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SERIES K: PROTECTION AGAINST INTERFERENCE

Operator responsibilities in the management of electromagnetic interference by power systems on telecommunication systems

Recommendation ITU-T K.68

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Summary

Recommendation ITU-T K.68 deals with the management of electromagnetic (e.m.) interference produced by electric power systems and electrified traction systems on telecommunication systems.

This Recommendation defines the procedure to evaluate the acceptability of an e.m. interference and gives:

– the criteria defining the interference situations to be examined;
– the interference management voltages to be applied;
– the installation conditions of electric power, electrified traction and telecommunication systems under which the management voltages are applicable.

This Recommendation establishes an official agreement between telecommunication operators and power and railway operators in order to clearly share responsibilities, and, as a consequence, if necessary, the relevant expenses for mitigation measures.

Source

Recommendation ITU-T K.68 was approved on 13 April 2008 by ITU-T Study Group 5 (2005-2008) under Recommendation ITU-T A.8 procedure.

Keywords

Damage, danger, disturbance, immunity, malfunction, noise, power frequency interference, resistibility, responsibility, safety.

FOREWORD

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Introduction

The Directives (*Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines)* are the reference documents dealing with the electromagnetic interference (e.m. interference) produced by electric power systems and electrified railway systems on telecommunication systems. The Directives (1988, 1989, 1999 and 2008 editions) are divided into 9 volumes, each dealing with a separate part of the overall subject. Their use can be guided as follows:

– For a broad understanding of telecommunication, power and railway facilities and their mutual coupling effects, consult Volume I.

– For further information on inducing installations in power or electrified railway systems, consult Volume IV (railway systems) or Volume V (power systems).

– For understanding the physical-mathematical theory of the e.m. interference and to know calculation methods, at various levels of detail and precision, consult Volumes II and III.

– To understand the effects of induced voltages and currents, i.e., danger, damage and disturbance, and the recommended permissible values, consult Volume VI.

– For advice on protective components or complex protective devices, consult Volume VIII.

– For information on relevant testing and measuring techniques, consult Volume IX.

NOTE – The content of the Directives has been formally agreed by ITU, CIGRE and UIC.

Since their first edition (1952), the Directives have been the worldwide reference text in the field of e.m. interference, used for establishing regional or national standards, even for topics not identical to the ones dealt with in the Directives but strictly related to them, like e.m. interference produced by electric power systems and electric traction systems on pipelines or metallic structures.

The Directives were established when the number of actors involved in e.m. interference was low. Even if, in some countries, the liberalization in telecommunication, energy and transportation dates back a long time, in many countries there was only one telecommunication company, one energy company, one railway company. The solution of e.m. interference problems was managed by few specialists and had the character of scientific study. Now the number of actors is highly increased, and the solution of the e.m. interference problems must be treated as a normal design activity and the need of information and the guidance of such actors are necessary.

The Directives contain a very large amount of valuable information both at the scientific and practical design levels. Therefore, there is the need to guide through this information the mainly small companies or companies who could face the e.m. interference problems for the first time.

In fact, the Directives do not answer the following questions:

1) *who* is responsible for the e.m. interference;

2) *when* the e.m. interference has to be evaluated;

3) *how* this evaluation shall be carried out.

This Recommendation deals with the management of the e.m. interference; in particular, it aims to define:

– the maximum distance between the involved plants for evaluating the e.m. interference (*when*);

– the conditions (installation conditions, working conditions, energy flow, etc.) of the involved plants to which the management voltages are related (*how*);

– the Operator's responsibilities for the e.m. interference (*who*).

This Recommendation deals with all the aspects of the management of e.m. interference in a comprehensive manner.

Recommendation ITU-T K.68

Operator responsibilities in the management of electromagnetic interference by power systems on telecommunication systems

1 Scope

This Recommendation gives the criteria defining situations to be examined and the installation conditions of both power and telecommunication plants under which the management voltages are applicable to the e.m. interference produced on telecommunication systems by the following power systems:

– a.c. electric power systems;
– d.c. electric power systems;
– a.c. electrified traction systems;
– d.c. electrified traction systems;

resulting from the following physical mechanisms:

– inductive coupling;
– conductive coupling;
– capacitive coupling;

for different power system conditions:

– normal;
– fault;

in the frequency range 0 Hz to 9 kHz.

It covers the resulting effects of:

– danger to people;
– damage to the telecommunication system;
– disturbance to the telecommunication system (malfunction, noise).

This Recommendation is applicable to all telecommunication lines with metallic elements. Fibre-optic cables are to be considered only if a metal conductor, screen or sheath, is included in their construction.

The objective of this Recommendation is to establish:

– the procedure for evaluating the e.m. interference (clause 4);
– the maximum distance between power and telecommunication plants for studying the e.m. interference between them (clause 5);
– the installation conditions (clause 7) of both power and telecommunication plants under which the interference results shall be evaluated (through calculations in accordance with volume II or III of the Directives, through measurements, or through a suitable combination of both) in order to check the compliance (clause 8) of the induced voltages on the telecommunication line with the appropriate management voltages (clause 6);
– an official agreement between telecommunication operators and electric power and electrified railway operators in order to clearly share responsibilities and, as a consequence, if necessary, the relevant expenses for mitigation measures (clause 9);

– a reminder of the need to maintain a suitable monitoring of the technical characteristics evolution of the plants involved in the interference to avoid, due to modifications, an acceptable interference evolving into an unacceptable one (clause 10).

This Recommendation is applicable to all situations where a private or public telecommunication plant is liable to be influenced by one or more power plants.

This Recommendation is applicable to new telecommunication and new power plants and also to existing plants where modifications are proposed, such as changes of system earthing, line configuration, operating voltage and fault current (also due to modifications in plants connected to another under consideration), which will significantly increase the existing levels of e.m. interference.

This Recommendation shall be used in the determination of the types of coupling to be considered for various power system operating conditions, and in the comparison of predicted induced voltages with the management voltages given in clause 6.

This Recommendation does not apply to e.m. interference from electric power systems with a nominal operating voltage below 1 kV.

The definition of the mitigation measures, if necessary, is outside the scope of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions, which through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T K.10] Recommendation ITU-T K.10 (1996), *Low frequency interference due to unbalance about earth of telecommunication equipment*.

[IEC 60050-161] IEC 60050-161 (1990), *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*.
<http://webstore.iec.ch/webstore/webstore.nsf/artnum/000397>

[IEC 60050-448] IEC 60050-448 (1995), *International Electrotechnical Vocabulary – Chapter 448: Power system protection*.
<http://webstore.iec.ch/webstore/webstore.nsf/artnum/018396>

[IEC/TS 60479-1] IEC/TS 60479-1 (2005), *Effects of current on human beings and livestock – Part 1: General aspects*. <http://webstore.iec.ch/webstore/webstore.nsf/artnum/034455>

3 Definitions

This Recommendation defines the following terms:

Unless defined in this Recommendation, the definitions given in [IEC 60050-161] and [IEC 60050-448] shall be applicable.

3.1 system: Generic word to encompass all the elements, parts, equipment connected together, of a given technology (electric power system, electrified traction system, telecommunication system).

3.2 a.c. electric power system: Electrical system, operating with alternating current (a.c.), devoted to electrical energy transmission and distribution.

NOTE – Two-phase power systems operating at 16⅔ Hz dedicated to the supply of a.c. electrified traction systems shall be considered as a.c. electrified power systems, even if the relevant conductors are placed on the same poles of traction lines.

3.3 d.c. electric power system: Electrical system, operating with direct current (d.c.), devoted to electrical energy transmission from substation to substation.

NOTE – These substations are in fact a.c./d.c. rectifier stations and d.c./a.c. inverter stations.

3.4 a.c. electrified traction system: Electrical system, operating with alternating current (a.c.), devoted to electrical energy supply from traction substations to electric train units: the return path, metallic conductors and/or earth, is part of the traction system.

3.5 d.c. electrified traction system: Electrical system, operating with direct current (d.c.), devoted to electrical energy supply from traction rectifier stations to electric train units: the return path, metallic conductors and/or earth, is part of the traction system.

3.6 power system: General expression encompassing, in this Recommendation, both electric power systems and electrified traction systems.

3.7 wireline telecommunication system: A system which is able to transmit information between two or more points by means of physical links. The wireline telecommunication systems to be considered in this Recommendation are those with metallic parts (e.g., metallic pair, cable sheath, reinforced fibre-optic, etc.: the fibre optic itself is not involved in the physical phenomena dealt with in this Recommendation).

3.8 plant: A part of a system which is involved in an e.m. interference problem with one or more plants of other systems:

– a plant may be a power line connecting two substations or a substation (power plant);
– a plant may be a traction line connecting two railway stations or a feeding station (power plant);
– a telecommunication line connecting two exchanges or connecting an exchange to several customers through a single cable from the exchange, which is subdivided into several branches at cabinets (telecommunication plant).

3.9 normal operation: Operation of any system, which is deemed to be fault free. Transient phenomena due to switching taking place on power systems are considered to be normal.

3.10 fault condition (for power systems): Unintentional connection via contact, arc, etc. of an energized conductor to earth or to any earthed metallic object, i.e., shunt fault, or unintended disconnection or breakage of current-carrying conductors (including return path for traction systems), i.e., series fault.

Fault condition also includes cases of a short circuit between any two phases or one phase disconnected ("one-phase off").

3.11 fault duration: Time duration for which a single fault condition lasts.

NOTE – The fault duration of a shunt fault is determined by the fault clearance time, which is the time interval between the fault inception and the fault clearance [IEC 60050-448].

3.12 reference fault duration: The duration of the longest current interruption time of the associated circuit-breaker(s) for elimination of fault current in the case of correct operation of protection. When high impedance earth faults should also be considered, the reference earth fault duration is associated with the longest interruption time for the elimination of at least 65% of the total number of earth faults. [IEC 60050-448].

NOTE – The correct operation of protection means the initiation of a tripping signal and other commands from a protection in the intended manner in response to a power system fault or other power system abnormality and the operation of the circuit breaker(s) corresponding to the tripping signal.

3.13 e.m. interference: Electromagnetic phenomenon (explained by means of the three types of electromagnetic couplings), which a power plant can create in a neighbouring telecommunication plant and which may cause danger, damage or disturbance, on the latter.

3.14 inducing: Adjective used to identify the plant producing the e.m. interference and the relevant quantities (inducing line, inducing current, inducing voltage, etc.).

3.15 induced: Adjective used to identify the plant affected by the e.m. interference and the relevant quantities (induced line, induced current, induced voltage, etc.).

3.16 inductive coupling: Phenomenon whereby the magnetic field produced by a current-carrying line (inducing conductor(s)) influences another line (induced conductor(s)), the coupling being quantified by the mutual impedance between the two conductors with common earth return. The current carried by the inducing line is the inducing current.

3.17 capacitive coupling: Phenomenon whereby the electric field produced by a voltage-carrying line (inducing conductor(s)) influences another line (induced conductor(s)), the coupling being quantified by the capacitance coefficients between the conductors and between each conductor and earth. The voltage carried by the inducing conductor is the inducing voltage.

3.18 conductive coupling: Phenomenon whereby the current flowing from a conductor structure (inducing conductor(s)) to the earth influences another conductor structure (induced conductor), the coupling being quantified by the conductance between such conductors (structures). The current flowing from the inducing conductor to the earth is the inducing current.

3.19 danger: Effect of interference, which is able to produce a threat to a person in contact with the induced telecommunication plant.

3.20 damage: Effect of interference, which produces a permanent reduction in the quality of service, which can be offered by the induced telecommunication plant.

NOTE – When e.m. interference disappears, the damage remains. A damage requires a repair intervention.

3.21 disturbance: Effect of interference, which results in noise or malfunction of the induced telecommunication plant.

NOTE – When e.m. interference disappears, the disturbance disappears too. A disturbance does not require a repair intervention.

3.22 noise: Type of disturbance which produces a reduction in the quality of a voice-based service, which is offered by the induced telecommunication plant.

3.23 malfunction: Type of disturbance related to equipment installed along an induced telecommunication plant, resulting in loss of capability of equipment to initiate or sustain a manufacturer's declared function or the initiation of equipment emissions in excess of electromagnetic compatibility design limits.

3.24 influence distance: Distance from a power plant at which inductive coupling or capacitive coupling or conductive coupling or a combination of them can produce interference results on a telecommunication plant.

NOTE – From a theoretical point of view, the amount of the influence distance from a power plant tends to infinity: the larger the distance the lower the interference results.

3.25 reference influence distance: Maximum distance from a power plant at which exposure to interference must be considered.

NOTE – From the practical point of view, it is unnecessary to consider in this Recommendation distances greater than the reference influence distance.

3.26 induced length: The projection of a telecommunication line on an electric power or electrified traction line from the point at which a telecommunication line comes within the reference influence distance (d) of the electric power or electrified traction line and the subsequent point at which the telecommunication line moves beyond the reference influence distance (see Figure 1).

NOTE – The interference on the whole line should be examined when a part of the line or the whole line is within the exposure zone.

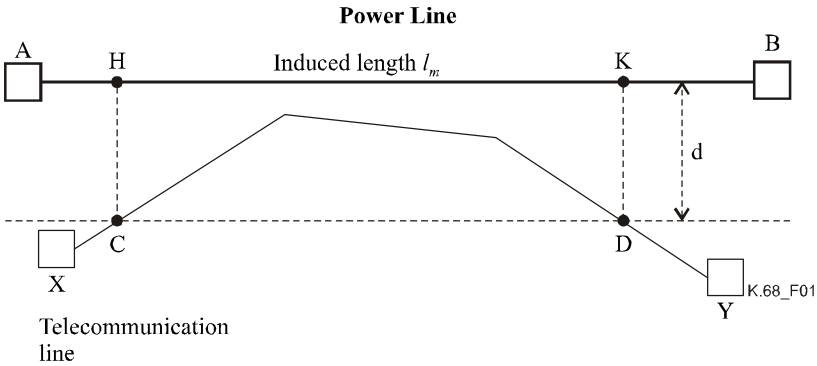

Figure 1 – Induced length

3.27 earth: The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero (in some countries the term "ground" is used instead of "earth").

3.28 induced voltage: Voltage produced in an induced telecommunication plant through e.m. interference due to one or more inducing power plants.

3.29 induced common mode voltage: The induced voltage common to all conductors of a group having identical common mode conditions appearing between that group and the earth at a given location of the telecommunication plant (see Figure 2).

NOTE – The highest common mode voltage generally occurs at one end of a conductor, when the other end of that conductor is earthed.

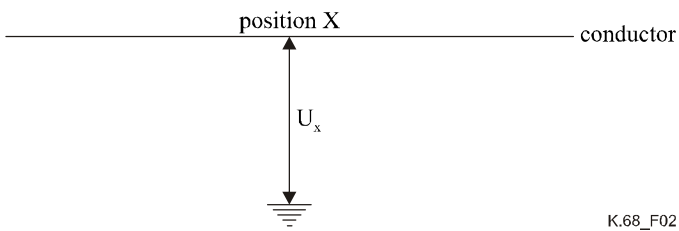

Figure 2 – Induced common mode voltage

3.30 induced differential mode voltage: The induced voltage between any two of a specified set of metallic conductors at a given location of the telecommunication plant (see Figure 3).

NOTE – Usually the voltage of importance is the one between the two conductors of a symmetrical pair. In some cases also, the voltage between two different pairs is important.

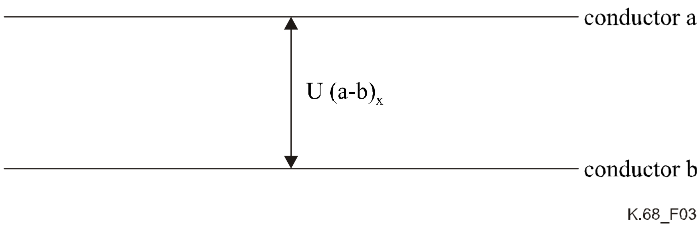

Figure 3 – Induced differential mode voltage

3.31 equivalent soil resistivity: Resistivity of homogenous soil representative of the various types of stratified soil present at the location of the considered power and telecommunication plants used for interference management.

NOTE – It is possible to have different values of the equivalent soil resistivity along the plants.

3.32 psophometric voltage or current: The psophometric voltage or current is the voltage or current on a telephone line (common or differential mode), U_p, or I_p, given by the expression:

$$U_\mathrm{p} = \frac{1}{p_{800}} \sqrt{\sum (p_f U_f)^2} \quad [\mathrm{V}] \tag{1a}$$

$$I_\mathrm{p} = \frac{1}{p_{800}} \sqrt{\sum (p_f I_f)^2} \quad [\mathrm{A}] \tag{1b}$$

in which:

U_f or I_f is the component at frequency *f* of the voltage [V] or of the current [A]

$\mathrm{p_f}$ is the weighting for this frequency, reflecting the responsiveness of the human ear to this frequency, given in the weighting table associated with the psophometer specification. The table in Appendix I gives values of $\mathrm{p_f}$ for the various frequencies, when $\mathrm{p_{800}}$ is equal by convention to 1000

3.33 rural area: Area, which has a low density of local metallic structures in direct electric contact with the soil.

3.34 urban area: Area, which contains a high density of local metallic structures in direct electric contact with the soil, such as water pipes, cables with bare metal sheaths, earth wires of bare copper, tracks of tramways or underground or overground traction systems and earth-terminations and structures of buildings, masts and foundations.

3.35 interference frame: The complete interference scenario pertaining to a single plant, to be examined as a whole.

The interference frame of an induced plant contains the induced plant itself and all the plants inducing it. The interference frame of an inducing plant contains the inducing plant itself and all the plants induced by it.

3.36 interference result: Electric quantity able to describe the amount of the interference. An interference result can be evaluated through calculations and measurements.

3.37 interference effect: Consequence of interference on people touching the induced plant and on the induced plant itself or the connected equipment.

3.38 immunity: The ability of a device, equipment or system to perform without degradation in the presence of a disturbance, see clause 3.21.

3.39 resistibility: The ability of a device, equipment or system to withstand, without damage, in the presence of an electromagnetic phenomena up to certain, specified extent, and in accordance with a specified criterion.

3.40 management voltage: General name encompassing all the induced voltages to be used to evaluate if an interference situation is acceptable, i.e.:

– the limit values related to danger to people working on the telecommunication plant;

– the limit value related to noise;

– the minimum resistibility voltage level of the equipment connected to the telecommunication plant;

– the minimum insulation withstand voltage level of the telecommunication plant;

– the minimum immunity voltage level of the equipment connected to the telecommunication plant.

3.41 typical situation: The typical situation of the e.m. interference due to power systems is characterized by the following aspects:

– the work on telecommunication plant is carried out by trained and experienced personnel;

– the working conditions are such that only current paths hand-to-hand and hand-to-feet are to be considered;

– the admissible current is the one given in [IEC/TS 60479-1] (Figure 20, curve c_2).

3.42 severe situation: The case where the aspects characterizing the typical situation of the e.m. interference due to power systems are not applicable is referred to as a severe situation. A severe situation is characterized by the following aspects:

– the working conditions are such that current paths hand-to-hand, hand-to-feet, hand-to-chest and hand-to-hip are to be considered;

– the source impedance value is assumed to be zero;

– the admissible current is the one given in [IEC/TS 60479-1] (Figure 20, curve c_1).

4 Procedure for evaluating the e.m. interference

4.1 General

In order to evaluate if an interference situation is acceptable, a designer must perform an activity which could be subdivided into various steps (see Figure 4).

The following clauses aim to recommend on how to proceed[1].

[1] The procedure described is referring to the case of a new telecommunication plant to be designed, facing existing power plants: of course, the reverse case can also happen. In the case of designing a new inducing plant, the procedure is similar with some "obvious" differences.

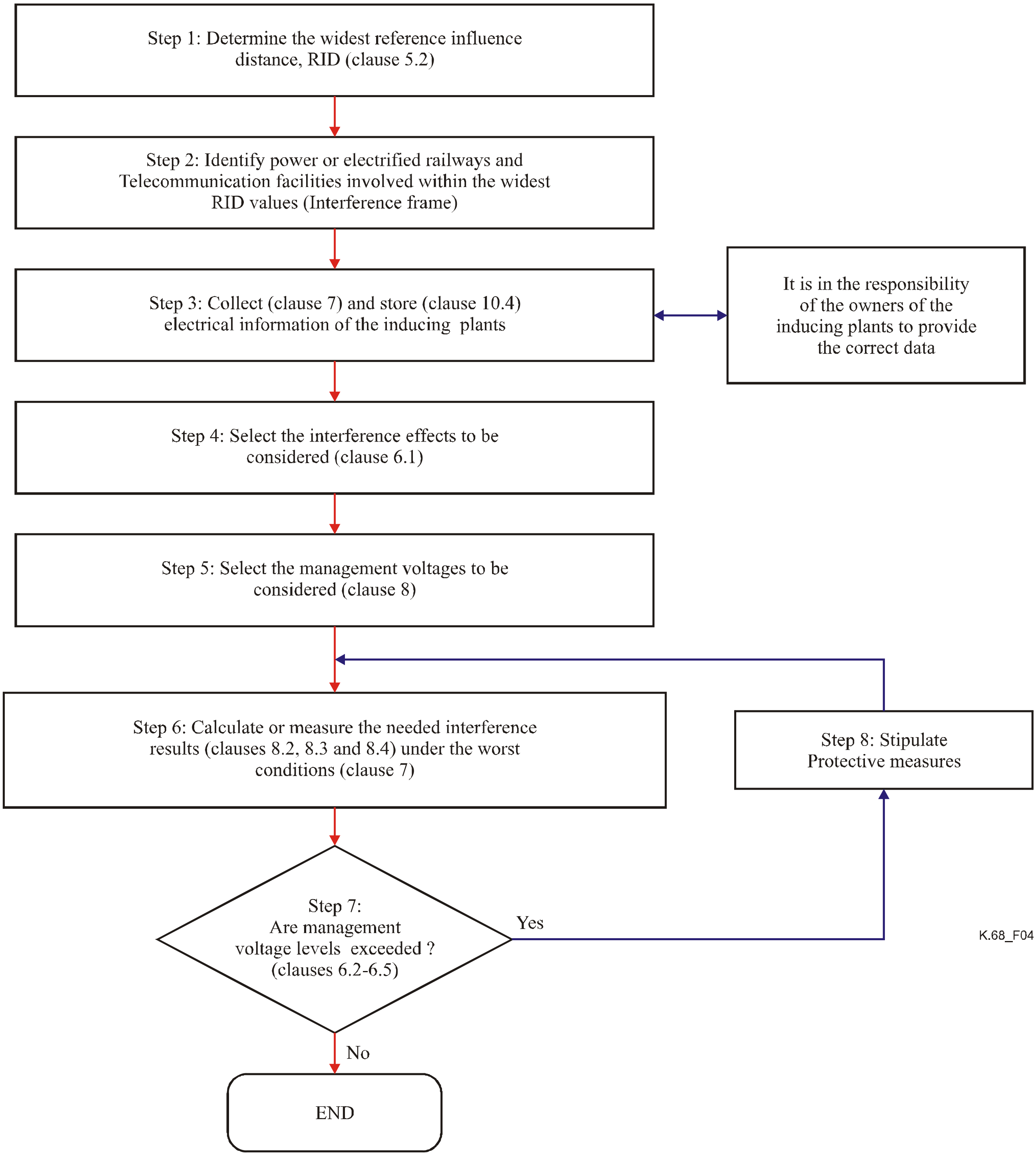

Figure 4 – Flow chart summarizing the procedure for evaluating the e.m. interference

4.2 Interference frame

According to the widest reference distance (given in clause 5.2), a census has to be performed of the possible inducing plants. This can be done by surveys and/or by contacting the owners of such plants to know the layouts of the latter. Then, according to the type of each plant, the relevant coupling types have to be selected (see clause 5.1), and the actual reference influence distances have to be determined (see clause 5.2) for each coupling type and for each possible inducing plant. Depending on the actual reference influence distances, some inducing plants can be ignored. At the end of this step the interference frame for the induced plant is known.

4.3 Collection of electrical information of inducing plants

When an inducing plant is planned to be built or altered, the owner must inform the owners of effected plants. Such information must include the electrical data needed to describe the reference interference conditions (clause 7).

It is the responsibility of the owners of the inducing plants to provide the correct data: thus, it is important to have a record of it (see clause 10.4).

4.4 Evaluation of the interference results and compliance with the management voltages

4.4.1 Background principles

As a function of the type of induced plant and, in connection with all the inducing plants of the interference frame, the designer must:

– select the interference effect(s) to be considered, according to clause 6.1;

– assess the interference result(s) for each effect selected in the previous step, according to clause 6.1;

– perform calculations or measurements or a suitable combination of both, in order to evaluate the needed interference results, according to clauses 8.2, 8.3 and 8.4. The interference situations to be examined (worst case interference) have to be selected according to clause 7.

4.4.2 First evaluation

By calculations or by measurements or by a suitable combination of both, compliance with the management voltages (clauses 6.2, 6.3, 6.4 and 6.5) shall be evaluated for the induced plant in its basic design configuration (see clause 8.1).

If the interference situation is acceptable, no more design activities are necessary.

If the interference situation is unacceptable, mitigation measures shall be applied.

4.4.3 Mitigation measures design: Subsequent evaluations

The designer has to select possible mitigation measures, and to make evaluations, by calculations or by measurements or by a suitable combination of both, to find the ones which are best suited for the induced plant.

Which measures shall be taken and whether the measures shall be taken at the inducing or the induced system will depend on the type and extent of the interference, on the cost of the mitigation measures, and whether systems already exist or are in the design phase. As in every design activity, the best solution is a good compromise between technical and economical needs.

The designer must manage this activity very carefully.

The designer must take into account that mitigation measures able to reduce the induction results in a part of the induced plant (e.g., an earth connection at one end of the plant) can produce an increase in other parts of the plant (e.g., on the opposite end of the plant); thus, it is important to consider various induction configurations.

The designer must also take into account that a mitigation measure able to solve an unacceptable interference situation produced by a given inducing plant can, at the same time, transform an acceptable interference situation produced by another inducing plant into an unacceptable one. This means that all the plants of the interference frame must be adequately considered.

NOTE – In general, except for conductive coupling at substations, the situation is expected to be acceptable if the induced line is a conductor in a cable with earthed metallic sheath or screen and is fitted with lightning protectors at both ends, and special precautions are used to prevent an inadmissible current flow through the body.

5 Interference situations to be examined

5.1 Coupling types to be considered

5.1.1 Planning stage

Tables 1, 2 and 3 define the coupling types requiring examination (calculation or measurement) before bringing new plant into service.

Table 1 relates to single earth fault conditions and allows for the fact that fault current values associated with isolated and resonant earthed systems are low.

Conductive coupling is only considered in areas where telecommunication systems enter an EPR (earth potential rise) zone of a power earthing grid.

Table 1 – Coupling types to be considered for power plants under various earth fault conditions – Planning stage

Power plant type		Telecommunication plant type		
		Overhead cable		Underground cable
		Without metal sheath	With metal sheath connected to earth	
2- and 3-phase a.c. overhead electric power system	neutral earthed directly or through small impedance	inductive conductive	inductive conductive	inductive conductive
	neutral isolated or resonant earthed	none	none	none
2- and 3-phase a.c. electric power cable system	neutral earthed directly or through small impedance	inductive conductive	inductive conductive	inductive conductive
	neutral not directly earthed	none	none	none
d.c. electric power system		none	none	none
a.c. electrified traction system		inductive conductive	inductive conductive	inductive conductive
d.c. electrified traction system		none	none	none

Table 2 – Coupling types to be considered for power plants under normal operation, which may cause danger to people or damage to a telecommunication plant – Planning stage

Power plant type		Telecommunication plant type		
		Overhead cable		Underground cable
		Without metal sheath	With metal sheath connected to earth	
3-phase a.c. overhead electric power system	all types of neutral earthing	inductive capacitive	inductive	inductive
3-phase a.c. electric power cable system	all types of neutral earthing	none	none	none
d.c. electric power system		none	none	none
a.c. electrified traction system		inductive	inductive conductive	inductive conductive
d.c. electrified traction system		none	conductive	conductive

Table 3 – Coupling types to be considered for power plants under normal operation which may cause disturbance to a telecommunication plant – Planning stage

Power plant type		Telecommunication plant type		
		Overhead cable		Underground cable
		Without metal sheath	With metal sheath connected to earth	
3-phase a.c. overhead electric power system	all types of neutral earthing	inductive	inductive	inductive
3-phase a.c. electric power cable system	all types of neutral earthing	none	none	none
d.c. electric power system		none	none	none
a.c. electrified traction system		inductive	inductive conductive	inductive conductive
d.c. electrified traction system		none	none	none

5.1.2 Operation stage

All coupling types, other than those found in Tables 1, 2 and 3, do not usually result in danger, damage or disturbance, thus calculations or measurements are only required if effects of interference appear.

5.2 Reference influence distance

5.2.1 General

Power plants located at a distance less than or equal to the reference influence distance (RID) from a given telecommunication plant shall be considered as inducing plants for this telecommunication plant. This allows for establishing the interference frame for the induced telecommunication plant.

Telecommunication plants located at a distance less than or equal to the RID from a given power plant shall be considered as induced plants for this power plant. This allows for establishing the interference frame for the inducing power plant.

The objective of RID is to limit the number of inducing plants to be considered and for which the inducing current/voltages values are necessary.

This Recommendation suggests the values of RID given in the following clauses: they have been evaluated with the method presented in Annex A and the assumptions described in Appendix II under the worst conditions represented by the fault conditions for the electric power lines and normal conditions for electric traction lines (the values reported in the tables refer to the worst case, i.e., larger RID values); however, different values may be defined in each country, e.g., by the national committee or authority, or should be agreed by the involved parties, using the method given in Annex A and assuming different values of the involved parameters with respect to the values shown in clause II.2, in order to better meet the national conditions. A range of values for these parameters is described in clause II.1.

The RID has the practical goal of allowing one to know which are the plants whose electrical data have to be asked for from the power/traction/telecom administration or network operator. However, the RID concept does not eliminate the responsibility of the concerned parties on the interference which could occur at distances greater than RID values.

RID should be measured from the projection to earth of the centre of the power line.

5.2.2 Inductive coupling

5.2.2.1 Fault conditions

5.2.2.1.1 a.c. electric power line

The RID values reported in Table 4 for typical situations and Table 5 for severe situations should be applied for f = 50/60 Hz.

These tables give the RID values for unshielded short (e.g., access network) or long telecommunication lines as a function of the equivalent soil resistivity, for overhead and underground a.c. electric power lines having directly earthed neutrals in both rural and urban area.

Table 4 – RID values for a.c. power systems at 50/60 Hz in typical situations

<table>
<tr><th rowspan="4">Length of the telecommunication system</th><th rowspan="4">Equivalent soil resistivity [Ω · m]</th><th colspan="4">RID [m]</th></tr>
<tr><th colspan="4">Power system/environment</th></tr>
<tr><th colspan="2">Overhead</th><th colspan="2">Underground</th></tr>
<tr><th>Rural</th><th>Urban</th><th>Rural</th><th>Urban</th></tr>
<tr><td rowspan="3">Short line</td><td>50</td><td>550</td><td>70</td><td>(Note)</td><td rowspan="3">(Note)</td></tr>
<tr><td>500</td><td>1700</td><td>100</td><td>(Note)</td></tr>
<tr><td>5000</td><td>5400</td><td>100</td><td>300</td></tr>
<tr><td rowspan="3">Long line</td><td>50</td><td>1200</td><td>500</td><td>300</td><td rowspan="3">20</td></tr>
<tr><td>500</td><td>3700</td><td>1200</td><td>1000</td></tr>
<tr><td>5000</td><td>12000</td><td>2400</td><td>3100</td></tr>
<tr><td colspan="6">NOTE – No interference.</td></tr>
</table>

Table 5 – RID values for a.c. power systems at 50/60 Hz in severe situations

Length of the telecommunication system	Equivalent soil resistivity [Ω · m]	RID [m]			
		Power system/environment			
		Overhead		Underground	
		Rural	Urban	Rural	Urban
Short line	50	1000	400	250	(Note)
	500	3300	800	750	
	5000	10000	1450	2400	
Long line	50	1800	1050	750	200
	500	5800	2600	2400	400
	5000	18000	6500	7500	600
NOTE – No interference.					

The a.c. electric power line, having no directly earthed neutral in general, does not cause interference on telecommunication lines in typical situations (interference can only occur in exceptional cases, see clause II.1); in severe situations, only a.c. electric overhead power lines in rural areas can cause interference on long telecommunication lines. In this case, the following RID values should be applied:

– 30 m for Ω = 50 ρm;

– 100 m for Ω = 500 ρm;

– 300 m for Ω = 5000 ρm.

The RID values reported in Table 6 for both typical and severe situations should be applied for the a.c. electric two-phase power plants at the f = 16⅔ Hz.

Table 6 gives the RID values for unshielded short (e.g., access network) or long telecommunication lines as a function of the equivalent soil resistivity for overhead a.c. lines in rural areas.

NOTE 1 – An underground power line is assumed to be a shielded line. If the shield with an insulated plastic covering is connected to earth at one end point only, the underground line should be considered as an overhead line.

NOTE 2 – An a.c. electric power line is an "overhead" line in rural areas whereas in urban areas only underground lines are installed.

Table 6 – RID values for a.c. electric two-phase a.c power systems at 16⅔ Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m]			
		Telecommunication system			
		Typical situation		Severe situation	
		Short line	Long line	Short line	Long line
Overhead/rural	50	100	700	800	1800
	500	300	2200	2500	5800
	5000	1000	7000	8000	18000

5.2.2.1.2 d.c. electric power line

Under study.

5.2.2.2 Normal operation

5.2.2.2.1 a.c. electrified traction line

5.2.2.2.1.1 RID for fundamental frequency induction

The RID values reported in Table 7 for 50/60 Hz and in Table 8 for 16⅔ Hz should be applied to a.c. electrified traction lines with a simple rail and earth return (RR) feeding system for both typical and severe situations.

The RID values reported in Table 9 for 50/60 Hz and in Table 10 for 16⅔ Hz should be applied to a.c. electrified traction lines with special (autotransformer (AT) or booster transformer (BT)) feeding systems for both typical and severe situations.

These tables give the RID values for unshielded short (e.g., access network) or long telecommunication lines as a function of the equivalent soil resistivity, for overhead and underground a.c. lines in both rural and urban areas.

Table 7 – RID values for a.c. traction lines with simple rail return (RR) feeding systems at 50/60 Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m] Telecommunication system	
		Short line	Long line
Overhead/rural	50	700	1350
	500	2200	4300
	5000	7000	13500
Overhead/urban	50	140	600
	500	250	1600
	5000	300	3500

Table 8 – RID values for a.c. traction lines with simple rail return (RR) feeding systems at 16⅔ Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m] Telecommunication system	
		Short line	Long line
Overhead/rural	50	450	1400
	500	1400	4300
	5000	4500	13500
Overhead/urban	50	15	400
	500		800
	5000		1200

Table 9 – RID values for a.c. traction lines with special (AT or BT) feeding systems at 50/60 Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m]	
		Telecommunication system	
		Short line	Long line
Overhead/rural	50	160	600
	500	500	2000
	5000	1000	2800
Overhead/urban	50	(Note)	130
	500		240
	5000		300
NOTE – No interference.			

Table 10 – RID values for a.c. traction lines with special (AT or BT) feeding systems at 16⅔ Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m]	
		Telecommunication system	
		Short line	Long line
Overhead/rural	50	10	280
	500	30	900
	5000	500	5000
Overhead/urban	50	(Note)	(Note)
	500		
	5000		
NOTE – No interference.			

5.2.2.2.1.2 RID for psophometric frequency induction

The RID values calculated for traction units with frequency inverters and asynchronous motors are lower than those related to power frequency, whereas the RID values calculated for diode (thyristor) locomotive with filter or for mixed thyristor controlled and diode locomotive without filter are reported in Tables 11 and 12 respectively for both typical and severe situations. These RID values are greater than those related to power frequency.

Table 11 – RID values for psophometric induction due to a.c. traction lines with diode (thyristor) locomotive with filter at 50/60 Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m]	
		Telecommunication system	
		Short line	Long line
Overhead/rural	50	940	Not relevant
	500	3000	
	5000	9400	
Overhead/urban	50	650	
	500	1800	
	5000	5300	

Table 12 – RID values for psophometric induction due to a.c. traction lines with mixed thyristor controlled and diode locomotive without filter at 50/60 Hz in both typical and severe situations

Power system/ environment	Equivalent soil resistivity [Ω · m]	RID [m]	
		Telecommunication system	
		Short line	Long line
Overhead/rural	50	1900	Not relevant
	500	6000	
	5000	19000	
Overhead/urban	50	1250	
	500	3500	
	5000	9400	

5.2.2.2.2 d.c. electrified traction line

Under study.

5.2.3 Capacitive coupling

The reference influence distance should be 100 m only when both induced and inducing lines are overhead and unshielded. In all the other situations, the capacitive coupling is neglected.

5.2.4 Conductive coupling

When calculating the RID for conductive coupling, the resistivity of the surface soil layer, in which the earthing electrode (grid) system is embedded, shall be considered.

5.2.4.1 Substation earthing grid

The RID values reported in Table 13 for typical situations and Table 14 for severe situations should be applied for f = 50/60 Hz.

These tables give the RID values for unshielded short (e.g., access network) or long telecommunication lines as a function of the equivalent soil resistivity, for overhead, mixed and underground a.c. electric power lines having directly earthed neutrals in both rural and urban areas.

NOTE – It is unlikely that a substation would be located in an area of very high soil resistivity, therefore the RID values given for 5000 Ω · m are not expected to be used, considering that the 500 Ω · m value covers the range between 150 Ω · m and 1500 Ω · m, as indicated in Table II.1.

Table 13 – RID values for a.c. power systems at 50/60 Hz in typical situations (conductive coupling due to substation earthing grid)

Size of substation grid [m^2]	Soil resistivity [Ω · m]	RID [m]					
		Power system/environment					
		Overhead		Mixed		Underground	
		Rural	Urban	Rural	Urban	Rural	Urban
225 (15 m × 15 m)	50	40	15	10	(Note)	(Note)	(Note)
	500	450	150	200	60	90	30
	5000	4700	1150	1900	450	900	200
2500 (50 m × 50 m)	50	50	10	5	(Note)	(Note)	(Note)
	500	700	200	250	75	120	30
	5000	7000	1700	2800	680	1400	300
22500 (150 m × 150 m)	50	30	(Note)	(Note)	(Note)	(Note)	(Note)
	500	850	250	300	60	120	2
	5000	9300	2200	3700	850	1800	400
NOTE – No interference.							

Table 14 – RID values for a.c. power systems at 50/60 Hz in severe situations (conductive coupling due to substation earthing grid)

Size of substation grid [m^2]	Soil resistivity [Ω · m]	RID [m]					
		Power system/environment					
		Overhead		Mixed		Underground	
		Rural	Urban	Rural	Urban	Rural	Urban
225 (15 m × 15 m)	50	100	40	40	10	15	(Note)
	500	1100	400	430	150	200	70
	5000	11000	2700	4300	1000	2200	500
2500 (50 m × 50 m)	50	140	50	40	5	10	(Note)
	500	1600	500	600	200	300	90
	5000	16400	4000	6500	1600	3200	800
22500 (150 m × 150 m)	50	150	30	20	(Note)	(Note)	(Note)
	500	2100	700	800	200	350	80
	5000	21800	5400	8600	2100	4300	1000
NOTE – No interference.							

5.2.4.2 Earthing of power line tower

The RID values reported in Table 15 for typical situations and in Table 16 for severe situations should be applied for f = 50/60 Hz.

These tables give the RID values for unshielded short (e.g., access network) or long telecommunication lines as a function of the equivalent soil resistivity, for overhead a.c. electric power lines having directly earthed neutrals in both rural and urban areas.

If measurements show different values to those reported in Tables 15 and 16, then the measured values apply.

Table 15 – RID values for a.c. power systems at 50/60 Hz in typical situations (conductive coupling due to power line tower)

Shield wire configuration	Soil resistivity [Ω · m]	RID [m]	
		Power system/environment	
		Overhead/rural	Overhead/urban
1 sw	50	15	6
	500	25	8
	5000	30	8
2 sw	50	10	4
	500	15	6
	5000	20	5
1 sw + cp	50	3	1
	500	7	2
	5000	15	3

Table 16 – RID values for a.c. power systems at 50/60 Hz in severe situations (conductive coupling due to power line tower)

Shield wire configuration	Soil resistivity [Ω · m]	RID [m]	
		Power system/environment	
		Overhead/rural	Overhead/urban
1 sw	50	30	15
	500	55	30
	5000	80	30
2 sw	50	20	10
	500	40	15
	5000	50	15
1 sw + cp	50	6	3
	500	15	5
	5000	30	7

5.2.4.3 a.c. electrified traction systems

The RID value is 5 m for both typical and severe situations.

6 Management voltages

6.1 Criteria defining the application of the management voltages

The effects to be considered and results of e.m. interference to be evaluated in order to quantify the amount of the electromagnetic interference in worst-case situations are the ones given in Table 17: the relevant management voltages are given in clauses 6.2, 6.3, 6.4 and 6.5.

Table 17 – Effects to be considered and relevant results

Effect on the induced plant	Inducing plant	Is the effect to be considered?	Interference result
Danger	in normal operation	yes	voltage to earth
	in fault condition	yes	voltage to earth
Damage	in normal operation	yes	voltage to earth
	in fault condition	yes	voltage to earth
Disturbance	in normal operation	yes	voltage between the two wires of a pair
	in fault condition	no	-------

6.2 Danger voltages: Limits

6.2.1 General

This clause gives the induced voltage values and durations on a telecommunication plant caused by influence from a nearby a.c. electric power or electrified traction plant during normal operation and fault condition that power and traction operators are allowed to cause by any type of electromagnetic coupling on an induced telecommunication plant without causing danger to people working on the telecommunication plant.

NOTE – Customers of telecommunication services are not allowed to touch any metallic element of the telecommunication network. (See [b-ITU-T K.50].)

6.2.2 Fault condition

The limit values of the induced common mode voltage with respect to the earth, at any point of the induced telecommunication plant, are given in Table 18 for typical situations and in Table 19 for severe situations.

NOTE 1 – Different limiting values may be calculated using Volume VI of the Directives.

NOTE 2 – Volume VI of the Directives explains the rationale of the values appearing in these tables.

Table 18 – Limits related to danger in case of e.m. interference produced by a.c. power plants in fault condition: Typical situations

Reference fault duration t [s]	Induced voltage r.m.s. [V]
t ≤ 0.10	2000
0.10 < t ≤ 0.20	1500
0.20 < t ≤ 0.35	1000
0.35 < t ≤ 0.50	650
0.50 < t ≤ 1.00	430
1.00 < t ≤ 3.00	150
3.00 < t	60

Table 19 – Limits related to danger in case of e.m. interference produced by a.c. power plants in fault condition: Severe situations

Reference fault duration t [s]	Induced voltage r.m.s. general [V]	Induced voltage r.m.s. when current paths through chest or hip need not be considered [V]
t ≤ 0.06	430	650
0.06 < t ≤ 0.1	430	430
0.1 < t ≤ 1.0	300	300
t > 1.0	60	60

For faults on d.c. power systems, the induced common mode voltage, under the transitory conditions, with respect to the earth, at any point of the induced telecommunication plant, shall not exceed the peak values given in Tables 18 and 19 for typical and severe conditions respectively.

NOTE 3 – Protection against danger is achieved if the induced line is a conductor in a cable with earthed metallic sheath or screen and all conductors are fitted with lightning protectors at both ends, the sheath is earthed at prescribed intervals and special precautions are used to prevent inadmissible current flow through the body.

6.2.3 Normal operation

The limit value of the induced common mode voltage with respect to the earth, at any point of the induced telecommunication plant, produced by all the inducing power plants of the interference frame, in normal operating conditions, acting together, is 60 V r.m.s.

6.3 Damage voltages

This clause gives the induced voltage values and durations on a telecommunication plant caused by influence from nearby power or traction plants during normal operation and fault condition that power and traction operators are allowed to cause by any type of electromagnetic coupling on an induced telecommunication plant without being responsible for mitigation measures against damages to the insulation and/or to the equipment of the telecommunication plant.

The values of the induced common mode voltages with respect to the earth at any point of the induced telecommunication plant, which can cause damages during fault condition of power plants, are:

1) the values given in Table 20 which are the minimum resistibility levels of the equipment connected to telecommunication plant;

   NOTE 1 – When the e.m. interference is produced by a d.c. power plant under transitory conditions, the limit values are the peak values of the r.m.s. induced voltages reported in Table 20.

2) 1000 V r.m.s. which is the minimum insulation withstand voltage for telecommunication plants comprised of symmetric cables with paper insulated conductors, irrespective of the reference fault duration;

3) 2000 V r.m.s. which is the minimum insulation withstand voltage for telecommunication plants comprised of coaxial cables, irrespective of the reference fault duration;

4) 2000 V r.m.s. which is the minimum insulation withstand voltage for telecommunication plants comprised of optical fibre cables containing metallic parts, irrespective of the reference fault duration.

   NOTE 2 – Protection against damages to the insulation and/or to the equipment of the telecommunication plant is achieved if the induced line is a conductor in a cable with earthed metallic sheath or screen and all conductors are fitted with lightning protectors at both ends.

Table 20 – Minimum resistibility level of the equipment connected to telecommunication plants as a function of the fault duration in a.c. power plants

Reference fault duraion t [s]	Induced voltage r.m.s. [V]
t ≤ 0.20	1030
0.20 < t ≤ 0.35	780
0.35 < t ≤ 0.50	650
0.50 < t ≤ 1.0	430
1.0 < t ≤ 2.0	300
2.0 < t ≤ 3.0	250
3.0 < t ≤ 5.0	200
5.0 < t ≤ 10.0	150
t > 10.0	60

6.4 Immunity voltages

The values of the induced voltage, produced by all the inducing power plants of the interference frame, in normal operating conditions, acting together, which can cause malfunctions of the equipment connected to the telecommunication plant, are:

– 60 V r.m.s. for the induced common mode voltage with respect to the earth at any point of the induced telecommunication plant;

– 60 V r.m.s. for the induced voltage between any two metallic parts at the same location, at any point of the induced telecommunication plant.

6.5 Noise voltage: Limit

The limit value of the induced psophometric voltage between the two wires of a pair of the induced telecommunication plant, produced by all the inducing power plants of the interference frame, in normal operating conditions, acting together, which can degrade the quality of a voice-based service which can be offered by the induced telecommunication plant, is 0.5 mV at any terminal of the induced telecommunication plant.

NOTE 1 – LCL values as indicated in clause 6 of [ITU-T K.10] lead to a permissible induced psophometric longitudinal voltage of 200 mV at any terminal of a telecommunications line.

NOTE 2 – In the case of e.m. interference from traction systems, if the induced psophometric voltage is greater than the noise limit value given in this clause but lower than 2.5 mV, the noise is tolerable if, in any interval lasting up to one minute, the sum of the products of the psophometric voltage values greater than 0.5 mV and the relevant duration is less than or equal to 30 mVs.

7 Reference interference conditions

7.1 General

The management voltage values given in clause 6 are referred to interference conditions which must be, at the same time, realistic (their probability to appear must not be too low) and the most severe ones.

Looking at the inducing plant, the reference interference condition is usually the one that is represented by the highest values of the inducing parameters (current, voltages, length of the approach, etc.).

Having this in mind, this Recommendation can only give guidelines about the reference interference conditions: this is most true for complex plants (e.g., a.c. electrified traction plants with autotransformers or booster transformers). Due to the fact that many parameters are involved, in most cases it is impossible to define *a priori* the worst interference condition: the worst situation on the induced plant is not necessarily characterized by the highest value of the induced voltage, it could be characterized by the widest part of the induced plant where unacceptable induced voltages appear.

It is up to the designer to examine different interference conditions in order to evaluate the worst one after examining the complete set of interference results.

Looking at the induced plant, the reference interference condition is the one that is represented by the best protective configuration, according to the design data.

The unbalance of the telecommunication plant must be in accordance with [ITU-T K.10].

7.2 Conditions related to the inducing plant

7.2.1 a.c. electric power system

7.2.1.1 Fault conditions

The fault condition to be considered is the phase to earth fault.

NOTE – These values are related to the transient phase to earth short-circuit currents. The first peak of the sub-transient should also be considered, i.e., in a substation of a generation station.

The value of the fault current shall be provided by the operating agency of the a.c. electric power plant concerned. The current should allow for planned increases in the fault current level of the plant.

The earth fault current shall be provided for all points along the length of the inducing plant including the substations as all these points of the inducing line are possible fault points.

The fault current values shall be provided in the form of diagrams, expressions or tables as values of the real inducing current, taking into account the reducing effect of, e.g., earthed top wires.

The reference fault duration shall be provided by the power company on the basis of the settings of the relay protection or statistical fault data applicable to the plant under examination.

7.2.1.1.1 Conductive coupling

The voltages appearing in the telecommunication system due to conductive coupling at a substation have to be measured because there is a big variation locally. The measurements are performed using a test generator with a current of a couple of tens of amperes. It is preferred to use a frequency other than the fundamental frequency, but near to that, e.g., 5-10 Hz below. With the use of a frequency selective voltmeter, you will avoid interference from the fundamental frequency in the test results. The current that results in the EPR is the current that flows through the substation earthing grid, which is only a part of the total fault current.

The reference interference voltages are achieved by multiplying the test results with the ratio (earthing grid current)/(test current).

The voltages appearing in the telecommunication system due to conductive coupling at a substation can be calculated if the parameters of the substation earthing grid and the earthing current are known. If parameters are not known or the substation is in an urban area or the soil near the substation has significant inhomogeneities, these voltages may have to be measured.

The current probe associated with the injection generator should be placed sufficiently far from the substation to avoid significant coupling between the grid and the probe. The conductors associated with the injection and EPR measurement probes should be placed at an angle of at least 90 degrees to avoid mutual inductance between them.

7.2.1.1.2 Inductive coupling

The fault location to be considered for evaluating the interference results to be compared with the limits shall be selected by the evaluating engineer as the one giving rise to the worst induced situation for a specific telecommunication line.

Figure 5 shows the length profile of the fault currents flowing from substations A and B as a function of the fault location along the power line. In this case, the impedance of the power line to earth at any point is the same, e.g., 0 Ω.

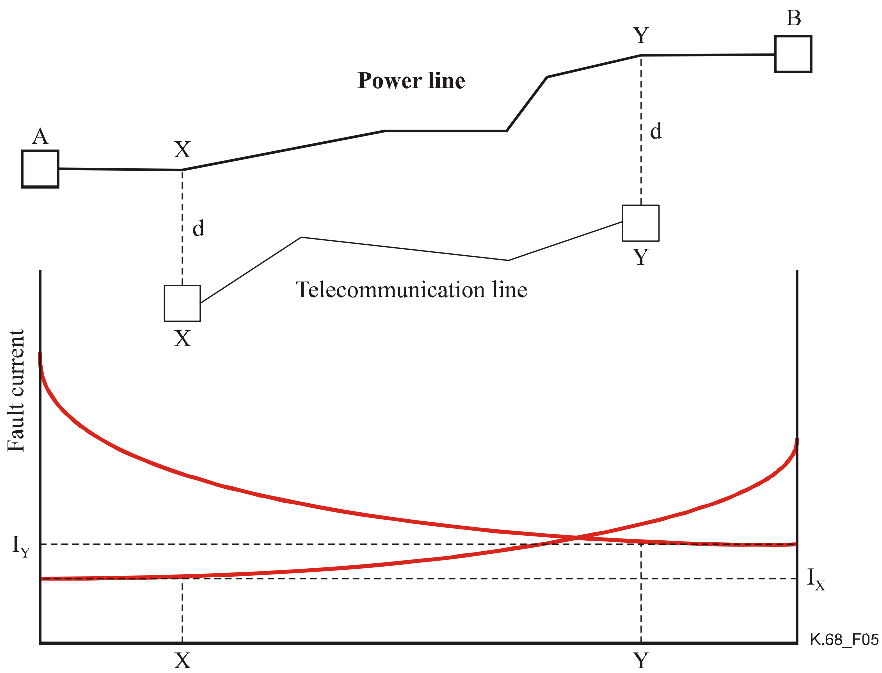

Figure 5 – Typical variation of the earth fault current with the fault location (e.g., X and Y) relevant to plants where the fault impedance is identical along the line

The fault current from substation A decreases from A along the line to substation B. A fault in position Y, which is one end of the projection of the telecommunications line X – Y, will normally give the highest induced voltage from substation A.

The current from substation B will give the highest induced voltage in the fault position X. Since I_Y is larger than I_X, I_Y will give the worst case.

Figure 6 shows the case where the fault impedance of the power line to earth is smaller at the ends, because of an impedance of 0 Ω at the substations. The impedance at any point along the line may be, e.g., 15 Ω. Therefore, there will be a step in the current profile outside the substations and the fault current shall be checked and compared for faults occurring not only at the two ends X and Y, but also in the feeding substations A and B.

The current from the substation A, I_Z, will give the highest voltage in this case, since it is larger than both I_X and I_Y.

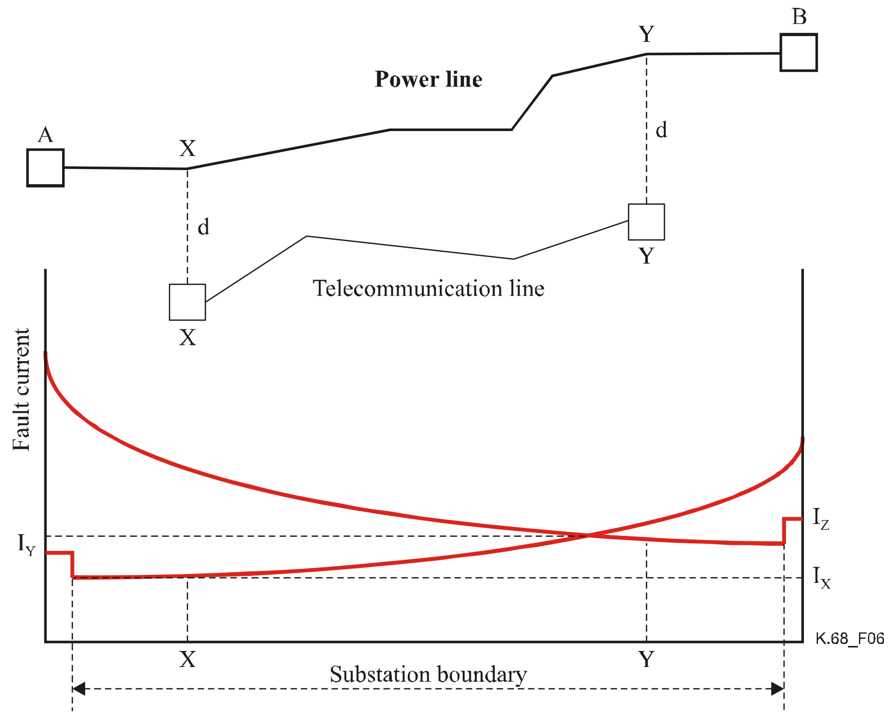

Figure 6 – Typical length profile of the earth fault current relevant to plants where the fault impedance is small at the ends (substations) but higher along the line (more realistic case)

7.2.1.2 Operating conditions

With respect to the inductive coupling, the inducing current is the continuous phase current rating with an unbalance of 2%. When the one phase off operation is applied, the inducing current to be considered is two-thirds of the rated current of the power line.

With respect to the capacitive coupling, the inducing voltage is 110% of the nominal voltage.

7.2.2 d.c. electric power system

7.2.2.1 Fault conditions

Under study.

7.2.2.2 Operating conditions

With respect to the inductive coupling, the inducing current is the ripple current resulting from rectification, relevant to the worst operating conditions (for example, during maintenance of the plant).

The power supply administration shall provide such values.

7.2.3 a.c. electrified traction system

7.2.3.1 Fault conditions

The fault condition to be considered is the earth fault current of one conductor of the traction line (usually the contact wire: conductors other than the contact wire shall be considered in turn to identify the worst-case condition).

The fault current shall be evaluated from knowledge of the source and line impedances pertaining to the inducing plant. It shall be assumed that the source voltage is at its maximum value at the time of the fault (110% of the nominal voltage) and that the fault impedance is 0 Ω.

The traction operator shall provide such values.

The fault location to be considered for evaluating the interference results to be compared with the limits shall be selected by the designer as the one giving rise to the worst-case induced situation.

It may be necessary to examine a number of cases to identify the worst-case fault location, especially in the case of special feeding systems, such as autotransformer or booster transformer systems.

7.2.3.2 Operating conditions

a) *Currents at the fundamental frequency*

The traction operator shall provide the values of the operating currents in all the conductors of the traction plant (tracks and earth included) along the whole plant allowing for:

- construction of the electrical system;
- position of the train sets relative to the cross-bonds between traction return conductors and other electrification features such as booster or auto-transformers;
- and current in all relevant tracks.

b) *Currents at harmonic frequencies*

The traction operator shall provide the values of all relevant current harmonics considering system resonance, system capacitance and considering each electric train unit as a current source. Alternatively, the traction operator shall provide the psophometric current value.

The load pattern of the train sets shall correspond with the one used for a) above.

c) *Line switching*

The frequency f of the inducing current to be used in the calculation of induced voltages produced by the energizing of an a.c. traction line is given by:

$$f = \frac{v}{4l} \quad \text{[Hz]} \qquad (2)$$

where:

v is the velocity of propagation [km/s] (= 290 000 km/s)

l is the length of the energized line section [km]

The value of the current is given by:

$$I_s = E / Z_c \quad [A] \tag{3}$$

where:

E is the ridge value of the supply voltage [V]

Z_c is the characteristic impedance of the catenary to earth loop [Ω]

7.2.4 d.c. electrified traction system

7.2.4.1 Fault conditions

Under study.

7.2.4.2 Operating conditions

With respect to the inductive coupling, the inducing currents are both:

a) the ripple current resulting from rectification, evaluated (through calculations or measurements) in the worst-operating conditions (for example, during maintenance of plants);

b) the current resulting from the load pattern of the train sets.

The traction administration shall provide such values.

7.3 Conditions related to the telecommunication plant

The reference condition for the induced telecommunication plant is the one specified by the plant design for the installation.

Lack of maintenance resulting in less effective protection against interference shall not be considered.

The telecommunication operator shall provide such values.

When required, the parameters describing the unbalance shall be provided (it must be remembered that the unbalance of the telecommunication plant must be in accordance with [ITU-T K.10]).

8 Determination of compliance with the management voltages

8.1 General

In order to determine the compliance with the management voltage values, the level of induced voltages shall be evaluated by calculations or by measurements or by a suitable combination of both.

Where the danger to people is relevant, the induced voltages shall not be greater than the danger voltages, i.e., the limits related to danger (in typical or severe conditions, according to the case) stated in clause 6.2.

Where the damage of the equipment is relevant, there are two options:

1) the induced voltage in the point where the equipment is or can be installed shall not be greater than the damage voltage values stated in clause 6.3; or

2) the induced voltage in the point where the equipment is or can be installed may be greater than the damage voltage values stated in clause 6.3, provided that, alternatively:

   a) the equipment, having a resistibility level lower or equal to the values given in clause 6.3, shall be adequately protected;

   b) an equipment, with enhanced resistibility level (resistibility level greater than the values given in clause 6.3), shall be installed.

NOTE 1 – The voltage values relevant to damage, stated in clause 6.3, have the only goal of defining how the responsibilities (e.g., expenses) must be shared among the owners of the inducing and the induced plant (see clause 9).

Where the malfunction of the equipment is relevant, there are two options:

1) the induced voltage in the point where the equipment is or can be installed shall not be greater than the voltage values related to malfunction stated in clause 6.4; or

2) the induced voltage in the point where the equipment is or can be installed may be greater than the voltage values related to malfunction stated in clause 6.4, provided that an equipment with enhanced immunity level (immunity level greater than the values given in clause 6.4) shall be installed.

   NOTE 2 – The voltage values relevant to malfunction, stated in clause 6.4., have the only goal of defining how the responsibilities (e.g., expenses) must be shared among the owners of the inducing and the induced plant (see clause 9).

Where the noise is relevant, the evaluated psophometric voltage value between the two wires of a pair at any terminal of the induced telecommunication plant shall be less than or equal to the noise limit value given in clause 6.5.

8.2 Superposition of the effects

When considering the interference frame of an induced plant, the following hypotheses apply:

– faults on the inducing plants (each being of very short duration) do not occur simultaneously: This means that the interference results produced on the induced plant by a single inducing plant in fault condition shall be evaluated alone and directly compared with the relevant management voltages;

– normal operating conditions of all the inducing plants occur simultaneously: This means that the interference results produced on the induced plant by all the inducing plants in normal operating conditions shall be evaluated, and these "cumulative" results shall be compared with the relevant management voltages.

8.3 Determination of compliance through calculations

It is commonly used to determine the compliance through calculations.

The calculations shall be done according to what has been stipulated between the involved parts: the agreed calculation methods should be selected in accordance with the ones given in the Directives.

8.4 Determination of compliance through measurements

It is not commonly used for many reasons, e.g., because a comprehensive measuring campaign can be very expensive. Moreover, it must be reminded that, usually, measurement results cannot directly be compared with the management voltages because it is very difficult to perform measurements in the reference interference conditions related to the management voltages. It means that the measurement results, performed in a non-worst case interference condition, require a suitable elaboration through calculation methods in order to obtain the values to be compared with the management voltages.

On the other hand, in some cases it is preferable to use measurements instead of calculations, e.g., when input data for calculations are known with a low degree of precision or when the calculation algorithm is approximated. For example, it could be preferable to measure the noise amount instead of calculating it.

9 Operator's responsibilities

The management voltage levels are defined in clause 6 in order to guarantee satisfactory coexistence between telecommunication systems and power and traction systems, taking into account that these voltages can represent a danger to the personnel working on the telecommunication plant and may produce damage, malfunction or disturbance to the equipment installed in it.

From another point of view, the levels represent an agreement between the owners of the systems (the so-called operators). Thus, such an agreement is of interest for the operators and of those companies involved in the design and the maintenance of the telecommunication, power and traction plants.

Management voltages represent permissible voltages in telecommunication lines caused by the electromagnetic influence from nearby power and traction plants during normal operation and fault condition. They are related to the worst-interference situation.

The permissible voltages are those, whose power and electrified railways systems are allowed to cause to a telecommunications line, without the operators of power and electrified railways systems being responsible for mitigation measures or the relevant expenses for mitigation measures.

The definition of the mitigation measures is out of the scope of this Recommendation, as indicated in the scope.

The responsibility should be based on the principle of priority (first coming), taking into account national regulations and existing agreements between operators.

10 Management of interference

10.1 General

Each interference situation deals with the safety of people and damage or malfunction of the plant. This means that it must be managed carefully (see clause 4), with the goal of ensuring that at the end of the design phase the interference is acceptable; if needed, adequate mitigation measures shall be provided (see clause 4.4.3).

It is in the interest of all the owners of the involved plant to cooperate to solve the e.m. interference problems.

10.2 Plant life

It must be reminded that the technical characteristics of a plant often vary during the plant life: as a consequence, also the status of an interference can vary during the plant life.

A critical situation happens when, due to modifications of the technical characteristics of one or more plants, or due to the fact that a new inducing plant enters the interference frame of an induced plant, an acceptable interference evolves to an unacceptable one: this happening must be covered by a suitable monitoring of the time evolution of the technical characteristics of the plants involved in the e.m. interference.

10.3 Exchange of information

It must be considered that an interference frame can involve several inducing/induced plants belonging to various owners. This means that a correct, efficient, reliable and timely exchange of information among all the involved companies is highly important.

A possible way to manage this aspect is that each company should appoint an "interference manager" who has the complete overview of all the interference problems pertaining to the company, in order to be the reference point for each exchange of information related to the interferences pertaining to the company.

10.4 Plant documentation

A possible way to keep under control the interference situations is to maintain an interference dossier for each plant.

This dossier could be arranged in the form of as many sub-dossiers as there are interference situations for the plant: it means that a telecommunication plant dossier will contain as many sub-dossiers as there are inducing plants, while a power plant dossier will contain as many sub-dossiers as there are induced plants (a dossier is relevant to an interference frame).

Each sub-dossier will contain all the documents related to the problem, e.g.:

– the contacts with all the owners of the inducing plants (in case of a telecommunication plant dossier) or the owners of the induced plants (in case of a power plant dossier) in order to keep a record of when, how and from where the data have been collected;
– the geometrical and electrical descriptions of the plants involved in the interference;
– the results of calculations performed (one calculation if the interference is acceptable since the beginning; several calculations if the interference was not acceptable at the beginning, thus a mitigation measures design was necessary: the dossier should keep a record of such design);
– the results of measurements performed, if any;
– any other document treating the agreements between the owners of the plants, relevant to the sharing of the costs of interference, if any.

Each sub-dossier should be independent and complete.

As well as the plant characteristics varying during the plant life, also an interference dossier of a plant can vary during the plant life, thus it could be necessary to add new documents (documents can only be added to a dossier) to keep a record of the plant history.

Annex A

Method for the evaluation of the reference influence distance

(This annex forms an integral part of this Recommendation)

A.1 Inductive coupling

A.1.1 Principle of the calculation

The reference influence distance (RID) for the lines of power and traction systems can be derived from the management voltages U_m with the consideration of the value of the inducing current, the possible maximum inducing length and the different screening action. The first step is the calculation of the following normalized value u_m of management voltage by the following expression:

$$u_m = \frac{U_m}{l_m}\frac{1}{k_t}\frac{1}{k_u}\frac{1}{k_p}\frac{1}{I_p} \qquad \left[\frac{V}{km \cdot kA}\right] \tag{A-1}$$

where:

- U_m is the appropriate management voltage value relevant to the inducing condition (fault or normal operation) and the kind of the management voltage (damage, resistibility), in V
- l_m is the maximum inducing length relevant to the plants of a given induction case, in km
- k_t is the screening factor associated with the induced line, dimensionless quantity
- k_u is the screening factor due to the buried metallic structures (urban factor), dimensionless quantity
- k_p is the screening factor associated with the inducing power line, dimensionless quantity
- I_p is the current with earth return of the inducing power line, in kA

The numerical value of u_m given by the above expression is equal to the numerical value of the mutual impedance z_m, per unit length, between the inducing line and a hypothetical line laying in parallel with the inducing line at the reference influence distance, i.e.:

$$u_m = z_m \left[\frac{\Omega \cdot m}{km}\right] \tag{A-2}$$

The value of z_m is function of the following quantities:

- f the frequency of the inducing current, in Hz
- ρ the equivalent soil resistivity, in $\Omega \cdot$ m
- d the reference influence distance for inductive coupling, in m

thus:

$$z_m = f(f, \rho, d) \left[\frac{\Omega \cdot m}{km}\right] \tag{A-3}$$

For a given induction case, both the frequency f and the soil resistivity ρ is known, for the environment to be studied, thus the d reference influence distance can be evaluated from the above relation. Due to the complicated nature of the mathematical expression of the relation for z_m, no explicit expression can be given for the calculation of the d reference influence distance. However, one of the methods given in the following can identify the value of d.

A.1.2 Determination of the reference influence distance

A.1.2.1 Calculation method

In principle, any expression providing the relation between the mutual impedance z_m with earth return and the quantities appearing in the expression (A-3) could be used for the calculation of the RID values *d* for inductive coupling. Such relations are contained in Volume II of the Directives (clause 4.1 of [b-ITU-T Dir. II]). Considering the estimation nature of the RID evaluation, no high precision expression is required for z_m. Therefore, the following expressions given in polynomial forms can be applied:

for $x \leq 10$:

$$|z_m| = 2\pi f \cdot 10^{-3}\left(142.5 + 45.96x - 1.413x^2 - 198.4 \ln x\right) \quad \left[\frac{\Omega \cdot m}{km}\right] \qquad \text{(A-4a)}$$

for $x > 10$:

$$|z_m| = 2\pi f \cdot 10^{-3} \frac{400}{x^2} \quad \left[\frac{\Omega \cdot m}{km}\right] \qquad \text{(A-4b)}$$

where:

$$x = \alpha \cdot d = \sqrt{\mu_o \frac{\omega}{\rho}} \cdot d = 2.81 \cdot 10^{-3} \sqrt{\frac{f}{\rho}} \cdot d \qquad \text{(A-5)}$$

When the frequency *f* and the earth resistivity ρ are selected in accordance with the actual conditions, *x* will be given as a function of *d* by the formula (A-5). Substituting this *x* into (A-4) and identifying $|z_m|$ according to (A-1) and (A-2), the relation between $|z_m|$ and *d* will be obtained. From this the value of *d*, i.e., the required RID value can be calculated. For the performance of this calculation, a specialized computer code (applying, e.g., iteration technique) should be applied for practical purposes.

A.1.2.2 Determination by the use of graphs

In Figures A.1, A.2, A.3 and A.4, sets of curves are plotted which give the value of the RID as a function of the earth resistivity and the normalized managing voltage as a parameter of the curves for 50 Hz, 60 Hz 16⅔ Hz and 800 Hz, respectively. These graphs provide an easily manageable graphical tool for the identification the RID relevant to given normalized managing voltage u_m, per km and per kA, obtained from the expression (A-1) to the actual value of the specific earth resistivity ρ in Ω · m.

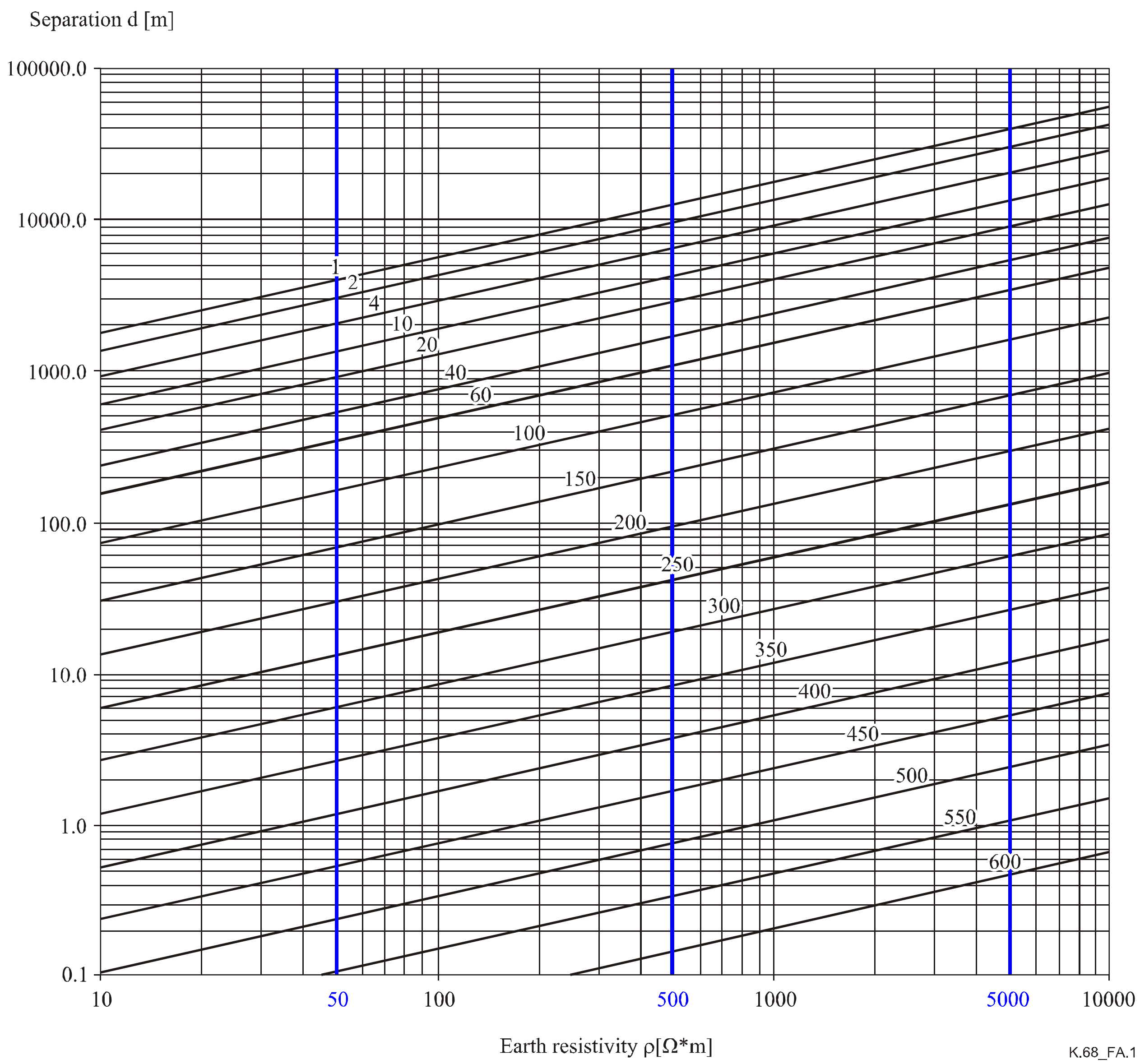

Figure A.1 – Graphical relation between the separation distance and the earth resistivity for given induced voltages as flag of the curves given in [V/(km·kA)] Frequency: 50 [Hz]

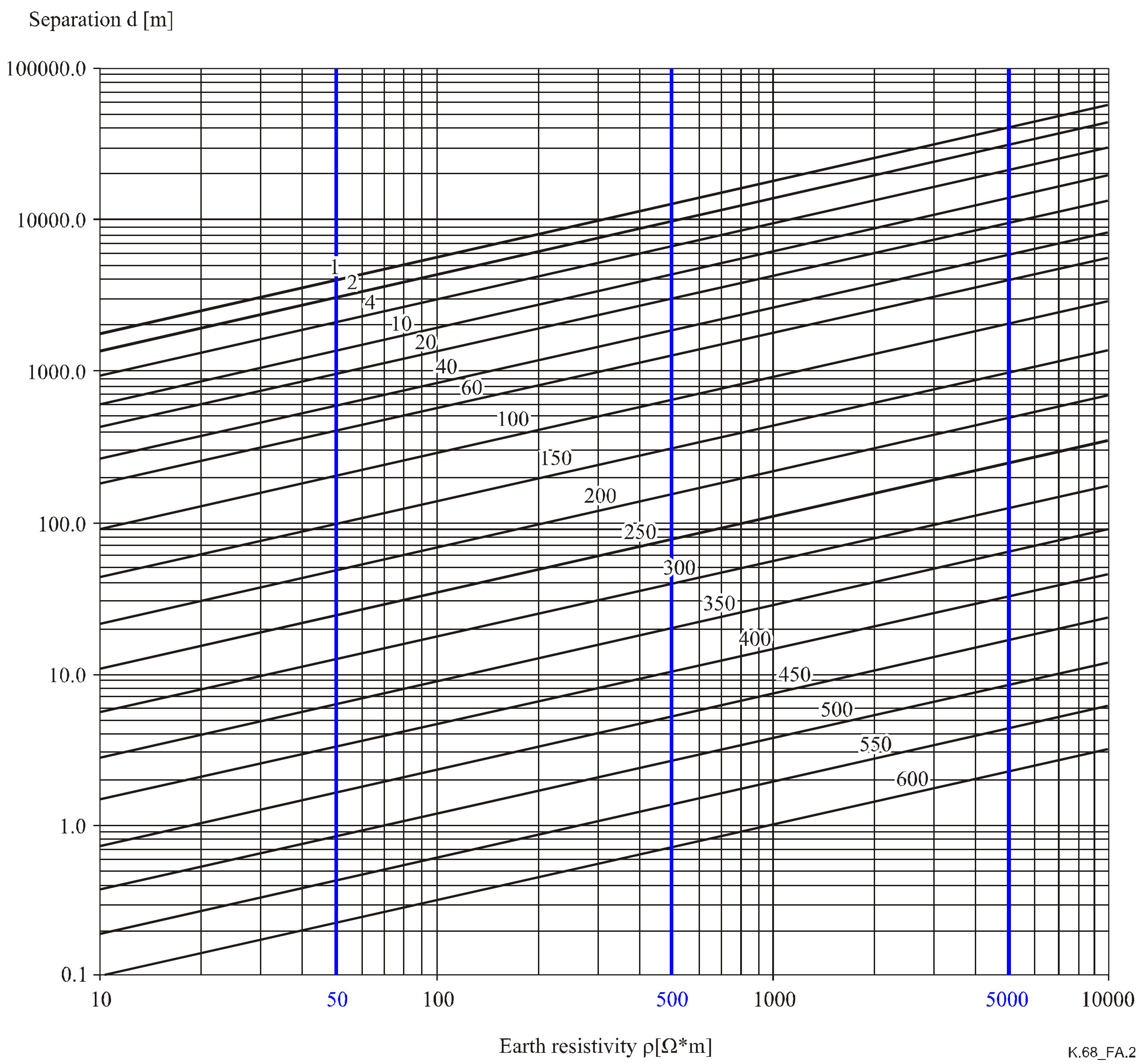

Figure A.2 – Graphical relation between the separation distance and the earth resistivity for given induced voltages as flag of the curves given in [V/(km·kA)] Frequency: 60 [Hz]

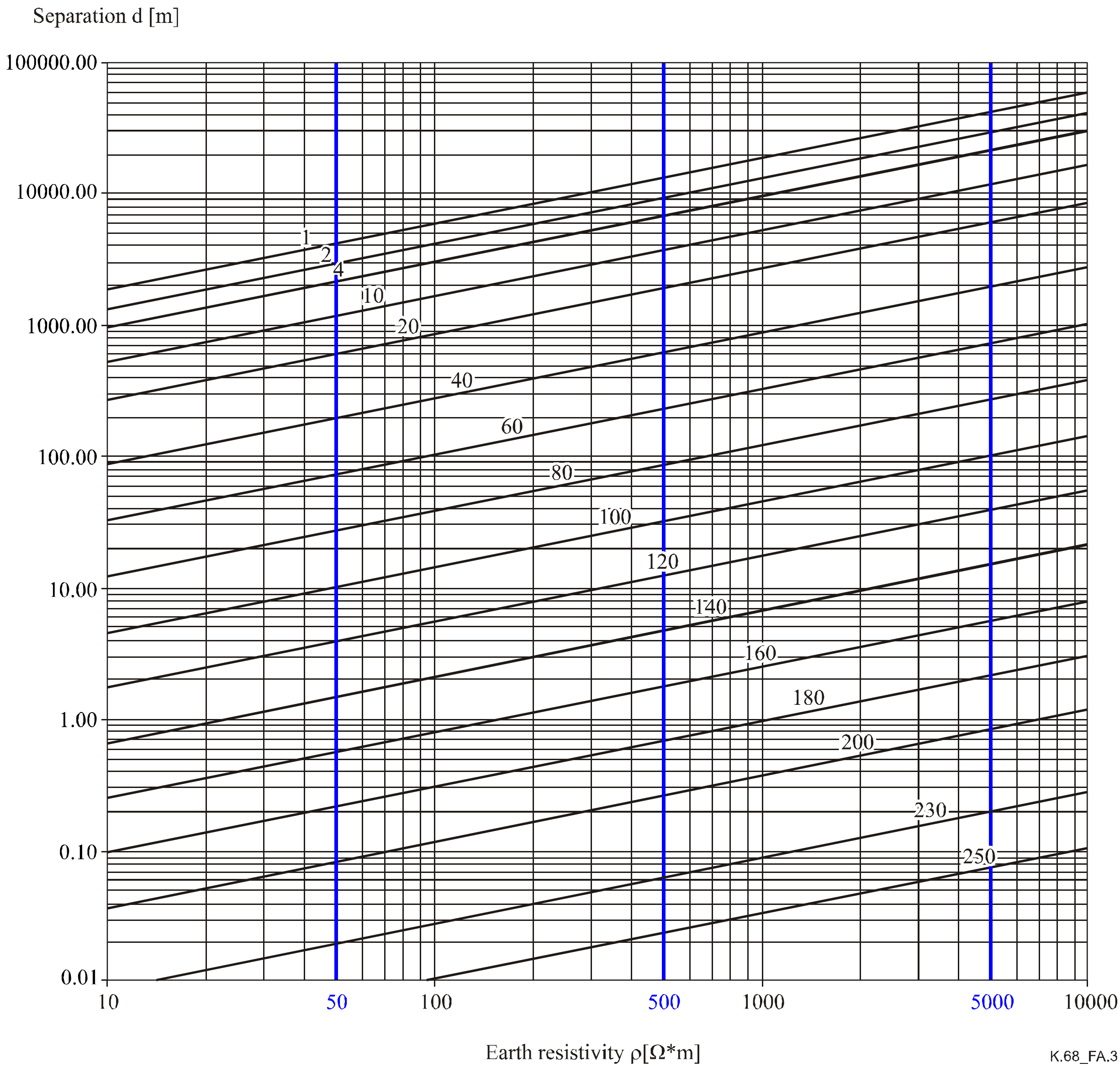

Figure A.3 – Graphical relation between the separation distance and the earth resistivity for given induced voltages as flag of the curves given in [V/(km·kA)] Frequency: 16⅔ [Hz]

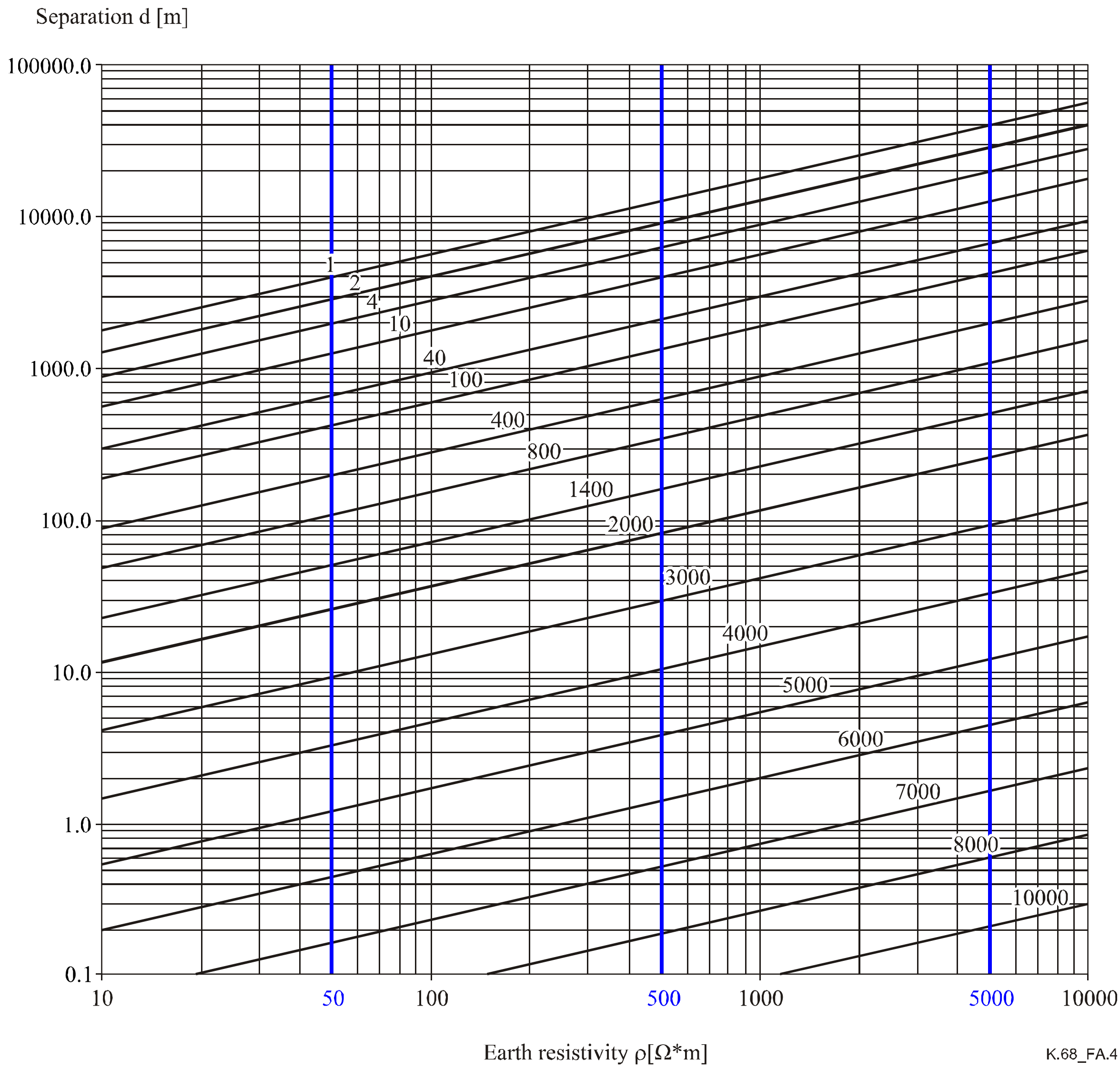

Figure A.4 – Graphical relation between the separation distance and the earth resistivity for given induced voltages as flag of the curves given in [V/(km·kA)] Frequency: 800 [Hz]

A.2 Conductive coupling

A.2.1 RID calculation for substation earthing grid

The current I_e flowing through the earthing resistance of an earthing grid of a substation causes the potential rise on the grid itself (electrode potential rise) and, due to this, an earth potential rise (EPR, "potential funnel") occurs in the region surrounding the substation. This potential can be transferred due to conductive coupling to the induced plant entering the substation or to the potential funnel at a distance closer than the RID for the conductive coupling.

The potential rise of the earthing grid can be calculated by the flowing expression [b-ITU-T K.57]:

$$U_e = R_e I_e = \frac{\rho}{4}\sqrt{\frac{\pi}{A}}\, k_p I_p \quad [\mathrm{V}] \tag{A-6}$$

where:

- $R_e = \frac{\rho}{4}\sqrt{\frac{\pi}{A}}$ is the earthing resistance of the grid, in Ω
- ρ is the specific resistivity of the earth (in the surface) in Ω · m
- A is the area of earthing grid, in m^2
- $I_e = k_p \cdot I_p$ is the substation earth current, i.e., that fraction of the fault current which is flowing from the grid to the earth, in A
- k_p is the earth current factor, identifying that fraction of the fault current which is flowing from the grid to the earth, dimensionless quantity
- I_p is the unbalanced (zero sequence) type fault current occurring in the substation, in A

It is worth mentioning that the substation potential rise increases linearly with the value of ρ and decreases with the increase of the area of the earthing grid.

The I_e earth current is the difference of the substation fault current and the current returning through the neutral of the substation transformer(s), through the earth wire(s) of the power line(s) and through the sheath(s) of the cable(s) connected to the substation. The last two can be expressed by the screening factor of the lines concerned.

The EPR is characterized by the *k(a)* potential distribution, which is, by definition, the normalized value of the earth potential *V(a)*, base is the grid potential U_e:

$$k(a) = \frac{V(a)}{U_e} \tag{A-7}$$

where *V(a)* is the EPR at a distance *a* measured from the edge of the grid.

The earth potential function can be given by the following expression:

$$k(a) = 0.674 \ln \frac{a + 0.815\sqrt{A}}{a + 0.185\sqrt{A}} \tag{A-8}$$

The earth potential distribution function *k(a)* is shown as a function of distance *a* from the edge of the ground grid in Figure A.5.

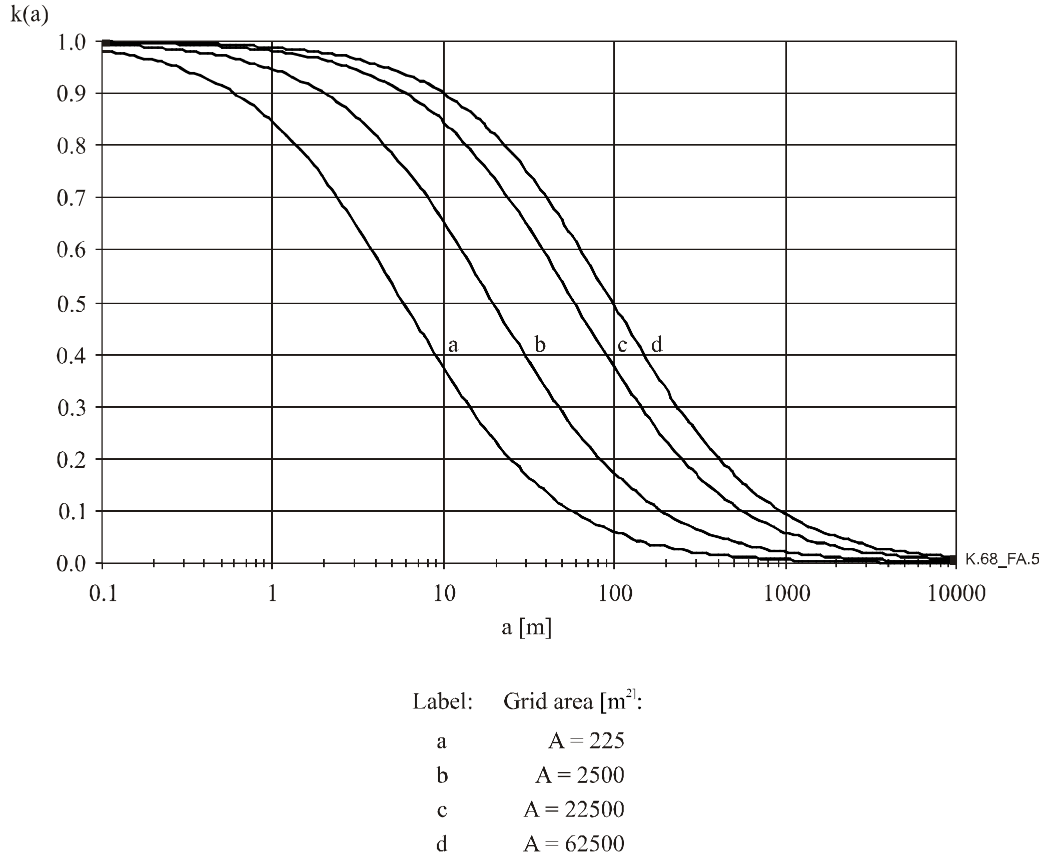

Figure A.5 – Earth potential distribution function *k(a)*, as a function of distance *a* from the edge of ground grid

From the expression (A-8), *a* can be expressed as a function of *k(a)* by the following formula:

$$a = \frac{0.815 - 0.185 \times 4.41^{k(a)}}{4.41^{k(a)} - 1}\sqrt{A} \qquad [\text{m}] \tag{A-9}$$

The earth potential *V(a)*, when reduced accordingly to the compensating effects, shall be equal to the management voltage U_m at a distance *a* which corresponds to the RID:

$$U_m = k_u\, k_t\, V(a) \qquad [\text{V}] \tag{A-10}$$

where:

k_u is the urban factor

k_t is the screening factor of the induced line

Expressing *V(a)* from (A-10):

$$V(a) = \frac{U_m}{k_u k_t} \qquad [\text{V}] \tag{A-11}$$

When substituting (A-6) and (A-11) into (A-7), the following expression is obtained for *k(a)*:

$$k(a) = \frac{\dfrac{U_m}{k_p k_u k_t}}{\dfrac{\rho}{4}\sqrt{\dfrac{\pi}{A}}\, I} = \frac{u_m}{U_e(A_k)} \tag{A-12}$$

where u_m is the normalized value of the management voltage relevant to the conductive coupling of the earthing grid of a substation.

Using *k(a)* obtained from (A-12), the RID distance equal to *a* can be determined either from the earth potential distribution function given in Figure A.5 or by the expression (A-9).

A.2.2 RID calculation for earthing of power line tower

A.2.2.1 Power line without shield-wire

The earth potential rise in the case of a power line without shield-wire is given by the following expression applicable to the hemispheric earthing electrode:

$$U_e = R_e I_{p\text{-}ef} = \frac{\rho}{2\pi \cdot r_e} I_{p\text{-}ef} \quad [\text{V}] \qquad \text{(A-13)}$$

where:

r_e is the equivalent radius of the tower footing earthing, in m

$I_{p\text{-}ef}$ is the fault current of the phase-to-earth short-circuit, in A

The *V(a)* EPR is characterized by the following potential distribution relevant to the generally used tower footing arrangements represented by hemispheric earthing electrode [b-ITU-T K.57]:

$$V(a) = 2.9 \frac{U_e}{a} \quad [\text{V}] \qquad \text{(A-14)}$$

where *V(a)* is the EPR at a distance *a* measured from the centre of the tower footing.

Expressing the distance *a* and considering the expressions (A-10) and (A-11), i.e., if $V(a) = u_m$, the distance *a* from the centre of the electrode structure equals RID:

$$RID = a = 2.9 \frac{U_e}{V(a)} = 2.9 \frac{U_e}{\dfrac{U_m}{k_u k_t}} = 2.9 \frac{U_e}{u_m} \quad [\text{m}] \qquad \text{(A-15)}$$

Alternatively, when substituting U_e from (A-13), the RID is given by:

$$RID = 2.9 \frac{\rho \, k_u k_t}{2\pi \cdot r_e \, U_m} I_{p\text{-}ef} \quad [\text{m}] \qquad \text{(A-16)}$$

A.2.2.2 Power line with shield-wire

The earth potential rise in the case of power lines equipped with shield-wire is essentially determined by:

– the magnitude of the earth fault current;

– average earthing resistance of the towers;

– the shield-wire configuration;

– the average span.

The tower potential rise values obtained from the simulations are given for the reference conditions identified in Table A.1 of [b-ITU-T K.57].

They can be recalculated to currents other than 10 kA proportionally to the current magnitude:

$$U_e = U_{10} \frac{I_{p\text{-}ef}}{10} \quad [\text{V}] \qquad \text{(A-17)}$$

where:

U_{10} is the tower potential rise for the reference condition given in Table A.1, in V/10 kA

$I_{p\text{-}ef}$ is earth fault current, in kA

Table A.1 – Potential rise of the faulty tower for the reference conditions and parameters per 10 kA earth fault current

Earthing resistance [Ω]	Tower potential rise U_{10}, [V/10 kA]		
	Shield-wire configuration		
	1 sw [kV]	2 sw [kV]	1 sw + cp [kV]
8	4663	3237	872
25	8208	5589	2290
50	11413	7432	4316
sw shield-wire cp counterpoise			

When substituting the U_e given by (A-17) into the expression (A-15), the value of RID is given by the following expression:

$$RID = 2.9 \frac{U_{10}}{u_m} \frac{I_{p\text{-}ef}}{10} = 2.9\, k_u k_t \frac{U_{10}}{U_m} \frac{I_{p\text{-}ef}}{10} \quad [\mathrm{m}] \qquad \text{(A-18)}$$

A.2.3 RID calculation for the conductive coupling of a.c. electrified traction systems

In the case of a.c. electrified traction systems, the conductive coupling effect is originated from the rail potential rise (as electrode potential) occurring at the locations where the current is injected into the rail or is sucked up from the rail (e.g., at the train, BT bond, AT location, feeding point).

The rail potential rise is characterized by the following tendencies:

1) Quite significantly depends on the rail-to-earth leakage conductance G (decreases with increasing G).
2) Different for 50 Hz (higher) and 16⅔ Hz (lower) systems.
3) Increases with the length between the points where the current is injected into the rail and sucked up from the rail (this tendency exists only until that length which is less than twice of the length of the end-effect zone of the rail-earth loop). Due to this fact, the rail potential rise is smaller for special feeding (AT or BT) systems than for simple RR systems, especially in the case of small AT or BT spacing. The difference is about 20% that is neglected in the RID calculation, thus resulting in maximizing RID values for the special feeding systems.

The tendencies mentioned in 1) and 2) can be observed in Figure A.6 of [b-EN 50122-1].

When considering G = 0.25 S/km as reference for the rail-earth leakage, the following normalized rail potential values taken from Figure A.6 of [b-EN 50122-1] apply:

– U_{e50} = 25 V per 100 A for 50 Hz; and
– $U_{e16⅔}$ = 15 V per 167 A for 16⅔ Hz.

It should be noted that the traction current involved in given traction power i.e., in 2500 kVA causes practically identical rail potential in the 25 kV and 15 kV traction systems, i.e., in the case of 25 kV systems the current is 100 A causing $1 \times 25V = 25$ V, and in case of 15 kV systems the current is 167 A causing 1.67×15 V = 25.05 V rail potential.

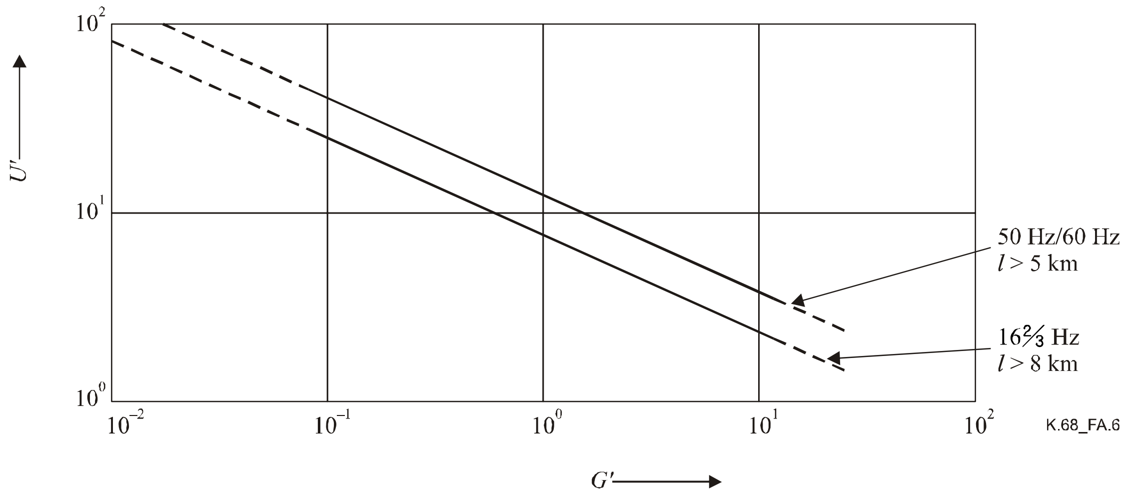

Figure A.6 – Guide values for the normalized rail potential U', V per 100 A, in an a.c. traction system vs the rail-to-earth leakage conductance in S/km

The rail potential relevant to traction power is given by the following expression:

$$U_e = U_{RE} = 25\frac{S}{2500} = \frac{S}{100} \quad [\text{V}] \tag{A-19}$$

where S is the traction power in kVA.

The normalized value of the EPR U_{PE}, base is the rail potential U_{RE}, is given vs the lateral distance a for double track a.c. traction line in Figure A.7 of [b-EN 50122-1].

The earth potential U_{PE}, when reduced accordingly to the compensating effects, should be equal to the management voltage U_m at a distance a which corresponds to the RID:

$$U_m = k_u\, k_t\, U_{PE}(a) \quad [\text{V}] \tag{A-20}$$

where:

k_u is the urban factor

k_t is the screening factor of the induced line

Expressing $U_{PE}(a)$ from (A-20):

$$U_{PE}(a) = \frac{U_m}{k_u k_t} \quad [\text{V}] \tag{A-21}$$

Using the expressions (A-19) and (A-21), the ratio of U_{PE}/U_{RE} can be expressed as:

$$100\frac{U_{PE}(a)}{U_{RE}} = \frac{10^4}{S}\frac{U_m}{k_u k_t} \quad [\%] \tag{A-22}$$

Using the percentage value given by (A-22), the *RID* = *a* can be read out from Figure A.7.

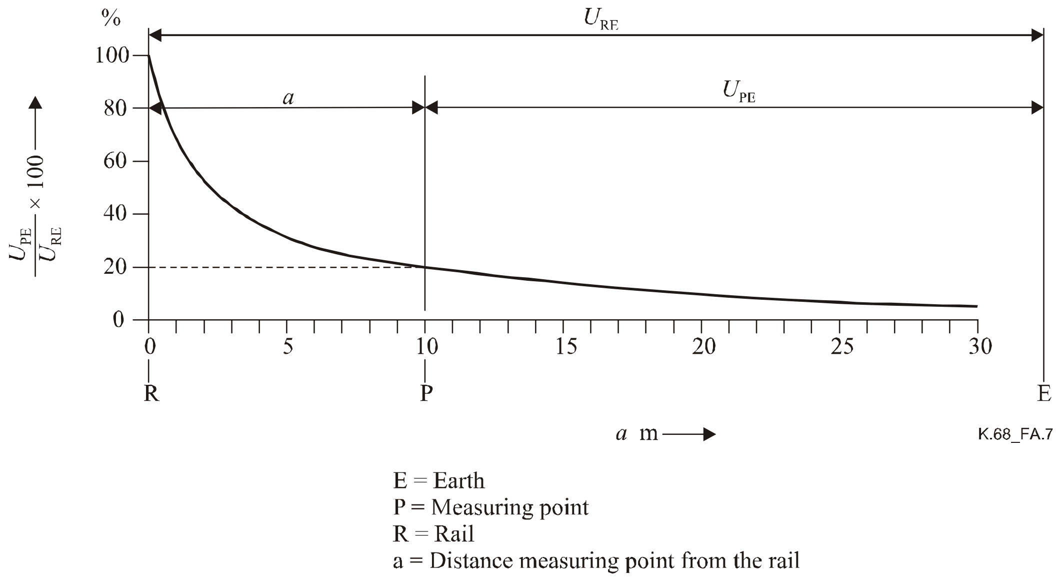

Figure A.7 – Normalized value of the EPR U_{PE}, base is the rail potential U_{RE}, vs the lateral distance *a* for a double track a.c. traction line

It is worth mentioning that, in the above method, it is assumed that the stringent value of the RID is resulted by the operational current rather than by the short-circuit current.

Appendix I

Weighting factors for use in determining the psophometrically weighted voltage

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

The following tables give numerical values of weighting factors within the frequency range 16⅔ Hz to 6000 Hz, which are used in the definition of psophometrically weighted voltage (see definition 3.32).

Frequency [Hz]	**Weighting factor**
16.66	0.056
50	0.71
100	6.91
150	35.5
200	89.1
250	178
300	295
350	376
400	484
450	582
500	661
550	733
600	794
650	851
700	902
750	955
800	1000
850	1035
900	1072
950	1109
1000	1122
1050	1109
1100	1072
1150	1035
1200	1000
1250	977
1300	955
1350	928
1400	905
1450	881
1500	861

Frequency [Hz]	Weighting factor
1550	842
1600	824
1650	807
1700	791
1750	775
1800	760
1850	745
1900	732
1950	720
2000	708
2050	698
2100	689
2150	679
2200	670
2250	661
2300	652
2350	643
2400	634
2450	626
2500	617
2550	607
2600	598
2650	590
2700	580
2750	571
2800	562
2850	553
2900	543
2950	534
3000	525
3100	501
3200	473
3300	444
3400	412
3500	376
3600	335
3700	292
3800	251
3900	214

Frequency [Hz]	**Weighting factor**
4000	178
4100	144.5
4200	116
4300	92.3
4400	72.4
4500	56.2
4600	43.7
4700	33.9
4800	26.3
5000	20.4
> 5000	15.9
> 6000	7.1

Appendix II

Values for the quantities affecting the reference influence distance for inductive coupling

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

II.1 Guidance values

II.1.1 General

This appendix provides guidance values for the quantities affecting the reference influence distance (RID) for inductive coupling (see clause A.1), thus supporting the realistic estimation of the RID values.

The main classifications of the guidance values are with respect to the following:

- quantities characterizing the electromagnetic environment;
- quantities characterizing the inducing plants;
- quantities characterizing the induced plants.

Further classifications are made with respect to the plant type and the conditions of the plants concerned.

II.1.2 Quantities characterizing the electromagnetic environment

Quantities, which cannot be linked with either the inducing or the induced plants because they are affecting the whole induction process, are classified into this category.

II.1.2.1 Management voltages, U_m

The management voltage value is the appropriate value given in clause 6.

II.1.2.2 Specific earth resistivity, ρ

In low frequency inductive coupling, the resistivity of the deep soil layers (several hundreds to several thousands of metres) has key importance due to the deep penetration in the earth.

For practical purposes, only the values given in Table II.1 will be considered by this Recommendation.

Table II.1 – Guidance values for the earth resistivity

	Soil resistivity [Ω · m]		
Value	50	500	5000 (Note)
Range	10-150	150-1500	1500-15000 (Note)
NOTE – For areas with deep layers composed of primitive rocks.			

II.1.2.3 Screening factor of the buried structures (urban factor), k_u

In rural areas, there exists an overall screening action due to the buried metallic structures. This can be taken into consideration by urban factor k_u. Its proposed value is given in Table II.2.

Table II.2 – Guidance values for the urban factor, k_u

	Environment	
	Urban area	**Rural area**
Urban factor k_u	0.1-0.4-0.7 (Note)	1.0
NOTE – 0.1 for large cities with high soil resistivity.		

It should be noted that the screening action in the urban areas becomes more and more weak due to the decreasing use of the metallic system of public utilities.

II.1.3 Quantities characterizing the inducing plants

II.1.3.1 Guidance values for a.c. electric power plants

II.1.3.1.1 Electric power plants with directly earthed neutral

The directly earthed network involves networks the neutral of which is earthed directly or through small impedance or their combination. The high voltage (including the high-, extra high- and ultra high-voltage) networks belong to this category.

II.1.3.1.1.1 Inducing current

a) Phase-to-earth short-circuit current, $I_{p\text{-}sc}$

In the high voltage (HV) networks with directly earthed neutral, a phase-to-earth short circuit results in high earth fault current. A significant portion of the fault current returns through the earth causing induction into the neighbouring induced plants. On the other hand, the earth faults in these systems are clearly detected by the relay protection and cleared in short time typically in 60 to 100 milliseconds.

The magnitude of the fault current increases with the increase of the short-circuit power of the feeding substation(s) and decreases with distance between the substation and the faulty point.

For practical purposes, the guidance values given in Table II.3 are proposed for the earth fault current in lines of networks with directly earthed neutral when an earth fault resistance value of 0 Ω or 15 Ω is considered.

Table II.3 – Guidance values for earth fault current $I_{p\text{-}ef}$ in lines of networks with directly earthed neutral

Earth fault resistance values [Ω]	Earth fault current [kA]		
	Far distant fault, low short circuit power	**Intermediary conditions**	**Close fault, high short circuit power**
0	10	20	40
15	7	10	15

b) Phase-to-earth short circuit current of 16⅔ Hz HV line, $I_{p\text{-}sc}$

In case of high voltage (typically 110-130 (2 × 65) kV level), 16⅔ Hz two-phase networks, feeding electrified traction systems, the reference inducing current is also the phase-to-earth short-circuit current. Guidance values for earth fault current $I_{p\text{-}rw}$ in HV two-phase transmission lines feeding 16⅔ traction systems are given in Table II.4.

Table II.4 – Guidance values for earth fault current I_{p-rw} in HV two-phase transmission lines feeding 16⅔ traction system

Type of feed of the HV 16⅔ traction system	Earth fault current I_{p-rw} [kA]
Fed by 50/16⅔ Hz converters only	3-5-8
Fed by 16⅔ Hz generator units	4-10-30

c) Earth fault current for fault through high fault impedance, I_{p-imp}

In certain cases, an earth fault in a line of HV networks with directly earthed neutral can occur through high impedance, e.g., through arcing to trees. This can produce low magnitude earth fault current. This kind of fault could not be detected and cleared by the base protection in short time. Therefore, the duration of the high impedance earth fault can be a couple of seconds, thus the limit values for durations over one second apply. A guidance value for the earth fault current of HV lines I_{p-imp} in cases of high fault impedance is given in Table II.5.

Table II.5 – Guidance values for the earth fault current of HV lines I_{p-imp} in cases of high impedance earth fault

	High impedance earth fault
Earth fault current, kA	1.5

d) One-phase off fault current, I_{p-off}

A high voltage line of a network with directly earthed neutral might be operated under such a fault condition when one phase is off. This one-phase off operation is generally limited to networks operated on the 110-130 kV voltage level. (In practice, this occurs when the breaker does not close in one phase during the switching on the line.) This kind of faulty operation could be maintained occasionally even for hours. In this case, the earth return is replacing the off phase, therefore the earth current is practically identical to the current flowing in the healthy phases. Under the one-phase off operation, the transmitted power, and thus the current as well, is limited to the 70-80 percent of the normally permitted load.

For practical purposes, the values given in Table II.6 are proposed for the fault current in lines operated under one-phase off conditions.

Table II.6 – Guidance values for the fault current in a line operated under one-phase off condition, I_{p-off}

	Power transmission		
	Low (20 MVA) (Note)	Medium (60 MVA) (Note)	High (120 MVA) (Note)
Inducing current, A	100	300	600
NOTE – In 110-130 kV voltage level.			

The induction caused by the one-phase off current should be considered as long-term induction to which the management voltage relevant to normal operation applies.

II.1.3.1.1.2 Screening factor, k_p

The screening structures associated with the inducing plant, i.e., the shielding wire of overhead power lines and the sheath of underground power cables, serve as current return and therefore they reduce the fraction of the current returning through the earth. The amount of the reduction is expressed by the screening factor.

a) Screening factor of the shielding wires of overhead power lines

Guidance values for the screening factor of the shielding wires of overhead power lines are given in Table II.7.

Table II.7 – Guidance values for the screening factor of the shielding wires of overhead power lines

Shielding wire	Resistance of the shielding wire(s) [Ω/km]		
	< 0.1	< 0.5	< 1.0 (Note)
Single	0.55-0.70	0.65-0.75	0.80-0.90
Double	0.40-0.50	0.5-0.65	0.65-0.75
NOTE – Composed of steel strand.			

b) Screening factor of the sheath of HV power cables

In the case of high voltage power cables, a very high fraction of the earth fault current returns through the cable sheath due to the close coupling between the cable conductor and the sheath. Therefore, the sheath of a high voltage cable provides very good (small) screening factors.

Guidance values for the screening factor of the sheath of high voltage power cables are given in Table II.8.

Table II.8 – Guidance values for the screening factor of the sheath of high voltage power cables

	Type of the sheath	
	Lead sheath	Aluminium sheath or concentric copper wire screen
Screening factor	0.15-0.25-0.30	0.04-0.1-0.15

II.1.3.1.2 Electric power plants with no directly earthed neutral

Firstly, it is worth mentioning that there are areas where according to the applied neutral earthing policy, the neutral is directly earthed in all kinds of networks, e.g., in case of the North-American practice.

The networks with no directly earthed neutral can heave the following three conditions:

1) isolated neutral;
2) neutral with resonant earthing;
3) neutral with high impedance (generally resistance) earthing.

Option 1 is generally used only in networks of industrial plants and not in public distribution networks.

Option 2 is typically used in rural MV distribution networks composed of aerial lines. This network might be temporarily (for a couple of seconds) earthed by a resistor connected between the neutral and the earth as well, thus allowing for the protection relay the discriminative identification of the faulty line.

Option 3 is used in MV cable or a mixture of cable and overhead line urban or suburban distribution networks when the capacitive earth fault current is high, and therefore the probability of self-extinguishing of the earth fault becomes very low in spite of the resonant earthing.

II.1.3.1.2.1 Inducing current

a) Earth fault current, $I_{p\text{-}sef}$

The earth fault is the typical fault type of networks with no directly earthed neutral. This is not a short-circuit type fault, thus the fault current is even less than the operational current. Typically, this is the case in networks with resonant earthing. Therefore, the induction due to earth fault current of networks with resonant earthing shall not be considered.

The earth fault current in networks with high impedance/resistance earthing still remains low. Its value depends on the magnitude of the earthing impedance, the distance of the fault from the feeding substation, and the fault impedance (arc and earthing resistance). Guidance values for earth fault current in networks with high impedance/resistance earthing are given in Table II.9.

The duration of the earth fault is within one second, thus management voltage values for durations up to one second apply.

Table II.9 – Guidance values for earth fault current $I_{p\text{-}sef}$ in networks with high impedance/resistance earthing

Magnitude of the impedance/resistance of neutral earthing	Earth fault current $I_{p\text{-}sef}$ [A]
High mixed overhead and cable networks	70-100-150
Moderately high cable networks	150-250-40

b) Double earth fault current, $I_{p\text{-}dbf}$

The double earth fault, i.e., simultaneous earth faults in two phases at different locations, is a less frequent fault event but creates much higher fault current, the zero sequence component of which returns in the earth path between the two faulty points. The magnitude of the double earth fault is affected by:

1) the short-circuit power of the substation feeding the fault (the maximum value of the double earth fault current could be, in principle, 86% of the 3-phase short-circuit current);
2) the impedance, per unit length, of the power line involved in the fault path;
3) the distance between the locations of the faulty point;
4) the fault impedances (arc plus earthing resistance) at the faulty points (this might be very significant in cases of faults occurring in a pole overhead line not equipped with shielding wire).

Guidance values for double earth fault current $I_{p\text{-}dbf}$ in networks with no directly earthed neutral are given in Table II.10.

Table II.10 – Guidance values for double earth fault current $I_{p\text{-}dbf}$ in networks with no directly earthed neutral

	Type of the faulty line	
	Overhead	Cable
Double earth fault current [kA]	1-2.5-5	2-4-7

Generally, the double earth fault is cleared in a short time ($t < 0.2$ s), except for a small magnitude of the double earth fault currents ($I_{p\text{-}dbf} < 1.5$ kA), for which the tripping time could be a couple of seconds, thus voltage limit values for durations over one second apply.

II.1.3.1.2.2 Screening factor of the sheath of MV power cables

Guidance values for the screening factor of the sheath of medium voltage power cables are given in Table II.11.

Table II.11 – Guidance values for the screening factor of the sheath of medium voltage power cables

Type of sheath	Screening factor, k_p
Thin aluminium foil	0.7-0.8-0.9
Lead sheath	0.4-0.5-0.6
Aluminium sheath or concentric copper wire screen	0.15-0.2-0.3

II.1.3.2 Guidance values for a.c. electric traction plants

II.1.3.2.1 Operational current

In case of a.c. electrified traction systems, the ratio of the short-circuit current to the maximum value of the operational current is normally less than the ratio of the management voltage for short-term and long-term induction. Consequently, the reference influence distance for inductive coupling shall be identified on the basis of the induction of the operational current.

Guidance values for the operational current $I_{p\text{-}rw}$ of the a.c. electrified traction systems are given in Table II.12. These current values equal to about 20000 kVA peak traction power.

Table II.12 – Guidance values for operational current $I_{p\text{-}rw}$ of a.c. electrified railway systems

Supply system	Operational current [A]	
	One-side feeding	Both-side feeding
16⅔ Hz, 15 kV	(600)	1200
50 Hz, 25 kV	800	–

II.1.3.2.2 Psophometric current

Guidance values for psophometric current $I_{p\text{-}ps}$ of the a.c. electrified traction systems are given in Table II.13.

Table II.13 – Psophometric current I_{p-ps} of a.c. electrified traction systems

Type of traction unit	Equivalent disturbing (psophometric) current [A]
Unit with frequency inverter and asynchronous motor	1.5
Diode (thyristor) locomotive with filter	4
Mixed thyristor controlled and diode locomotive without filter	16

The inductive coupling due to the psophometric current is relevant only on the access network, i.e., on short lines.

II.1.3.2.3 Screening factor of the return rails

In the case of the simple feeding systems with rail and earth (RR) systems, the guidance values for the screening factor of the rails k_{p-rr} of the a.c. electrified traction systems with rail and earth return are given in Table II.14.

Table II.14 – Guidance values for the screening factor of the rails k_{p-rr} of a.c. electrified traction systems with rail and earth return (RR system)

Supply system	Operational frequency [Hz]		
	16⅔	50 or 60	800
Screening factor (Note)	0.4	0.50	0.55
NOTE – Single track line with double return rail.			

II.1.3.2.4 Equivalent compensating factor for special feeding systems

The special traction feeding systems such as the booster transformer system with rail return (BTRR) or with return conductor (BTRC) systems and the autotransformer (AT) system reduce the induction effect with a quite complex mechanism.

The compensating factor value applicable to a section of the inducing line between two adjacent BTs or ATs is different in the following two cases:

1) Induced section inside the trained section.
2) Induced section outside the trained section.

Guidance values of the compensating factors for special feeding systems are given in Table II.15.

Table II.15 – Guidance values of the compensating factors for special feeding systems

Inducing current	Frequency [Hz]	Compensating factor k_p	
		Induced length	
		Inside the trained section	Outside the trained section
Fundamental frequency	16⅔	0.1	0.04
	50	0.15	0.05
Psophometric	(800)	0.25	0.06

II.1.4 Quantities characterizing the induced plants

II.1.4.1 Screening factor of the induced telecom cables

From the point of view of the identification of the reference influence distance, the screening factor k_t of the sheath of the induced telecom cables is given in three classes corresponding to Table II.16.

The screening factor of open-wire line or unscreened cables is equal to one.

Table II.16 – Guidance values for the screening factor k_t of the sheath of the induced telecom cables

	Type of the sheath		
	Plastic sheath with thin aluminium foil R_{dc} > 2.5 Ω/km	Lead sheath R_{dc} < 0.5 Ω/km	Aluminium sheath or concentric copper wire screen R_{dc} < 0.1 Ω/km
Screening factor	> 0.9	< 0.5	< 0.15

II.1.4.2 Reference induced line lengths

Guidance values for the reference lengths l_m of induced telecom cables applied in different types of telecommunication networks are given in Table II.17.

Table II.17 – Guidance values for the induced lengths l_m of the different type of induced telecom cables

Environment	Induced lengths [km]	
	Type of the telecom network	
	Short lines (e.g., access network) (Note)	Long lines (e.g., long distance network)
Rural area	3-5-7	10-15-20
Urban area	1-3-5	5-10-15
NOTE – Applicable to short sections of traction cables induced by BT or AT feeding systems.		

II.2 Values of the parameters for the RID evaluation: Inductive coupling

On the basis of the guidance data reported in clause II.1, the RID values given in clause 5.2 have been evaluated with the following values of the parameters:

- The urban factor k_u characterizing overall screening action of the environment:
  - for rural environments: $k_u = 1$
  - for urban environments: $k_u = 0.45$ for $\rho = 50\ \Omega \cdot m$
    $k_u = 0.35$ for $\rho = 500\ \Omega \cdot m$
    $k_u = 0.25$ for $\rho = 5000\ \Omega \cdot m$
- The induced length l_m:
  - for short lines in rural areas: $l_m = 5$ km
  - for short lines in urban areas: $l_m = 3$ km
  - for long lines in rural areas: $l_m = 15$ km
  - for long lines in urban areas: $l_m = 10$ km

- Earth resistivity classes:
  - for low resistivity classes: ρ = 50 Ω · m
  - for moderate resistivity classes: ρ = 500 Ω · m
  - for high resistivity classes: ρ = 5000 Ω · m
- Screening factor of the inducing plant k_p:
  - HV a.c power line:
    - Overhead at 50/60 Hz: $k_p = 0.5$
    - Underground at 50/60 Hz: $k_p = 0.1$
    - Overhead at 16⅔ Hz: $k_p = 0.75$
  - MV a.c. power line:
    - Overhead at 50/60 Hz: $k_p = 1$
    - Underground at 50/60 Hz: $k_p = 0.5$
  - a.c. traction line:
    - Overhead with RR feeding system at 50 Hz: $k_p = 0.5$
    - Overhead with RR feeding system at 16⅔ Hz: $k_p = 0.4$
    - Overhead with RR feeding system for 800 Hz: $k_p = 0.55$
    - Overhead with special feeding system at 16⅔ Hz: $k_p = 0.1$
    - Overhead with special feeding system at 50 Hz: $k_p = 0.15$
    - Overhead with special feeding system for 800 Hz: $k_p = 0.25$
- Screening factor of the induced plant k_t:
  - Unshielded line $k_t = 1$

The inducing current values have been evaluated for the realistic worst-case conditions of the a.c. electric power system and a.c. electrified traction system; these values are reported in Table II.18 together with the associated management voltage value U_m.

NOTE – The curves of Figure A.1 are assumed to be valid even for 60 Hz frequency.

Table II.18 – Management voltage and inducing current values for RID evaluation

a.c. power system at 50/60 Hz	Situation	U_m [V]	I_p [kA]	Remark
HV network with directly earthed neutral	Typical	1000	10	Equal or less severe condition compared with the high impedance earth fault condition
	Severe	430		
High impedance earth fault of HV network with directly earthed neutral	Typical	150	1.5	Calculated RID values reported in clause 5.2
	Severe	60		
One phase-off condition of HV network with directly earthed neutral	Typical/ severe	60	0.3	Less severe condition
Earth fault of MV network with no directly earthed neutral: overhead line	Typical	430	0.1	Calculated RID values reported in clause 5.2
	Severe	300		
Earth fault of MV network with no directly earthed neutral: underground line	Typical	430	0.25	Less severe condition compared with the underground line
	Severe	300		
Double earth fault of MV network with no directly earthed neutral: overhead line	Typical	430	2.5	Condition not considered due to the low probability of occurrence of this event
	Severe	300		
Double earth fault of MV network with no directly earthed neutral: underground line	Typical	430	4	
	Severe	300		
a.c. power system at 16⅔ Hz				
Phase-to-earth short circuit of HV (2 × 65 kV) 16⅔ Hz traction network with directly earthed midpoint	Typical	1000	5	Only overhead lines in rural areas
	Severe	300		
a.c. traction system				
Operational current of electrified traction line	Typical/ severe	60	1.2	16⅔ Hz system
			0.8	50 Hz system
Psophometric current (800 Hz) of traction unit with frequency inverter and asynchronous motor	Typical/ severe	0.2	0.0015	Less severe condition compared with the power frequency induction
Psophometric current (800 Hz) of diode (thyristor) locomotive with filter			0.004	More severe condition compared with the power frequency induction
Psophometric current (800 Hz) of mixed thyristor controlled and diode locomotive without filter			0.015	More severe condition compared with the power frequency induction

II.3 Values of the parameters for the RID evaluation: Conductive coupling

On the basis of the guidance data reported in clause II.1, the RID values given in clause 5.2.4 have been evaluated with the following values of the parameters:

- The urban factor k_u characterizing overall screening action of the environment:
  - for rural environments: $k_u = 1$
  - for urban environments: $k_u = 0.45$ for $\rho = 50\ \Omega \cdot m$
    $k_u = 0.35$ for $\rho = 500\ \Omega \cdot m$
    $k_u = 0.25$ for $\rho = 5000\ \Omega \cdot m$
- Earth resistivity classes:
  - for low resistivity classes: $\rho = 50\ \Omega \cdot m$
  - for moderate resistivity classes: $\rho = 500\ \Omega \cdot m$
  - for high resistivity classes: $\rho = 5000\ \Omega \cdot m$
- Substations:
  - earthing grid dimensions and associated fault current:
    - $A = 225\ m^2$ $I_p = 10$ kA
    - $A = 2500\ m^2$ $I_p = 15$ kA
    - $A = 22500\ m^2$ $I_p = 20$ kA
- Power line tower:
  - fault current of 10 kA associated with the following tower earth resistance values:
    - $\rho = 50\ \Omega \cdot m$ $R_E = 8\ \Omega$
    - $\rho = 500\ \Omega \cdot m$ $R_E = 25\ \Omega$
    - $\rho = 5000\ \Omega \cdot m$ $R_E = 50\ \Omega$
- Screening factor of the inducing plant k_p:
  - HV a.c power line:
    - Overhead at 50/60 Hz: $k_p = 0.5$
    - Mixed (overhead and underground) at 50/60 Hz: $k_p = 0.2$
    - Underground at 50/60 Hz: $k_p = 0.1$
    - Overhead at 16⅔ Hz: $k_p = 0.75$
- Operational current I_p:
  - a.c. traction line:
    - Operational current at 50 Hz: $I_p = 800$ A
    - Operational current at 16⅔ Hz: $I_p = 1200$ A

    NOTE – The same operational currents apply for the simple feeding and the special feeding systems.
- Management voltage U_m:
  - Power line at 50/60 Hz for typical situations: $U_m = 1000$ V
  - Power line at 50/60 Hz for severe situations: $U_m = 430$ V
  - Traction line at 50/60 or 16⅔ Hz for both typical and severe situations: $U_m = 60$ V
- Screening factor of the induced plant k_t:
  - Unshielded line $k_t = 1$

Appendix III

Steps for determining the RID values due to a.c. power or electrified traction line

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

The different steps for the determination of the RID values are reported in Figures III.1 and III.2 for an a.c power line or a.c. electrified traction line respectively.

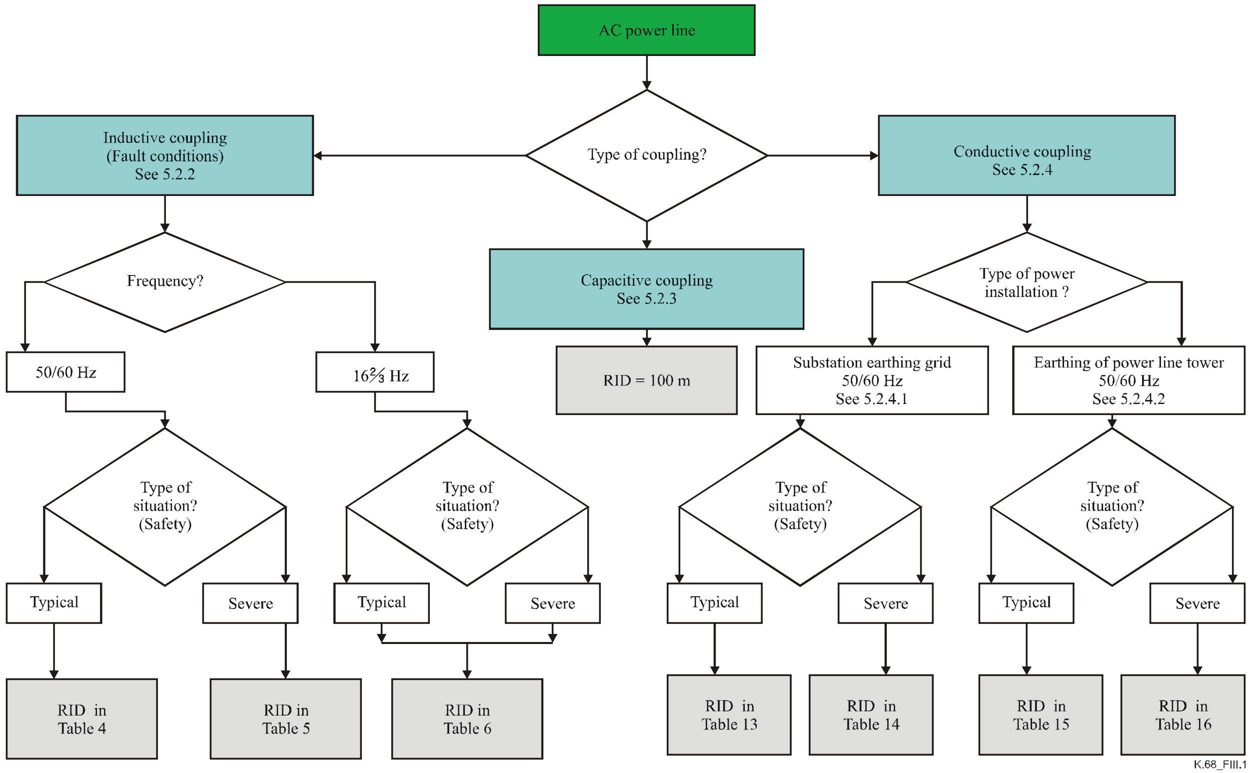

Figure III.1 – Flow chart for the determination of the RID values due to an a.c. power line

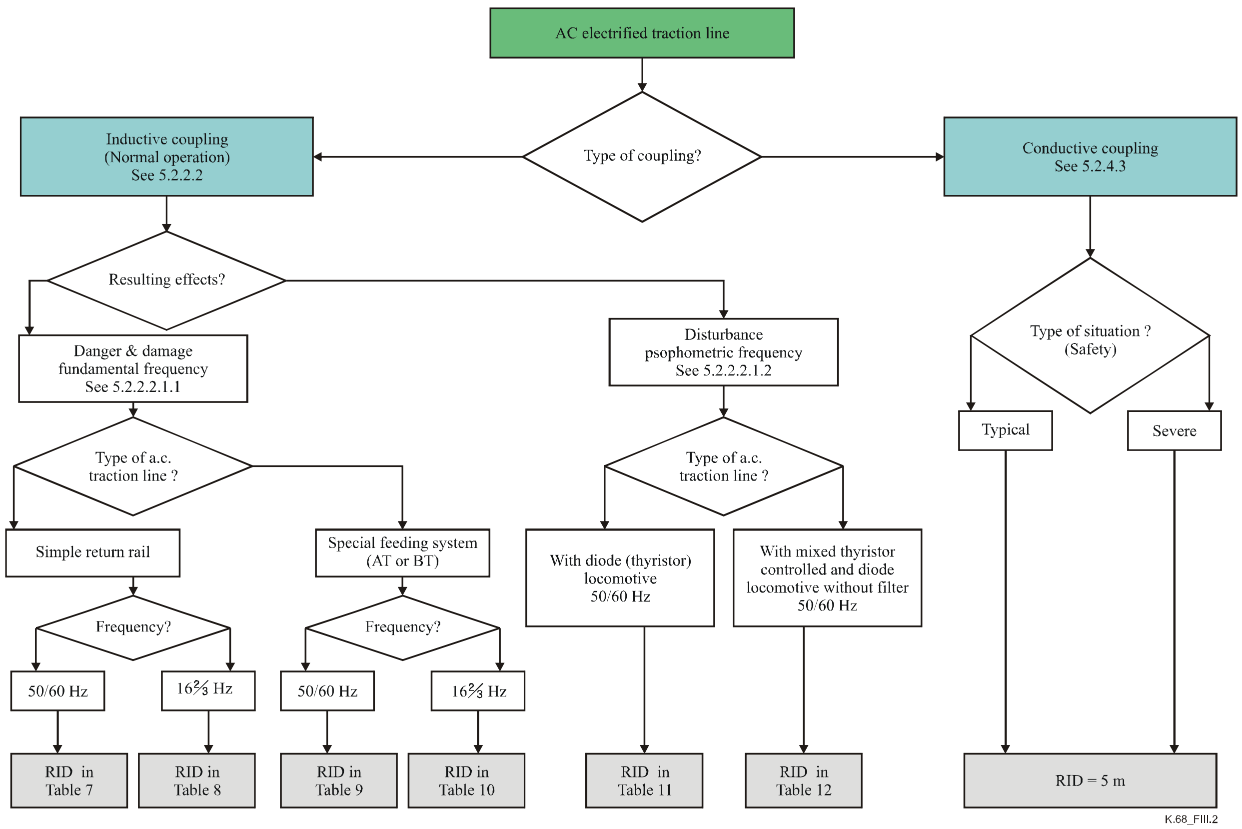

Figure III.2 – Flow chart for the determination of the RID values due to an a.c. electrified traction line

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