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Edition 3.0 2017-10

TECHNICAL REPORT

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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Radio interference characteristics of overhead power lines and high-voltage equipment –
Part 2: Methods of measurement and procedure for determining limits

CISPR TR 18-2:2017-10(en)

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Radio interference characteristics of overhead power lines and high-voltage equipment –
Part 2: Methods of measurement and procedure for determining limits

INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

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

Part 2: Methods of measurement and procedure for determining limits

FOREWORD

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CISPR 18-2, 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 third edition cancels and replaces the second edition published in 2010. This edition constitutes a technical revision.

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This edition includes the following significant technical changes with respect to the previous edition:

a) updated description of the RF characteristics of spark discharges;

b) measurement method for radiated disturbances in the frequency range from 300 MHz to 3 GHz.

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

DTR	Report on voting
CIS/B/654/DTR	CIS/B/675/RVDTR

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 publication 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
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INTRODUCTION

This Technical Report is the second of a three-part series dealing with radio noise generated by electrical power transmission and distribution facilities (overhead lines and substations). It contains recommendations for performance of on-site measurements of electromagnetic noise fields in the vicinity of high-voltage (HV) overhead power lines and substations and for determination of limits for protection of radio reception.

The recommendations given in this Part 2 of the CISPR 18 series are intended to be a useful aid to engineers involved in maintenance of overhead power lines and substations and also to anyone concerned with checking the radio noise performance of a line to ensure satisfactory protection of radio reception. Information on the physical phenomena involved in the generation of electromagnetic noise fields is found in CISPR TR 18-1. It also includes the main properties of such fields and their numerical values. CISPR TR 18-3 eventually contains a Code of Practice for minimizing the generation of radio noise.

This third edition of CISPR TR 18-2 is adapted to the modern structure and content of technical reports issued by IEC. The second edition of CISPR TR 18-2 underwent thorough edition and adaptation to modern terminology. This third edition now also covers an adequate method of measurement for radiated disturbances from HV overhead power lines and substations in the range 300 MHz to 3 GHz, since gap-type discharges can be a potential noise source disturbing modern digital radio communication. However, because

1) there is not sufficient experience and information regarding gap-type noise and thus further investigations regarding noise characteristics and how gap noise disturbs digital radio communication are necessary,
2) gap noise is not persistent in normal operation of the electric power facility and tends to emerge from defective components,

there is no discussion in this edition regarding technical considerations for derivation of limits in the frequency range 300 MHz to 3 GHz.

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

The main content of this technical report is based on historical CISPR Rec. No. 56 given below:

RECOMMENDATION No. 56

METHODS OF MEASUREMENT OF RADIO INTERFERENCE CAUSED BY OVERHEAD POWER LINES AND HIGH-VOLTAGE EQUIPMENT AND THE PROCEDURE FOR DETERMINING LIMITS

The CISPR

CONSIDERING

a) that a general description of the radio interference characteristics of overhead power lines and high-voltage equipment has been published in CISPR 18-1,
b) that the methods of measurement of these characteristics need to be established,
c) that national authorities require guidance on the procedure for determining limits of such radio interference.

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RECOMMENDS

That the latest edition of CISPR TR 18-2, including amendments, be used for methods of measurement of radio interference characteristics of overhead power lines and high-voltage equipment and for procedures for determining limits.

CISPR TR 18-1 describes the main properties of the physical phenomena involved in the production of disturbing electromagnetic fields by overhead lines and provides numerical values of such fields.

In CISPR TR 18-2, methods of measurement and procedures for determining limits of such radio interference are recommended.

The methods of measurement in CISPR TR 18-2 detail the techniques and procedures for use when measuring electromagnetic fields arising from radio interference at sites close to overhead lines and also the techniques and procedures for making laboratory measurements of interference voltages and currents generated by line equipment and accessories.

The procedures for determining limits define the expected values of radio noise field and the width of the "disturbed" corridor following the route of the line.

This corridor takes into account the effective field strength of the wanted signal, the signal-to-noise ratio selected and the expected strength of the noise field for a given line.

The procedures are only valid for long and medium waves because procedures applicable to VHF analogue television broadcasting and digital terrestrial television broadcasting have not yet been decided, due to insufficient knowledge.

It is emphasized that this part of CISPR 18 does not specify a single set of limits to be applied internationally. Rather it details the procedures to enable national authorities to specify limits where it is decided that there is a need for regulations.

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

Part 2: Methods of measurement and procedure for determining limits

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 frequency range covered by this publication is 0,15 MHz to 3 GHz.

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

The clause on limits concentrates on the low frequency and medium frequency bands and it is only in these bands where ample evidence, based on established practice, is available. No examples of limits to protect radio reception in the frequency band 30 MHz to 3 GHz 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 in normal operation 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 boundary of the recognized service areas of the appropriate transmitters in the radio frequency bands used for a.m. radio broadcasting, 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.

The measuring apparatus and methods used for checking compliance with limits should comply with the respective CISPR specifications, as e.g. the basic standards series CISPR 16, see [1][1].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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*

IEC 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

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[1] The figures in square brackets refer to the Bibliography.

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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*

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 IEC 60050-161 and the ISO IEC Guide 99 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Measurements

4.1 Measuring instruments

4.1.1 Response of a standard quasi-peak CISPR measuring receiver to AC generated corona noise

CISPR 16-1-1 specifies the response characteristic of a measuring receiver to periodically repeated pulses, according to their repetition frequency, for a number of different frequency ranges and bandwidths including the range 0,15 MHz to 30 MHz and a resolution bandwidth of 9 kHz.

Figure 1 indicates the form these pulses take as they progress through the various stages of the measuring receiver. However, in the special case of corona pulses generated by high-voltage AC power systems, the individual pulses are not equally spaced throughout a cycle but occur in closely packed groups or bursts around the peak of the voltage waveform. A burst has a duration not exceeding 2 ms to 3 ms and this is followed by a quiescent no-corona period.

Owing to its inherent time constants, a standard quasi-peak CISPR measuring receiver is unable to respond to individual pulses within a burst, which is seen as a single pulse whose amplitude is discussed below.

Hence, the pulse repetition frequency, in the meaning of the CISPR definition, is constant at 2 *f* (where *f* is the power system frequency) for single phase and 6 *f* for three-phase single or multi-circuit systems, provided that the individual circuits are part of the same system.

Figure 2 indicates the usual case where individual corona pulses generated around the positive peaks of the voltage waveform are much greater in amplitude than those generated around the negative peaks. Hence in a three-phase power line there are three bursts of higher amplitude and three burst of lower amplitude noise during each period of 1/*f*.

Also, in the measurement of the radio noise field strength in close vicinity of an operational line, the antenna of the measuring receiver is not located at the same distance from all the phase conductors. Because a quasi-peak detector responds only to the higher amplitude bursts and disregards the lower ones, rules of summation of the radio noise generated by the individual phases of a line can be formulated which are specific to the CISPR characteristics

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and are given in Clause 4 of CISPR TR 18-3:__[2]. It should be noted that the loudspeaker of a radio receiver, and consequently the listener, perceives the overall generated noise.

To examine the response of the CISPR measuring receiver to a given burst of pulses, it should be borne in mind that each individual pulse becomes, at the output of the amplifier of Figure 1 of pass-band Δf, a damped oscillation whose duration can be taken as approximately 2/RBW (i.e. 0,5 times its IF amplifier resolution bandwidth), or 0,22 ms for 9 kHz. When there are a large number of pulses distributed at random within a burst, the resulting oscillations will overlap randomly and the overall quasi-peak signal will be approximately equal to the quadratic sum of the individual quasi-peak values. This statement, which is difficult to prove mathematically, has been well proven by experience and justifies the use, in quasi-peak detection, of the quadratic summation law which would moreover be rigorous if the noise levels were expressed in RMS values.

4.1.2 Other measuring instruments

Measuring instruments differing from standard CISPR instruments are referred to in Annex A although measuring instruments having detectors other than quasi-peak are also referred to in CISPR 16-1-1.

4.2 On-site measurements on HV overhead power lines

4.2.1 General

On-site measurements in the vicinity of HV overhead power lines should be carried out in accordance with the instructions given in this subclause. Further information about a possible assessment and documentation of measured data is found in 5.3.5 and 5.4.

4.2.2 Measurements in the frequency range 0,15 MHz to 30 MHz

4.2.2.1 Reference frequency

The reference measurement frequency is 0,5 MHz. It is recommended that measurements are made at a frequency of 0,5 MHz ± 10 % but other frequencies, for example 1 MHz, may also be used. The frequency of 0,5 MHz (or 1 MHz) is preferred because, usually, the level of radio noise at this part of the spectrum is representative of the higher levels and also because 0,5 MHz lies between the low and medium frequency broadcast bands.

Because of the possibility of error due to the presence of standing waves, it is inadvisable to rely on the measured value of the radio noise field strength at a single frequency but to draw a mean curve through the results of a number of readings throughout the noise spectrum. Measurements should be made at, or near, the following frequencies: 0,15 MHz, 0,25 MHz, 0,5 MHz, 1,0 MHz, 1,5 MHz, 3,0 MHz, 6,0 MHz, 10,15 MHz and 30 MHz although, clearly, frequencies at which interference to the wanted noise is received, should be avoided.

4.2.2.2 Measurement antenna

The antenna used for the measurements shall be an electrically-screened vertical loop, whose dimensions are such that the antenna will be completely enclosed by a square having a side of 600 mm in length. The balance shall be such that in a uniform field the ratio between the maximum and minimum indications on the measuring receiver when the antenna is rotated shall not be less than 20 dB. The base of the loop should be about 2 m above ground. The antenna shall be rotated around a vertical axis and the maximum indication noted. If the plane of the loop is not effectively parallel to the direction of the power line, the orientation should be stated.

[2] Under preparation. Stage at the time of publication: CISPR/RPUB 18-3:2017.

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According to the ANSI/IEEE Standard 430 (1986) [4], the antenna height using measurement vehicle is recommended as below:

If a vehicle-mounted antenna is used, the antenna should be at least 2 m above the roof of the vehicle. The effects of vehicles on vehicle-mounted antennas have been found to be negligible if this minimum height of 2 m is maintained; however, the vehicle and antenna combination should be calibrated to confirm the antenna factors and to check for existence of azimuthal asymmetries in the antenna pattern, as described in Section 5 of IEEE Standard 473 (1985) [5].

A check shall be made to ensure that the supply mains, if used, or other conductors connected to the measuring apparatus do not affect the measurements.

4.2.2.3 Selection of measurement points along the pathway of the overhead HV power transmission line

To determine the radio noise performance of a line, certain positions of measurement should be avoided; but these restrictions would not apply when an investigation into a case of interference is being carried out.

Measurements should be made at mid-span between the towers and preferably at several such positions. Measurements should not be made near points where lines change direction or intersect.

Sites at an abnormal height of span should be avoided. The measuring site should be flat, free from trees and bushes and remote from large metal structures and other overhead power and telephone lines.

Ideally the measuring site should be at a distance greater than 10 km from a line termination, in order to avoid reflection effects and consequently inaccurate results, but lower voltage distribution lines are sometimes too short to enable this condition to be met. However, the results of measurement (see reference [6]) indicate that the level of the radio noise field strength in the absence of reflections corresponds to the geometric mean of the maximum and minimum values, in microvolt per metre (μV/m), of the frequency spectrum from a line subjected to reflections.

If the line is transposed, the measuring site should be located as far as possible from the transposition towers.

The atmospheric conditions should be approximately uniform along the line. Measurements under rain conditions will be valid only if the rain extends over at least 10 km of the line on either side of the measuring site.

Annex B gives a list of such information.

4.2.2.4 Selection of measurement points lateral to the pathway of the overhead HV power transmission line

Measurements are performed e.g. for determination of the lateral field strength profile of the radio noise field generated by overhead HV power transmission lines. In these conditions, a number of measurement points at mid-span in between two towers should be chosen along a straight line departing perpendicular from the pathway of the overhead HV power transmission line under test. The distances of measurement shall be taken laterally from the vertical projection to ground of the outmost sub-conductor of the transmission line (reference point (x,y,z), i.e. x = place along the line at mid-span where the measurements are made, y = 0 m and z = 0 m corresponding to the vertical projection to ground of the outmost sub-conductor) to the centre of the antenna used for the measurements. For determination of the overall typical lateral field strength profile of the radio noise field of a given overhead HV power

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transmission line, it may be sufficient to consider lateral distances y in the range from 0 m to 200 m.

In order to allow for comparison of measured lateral profiles of the radio noise fields generated by several individual HV power transmission lines of the same type or by several HV power transmission lines of different types, it is necessary to determine a reference distance at which the observed profile curves converge through the same indication level. Practice proved that this is the case for a distance of 15 m taken laterally from the vertical projection to ground of the outmost sub-conductor (i.e. the reference point) of the transmission line concerned. That is why this 15 m distance is defined as the lateral reference distance y_0 for comparison of different lateral profiles.

In order to allow for subsequent comparison with other lateral radio noise field profiles, normalised profiles should either be related directly to that lateral reference distance of 15 m or, in case that measurements could not be performed at that distance, the results obtained should be normalised to the reference distance by means of the interpolation described in the next paragraph.

NOTE In the case of most conventional overhead HV power transmission lines already in operation, the normalised versions of lateral profiles of the radio noise fields obtained in a direct distance of 20 m from the nearest conductor converge through the same indication level as those obtained in the new lateral reference distance of 15 m, due to the usual height of the conductors above ground. However, the direct distance of 20 m used so far can prove impractical for prediction of the radio noise for transmission lines utilising higher voltages and for which high towers can be used. In order to also allow for measurements at ground level also in these conditions, the CISPR reference distance of 20 m taken directly from the nearest sub-conductor of the line was changed to a lateral distance of 15 m, see explanation above.

When the profile of the radio noise field is plotted as a function of the distance using a logarithmic scale, a substantially straight line is obtained. Under these conditions, the field at 20 m (direct distance) or simultaneously 15 m (lateral distance) is readily obtained by interpolation or extrapolation (see Figure 3).

The height of the axis of the lowest phase bundle of sub-conductors above ground should be measured at mid-span and recorded in the test report.

Regarding the prediction formula covered in CISPR TR 18-3, care should be taken when calculating the emissions since it still refers to the direct distance.

4.2.3 Measurements in the frequency range from 30 MHz to 300 MHz

4.2.3.1 Reference frequency

Because the frequency bands dedicated to television broadcasting vary in the countries around the word, a single reference measurement frequency for interference in television broadcast frequency bands cannot be fixed in the same way as done in the a.m. sound broadcasting frequency ranges. However, it is recommended that measurements are made at a frequency of 75 MHz but other frequencies, for example 150 MHz, may also be used. These frequencies should be selected since the noise strongly affects the video signal of broadcasting in the lower v.h.f. bands. The frequency of 75 MHz (or 150 MHz) belongs to these low v.h.f. broadcasting frequency bands.

4.2.3.2 Measurement antenna

The antenna used for the measurements shall be a passive antenna, for example a biconical antenna. Under the transmission line, strong electric induction effects from the power-frequency voltage can provoke a malfunction of an active antenna. The biconical antenna should be positioned about 3 m above ground. The antenna is to be rotated around a horizontal axis and the maximum indication noted. Generally, the plane of the biconical antenna is not perpendicular to the direction of the power line, but tilts about 5° to 10° to the perpendicular direction of the power line.

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4.2.3.3 Selection of measurement points along the pathway of the overhead HV power transmission line

To determine the radio noise performance of a line in the v.h.f. frequency range, certain positions of measurement should be avoided; however, these restrictions would not apply when an investigation into a case of radio interference is being carried out.

As there are no standing wave phenomena as in the lower frequency range, measurements can be made at any position in the span. Sites at an abnormal height of span should be avoided. The measuring site should be flat, free from trees and bushes and remote from large metal structures and other overhead power and telephone lines.

Measurement results should be expressed in units of microvolts per metre (μV/m) or the logarithmic equivalent (dBμV/m).

If the line is transposed, the measuring site should be located as far as possible from the transposition towers.

The atmospheric conditions should be approximately uniform along the line. Measurements under rain conditions will be valid only if the rain extends over at least 10 km of the line on either side of the measuring site.

Annex B gives a list of such information.

4.2.4 Measurements in the frequency range from 300 MHz to 3 GHz

4.2.4.1 General

In the frequency range from 300 MHz to 3 GHz, a potential noise source disturbing modern digital radio communication might be the gap-type discharges that are described in Clause 7 of CISPR TR 18-1:__ [3]; however, in order to facilitate the measurement method in this frequency range, further investigations regarding noise characteristics and how gap noise disturbs radio communication are necessary.

4.2.4.2 Measurement antenna, reference frequencies, and setting of measuring instruments

The antenna used for the measurements shall be a passive antenna, for example a log-periodic antenna. Under the transmission line, strong electric induction effects from the power-frequency voltage can provoke a malfunction of an active antenna. The log-periodic antenna should be positioned about 3 m above ground. The antenna is to be rotated around a horizontal axis and the maximum indication noted.

It is recommended that measurements are made at a frequency of 440 MHz but other frequencies, for example 1 690 MHz, may also be used. These frequencies should be selected to protect service quality of digital terrestrial broadcast and other (mobile) radio communication services.

The above is a tentative recommendation until adequate information and experience is obtained by further investigations in the future.

4.3 Statistical evaluation of the radio noise level of a line

When compliance with limits is required, it may be appropriate to use the statistical method given below. Further information about a possible assessment and documentation of measured data is found in 5.3.5 and 5.4.

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[3] Under preparation. Stage at the time of publication: CISPR/RPUB 18-1:2017.

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CISPR TR 16-4-3 describes statistical sampling methods for establishing the compliance of mass-produced appliances with CISPR limits. The so-called 80 %/80 % rule is based on the application of statistical techniques that have to give the consumer an 80 % degree of confidence that 80 % of the appliances of a type being investigated are below the specified radio noise limit. The method is based on the non-central *t*-distribution (sampling by variables) and the spirit of the 80 %/80 % CISPR rule is interpreted for overhead lines, such that the radio noise level should not exceed the limit for more than 80 % of the time with at least 80 % confidence.

Definitions of readings and sets of measurements are given below:

1) A reading is the result of a single measurement of the field strength level in dB(μV/m), at a given location, under given meteorological conditions. If the meter readings fluctuate, then an average value taken over a period of at least 10 min should be used.
2) Each set of measurements consists of averaging the readings taken, for a given meteorological condition, at three different locations approximately evenly distributed along the line. Not more than one set of measurements should be taken on any particular day for the given meteorological conditions. The three different locations will help to eliminate the effects of local irregularities (for example standing waves), although, as stated in 4.2.2.3 and 4.2.2.4, measurement positions where unrepresentative readings are likely to be obtained should be avoided.

Number of measurements:

1) Using the measurement techniques described in 4.2, at least 15 but preferably 20 or more sets of measurements should be taken.
2) The number of measurement sets for each weather condition (dry, rain, snow, etc.) shall be proportional to the frequency of occurrence of each weather condition for the area.

Compliance with a specified noise limit is judged from the following relationship taken from CISPR TR 16-4-3:

$$\overline{X} + k\,S_n \leq L$$

where

L is the permissible upper limit of radio noise;

$\overline{X}$ is the mean value of the (n) number of sets of radio noise level measurements of the line, namely:

$$\overline{X} = \frac{X_1 + X_2 ... + X_i + ... + X_n}{n}$$

S_n is the standard deviation of the (n) sets of measurements, namely:

$$S_n = \sqrt{\frac{\sum_1^n \left(X_i - \overline{X}\right)^2}{n-1}}$$

k is the constant depending on (n) and is determined in such a way that the above stated 80 %/80 % rule is satisfied.

The k value to be used for (n) number of sets of measurements is shown in the Table 1 below.

Table 1 – Number of *n* sets of the radio noise level measurements and corresponding values for factor *k*

n	15	20	25	30	35
k	1,17	1,12	1,09	1,07	1,06

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This equation, based on a limited number of samples, is similar to that relating to a Gaussian distribution valid for an infinite number of samples, the samples being represented by sets of measurements.

In the equation, S_n can be compared with the standard deviation relating to an infinite number of samples and k depends on both the required confidence (80 %/80 %) and on the number of samples. The lower the number of samples, the higher the value of k becomes for any percentage specified to meet the limit, with a given confidence.

Studies indicate, that even for a non-Gaussian distribution, the use of the above statistical method does not introduce a significant error provided that at least 15 but preferably 20 or more sets of measurements are used in the evaluation.

4.4 Additional information to be given in the report

To ensure that extraneous interference is not influencing the radio interference measurement level, it may be necessary to measure the background noise level (spectrum) with the line de-energized.

When the results of the measurements are reported, as much relevant information as possible should be given on the line and on the conditions under which the measurements were carried out.

4.5 Measurements on HV equipment in the laboratory

4.5.1 Overview

This subclause gives the method to be used for the measurement, in a laboratory or test area, of radio noise generated by items of plant and components used on high-voltage lines and in substations, such as circuit-breakers, bushings, insulators, and associated hardware. This method is valid for type tests and for routine or sample tests and also for investigational tests.

It is usual practice to carry out laboratory measurements of radio noise in a prescribed test circuit by measuring conducted quantities (current or voltage) and not the emitted field strength.

Furthermore, the selection of test conditions should be based on the following principle: ideally, the measurements should be made with the conditions and circuit simulating, as far as possible, actual service conditions and, if necessary, the most severe conditions likely to occur for the type of apparatus being tested. Before the establishment of a reliable method of radio noise testing in a laboratory, reliance was placed on the voltage at which inception or extinction of visual corona occurred on the test object. The voltages so determined were very dependent on the observer and this method is now being replaced by the laboratory measurement methodology described below.

4.5.2 State of the test object

It is well known that the level of the radio noise produced by high-voltage equipment is very dependent on the state of the surface of the item equipment. In laboratory tests, the state of a particular test object should consequently be clearly defined with regard to the following aspects:

a) new or already used;

b) clean or slightly polluted; the nature of the pollution should be specified;

c) dry, slightly damp, or wet (for example artificial rain conditions);

d) combination of these states, for example polluted and damp.

Generally, standards and normal practice are restricted to laboratory tests on clean and dry objects, reproducibility of the other test conditions (dampness, pollution) being often difficult

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to achieve. However, tests on objects submitted to (standardized) rain conditions may be very useful, since these conditions occur frequently in practice and may lead to significantly higher radio noise levels than dry conditions.

When only one surface condition is taken into consideration, it is desirable that the tests be performed on adequately polluted and wetted samples, in order to get as close as practicably possible to approximate actual conditions at normal operating voltage.

When the object is to be tested in a clean and dry state, it may be wiped with a dry cloth to remove dust and fibres that might affect the surface.

Unless otherwise stated, test conditions described in this clause are valid for used, wet and/or polluted objects as well as for new, clean and dry objects.

4.5.3 Test area

The tests should preferably be performed inside a screened room which is large enough to prevent the walls and the floor from having any significant effect on the distribution of the electric field at the surface of the test objects. Circuits entering the screened test area, for example supply cabling for power and lighting, should ideally be filtered so as to avoid introduction of external interference (see 4.5.11).

If a screened room is available, the tests may be carried out at any place where the background noise level is sufficiently low compared with the levels to be measured (see 4.5.11).

4.5.4 Atmospheric conditions

The normal reference atmosphere for tests described herein is:

– temperature: 20 °C;
– pressure: 1,013 x 10^5 N/m^2 (1 013 mbar);
– relative humidity: 65 %.

However these tests may also be performed under the following atmospheric conditions:

– temperature: between 15 °C and 35 °C;
– pressure: between 0,870 x 10^5 N/m^2 and 1,070 x 10^5 N/m^2 (870 mbar and 1 070 mbar);
– relative humidity (for tests on objects in the dry state): 45 % to 75 %.

In the case of investigational tests, other conditions may be selected according to the test objective.

When tests are made on a dry object, it shall be in thermal equilibrium with the test area atmosphere to avoid any condensation on the surface of the object.

As far as the radio noise levels generated by a test object are concerned, the effects of changes in atmospheric conditions with respect to the normal reference conditions (even while staying within the limits stated above) are little known. Thus no correction shall be applied to the measured results but the air temperature, air pressure and relative humidity obtaining during the tests shall be recorded.

4.5.5 Test circuit – Basic diagram

Figure 4 shows the principle of the test circuit. The radio-frequency currents generated by the test object flow through that part of the circuit shown by heavy lines which include impedance Z_s and resistance R_L. The radio-frequency rejection filter F virtually prevents these currents from flowing in the high-voltage connections to the transformer and, conversely, any

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interference currents from other sources present in this high-voltage connection are attenuated by the filter before entering the high frequency part of the circuit. Ideally the impedance of Z_s should be zero at the measurement frequency and infinite at the power supply frequency. Also, if R_L represents the resistive load of the test object in service, for example the characteristic impedance of a high voltage line, the radio noise voltage which the test object would inject onto a line conductor or substation connection may be measured across R_L.

CISPR 16-1-2 [2] specifies a value of 300 Ω for R_L and in a practical test circuit (see Figure 5), R_L is the equivalent resistance of R_2 in series with the parallel combination of R_1 and the input resistance of the measuring receiver, R_m.

The test consists of taking measurements of the pulse-type voltages appearing across a fraction of R_L when a given power-frequency voltage is applied to the object under test. These measurements are/shall be expressed in μV (or in dB(μV)).

4.5.6 Practical arrangement of the test circuit

Figure 5 shows the standard test circuit which should be used for the laboratory measurement of the radio noise voltages generated by medium and/or high voltage equipment. The connections to the measuring receiver are shown in a simplified form in Figure 5 and, depending on the distance between the measuring receiver and the test circuit, the arrangement shown in either Figure 6 or Figure 7 is incorporated into the circuit of Figure 5.

NOTE In the special limited case of the need for rapid comparative measurements to be made on a number of identical small objects, such as cap and pin insulator units for overhead lines, the special test circuit of Figure 8 can be used. The decoupling capacitor C_m can be omitted when the number of test objects exceeds five.

The impedance Z_s in the basic circuit of Figure 4 can consist of i) a series circuit L_2C_2 or ii) simply a capacitor C_3, as shown in Figure 5.

i) L_2C_2 is tuned to the measurement frequency along with L_1 in parallel with C_1, forming the rejection filter F. The advantage of this arrangement is that C_2 may have a relatively low value of capacitance, say 50 pF to 100 pF and therefore be cheaper, but the disadvantage is that measurements at frequencies other than the reference frequency involve the retuning of L_2C_2 and L_1C_1.

ii) As stated in item d) of 4.5.7, a value of 1 000 pF for C_3 should be satisfactory, which makes an inductor in series with C3 unnecessary and this part of the test circuit aperiodic. By making the rejection filter F also aperiodic by using, for example, an inductor damped by parallel resistors, measurements at frequencies other than the reference frequency can be carried out relatively simply. If, however, the laboratory or test area is near to industrial premises where high levels of radio noise can be produced, a very high filter impedance is usually required (see item c) of 4.5.7).

4.5.7 Test circuit components

The components that are used in the test circuit shall meet the following requirements.

a) High-voltage connections

The radio noise level produced by the high-voltage connections and terminations of the test circuit shall be insignificant compared with the values to be measured from the test object at the test voltage.

b) High-voltage transformer T_1

This transformer shall provide a voltage waveform consistent with the specifications of IEC 60060-2.

c) Rejection filter

Filter F shall have an impedance of not less than 20 kΩ, corresponding to an attenuation of at least 35 dB, in either direction at the measurement frequency.

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To be fully effective, the filter should be located as near as possible to the high frequency part of the test circuit. When the filter consists of a tuned circuit (L_1C_1), it should be tuned to the measurement frequency by using, for example, a signal generator connected across the secondary terminals of transformer T_1. Tuning is achieved by varying C_1 to give a minimum reading on the measuring receiver. The filter impedance may be assessed by measuring its insertion loss by taking the difference in the measuring receiver readings with the filter short-circuited and then with the short-circuit removed.

At the reference measurement frequency of 0,5 MHz ± 10 %, the value of L_1 should be about 200 μH, whereas C_1 should be variable up to a maximum of 600 pF.

d) Measuring impedance

The impedance between the live conductor and earth (Z_s + R_L in Figure 4) shall be (300 ± 40) Ω with a phase angle not exceeding 20°, at the measurement frequency.

A coupling capacitor C_3 (Figure 5) may be used in place of Z_s provided that the capacitance of C_3 is at least five times greater than the capacitance to earth of the test object and its high voltage connection. In practice, a value of 1 000 pF should be satisfactory for C_3.

Capacitor C_3 shall be capable of withstanding the maximum test voltage and have a low partial discharge level at that voltage.

4.5.8 Measuring receiver connections

The more usual method of connecting the measuring receiver to the test circuit, i.e. where the length of cable is less than about 20 m and coaxial cable is used, is shown in Figure 6. Where the length of cable is greater than 20 m, balanced screened cable is used, and this arrangement is shown in Figure 7.

a) Matching resistor R_1

To reduce the possibility of errors due to reflections within the connections to the measuring receiver, the co-axial cable, in the case of Figure 6, shall be terminated in its characteristic impedance at each end. Also, in the circuit of Figure 7, the cable/transformer assembly shall be similarly terminated.

The effective input resistance R_m of the measuring receiver usually provides one matching termination and the other termination is provided by R_1 which shall be of the high stability, non-inductive type.

b) Series resistor R_2

To meet the requirement of 300 Ω resistance across the test object, the input resistance R_m of the measuring receiver in parallel with R_1 has to be increased using a series resistor R_2 which shall be of the high stability, non-inductive type. In the case of a measuring receiver where R_m is 50 Ω, the value of R_2 should be 275 Ω.

NOTE 1 In some countries other resistance values are assigned to R_L: for example the National Electrical Manufacturers' Association (NEMA), of the USA, in its Publication 107 (1964) [7], specifies the value of 150 Ω for R_L. Usually a simple conversion can be applied to the results obtained from tests to other specifications. This is because a radio noise source in a test object almost invariably produces a constant current, provided R_L is within the range 100 Ω to 600 Ω and the voltage measured across R_L is simply proportional to its value.

c) Inductor L_3

This inductor provides a low-impedance path to divert the power frequency currents which flow in C_2 or C_3 away from the measuring receiver and its associated components. At the reference measurement frequency of 0,5 MHz, L_3 shall have a value of at least 1 mH, with a low self-capacitance, to avoid errors exceeding 1 % or 0,1 dB. For safety reasons, L_3 should be robust and have sturdy and secure electric connections.

d) Spark gap

To reduce the possibility of high voltages appearing on the connections to the measuring receiver, the provision of a protective spark gap across L_3 is recommended. This spark gap should preferably be of the gas-filled type with a maximum breakdown voltage of 500 V on a power frequency sine wave (see note below).

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NOTE 2 In the event of a relatively high power frequency voltage appearing across the spark gap, due for example to a failure of the inductor L_3 or its connections, there could be an increase in the test circuit background noise level, because of corona discharges at the electrodes of the spark gap.

e) Balanced cable and balun transformers (T_2 and T_3)

Where the test object is large and/or where very high voltages are involved, the measuring receiver may have to be located at some distance from the base of (C_2,L_2) or C_3, where R_1 and R_2 are located. Under such conditions, the length of co-axial cable shown in Figure 6 may exceed 20 m. To reduce the possibility of the measurements being affected by interference picked up on this cable, it is recommended that the arrangement shown in Figure 7 be used.

The balun or coupling transformers T_2 and T_3 should be located close to R_1/R_2 and to the measuring receiver, respectively, and the connection between the transformers should be made by means of a balanced screened cable. Short lengths of co-axial cable should be used to connect T_2 to R_1/R_2 and T_3 to the measuring receiver, and all these cables should have suitable characteristic impedances to ensure correct matching.

f) Measuring instrumentation

To comply with CISPR recommendations, the measuring instrumentation shall be consistent with the specifications of CISPR 16-1-1. If a measuring receiver with different characteristics is used, a conversion of the results into values which would have been obtained with a CISPR instrument is usually possible, but this can lead to some inaccuracy. This conversion should be carried out as detailed in 4.1.

4.5.9 Mounting and arrangement of test object

The object under test shall be mounted and arranged in accordance with the requirements of the standard applicable to the particular apparatus concerned (for example, IEC 60437:1997, see [3]). When no such standard is available, the test object shall be arranged, as far as possible, in the same manner and with the same circuit configuration as is typical of service conditions.

The object under test shall be provided with all its normal hardware which may affect the distribution of the electric field at the surface of the test object, for example as arcing horns and stress-control hardware. Where the test object can be in more than one condition, for example a circuit-breaker which can be open or closed, it shall be tested in each of these conditions.

The high-voltage connections to the object under test shall be short and shall not contribute to the measured values of radio noise from the test object nor influence the distribution of the electric field at its surface.

The coupling impedance, L_2C_2 (or C_3) shall be located near to the test object without significantly disturbing the distribution of the electric field at the surface of the test object.

4.5.10 Measurement frequency

The reference measurement frequency is 0,5 MHz. It is recommended that measurements are made at a frequency of 0,5 MHz ± 10 % but other frequencies, for example 1 MHz, may be used.

4.5.11 Checking of the test circuit

The test circuit shall be arranged so as to permit an accurate measurement of the radio noise level generated by the object under test. Any interference from outside the test circuit, including the supply, or from other parts of the circuit, shall be at a low level and, preferably, at least 10 dB below the level specified for the test object.

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With the specified test voltage applied to the circuit, the level of background noise shall be at least 6 dB below the lowest level to be measured. These conditions may be checked by substituting a similar but noise-free test object for the object under test.

Background noise levels may be relatively high when the tests are made in an unscreened area, especially when there are industrial premises nearby. When these high levels are of short duration, this condition may be acceptable provided that the quiet periods are of sufficient duration for a reliable measurement to be made and that, during the measurements, the character of the interfering peaks can be clearly distinguished from that of the noise being generated by the test object, possibly by means of an oscilloscope or a loudspeaker.

Interference may also result from broadcast stations; this may be overcome by selecting a measurement frequency from within the specific range but which is clear of interference. Additionally, the use of a resonant circuit L_1C_1, correctly tuned as the rejection filter F, can often be most effective in reducing such background interference.

4.5.12 Calibration of the test circuit

The test circuit shown in Figure 5 together with the circuit shown in either Figure 6 or Figure 7 shall be calibrated to obtain the value of the correction factor that shall be applied to the measuring receiver readings. This factor is the sum of the circuit attenuation and the resistance network factor, both expressed in dB. Such calibration is required where the test assembly is being used for the first time, or has been re-arranged, or where the test object have been changed to one of a significantly different capacitance. The power supply to the high-voltage transformer should be disconnected during calibration.

a) Circuit attenuation A

Before starting the calibration, the rejection filter F, if applicable, shall be tuned to the particular measurement frequency as described in item c) of 4.5.7. A signal generator with an output impedance of at least 20 kΩ shall then be connected in parallel with the test object, the test circuit being complete, as shown in Figure 5 together with the circuit shown in either Figure 6 or Figure 7. (Such a generator is easily arranged by connecting a 20 kΩ resistor in series with the output of a standard signal generator.) The generator shall be set to deliver a sine wave output of 1 V at the measurement frequency; this will result in a current of about 50 μA being injected into the test circuit. This current will ensure that the level of the reading obtained with a CISPR measuring receiver will be well in excess of the typical background noise level. The level of this reading shall be noted.

With the settings of the generator unchanged, the test object shall be disconnected from the high-voltage part of the test circuit and connected as shown in Figure 9. The level of this new reading shall be noted. The difference between the two readings is the circuit attenuation A.

NOTE 1 To avoid removing R_1 and R_2 from the test circuit during the calibration procedure, other high-stability, non-inductive resistors of the same value can be used.

NOTE 2 In Figure 9, the test object can be replaced by an equivalent capacitance, if this is known.

b) Resistance network factor

Levels of radio noise voltage generated by the types of apparatus being considered in this subclause are usually expressed in dB(μV) across 300 Ω.

Then, if $R_1 = R_m$, the network factor will be as follows:

$$R = 20 \lg \frac{600}{R_1}, \text{ expressed in dB.}$$

The radio noise level of the object being tested is then given by

$$V = V_m + A + R \quad \text{in dB(μV) across 300 Ω}$$

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where V_m is the voltage, in dB(μV), indicated by the measuring receiver and corresponding to its input voltage.

NOTE 3 A less complicated alternative method of overall calibration of the test circuit can be carried out in a single operation if a calibrated sine-wave current generator is used. This method involves an accurate measurement of both the output voltage V_0 of the signal generator and the value of a 20 kΩ resistor R_r in series with the generator output. Thus, when the signal generator (along with the 20 kΩ series resistor) is connected in parallel with the test object, the reading V_1 (in μV) appears on the measuring receiver; this reading corresponds to the current i_1 injected into the circuit as follows:

$$i_1 = \frac{V_0}{R_r} \text{ in } \mu\text{A}$$

Under these circumstances, the radio noise level of the apparatus being tested is directly given by:

$$V = V_m = 20 \lg 300 \frac{i_1}{V_1} \text{ in dB}(\mu\text{V}) \text{ across } 300\ \Omega$$

where V_m is the voltage, in dB(μV), indicated by the measuring receiver at the time of the test.

The sine-wave signal generator may be replaced by a pulse generator with a constant frequency spectrum, at least up to the measurement frequency. Correspondence of amplitudes between pulse and sinusoidal signals should meet the data included in CISPR 16-1-2 [2].

4.5.13 Test procedure

Radio noise generated by high-voltage equipment depends mainly on the distribution of the electric fields at the surface of the equipment. Ideally, the goal is to reproduce these field distributions during tests in the laboratory.

The radio noise level generated by a test object is not entirely determined by a particular value of the test voltage. A hysteresis effect often occurs, with the result that noise may or may not be present at a given test voltage, as it depends on whether this voltage was reached by decreasing or increasing values. Pre-conditioning of the test object, by subjecting it to a voltage which is equal to or greater than the specified test voltage for a specific period of time, can also have an effect on the measured level of radio noise.

The procedure for applying the test voltage should therefore be accurately specified.

The test voltage shall be a sine wave at power-supply frequency and be consistent with IEC 60060-2. It shall be applied either:

a) between phases of the object under test (for example a three-phase circuit-breaker), in which case the test voltage is related to the system's line voltage, or

b) between phase and earth (for example a complete insulator string), in which case the test voltage is related to the system's phase voltage.

The test voltage of the object to be tested is usually specified in the standard applicable to the type of object. In the absence of such a specification, the test voltage shall be 1,1 times the nominal voltage of the system or the rated voltage of the equipment ($U/\sqrt{3}$ for apparatus tested with respect to earth). In some cases, the test voltage is agreed between manufacturer and purchaser at a value between 1,1 and 1,4 times the nominal voltage of the system or the rated voltage of the equipment.

A voltage 10 % higher than the specified test voltage should be applied to the object under test and maintained for at least 5 min. The voltage should then be decreased in steps to 30 % of the specified test voltage, raised in steps to the initial value, maintained there for 1 min and, finally, decreased in steps to the 30 % value. Each voltage step should be approximately 10 % of the specified test voltage. At each step, a radio noise measurement should be made and

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