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TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Radio interference characteristics of overhead power lines and high-voltage equipment –
Part 1: Description of phenomena

TR CISPR 18-1:2010(E)

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CONTENTS

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FOREWORD

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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

CISPR 18-1, which is a technical report, has been prepared by CISPR subcommittee B: Interference relating to industrial, scientific and medical radio-frequency apparatus, to other (heavy) industrial equipment, to overhead power lines, to high voltage equipment and to electric traction.

This second edition cancels and replaces the first edition published in 1982. It is a technical revision.

This edition includes the following significant technical changes with respect to the previous edition: while the first edition of CISPR 18-1 only covered the direct distance D_0 for the establishment of standard profiles for the lateral radio noise field emanating from HV overhead power lines, this second edition now also allows for use of the lateral distance y_0 for these purposes. This way it allows for the establishment of standard profiles for the lateral radio noise field also from modern HV overhead power line constructions with tall suspension towers.

The text of this technical report is based on the following documents:

DTR	Report on voting
CISPR/B/493/DTR	CISPR/B/501/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This technical report has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the CISPR 18 series can be found, under the general title *Radio interference characteristics of overhead power lines and high-voltage equipment*, on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

This technical report forms the first of a three-part publication dealing with radio noise generated by electrical power transmission and distribution facilities (overhead lines and substations). It contains information in relation of the physical phenomena involved in the generation of electromagnetic noise fields. It also includes the main properties of such fields and their numerical values. Its content was adjusted such as to allow for use of the lateral distance *y* for the establishment of standard profiles for the lateral radio noise field emanating from HV overhead power lines.

The technical data given in this part 1 of the CISPR 18 series are intended to be a useful aid to overhead line designers and also to anyone concerned with checking the radio noise performance of a line to ensure satisfactory protection of wanted radio signals. The data should facilitate the use of the recommendations given in its parts 2 and 3 dealing with

– methods of measurement and procedures for determining limits, and a
– code of practice for minimizing the generation of radio noise.

The CISPR 18 series do not deal with biological effects on living matter or any issues related to exposure in electromagnetic fields.

This technical report has been prepared in order to provide information on the many factors involved in protecting the reception of radio and television broadcasting from interference due to high voltage overhead power lines and associated equipment. The information given should be of assistance when means of avoiding or abating radio noise are being considered.

Information is mainly given on the generation and characteristics of radio noise from a.c. power lines and equipment operating at 1 kV and above, in the frequency ranges 0,15 MHz to 30 MHz (a.m. sound broadcasting) and 30 MHz to 300 MHz (f.m. sound broadcasting and television broadcasting). The special aspect of spark discharges due to bad contacts is taken into account. Some information is also given on interference due to d.c. overhead lines for which corona and interference conditions are different from those of a.c. power lines.

The general procedure for establishing the limits of the radio noise from the power lines and equipment is given, together with typical values as examples, and methods of measurement.

The clause on limits concentrates on the low frequency and medium frequency bands as it is only in these where ample evidence, based on established practice, is available. No examples of limits to protect reception in the frequency band 30 MHz to 300 MHz have been given, as measuring methods and certain other aspects of the problems in this band have not yet been fully resolved. Site measurements and service experience have shown that levels of noise from power lines at frequencies higher than 300 MHz are so low that interference is unlikely to be caused to television reception.

The values of limits given as examples are calculated to provide a reasonable degree of protection to the reception of broadcasting at the edges of the recognized service areas of the appropriate transmitters in the a.m. radio frequency bands, in the least favourable conditions likely to be generally encountered. These limits are intended to provide guidance at the planning stage of the line and national standards or other specifications against which the performance of the line may be checked after construction and during its useful life.

Recommendations are made on the design, routing, construction and maintenance of the lines and equipment forming part of the power distribution system to minimize interference and it is hoped that this publication will aid other radio services in the consideration of the problems of interference.

RADIO INTERFERENCE CHARACTERISTICS OF OVERHEAD POWER LINES AND HIGH-VOLTAGE EQUIPMENT –

Part 1: Description of phenomena

1 Scope

This part of CISPR 18, which is a technical report, applies to radio noise from overhead power lines and high-voltage equipment which may cause interference to radio reception. The scope of this publication includes the causes, measurement and effects of radio interference, design aspects in relation to this interference, methods and examples for establishing limits and prediction of tolerable levels of interference from high voltage overhead power lines and associated equipment, to the reception of radio broadcast services.

The frequency range covered is 0,15 MHz to 300 MHz.

Radio frequency interference caused by the pantograph of overhead railway traction systems is not considered in this technical report.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

CISPR 16-1-1, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR/TR 18-2:2010, *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 2: Methods of measurement and procedure for determining limits*

ISO/IEC Guide 99, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

NOTE Informative references are listed in the Bibliography.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in the IEC 60050-161 and the ISO/IEC Guide 99 apply.

4 Radio noise from power lines

4.1 General

Radio noise from high voltage, which is to say above 1 kV, overhead power lines may be generated over a wide band of frequencies by

a) corona discharges in the air at the surfaces of conductors, insulator assemblies and hardware;

b) discharges and sparking at highly stressed areas of insulators;

c) sparking at loose or imperfect contacts of hardware.

The sources of a) and b) are usually distributed along the length of the line, but source c) is usually local. For lines operating above about 100 kV, the electric stress in the air at the surface of conductors and hardware can cause corona discharges. Sparking at bad contacts or broken or cracked insulators can give rise to local sources of radio noise. High voltage apparatus in substations may also generate radio noise which can be propagated along the overhead lines.

If the field strength of the radio noise at the antennas used for receiving broadcast sound and television services is too high, it can cause degradation of the sound output and, in the case of television, the picture also.

The generation of radio noise is affected by weather conditions, for example, conductor corona is more likely to occur in wet weather because of the water droplets which form on the conductors whereas, under these conditions, bad contacts can become bridged with water droplets and the generation of radio noise, by this process, ceases. Consequently, loose or imperfect contacts are more likely to spark in dry weather conditions. Dry, clean insulators may cause interference in fair weather, but prolonged sparking on the surfaces of insulators is more likely to occur when they are polluted, particularly during wet, foggy or icy conditions.

For interference-free reception of radio and television signals it is important that a sufficiently high ratio is available at the input to the receiver between the level of the wanted signal and the level of the unwanted radio noise. Interference may therefore be experienced when the signal strength is low and the weather conditions are conducive to the generation of radio noise.

When investigating radio noise it should be borne in mind that the local field may be caused by a distant source or sources as the noise may be propagated along the line over a considerable distance.

4.2 Physical aspects of radio noise

4.2.1 Mechanism of formation of a noise field

4.2.1.1 General

Corona discharges on conductors, insulators or line hardware or sparking at bad contacts can be the source of radio noise as they inject current pulses into the line conductors. These propagate along the conductors in both directions from the injection point. The various components of the frequency spectrum of these pulses have different effects.

In the frequency range 0,15 MHz to a few megahertz, the noise is largely the result of the effect of propagation along the line. Direct electromagnetic radiation from the pulse sources themselves does not materially contribute to the noise level. In this case the wavelength is long in comparison with the clearances of the conductors and thus the line is not an efficient radiator. However, associated with each spectral voltage and current component, an electric and a magnetic field propagate along the line. In view of the relatively low attenuation of this propagation, the noise field is determined by the aggregation of the effects of all the discharges spread over many kilometres along the line on either side of the reception point. It should be noted that close to the line the guided field predominates, whereas further from the line the radiated field predominates. The change-over is not abrupt and the phenomenon is not well known. This effect is not important at low frequencies but is apparent at medium frequencies.

However, for spectral components above 30 MHz where the wavelengths are close to or less than the clearance of the line conductors, the noise effects can be largely explained by antenna radiation theory applied to the source of noise, as there is no material propagation along the line.

It should be appreciated, however, that 30 MHz does not represent a clear dividing line between the two different mechanisms producing noise fields.

4.2.1.2 Longitudinal propagation

In the case of a single conductor line mounted above the ground there is a simultaneous propagation of a voltage wave $U(t)$ and a current wave $I(t)$.

For a given frequency the two quantities are related by the expression $U(\omega) = Z(\omega) \times I(\omega)$ where Z, also a function of ω, is the surge impedance of the line.

During propagation the waves are attenuated by a common coefficient α where:

$$U_x = U_0 e^{-\alpha x}$$

$$I_x = I_0 e^{-\alpha x}$$

U_0 and I_0 are the amplitudes at the source and x is the distance of propagation along the line.

In case of multi-phase lines, experience shows that any system of voltages or currents becomes distorted in propagation, that is to say, the attenuation varies with the distance propagated and it differs for each conductor. Theory of propagation and actual measurements on power lines have shown that noise voltages on the phase conductors can be considered as being made up of a number of "modes", each one having components on every conductor. One mode propagates between all conductors in parallel and earth. The others propagate between conductors. Each mode has its own different propagation attenuation. The complete theory of modal propagation is complex and involves matrix equations outside the scope of this publication. Reference is made here to CIGRÉ and other published works. It is important to note that the attenuation of the conductor-to-earth mode propagation is fairly high, that is to say 2 dB/km to 4 dB/km, while the attenuation of the various conductor-to-conductor modes is a small fraction of 1 dB/km at a frequency of 0,5 MHz.

4.2.1.3 Electromagnetic field

The radio noise voltages and currents propagating along the line produce an associated propagating electromagnetic field near the line.

It should be noted here that in free space the electric and magnetic components of the field associated with radiated electromagnetic waves are at right angles both to each other and to the direction of propagation. The ratio of their amplitudes represents a constant value:

$$\frac{E_{(\mathrm{V/m})}}{H_{(\mathrm{A/m})}} = 377\,\Omega$$

and is called the intrinsic impedance or impedance of free space.

On the other hand, the fields near the line are related to the radio frequency voltages and currents propagating along the line and their ratio depends on the surge impedance of the line for the various modes. Furthermore, the directions of the electric and magnetic field components differ from those for radiated fields in free space as they are largely determined by the geometrical arrangements of the line conductors. The matter is further complicated by the fact that soil conditions affect differently the mirror image in the ground of the electric and magnetic field components, respectively.

The electric field strength $E(y)$ at ground level of a single conductor line, which is the vertical component of the total electric field strength, can be predicted by the following empirical formula that has, in a lot of cases, proven to give a good approximation:

$$E(y) = 120\, I \frac{h}{h^2 + y^2}$$

where

I is the radio noise current, in A, propagating in the conductor;

h is the height above ground, in metres, of the conductor;

y is the lateral distance, also in metres, from a point at ground level directly under the conductor to the measuring point; and

E is the electric field strength in V/m.

Furthermore, for an infinitely long single conductor line, the induction zone, or near field, has the same simple ratio of electric and magnetic field strength as the far field from a radio transmitter, that is to say 377 Ω and this is approximately true for all values of ground conductivity.

In the case of a multi-phase line the total electric field strength is the vectorial sum of the individual field strength components associated with each phase conductor. A more comprehensive treatment, together with practical methods of assessing the electromagnetic field, is discussed in 5.2 of CISPR/TR 18-2. The formula given above is a simplified version accurate for a distance of D = 20 m and f = 0,5 MHz where D is the direct distance, in metres, between the measuring antenna and the nearest conductor of the line, and f is the measurement frequency. For conventional power transmission lines (i.e. with a conductor height above ground which is less than 15 m), this direct distance D approximately corresponds to a lateral distance y of 15 m. For a wider range of D and f it would be necessary to take into account all the parameters affecting the formula.

4.2.1.4 Aggregation effect

In the case of uniformly distributed noise sources, the field strength generated by a unit length of a phase conductor can be expressed at any point along the line as a function of the longitudinal distance x and the lateral distance y, that is to say, $E(y,x)$. At a given lateral distance of y,

$$E(y,x) = E_0(y)e^{-\alpha x}$$

The random pulses on a long line with uniformly distributed noise sources combine together to form the total field. The manner in which they combine is not unanimously agreed upon. Some investigators consider that they combine quadratically:

$$E^2(y) = 2\int_0^{\infty} E_0^2(y)e^{-2\alpha x}\mathrm{d}x$$

or $$E(y) = \frac{E_0}{\sqrt{\alpha}} \ .$$

Other investigators believe that, if a quasi-peak detector is used to measure the field strength, the individual pulses do not add and others have obtained results between the two extremes. This disagreement is only important in analytical prediction methods, the results obtained by the different methods vary by only 1 dB or 2 dB.

In case of multi-phase lines, the calculation follows the sample principle but is complicated by the presence of several modes, each mode having a different attenuation coefficient. A more detailed discussion, with examples of calculation, is given in Clause 6.

4.2.2 Definition of noise

The instantaneous value of the noise varies continuously and in a random manner, but its average power level over a sufficiently long period, for example, 1 s, gives a stationary random quantity which can be measured. Another quantity suitable for measurement is the peak or some weighted peak value of the noise level.

A noise measuring instrument is basically a tuneable selective and sensitive voltmeter with a specified pass-band. When connecting to a suitable rod or loop antenna and properly calibrated, it can measure the electric or magnetic component of the noise field. For measurements of the magnetic component of the noise field in the frequency range up to 30 MHz, normally a loop antenna is used. For measurements of the electric component of the noise field in the frequency range above 30 MHz, use of a biconical antenna is recommended.

Depending on the design of the measuring receiver, the noise level can be measured in terms of r.m.s., peak or quasi-peak values. The r.m.s. value defines the noise in terms of energy. Many types of noise from electrical equipment, as well as noise due to power-line corona, consist of a succession of short pulses with approximately stable repetition frequencies. In such cases the nuisance effect of the noise can be realistically indicated by a quasi-peak type of voltmeter rather than by the r.m.s. type. The quasi-peak value is obtained from a circuit which includes a diode and a capacitor with relatively short charge and long discharge time constants. The voltage on the capacitor floats at a value somewhat below the peak value and depends on the repetition rate, that is to say a weighting feature is included in the response. This principle is adopted in the CISPR measuring receiver, details of which are given in CISPR 16-1-1. The noise level is thus defined by the value measured by such an instrument expressed in microvolts (µV) or microvolts per metre (µV/m). Using the ratio of the electric to magnetic field components, E/H = 377 Ω, the measured values can also be expressed by convention in µV/m even for instruments using a loop antenna responding to the magnetic field component.

4.2.3 Influence of external parameters

To determine the corona inception gradient g_c of a cylindrical conductor with smooth surface, Peek's formula is often used:

$$g_c \text{ (kV/cm)} = 31\ \delta \left(1 + \frac{0{,}308}{\sqrt{\delta r}}\right)$$

For a.c. voltages, g_c is the peak value of the gradient, r is the radius of the conductor in centimetres, $\delta = \dfrac{0{,}294p}{273+T}$ is the relative air density (δ = 1 for p = 1 013 mbar and T = 25 °C).

However, practical conditions on overhead lines do not agree with these idealized assumptions. Stranding of the conductors, surface imperfections and irregularities lead to local enhancements of the electric field strength and consequently to a lower corona inception voltage than is obtained from the above formula. This often means that the critical gradient for initiating radio noise has, under foul weather conditions, about half the value given by Peek's formula.

Atmospheric conditions likewise play an important part in occurrence of corona and spark discharges. In conditions of rain, fog, snow or dew, drops of water form on the surface of the conductor and at low temperatures ice can form. This further reduces the corona inception voltage and increases the noise level as shown in Clauses 5 and 6.

With regard to bad contacts and the production of small sparks, the effect of rain and humidity is to bridge the relevant gaps either by water droplets or by humid layers, thus reducing the level of this type of noise.

Rain and humidity thus affect the corona noise from conductors in a way opposite to that due to bad contacts. Hence when interference is observed during rain or fog, it can be concluded that it is caused by corona. On the other hand, when interference is observed during fair weather and disappears or decreases during rain or fog, it is due to bad contacts.

4.3 Main characteristics of the noise field resulting from conductor corona

4.3.1 General

To rationalize the measurement of radio noise from a transmission line and facilitate comparisons between different lines, it is desirable to standardize the conditions under which the measurement is to be carried out.

The main characteristics of the noise field are the frequency spectrum, its lateral field strength profile and the statistical variation of the noise with weather conditions. It is assumed as a first approximation that these characteristics are independent of each other.

4.3.2 Frequency spectrum

The frequency spectrum is the variation of the radio noise measured at a given point in the vicinity of a line, as a function of the measurement frequency. Two phenomena are involved:

a) Current pulses

   The current pulses generated in the conductors by the discharges show a particular spectrum dependent on the pulse shape. For this type of discharge the measured noise level decreases with an increase of the measurement frequency. In the range of broadcasting frequencies, where the positive discharges have a predominant effect, the spectrum is independent of the conductor diameter.

b) Attenuation along the line

   The attenuation of noise propagating along the line increases with frequency. This effect modifies the spectrum by reducing still further the noise level with increase in frequency.

The measured spectra are often fairly irregular because of the standing waves caused by discontinuities such as angle or terminal towers or abrupt ground level variations. In addition, the noise generation might vary whilst the measurements are being made.

To aid prediction calculations, "standard spectra" are used. Experience has shown that all spectra can be put into two families, one applying to horizontal conductor configurations, the other to double-circuit and triangular or vertical conductor configurations. The difference between these two families originates from the phenomenon mentioned in item b) above, the propagation differing slightly according to the type of line. However, as the difference is not material in relation to the accuracy of such calculations, only one standard spectrum is given in relative values, the reference point being taken at 0,5 MHz.

The following formula is a good representation of this spectrum: