a conductor may melt and disconnect an excessive current;

— conductor insulation may break down and reduce an overvoltage;

— air-gaps in connection devices may break down and reduce overvoltages.

3.1.2 The increased robustness of plastic insulated cables has the effect of increasing the levels of overvoltages and overcurrents which can circulate in the lines and be applied to equipment. By contrast the use of miniature electronic components in exchange and transmission equipment tends to increase its vulnerability to electrical disturbances.

For these reasons, in districts exposed to frequent and serious disturbances (lightning, power lines, soil of low conductivity), it is usually necessary to interpose protective devices of the types described in § 1.3 between the cable conductors and the equipment to which they are connected, preferably on the MDF. This will prevent cables from the MDF to equipment from having to carry heavy overcurrents.

The protective devices are fitted to the line side of the MDF to avoid the need to carry discharge currents in the MDF jumper field and to expose as little of the MDF wiring and terminal strips as possible to mains voltage in the event that a mains voltage line contact causes a series protective device to disconnect the line.

3.1.3 In less exposed locations it may be that disturbances (voltages and currents) have statistical characteristics of level and frequency so low that in practice the risks do not exceed those resulting from the residual effects indicated in § 1.4 for exposed regions. Protective devices then serve no purpose and are an unnecessary expense.

3.2 *Need for equipment to have a minimum level of electrical robustness*

In locations where lines are exposed and protective devices are provided, the residual effects considered in § 1 can cause overvoltages and overcurrents to appear in the equipment. In less exposed environments the disturbances described in § 3.1.3 can cause similar effects. It is necessary for equipment to be designed to withstand these conditions and detailed recommendations on the resistibility which equipment should possess are given in Recommendation K.20.

3.3 *Effect of switching conditions*

Since the configuration and interconnection of equipment connected to a given line is required to vary during the successive stages of connecting a call, it is important not to limit the study of protection solely to individual line equipments. Much equipment is common to all lines and can be exposed to disturbances when connected to a particular line.

The effectiveness of the protection provided can be influenced by the reduction in the probability of exposure if the effective duration of the connection to lines is short. On the other hand common equipment should be better protected since its failure risks more serious degradation in the performance of the exchange or the district.

4 Protection of subscribers' terminal equipment

The protection methods already set out for exchange equipment can often be usefully applied to subscribers' equipment. Detailed tests to determine the resistibility of subscriber equipment are given in Recommendation K.21. It is also appropriate to consider the specific aspects described below.

4.1 *Degree of exposure*

Lines to installations near exchanges in urban or industrial zones are usually little exposed to surges on account of the screening effect of numerous nearby metallic structures as described in § 2.1.

On the other hand, lines to installations remote from built-up areas can be very exposed on account of their length, the absence of a protective environment, overhead construction at the subscriber's end and the high resistivity of the soil. The mechanical robustness of the overhead cables at the subscriber's end makes the effect of surges all the more serious since the line itself can carry higher voltages and currents.

4.2 *Dielectric strength*

It is desirable to have a high dielectric strength for the insulation between the conducting parts connected to the lines and all parts accessible to the user.

4.3 *Use of protectors*

Where telephone lines are exposed to frequent and severe disturbances from power line faults or lightning, the voltage of the lines relative to local earth potential should be limited by connecting protective devices of the types described in § 1.3 between the line conductors and the earth terminal.

The terminal equipment dielectric strength should be chosen taking account of the breakdown voltage of the protective device and the impedance of the protector-line to earth connection.

4.4 *Common bonding*

At installations of subscriber terminal equipment a low resistance earth for overvoltage protectors may be unavailable, or the costs of procuring a suitable low-resistance earth may be excessive compared to other installation costs. Furthermore, the terminal equipment may be located adjacent to earthed systems, such as water pipes, or may receive power from an electricity system.

To minimize both equipment damage and exposure of the subscriber to high voltages, even if the earth resistance is not sufficiently low, all earthed systems, signalling earths and the power neutral should be bonded

together either directly or by means of a spark gap. Although this bonding may be expensive it allows the difficulty of providing a low resistance earth to be resolved and is a technique widely used. In some countries connection to the electricity system neutral is governed by national regulations, so that agreement with the electrical Authority should be obtained.

4.5 *National regulations*

Many countries have national standards covering the protection of users of telecommunications equipment not only from the risks associated with connection to the electricity mains but also from conditions which may appear on the telephone line.

4.6 *High cost of maintenance of subscribers' installations*

The cost of repairs at exposed terminal installations may be high by reason of the distance from the maintenance centre, transport delays and, possibly, the seriousness of the damage. Moreover, insufficient protection is the cause of repeated interruptions of service which are particularly damaging to the quality of service and the satisfaction of the customer. This justifies the granting of special attention to protection measures.

References

[1] CCITT manual *The protection of telecommunication lines and equipment against lightning discharges* , ITU, Geneva 1974, 1978.

[2] CCITT *Directives concerning the protection of telecommunications lines against harmful effects from electric power and electrified railway lines* , ITU, Geneva, 1988.

Recommendation K.12

CHARACTERISTICS OF GAS DISCHARGE TUBES FOR THE PROTECTION OF TELECOMMUNICATIONS INSTALLATIONS

(Geneva, 1972, modified at Malaga-Torremolinos, 1984 |
and at Melbourne, 1988)

Introduction

This Recommendation gives the basic requirements to be met by gas discharge tubes for the protection of exchange equipment, subscribers' lines and subscribers' equipment from over-voltages. It is intended to be used for the harmonization of existing or future specifications issued by gas discharge tube manufacturers, telecommunication equipment manufacturers, or Administrations.

Only the minimum requirements are specified for essential characteristics. As some users may be exposed to different environments or have different operating conditions, service objectives or economic constraints,

these requirements may be modified or further requirements may be added to adapt them to local conditions.

This Recommendation gives guidance on the use of gas discharge tubes to limit over-voltages on telecommunications lines.

1 Scope

This Recommendation:

a) gives the characteristics of gas discharge tubes used in accordance with CCITT Recommendation K.11 for protection of exchange equipment, subscribers' lines and subscribers' equipment against over-voltages,

b) deals with gas discharge tubes having 2 or 3 electrodes,

c) does not deal with mountings and their effect on tube characteristics. Characteristics given apply to gas discharge tubes by themselves mounted only in the ways described for the tests,

d) does not deal with mechanical dimensions,

e) does not deal with quality assurance requirements,

f) does not deal with gas discharge tubes which are connected in series with voltage-dependent resistors in order to limit follow-on currents in electrical power systems,

g) may not be sufficient for gas discharge tubes used on high frequency or multi-channel systems.

2 Definitions

Appendix I gives definitions of a number of terms used in connection with gas discharge tubes. It includes some terms not used in this Recommendation.

3 Environmental conditions

Gas discharge tubes shall be capable of withstanding during storage the following conditions without damage:

— Temperature: —40 to +90 | (deC;

— Relative humidity: up to 95%.

See also §§ 7.5 and 7.7.

4 Electrical characteristics

Gas discharge tubes should have the following characteristics when tested in accordance with § 5.

Paragraphs 4.1 to 4.5 apply to new gas discharge tubes and also, where quoted in § 4.6, to tubes subjected to life tests.

4.1 *Spark-over voltages* (see §§ 5.1, 5.2 and Figures 1/K.12, 2/K.12 and 3/K.12)

4.1.1 Spark-over voltages between the electrodes of a 2-electrode tube or between either line electrode and the earth electrode of a 3-electrode tube shall be within the limits in Table 1/K.12.

H.T. [T1.12]

lw(42p) | lw(42p) | lw(42p) | lw(54p) | lw(48p) .

Table 1/K.12 [T1.12], p.

4.1.2 For 3-electrode tubes, the spark-over voltage between the line electrodes shall not be less than the minimum d.c. spark-over voltage in Table 1/K.12.

4.2 *Holdover voltages* (see § 5.5 and Figures 4/K.12 and 5/K.12)

All types of tube shall have a current turn-off time less than 150 ms when subjected to one or more of the following tests according to the projected use:

4.2.1 2-electrode tubes tested in a circuit equivalent to Figure 4/K.12 where the test circuit components have the values in Table 2/K.12.

H.T. [T2.12]

lw(72p) | lw(36p) | lw(36p) | lw(36p) .

Table 2/K.12 [T2.12], p.

4.2.2 3-electrode tubes tested in a circuit equivalent to Figure 5/K.12 where components have the values in Table 3/K.12.

H.T. [T3.12]

TABLE 3/K.12

Component	Test 1	Test 2	Test 3		
PS1	52 V	80 V	135 V		
PS2	0 V	0 V	52 V		
R3	260 Ω	330 Ω	1300 Ω		
R2	a)	150 Ω	272 Ω | ub)	150 Ω	272 Ω | ub)
C1	a)	100 nF	43 nF | ub)	100 nF	43 nF | ub)
R4 | uc)	136 Ω	136 Ω	136 Ω		
C2 | uc) 83 nF	83 nF	83 nF	{		
a) Components omitted in this test. b) Optional alternative. c) Optional. }					

Table 3/K.12 [T3.12], p.

4.3 *Insulation resistance* (see § 5.3)

Not less than 1000 Mohms initially.

4.4 *Capacitance*

Not greater than 20 pF.

4.5 *Impulse transverse voltage — 3-electrode tubes* (see § 5.9 and Figure 6/K.12)

The difference in time not to exceed 200 ns.

4.6 *Life tests* (§§ 5.6, 5.7 and 5.8)

The currents specified in § 4.6.1 for the appropriate nominal current rating of the tube shall be applied. After each current application, the gas discharge tube shall be capable of meeting the requirements of § 4.6.2. On completion of the number of current applications specified, the tube shall be capable of meeting the requirements of § 4.6.3.

4.6.1 *Test currents*

Gas discharge tubes intended for use only on main distribution frames or similar situations where connection to lines is via cable pairs, shall be subjected to the currents of Columns 2 and 3 of Table 4/K.12. Gas discharge tubes intended for applications where they are directly connected to open wire lines will be designated EXT by the purchaser and shall be subjected to the currents of Columns 2, 3 and 4 of Table 4/K.12.

H.T. [T4.12]

lw(24p) | lw(36p) | lw(48p) | lw(60p) | lw(60p) .

Table 4/K.12 [T4.12], p.

4.6.2 *Requirements during life test*

Insulation resistance: not less than 10 Mohms.

D.c. and impulse spark-over voltage: not more than the relevant value in § 4.1.

4.6.3 *Requirements after completion of life test*

Insulation resistance: not less than 100 Mohms (10 Mohms if particularly specified by the purchaser).

D.c. and impulse spark-over voltage : as in § 4.1.

Holdover voltage: as in § 4.2.

5 Test methods

5.1 *D.c. spark-over voltage* (see § 4.1 and Figures 1/K.12 and 2/K.12)

The gas discharge tube shall be placed in darkness for at least 24 hours immediately prior to testing and tested in darkness with a voltage which increases so slowly that the spark-over voltage is independent of the rate of rise of the applied voltage. Typically, a rate of rise of 100 V/s is used, but higher rates may be used if it can be shown that the spark-over

voltage is not significantly changed thereby. The tolerances on the wave-shape of the rising test voltage are indicated in Figure 1/K.12. The voltage is measured across the open-circuited terminals of the generator. $U_{m\backslash da\backslash dx}$ of Figure 1/K.12 is any voltage greater than the maximum permitted d.c. spark-over voltage of the gas discharge tube and less than three times the minimum permitted d.c. spark-over voltage of the gas discharge tube.

The test shall employ a suitable circuit such as that shown in Figure 2/K.12. A minimum of 15 minutes shall elapse between repetitions of the test, with either polarity, on the same gas discharge tube.

Each pair of terminals of a 3-electrode gas discharge tube shall be tested separately with the other terminal unterminated.

Note — The use of Figure 1/K.12 may be explained as follows:

A single mask will do for all values of $U_{m\backslash da\backslash dx}$ and the nominal rate of rise, provided that it is a suitable size for the display of the waveform and that the scales of U and T of the waveform can be adjusted. This follows because the Y-axis has arbitrary points marked 0 and $U_{m\backslash da\backslash dx}$ with 0.2 $U_{m\backslash da\backslash dx}$ at the appropriate point between them while the X-axis has arbitrary

points marked 0 and T_2 with T_1 (= 0.2 T_2), 0.9 T_1, 1.1 T_1, 0.9 T_2, 1.1 T_2 marked at the appropriate points. The X and Y zeros need not coincide and, in fact, need not be shown at all.

To compare a waveform trace with the mask, it is necessary to know the values of $U_{m\backslash da\backslash dx}$ and the nominal rate of rise for the waveform in question. As an example, consider a waveform with $U_{m\backslash da\backslash dx}$ = 750 V and nominal rate of rise = 100 V/sec.

Then 0.2 $U_{m\backslash da\backslash dx}$ = 150 V, T_2 = 7.5 s, T_1 = 1.5 s.

Hold the mask against the trace and adjust the vertical scale so that the 150 V calibration is against 0.2 $U_{m\backslash da\backslash dx}$ and the 750 V point against $U_{m\backslash da\backslash dx}$. Adjust the horizontal scale similarly for 1.5 s = T_1 and 7.5 s = T_2. Slide the mask so that the 150 V point on the trace is within the bottom boundary of the test window; the remainder of the trace up to 750 V must be within the test window.

5.2 *Impulse spark-over voltage* (§ 4.1 and Figures 1/K.12 and 3/K.12)

The gas discharge tube shall be placed in darkness for at least

15 minutes immediately prior to testing and tested in darkness. The voltage waveform measured across the open circuit test terminals shall have a nominal rate of rise selected from § 4.1 and shall be within the enclosed limits indicated in Figure 1/K.12. Figure 3/K.12 shows a suggested arrangement for testing with a voltage impulse having a nominal rate of rise of 1.0 kV/µs.

A minimum of 15 minutes shall elapse between repetitions of the test, with either polarity, on the same gas discharge tube.

Each pair of terminals of a 3-electrode gas discharge tube shall be tested separately with the other terminal unterminated.

5.3 *Insulation resistance* (§ 4.3)

The insulation resistance shall be measured from each terminal to every other terminal of the gas discharge tube. The measurement shall be made at an applied potential of at least 100 V and not more than 90% of the minimum permitted d.c. spark-over voltage. The measuring source shall be limited to a short circuit current of less than 10 mA. Terminals of three-electrode gas discharge tubes not involved in the measurement shall be left unterminated.

5.4 *Capacitance* (§ 4.4)

The capacitance shall be measured between each terminal and every other terminal of the gas discharge tube. In measurements involving 3-electrode gas discharge tubes, the terminal not being tested shall be connected to a ground plane in the measuring instrument.

5.5 *Holdover test* (§ 4.2)

5.5.1 *2-electrode gas discharge tube* (Figure 4/K.12)

Tests shall be conducted using the circuit of Figure 4/K.12. Values of PS1, R2, R3 and C1 shall be selected for each test condition from Table 2/K.12. The current from the surge generator shall have an impulse waveform of 100 A, 10/1000 or 10/700 measured through a short circuit replacing the gas discharge tube under test. The polarity of the impulse current through the gas discharge tube shall be the same as the current from PS1. The time for current turn-off shall be measured for each direction of current passage through the gas discharge tube. Three impulses shall be applied at not greater than 1-minute intervals and the current turn-off time measured for each impulse.

5.5.2 *3-electrode gas discharge tube* (Figure 5/K.12)

Tests shall be conducted using the circuit of Figure 5/K.12. Values of circuit components shall be selected from Table 3/K.12. The simultaneous currents that are applied to the gaps of the gas discharge tube shall have impulse waveforms of 100 A, 10/1000 or 10/700 measured through a short circuit replacing the gas discharge tube under test. The polarity of the impulse current through the gas discharge tube shall be the same as the current from PS1 and PS2.

For each test condition, measurement of the time to current turn-off shall be made for both polarities of the impulse current. Three impulses in each direction shall be applied at intervals not greater than 1 minute and the time to current turn-off measured for each impulse.

5.6 *Impulse life — all types of gas discharge tube* (§ 4.6)

Fresh gas discharge tubes shall be used and impulse currents shall be applied as specified in Table 4/K.12, Column 3, for the relevant nominal current of the tube. Half the specified number of tests shall be carried out

with one polarity followed by half with the opposite polarity. Alternatively, half the tubes in a sample may be tested with one polarity and the other half with the opposite polarity. The pulse repetition rate should be such as to prevent thermal accumulation in the gas discharge tube.

The voltage of the source shall exceed the maximum impulse spark-over voltage of the gas discharge tube by not less than 50 per cent. The specified impulse discharge current and waveform shall be measured with the gas discharge tube replaced with a short circuit. For 3-electrode gas discharge tubes, independent impulse currents each having the value specified in Table 4/K.12, Column 3, shall be discharged simultaneously from each electrode to the common electrode.

The gas discharge tube shall be tested after each passage of impulse discharge current or at less frequent intervals if agreed between the supplier and the purchaser to determine its ability to satisfy the requirements of § 4.6.2.

On completion of the specified number of impulse currents the tube shall be allowed to cool to ambient temperature and tested for compliance with § 4.6.3.

5.7 *Impulse life — additional tests for tubes designated EXT* (§ 4.6)

As in § 5.6, but applying the conditions of Table 4/K.12, column 4.

5.8 *A.c. life — all types of tube* (§ 4.6)

Fresh tubes shall be used and alternating currents applied as specified in Table 4/K.12, Column 2, for the relevant nominal current of the tube.

The time between applications should be such as to prevent thermal accumulation in the tube. The rms a.c. voltage of the current source shall exceed the maximum d.c. spark-over voltage of the gas discharge tube by not less than 50 per cent.

The specified a.c. discharge current and duration shall be measured with the gas discharge tube replaced with a short circuit. For 3-electrode gas discharge tubes, a.c. discharge currents each having the value specified in Table 4/K.12 shall be discharged simultaneously from each electrode to the common electrode.

The gas discharge tube shall be tested after each passage of a.c. discharge current to determine its ability to satisfy the requirements of § 4.6.2.

On completion of the specified number of current applications, the tube shall be allowed to cool to ambient temperature and tested for compliance with § 4.6.3.

5.9 *Impulse transverse voltage* (§ 4.5 and Figure 6/K.12)

The duration of the transverse voltage shall be measured while an impulse voltage having a virtual steepness of impulse wavefront of 1 kV/µs is applied simultaneously to both discharge gaps. Measurement may be made with an arrangement as indicated in

Figure 6/K.12. The difference in time between the spark-over of the first gap and that of the second is specified in § 4.5.

6 Radiation

The emerging radiation from any radioactive matter used to pre-ionize the discharge gaps must be within the limits specified as admissible in the regulations concerning the protection from radiation which are issued by the country of the manufacturer as well as of the user. This provision applies both to individual and to a batch of gas discharge tubes (for example, when packed in a cardboard box for dispatch, storage, etc.).

The supplier of gas discharge tubes containing radioactive materials shall provide recommendations, complying with the International Atomic Energy Agency (IAEA) ''Regulations for the safe transport of radio active materials'' and with all other relevant international requirements, on the following matters:

a) maximum number of items per package,

b) maximum quantity per shipment,

c) maximum quantity which may be stored together,

d) any other storage requirements,

e) handling precautions and requirements,

f) disposal arrangements.

7 Environmental tests

7.1 *Robustness of terminations*

The user shall specify a suitable test from International Electrotechnical Commission (IEC) standard 68-2-21 (1975) if applicable.

7.2 *Solderability*

Soldering terminations shall meet the requirements of IEC standard 68-2-20 (1979) Test Ta Method 1.

7.3 *Resistance to soldering heat*

Gas discharge tubes with soldering terminations shall be capable of withstanding IEC standard 68-2-20 (1979) Test Tb Method 1B. After recovery, the gas discharge tube shall be visually checked and show no signs of damage and its d.c. spark-over shall be within the limits for that tube.

7.4 *Vibration*

A gas discharge tube shall be capable of withstanding IEC standard 68-2-6 (1970) 10-500 Hz, 0.15 mm displacement for 90 minutes without damage. The user may select a more severe test from the document. At the end of the test, the tube shall show no signs of damage and shall meet the d.c. spark-over and insulation resistance requirements specified in §§ 4.1 and 4.3.

7.5 *Damp heat cyclic*

A gas discharge tube shall be capable of withstanding IEC standard 68-2-4 Test D Severity IV. At the end of the test, the tube shall meet the insulation resistance requirement specified in § 4.3.

7.6 *Sealing*

A gas discharge tube shall be capable of passing IEC standard 68-2-17 (1978) Test Qk, severity 600 hours, for fine leaks. Helium shall be used as the test gas. The fine leak rate shall be less than 10^{D}lF261^{7} bar | (mu | m^{3} | (mu | ^{D}lF261^{1}.

The tube shall then be capable of passing the coarse leak test Qc Method 1.

7.7 *Low temperature*

A gas discharge tube shall be capable of withstanding IEC standard 68-2-1 Test Aa. —40 | (deC, duration 2 hours, without damage. While at —40 | (deC the tube must meet the d.c. and impulse spark-over requirements of § 4.1.

8 Identification

8.1 *Marking*

Legible and permanent marking shall be applied to the tube as necessary to ensure that the purchaser can determine the following information by inspection:

a) manufacturer,

b) year of manufacture,

c) type.

The purchaser may specify the codes to be used for this marking.

8.2 *Documentation*

Documents shall be provided to the purchaser so that from the information in § 8.1 he can determine the following further information:

a) full characteristics as set out in this Recommendation,

b) name of radioactive material used in the tube or statement that such material has not been used.

9 Ordering information

The following information should be supplied by the purchaser:

a) drawing giving all dimensions, finishes and termination details (including numbers of electrodes and identifying the earth electrode),

b) nominal d.c. spark-over voltage, chosen from § 4.1.1,

c) nominal current rating chosen from § 4.6.1,

d) the designation EXT if the tests of Table 4/K.12, column 4, are required,

e) holdover voltage tests required in § 4.2,

f) marking codes required for § 8.1,

g) robustness of terminations — test required for § 7.1,

h) destruction characteristic, if required, including failure mode (see Note),

i) quality assurance requirements.

Note — After passage of an alternating or impulse current of value much higher than that shown in § 4.6.1, the gas discharge tube may be destroyed, i.e. its electrical characteristics may be greatly modified. Two situations may occur:

1) The gas discharge tube becomes in effect an insulator and presents a higher dielectric strength than it had initially — that is to say, it becomes open circuit.

2) The gas discharge tube becomes of limited resistance — generally a low value which does not allow normal operation of the line — that is to say it becomes a short circuit. (This situation may be preferable from the point of view of protection and maintenance.)

Test methods and the relations between the value and duration of the destructive current are not detailed in this Recommendation nor is the state of the element after destruction. Administrations should cover their requirements in these respects in their own documentation.

Figure 1/K.12, p.11

Figure 2/K.12, p.12

Figure 3/K.12, p.13

Figure 4/K.12, p.14

Figure 5/K.12, p.15

Figure 6/K.12, p.16

APPENDIX I
(to Recommendation K.12)

Definitions of terms associated with gas discharge tubes

I.1 **arc current**

The current which flows after spark-over when the circuit impedance allows a current that exceeds the glow-to-arc transition current.

I.2 **arc voltage**

The voltage appearing across the terminals of the gas discharge tube during the passage of the arc current.

I.3 **breakdown**

See ‘‘spark-over’’.

I.4 **current turnoff time**

The time required for the gas discharge tube to return itself to a nonconducting state following a period of conduction.

I.5 **destruction characteristic**

The relationship between the value of the discharge current and the time of flow until the gas discharge tube is mechanically destroyed (break, electrode short circuit). For periods of time between 1 μs and some ms, it is based on impulse discharge currents, and for periods of time of 0.1 s and greater, it is based on alternating discharge currents.

I.6 **discharge current**

The current that passes through a gas discharge tube when spark-over occurs.

I.7 **discharge current, alternating**

The r.m.s. value of an approximately sinusoidal alternating current passing through the gas discharge tube.

I.8 **discharge current, impulse**

The peak value of the impulse current passing through the gas discharge tube.

I.9 **discharge voltage**

The voltage that appears across the terminals of a gas discharge tube during the passage of discharge current. Also referred to as ‘‘residual voltage’’.

I.10 **discharge voltage/current characteristic**

The variation of crest values of discharge voltage with respect to discharge current.

I.11 **follow current**

The current from the connected power source that passes through a gas discharge tube during and following the passage of discharge current.

I.12 **gas discharge tube**

A gap, or several gaps, in an enclosed discharge medium, other than air at atmospheric pressure, designed to protect apparatus or personnel, or both, from high transient voltages. Also referred to as ‘‘gas tube surge arrester’’.

I.13 **glow current**

The current which flows after spark-over when circuit impedance limits the discharge current to a value less than the glow-to-arc transition current.

I.14 **glow-to-arc transition current**

The current required for the gas discharge tube to pass from the glow mode into the arc mode.

I.15 **glow voltage**

The voltage drop across the terminals of the gas discharge tube during the passage of glow current.

I.16 **holdover voltage**

The maximum d.c. voltage across the terminals of a gas discharge tube under which it may be expected to clear and to return to the high impedance state after the passage of a surge, under specified circuit conditions.

I.17 **impulse spark-over voltage/time curve**

The curve which relates the impulse spark-over voltage to the time to spark over.

I.18 **impulse waveform**

An impulse waveform designated as x/y has a rise time of x µs and a decay time to half value of y µs as standardized in IEC Publication 60.

I.19 **nominal alternating discharge current**

For currents with a frequency of 15 Hz to 62 Hz, the alternating discharge current which the gas discharge tube is designed to carry for a defined time.

I.20 **nominal d.c. spark-over voltage**

The voltage specified by the manufacturer to designate the gas discharge tube (type designation) and to indicate its application with respect to the service conditions of the installation to be protected. Tolerance limits of the d.c. spark-over voltage are also referred to the nominal d.c. spark-over voltage.

I.21 **nominal impulse discharge current**

The peak value of the impulse current with a defined wave shape with respect to time for which the gas discharge tube is rated.

I.22 **residual voltage**

See ‘‘discharge voltage’’.

I.23 **spark-over**

An electrical breakdown of a discharge gap of a gas discharge tube. Also referred to as ‘‘breakdown’’.

I.24 **spark-over voltage**

The voltage which causes spark-over when applied across the terminals of a gas discharge tube.

I.25 **spark-over voltage, a.c.**

The minimum r.m.s. value of sinusoidal voltage at frequencies between 15 Hz and 62 Hz that results in spark-over.

I.26 **spark-over voltage, d.c.**

The voltage at which the gas discharge tube sparks over with slowly increasing d.c. voltage.

I.27 **spark-over voltage, impulse**

The highest voltage which appears across the terminals of a gas discharge tube in the period between the application of an impulse of given waveshape and the time when current begins to flow.

I.28 **transverse voltage**

For a gas discharge tube with several gaps, the difference of the discharge voltages of the gaps assigned to the two conductors of a telecommunications circuit during the passage of discharge current.

Recommendation K.13

INDUCED VOLTAGES IN CABLES WITH PLASTIC-INSULATED CONDUCTORS

(Geneva, 1972)

According to [1], when a fault occurs on a power line near a telecommunication cable having all its circuits terminated by transformers, the permissible induced longitudinal voltage in the cable conductors should not exceed 60% of the voltage used to check the dielectric strength of the cable, as required by individual specifications for checks of the breakdown strength between the cable conductors and the sheath. This induced voltage is generally 1200 V r.m.s. value for paper-insulated conductors (60% of 2000 V). The *Directives* give no indication of the frequency of occurrence of such a voltage or of its permissible duration. In order that such voltages do not endanger line maintenance staff, the safety precautions for staff given in [2] must be observed.

Plastic-insulated cables can have a much higher dielectric strength than paper-insulated cables. Moreover, this dielectric strength is retained following the mechanical stresses that occur during the laying of the cable. There should thus be no danger of breakdown of the insulation between the conductors and the metal sheath when it is subjected to induced logitudinal e.m.f. sufficiently below the breakdown voltage of the cable. A sufficient safety margin is ensured if induced voltages are kept below 60% of the voltage used for checking the dielectric strength of the cable as given in the individual specifications; this voltage is, of course, related to the breakdown voltage

At very little extra expense, sleeves and joints can be made to have the same dielectric strength as the insulation between the conductors and the metallic sheath, although transformers and terminal equipments must be suitably protected when their dielectric strength is not up to the conditions concerned.

If the source of the induced longitudinal e.m.f. is a high-reliability power line, as defined in the *Directives* , there is only a very small probability that staff will be in contact with a line at the precise moment

when such a voltage of short duration occurs in the telecommunication cable. Any danger to staff is very slight given due observation of the safety precautions for maintenance staff working on telephone lines in which high voltages may be induced by neighbouring electricity lines.

For a cable not having its circuits terminated by transformers the above conditions also apply provided that surge voltages are prevented from reaching the telecommunication equipment by the striking of the lightning protectors installed at the ends of the circuits.

For these reasons, the CCITT is unanimously of the opinion that:

1 It is possible to make telecommunication cables with conductors that are insulated from each other and from the metallic sheath by high breakdown strength plastics. For such cables, when there is a fault on a neighbouring electricity line, the value of induced longitudinal e.m.f. that can be allowed is that which does not exceed 60% of the test voltage applied between the conductors and the metallic sheath for checking the dielectric strength (this test voltage, which is given in the individual cable specifications, is related to the breakdown voltage) provided the following conditions are observed:

a) circuits in such cables are terminated at their ends and at branching points on transformers or are provided with lightning protectors ;

b) equipment, joints and cableheads associated with such cables must have a dielectric strength at least equal to that of the insulation between the conductors and the metallic cable sheath of the cable, given that the transformers mentioned in a) above must be provided with lightning protectors when their dielectric strength does not meet the required conditions;

c) the power line causing the induction must meet the conditions for high-reliability power lines given in [1];

d) staff working on telecommunication cables must take the safety precautions specified in [2].

2

When the circuits of such a cable are connected direct to the telecommunication equipment, that is, when no transformers or lightning protectors are inserted, and when the condition laid down in § 1c) above is fulfilled, the maximum permissible induced longitudinal e.m.f. should be 650 V.

References

[1] CCITT manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines* , Vol. VI, ITU, Geneva, 1988.

[2] *Ibid.* , Vol. VII.

Recommendation K.14

PROVISION OF A METALLIC SCREEN IN PLASTIC-SHEATHED CABLES

(Geneva, 1972; modified at Malaga-Torremolinos, 1984)

A metal sheath provides a cable with electrostatic screening and a degree of magnetic screening. A plastic sheath has no intrinsic screening properties. Some plastic-sheathed cables, for example those with paper-insulated cores, incorporate a metal screen as a water barrier. Such a metal screen, which is usually in the form of a longitudinally applied

aluminium tape, provides the same screening properties as a nonferrous metal sheath of the same longitudinal conductivity. The tape must, however, be connected to the telephone exchange earth electrode systems at its ends and/or to conveniently located earthing points, such as metal cable sheaths, along its length. It is also important that at jointing points the tape be extended through by connections of very low resistance. Although the degree of screening provided by the tape may be small at 50 Hz, it can be considerable at frequencies which give rise to noise interference. The presence of a screen on a cable also reduces the induction arising from the high-frequency components of transients caused by power-line switching and also induced transients from lightning strokes; such transient induced voltages are of increasing importance with the increasing use of miniaturized telecommunication equipment with very small thermal capacity.

On the basis of the above considerations and experience with the use of plastic-sheathed cables,

the CCITT recommends that the following provisions be observed:

1 Since plastic-sheathed subscriber distribution cables without a screen give satisfaction for distribution from the exchange to subscribers, they may be used in localities where there are no alternating current electrified railways that may arise in the vicinity of electric railways, especially those with thyristor controlled equipment in the locomotives. Consideration should also be given to possible interference by radio transmitters which operate in the same frequency range as the circuits in the plastic-sheathed cable.

2 Trunk and junction cables should contain a screen which can have the form of an aluminium-tape water barrier that of a cable having the same core diameter, but with a lead sheath , have given complete satisfaction where there are no risks of severe magnetic induction.

3 If a plastic-sheathed cable is provided with a screen of a conductance equivalent to that of a conventional lead-sheathed cable, then in the presence of induction the plastic-sheathed cable can be used in entirely the same circumstances as the lead-sheathed cable.

4 If the effect of the screen according to §§ 2 and 3 above is not sufficient to limit the magnetic induction at mains frequencies, or to these harmonics arising from neighbouring power lines or electric railways, to permissible values the screening factor can be improved by increasing:

4.1 the inductance of the metal sheath , if necessary, by a lapping of steel tapes;

4.2 the conductance of the existing screen by additional metal tapes or wires which are arranged below the screen.

An improved screening effect may also become necessary if there is the risk of noise interference in the vicinity of electric railways equipped with thyristor controlled devices.

5 The screen must be connected to the earth electrode systems of the telecommunication centres. In the case of subscribers' cables the remote end should be connected to a suitable earth. It is also important for the screen of the cable to be extended through at cable joints by means of connections of very low resistance.

6 In view of the increase in the number of electrical installations and the level of harmonics resulting from new techniques, it is to be expected that the effects of interference will become worse. This being so, it may be extremely useful to improve the screening effect of plastic-covered cables as indicated above.

7 If cables have to be laid in areas where there is a danger of atmospheric discharges, attention is drawn to the importance of the metallic screen and of its construction in the protection of cables against lightning and also to the importance of the interconnections between the screen and other structures. (See the manual cited in [1].)

8 Screening factor

The following considerations enable the screening factor at the mains frequency to be determined fairly accurately for all types of cable regardless of the outer plastic covering used. In particular, they show how the screening factor to be used in practice may vary depending on the conditions in which the cable is used.

8.1 *General*

The screening effect produced by the metal screen of a cable mainly depends on:

— the frequency of the induced e.m.f. The limitation of this e.m.f. mains frequency (16 | /3 Hz, 50 Hz, 60 Hz) is therefore a determining factor in the choice of a cable from the standpoint of safety of staff and installations. On the other hand, the screening factor at higher frequencies should also be taken into account in seeking to protect equipment against interference. A substantial reduction of the induced e.m.f. at the mains frequency may suffice for complete protection;

— the level of induced e.m.f. per unit length in the case of screens made by ferromagnetic material. The screening effect of such a cable is optimum for a given value of induced e.m.f. per unit length, so that a cable designed for the reduction of high induced e.m.f. per unit length may be of no practical use for protection against low induced e.m.f. per unit length. The

composition of the screen must be adapted to the level of the induced e.m.f. per unit length;

— the quality of its earthing. The screening effect is determined by the value of the current circulating in the metal screen. The resistance of the parts ensuring current flow between screen and earth is therefore decisive. For cables with an insulating plastic outer covering, if earth connections are provided only at the ends, they must be of very low resistance: the sheath should preferably be earthed at intervals along the line. When the plastic outer covering is conductive, the sheath is in practice continuously earthed;

— the length of the induced section of the link to be protected. It is easier to improve the screening effect when this section is long. The concept of length in this case relates to the quality of earthing required.

8.1.1 *The screening factor* (for explanation of symbols, see Appendix I)

The following most frequently used screening factors are defined in the *Directives:*

— Nominal screening factor, k_n (see Figure 1/K.14). This factor can easily be measured in a laboratory and is used to qualify the efficiency of the screening effect.

Figure 1/K.14, p.

— Screening factor related to distant earth, $k_{f\backslash d f \backslash d'}$ (see Figure 2/K.14). This factor must be taken into account in ensuring protection against danger and interference, the conductors of the subscriber pairs being connected at their terminals to a neutral earth through certain parts of the equipments, without transformers.

Figure 2/K.14, p.

— Screening factor related to the sheath $k_{f\backslash dm}$ (see Figure 3/K.14). This factor must be taken into consideration in cases where the only accessible earths are those used for earthing the screen. This relates to cables connecting telecommunication centres to one another, their screens being connected to the earths of the centres.

Figure 3/K.14, p.

The *Directives* contain very detailed explanations and formulas for the accurate calculation of these factors in a wide variety of situations. On the other hand, these screening factors can be evaluated on the basis of simple expressions which often provide an adequate degree of accuracy. These expressions differ according to whether the outer cable covering is insulative or conductive and use the constants and variables listed in Appendix I.

8.2 *Cables with insulating outer covering*

The outer covering of the metallic cable sheath is made of an insulating plastic material. To obtain a screening effect, this sheath must be earthed at both ends and possibly at points in between.

8.2.1 *Calculation of the screening factor*

The screening factor can then be calculated by means of the expressions (see also the *Directives* , Vol. II):

$$k_{fE} = \left| \frac{fIZ \; \$\$Ei:E :i \_ L + W_A fR + W_B fR}{Z \; \$\$Ei:E :e \_ L + Z_s fR \; L + W_A fR + W_B fR} \right| \qquad (8\text{-}1)$$

$$k_{fm} = \left| \frac{fIZ \; \$\$Ei:E :i \_ L}{Z \; \$\$Ei:E :e \_ L + Z_s fR \; L + W_A fR + W_B fR} \right| \qquad (8\text{-}2)$$

Strictly speaking, the use of these expressions presupposes that the sheath is earthed only at the ends. It may be assumed, however, that in fairly comparable situations only the earths near the ends have any influence on the screening effect. The expression thus gives a good approximation of the screening effect in the case of intermediate earths.

As a general consequence, earthing connections at intermediate points tend to improve $k_{f\backslash df\backslash d'}$, but, on the other hand, make $k_{f\backslash dm}$ worse.

8.2.2 *Influence of length*

When the earths of a sheath required to obtain a screening factor $k_{f\backslash df\backslash d'}$ close to nominal value k_n have a resistance value which makes earthing very difficult, the link may be considered to be ‘‘short’’. In the contrary case, it is regarded as ‘‘long’’.

Note — ‘‘Link’’ is held to mean the cable length actually subjected to induction.

8.2.2.1 *‘‘Long’’ links*

Scrutiny of Equations (8-1) and (8-2) shows that for very long links, screening factors $k_{f\backslash df\backslash d'}$ and $k_{f\backslash dm}$ are close to k_n. This is true of lengths in excess of about

$$10 \frac{W|_A fR + W|_B fR}{fIZ \$\$Ei :E :i}$$

In this case, a non-armoured cable (Z^E_e close to Z^E_i) may be used. Moreover, the longer the link, the higher the resistance value of the sheath earthing may be.

This need not be taken into account in the choice of a cable, which can be based on the curve of values of nominal screening factor k_n for different values of induced e.m.f., since the efficiency obtained will be very similar.

8.2.2.2 *‘‘Short’’ links*

In this case, the value of $Z^E_i L$ is approximately the same order of magnitude as the sum of the extreme terminal earth values $W|_A + W|_B$. Screening factors $k_{f\backslash df\backslash d'}$ and $k_{f\backslash dm}$ may be calculated by means of Equations (8-1) and (8-2).

Armoured cables must be used to protect such links, and the screening effect is then provided through the increase in the value of impedance Z^E_e obtained by using material with high magnetic permeability for the outer part of the sheath.

To evaluate $k_{f\backslash df\backslash d'}$ and $k_{f\backslash dm}$ by means of Equations (8-1) and (8-2), it is necessary to know the curve of variations of Z^E_e as a function of the current flowing through the sheath (Figure 4/K.14).

The calculation then calls for some simple successive approximations for evaluating Z^E_e after choosing a value of $W|_A$ and $W|_B$ corresponding to earths which may be expected to be feasible in view of the ground resistivity at the ends of the link.

Figure 4/K.14, p.

8.3 *Cables with conductive outer covering*

The outer covering of the metallic cable sheath is made of a conductive plastic material providing electrical contact between the sheath and the earth surrounding the cable.

Intermediate connections of the sheath to the earth other than at the ends will be unnecessary if the resistivity of the conductive material is close to or better than that of the surrounding earth (values of about 50 Ω × m are easily obtained).

The current flowing through the sheath varies along the link, particularly near the terminals, and in the middle part remains at a value very close to $I_M = e/(Z^E_e + Z_s)$, corresponding to the current which would circulate in the sheath if it were completely earthed (earths with zero resistance value).

To calculate screening factor $k_{f\backslash df\backslash d'}$, we can thus use an equivalence consisting in replacing this cable by one with a sheath connected to the earth at each end by zero resistance earths and of a length equal to that of the link L, shortened at each end by a length l such that | | fIP | l = 1.

This means that the cable has a nominal screening factor on a shorter length equal to $L - 2l$.

$k_{f\backslash df\backslash d'}$ can then be evaluated approximately by means of the following expression:

$$k_{ff} = k_n\left(1 - \frac{l}{fIL}\right) + \frac{l}{fIL} \qquad (8\text{-}3)$$

In the same way, $k_{f\backslash dm}$ can be expressed by:

$$k_{fm} = k_n\left(1 - \frac{l}{fIL}\right)$$

Equation (8-3) is not applicable in cases where the earthing of the metallic sheath is really excellent. The link is then considered to be ‘‘long’’ and $k_{f\backslash df\backslash d'} = k_{f\backslash dm} = k_n$.

The parameters required for the calculation are those of the cable (Z^E_e, Z^E_i), the induced e.m.f. per unit length and the admittance per unit length Y of the sheath in relation to the earth, which may be chosen according to ground resistivities between 1 S and 10 S (1 S should be chosen if nothing is known about earthing quality).

8.3.1 *Influence of length*

The remarks relating to cables with insulating covering are also applicable in this case.

8.3.2 *‘‘Long’’ links*

The screening factor is close to k_n. The cable may or may not be armoured, according to the results required.

8.3.3 *‘‘Short’’ links*

Screening factor $k_{f\backslash d'}$ may be estimated by means of Equation (8-3). The cable should be armoured in most cases.

8.4 *Determination of cable parameters*

If the nominal screening factor and impedance per unit length

Z_i^E can be measured by means of the arrangement described in the *Directives* (Vol. IX), determination of impedance per unit length Z_e^E can be based:

— either on a calculation based on the phaser diagram, plotted from the measured parameters I , U_{oi} and U_{oe};

— or on the measurement of the voltage U_{oe} appearing between the end of a conducting wire laid on the outside of the sheath and reference point 3, the other end of the wire being connected to the sheath (Figure 5/K.14).

For certain cables with screens consisting of several non-ferromagnetic, highly-conductive layers, these parameters can be measured more approximately by a coaxial-type measuring device.

Figure 5/K.14, p.

APPENDIX I

(to Recommendation K.14)

Letter symbols used in Recommendation K.14

Z^E_i | Internal impedance per unit length with external return. For power frequencies, this value is close to resistance per unit length for direct current.

Z^E_e | External impedance with external return per unit length.

Z_s | Ground return impedance per unit length.

Y | Admittance per unit length of the sheath-earth circuit.

P | Propagation constant of the sheath-earth circuit.

K | Characteristic impedance of the sheath-earth circuit.

W |

$_A$, W |

$_B$ | Impedance value of earths at the ends of the sheath.

L | Length of link subject to induction.

e | Induced e.m.f. per unit length.

E | Total induced e.m.f.

I | Current flowing through the sheath.

Reference

[1] CCITT manual *The protection of telecommunication lines and equipment against lightning discharges* , Chapter 4, § 2.1, ITU, Geneva, 1974, 1978.