PD CISPR/TR 18-3:2017

BSI Standards Publication

Radio interference characteristics of overhead power lines and high-voltage equipment

Part 3: Code of practice for minimizing the generation of radio noise

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National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

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TECHNICAL REPORT

colour inside

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Radio interference characteristics of overhead power lines and high-voltage equipment –
Part 3: Code of practice for minimizing the generation of radio noise

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.100.01

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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 3: Code of practice for minimizing the generation of radio noise

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 18-3, 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) localisation system of spark discharges which might contain frequency components up to 3 GHz;

b) information regarding equations for predetermination of the radio noise level from HVDC overhead power lines.

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

DTR	Report on voting
CIS/B/655/DTR	CIS/B/676/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 website 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 later on.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

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INTRODUCTION

This Technical Report is the third 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 minimizing the generation of radio noise emanating from high-voltage (HV) power systems which include, but are not restricted to, HVAC or HVDC overhead power lines, HVAC substations and HVDC converter stations, hardware, etc., in order to promoting protection of radio reception.

The recommendations given in this Part 3 of the CISPR 18 series are intended to be a useful aid to engineers involved in design, erection and maintenance of overhead lines and HV stations 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 18-2 contains recommendations for methods of measurement for use on-site or in a laboratory. It furthermore recommends procedures for determination of limits for the radio noise from HV power systems.

The second editions of CISPR 18-1, -2, -3 underwent thorough edition in the maintenance work. The purpose of the maintenance work was to review for update in the measurement conditions, terminology, and the lateral profiles of radio noise, etc. Other updates belonged to the description of HVDC systems and to the upper edge measurement frequency.

The review for this third edition of CISPR 18-3 focused on the following issues:

a) description on gap noise locating system involved in the expansion of upper measuring frequency from 300 MHz to 3 GHz;

b) collation of predetermination formulae of radio noise level for DC power lines involved in update on DC description.

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

Considering

a) that the radiation of electromagnetic energy from overhead power lines causes interference,

b) that the level of this noise may be reduced by the design and lay-out of a line,

c) that when defects cause unusually high levels of interference there is need to detect and locate these faults,

this document recommends as CODE OF PRACTICE for minimizing the generation of radio noise, that the latest edition of CISPR Publication 18-3, including amendments, be used as guide for minimizing the generation of such noise caused by overhead power lines.

CISPR TR 18-1 describes the main properties of the physical phenomena involved in the production of 123 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 125 interference are recommended.

This CISPR TR 18-3 forms a "Code of Practice" to reduce to a minimum the production of radio noise by power lines and equipment.

NOTE The recommendation above is based on CISPR RECOMMENDATION No. 57.

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

Part 3: Code of practice for minimizing the generation of radio noise

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, excluding the fields from power line carrier signals.

The frequency range covered is 0,15 MHz to 3 GHz.

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*

CISPR TR 18-1:__[1], *Radio interference characteristics of overhead power lines and high-voltage equipment – Part 1: Description of phenomena*

CISPR TR 18-2:__[2], *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 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

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

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

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4 Practical design of overhead power lines and associated equipment in order to control interference to radio broadcast sound and television reception

4.1 Overview

This clause provides guidance on the techniques that may be applied during the design, construction and operation of high voltage overhead power lines and associated equipment in order to keep the various types of radio noise described in this document within acceptable levels.

4.2 Corona on conductors

During line design, consideration should be given to the geometric parameters of the line, in order to ensure that radio noise due to conductor corona will not exceed a specified acceptable level. The most important parameters are conductor diameter and number of conductors per phase. Other parameters that could be varied, such as distance between phases, height of conductors above ground or spacing of sub-conductors in the bundle, have a smaller effect. In practice, they are usually determined by mechanical or insulation requirements.

The quantitative laws that determine the level of radio noise caused by conductor corona are discussed in 4.3 of CISPR TR 18-1:__[3], and in Clause 7. These laws normally apply to both stranded and smooth conductors, since the surface unevenness caused by stranding does not, in general, substantially change the noise level, especially when conductors are damp or wet. The existence of scratched or broken strands or deposits of extraneous substances such as dirt or insects on the surface, on the other hand, may lead to severe localised corona discharges, due to high local voltage gradients. This may considerably increase the noise level of the line. For these reasons, it is necessary to avoid damage to the conductor surface during construction. It should be handled with great care in transportation and erection and suitable techniques should be used to avoid contact of the conductor with the ground or other objects during stringing. It is also advisable to avoid external greasing of the conductor for protection during transportation and tensioning; when the conductor is loaded, the increase in temperature, especially in hot weather, will cause this grease to run to the outside, gathering dirt and leading to areas with high local gradient and consequent radio noise. When the steel core or inside layers are greased for corrosion protection, a type of grease should be selected that will not migrate to the surface of the conductor even at the highest temperature.

4.3 Corona on metal hardware

Radio noise due to corona on metal hardware, such as suspension clamps, dead-end clamps, yokes, guard rings, horns, spacers, etc., can be controlled. Appropriate shapes and dimensions may be specified during the design stage in order to avoid points of high voltage gradient. All edges and corners should be well rounded, bolt heads should be rounded or shielded and sharp points and protrusions should be avoided. It is also important that the protective galvanized finish on hardware be smooth, particularly at points of maximum voltage gradient.

Guard devices are sometimes installed to protect an insulator string from the destructive effects of a power arc and to improve the distribution of the potential along the string. They also contribute to the reduction of the level of radio noise from the conductor clamps, since they screen sharp points or protrusions on the clamps. The type and dimensions of the guard devices should be chosen in such a way that they do not themselves produce radio noise. For example, the use of simple horns should be avoided at voltages exceeding about 150 kV, and the diameter of tubes forming guard rings should be sufficiently large to ensure that no corona occurs during rain.

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

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Present knowledge seems to indicate, however, that it may be relatively difficult to design guard rings suitable for rainy conditions, even if they are made of multiple tubes. In which case, it may be necessary to devise special arrangements for the yoke so that the string is screened directly by the conductor bundle and is protected from power arcs by suitable devices on the sub-conductors of the bundle.

As in the case of conductors, it is important to avoid damage to the hardware during manufacture, transportation, construction and maintenance by handling them with great care at all times.

4.4 Surface discharges on insulators

4.4.1 Clean or slightly polluted insulators

The radio noise produced by these insulators under dry conditions can be controlled by:

- the use of insulators of suitable design, especially as regards their geometry and the characteristics of the material at the more critical areas, or
- the use of guard devices designed to improve the distribution of voltage on the surface of the insulator or along the insulator string.

In insulator design, the use of conducting glaze, for example, improves the distribution of the surface voltage gradient on the insulator. In the design of a guard device, a metal ring as close as possible to the insulator, or to at least the first two or three insulators at the line end of an insulator string, may considerably improve the voltage distribution on the insulator or along the insulator string and reduce radio noise. The ring, however, shall remain compatible with other requirements such as insulation withstand, protection of the insulators from power arcs, screening of the clamps, etc. (see 4.3).

The radio noise produced in damp weather, fog or rain is usually more difficult to control than the noise under dry conditions. It is, however, seldom a critical factor in line design, since the increase in noise due to water droplets on the insulators is usually less important than the corresponding increase in noise produced by the conductors.

4.4.2 Very polluted insulators

Under dry conditions, in addition to the phenomena that cause noise on a clean insulator, other phenomena of the corona type may occur due to surface unevenness created by pollution deposits, as mentioned in 6.1 of CISPR TR 18-1:__[4]. Under these conditions even careful design of the various parts of an insulator may be of little benefit. Stress control devices suitable for improving the voltage distribution on the insulator or along the insulator string, however, may considerably improve the radio noise performance.

When the polluted insulator surface is wet, radio noise is generated by sparks across the dry bands, created by the leakage currents, as discussed in 6.1 of CISPR TR 18-1:__[5]. Occasionally, this noise has very high frequency components. It may affect both sound and television reception and is difficult to control. The only practical remedy is to limit the leakage current activity on the surface of the polluted insulator. This may be achieved by:

a) diminishing the voltage stress on the insulator – for example by using a longer surface creepage path than is necessary for electrical withstand;

b) using special types of insulators such as those made of organic material or coated with semi-conducting glaze, or designs with a longer creepage path such as fog type units, special shapes, etc.;

c) coating the insulators with silicone grease.

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4.5 Spark and microsparks due to bad contacts, commutation effects

Remedial measures for eliminating or reducing these types of radio noise are described in Clause 5 and in 8.4 of CISPR TR 18-1:__[6] respectively.

4.6 Defects on power lines and associated equipment in service

Even if all possible precautions have been taken during design and construction of a power line or substation to keep radio noise within acceptable limits, defects may occasionally occur during operation, resulting in intolerable noise. This may be caused by breakage of strands on the conductors, damage to clamps or insulators or accumulation of pollution on conductors and insulators. In general, these defects shall be eliminated in order that the power system may operate properly, whether or not they are sources of radio noise. In fact, the occasional noise caused by such defects may result in detection and location of potential power system faults.

These abnormal noise sources may be located by various instruments such as radio noise measuring sets, television receivers or ultrasonic and optical detectors. Location will often be easier when the noise affects television reception, since at very high frequencies longitudinal attenuation along the line is very high. When only low and medium wave frequencies are affected, location of the noise source may require the recording of the longitudinal attenuation of the radio noise field strength, combined with optical, ultrasonic or ultraviolet devices, as discussed in Clause 5.

5 Methods of prediction of the reference level of an overhead line

5.1 General

This document has been written to provide the engineer in the field with the theoretical and practical background necessary to deal with radio interference problems. Technical aspects have been dealt with in Part 1 and many of the aspects discussed are dealt with in this clause in a simplified manner to bring together the theoretical and practical issues.

The reference level of a line is the strength of the radio noise field at a reference frequency of 500 kHz and at a direct distance of 20 m from the nearest conductor of the line. Where the voltage gradient in the air at the surfaces of the conductors of a normal line is greater than about 12 kV/cm to 14 kV/cm, depending on conductor diameter, the radio noise performance of the line is determined by the performance of the conductors. The number and diameter of the conductors per phase of a proposed line are often decided by the current-carrying capacity required or by economic considerations and usually a prediction of the reference level is required for a particular weather condition. If a line is designed with the conductors at a high surface gradient, very little can be done to reduce the noise level once the line has been constructed.

Figure B.14 of CISPR TR 18-1:__[7] gives the correction to be applied to a radio noise level relating to a measurement frequency other than 500 kHz.

Where the voltage gradient in the air at the surfaces of the conductors of a line is less than about 12 kV/cm, the radio noise level is usually determined by the insulators and hardware. In this case the radio noise performance of the line is inherently good and it is usually desirable to preserve this good quality by selecting insulators and hardware of a matching quality. Most of the methods of prediction or predetermination are concerned with the conductor noise and do not apply to lines where the conductors are at a low surface gradient. None of the methods applies to sparking sources at loose or imperfect contacts.

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5.2 Correlation of data given elsewhere in this publication

This subclause contains information about the correlation of the radio noise voltage at the line and the resulting radio noise field strength at ground level at a certain lateral or direct distance slant to the respective line.

a) Methods relating to noise from conductors

Subclause 5.3 of CISPR TR 18-1:__ [8] gives a survey of methods of prediction or predetermination for AC lines, both analytical or semi-empirical and empirical or comparative.

The analytical method relies on the results of measurements carried out on a short length of sample conductor in a test cage and involves highly complex analyses. The sample conductor can be tested with any desired surface condition and the radio noise voltage measured by a circuit given in 4.5 of CISPR TR 18-2:__[9]. However, for AC lines, a reliable prediction of the reference level due to conductor corona can be calculated only from the wet test in this method since in this case the number of individual corona sources per unit length is sufficiently high to represent a statistically satisfactory sample.

The simple comparative formulae referred to in 5.3 of CISPR TR 18-1:__[10] rely on the results of radio-noise field strength measurements carried out on an existing line of similar design. These formulae take into account the effects of any difference between the reference and proposed lines such as the differences in surface voltage gradient or conductor diameter. If the design of the reference and the proposed lines are similar and the operating conditions, such as air pollution, etc., are also similar, a fairly accurate prediction may be obtained of the reference level to be expected from the proposed line due to conductor corona. The effects of weather may also be determined by taking measurements on the reference line in a variety of weather conditions.

In 5.4 and Annex B of CISPR TR 18-1:__[11] is given a catalogue of radio noise field strength profiles resulting from conductor corona for certain designs of single circuit overhead line. The profiles are correct when the value of the voltage gradient in the air at the surfaces of the conductors of the lines are sufficiently high to produce radio noise. The values of the field strength, at a measurement frequency of 500 kHz, are given for both heavy rain and average fair weather conditions, the heavy rain conditions producing a higher field strength of between 17 dB and 25 dB. The profiles show the attenuation of the field with distance normal to the lines for distances out to 150 m.

For DC lines, reference is made to 8.2 of CISPR TR 18-1:__[12] for the calculation of the noise level.

b) Method relating to noise from insulators and/or fittings

Subclause 6.2 of CISPR TR 18-1:__[13] gives a correlation between the radio noise voltage generated by a hardware or component of a line, when measured in accordance with the procedure given in 4.5 of CISPR TR 18-2:__[14], and the level of the reference field. This correlation applies where the line has a single noise source, for example a broken insulator, or where multiple sources are distributed uniformly along the line. The method, which includes a semi-empirical formula, is particularly useful where the conductors of a proposed line are to operate at a low surface gradient and a prediction is required of the reference level to be expected from the insulators of the line. When the measurement procedure according to 4.5 of CISPR TR 18-2:__[15] is carried out on insulators, then they

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

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

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

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

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

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

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

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

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are usually in a clean and dry condition, since this condition is normally specified. But the procedure is not restricted to measurements on clean and dry objects and specially polluted sample insulators could be tested when damp and when dry and the results inserted into the formula to predict the reference level of a proposed line.

c) Methods relating to aggregate noise from the conductors, insulators and/or hardware

Subclause 5.2 of CISPR TR 18-1:__[16] gives information on the use of test lines. Where conditions relating to a new design of line are such that they cannot be related to data available from an existing line, the expected performance is sometimes studied on a relatively short test line. Such test line studies are particularly useful when a new system, for operation at a much higher voltage than hitherto, is in the planning stage. The radio noise performance of the experimental line is monitored in a range of weather and atmospheric conditions so that the performance of the proposed line can be assessed under the conditions it will experience in service. This could also include the effects of insulator pollution. Other important data, such as corona loss and acoustic noise performance, can also be obtained from the test line at the same time.

In 5.4 of CISPR TR 18-2:__[17] a method is given whereby the reference level of a line may be found which will protect a given broadcast signal strength at a given distance from the line for 80 % of the time with 80 % confidence.

5.3 CIGRÉ formula

A simple direct formula has also been evolved for predicting the level of the radio noise field strength to be expected from the conductors of AC lines. The formula, which is empirically based, gives the most probable level to be expected from aged conductors in fair weather at a direct distance D0 of 20 m from the nearest conductor at a measurement frequency of 500 kHz. The formula is derived from lines operating at voltages between 200 kV and 765 kV and at maximum voltage gradients between 12 kV/cm and 20 kV/cm. Strictly seen, the formula gives the noise from one phase conductor or bundle of a line and the effects of the other conductors may be taken into account by a summation process. However, for a number of designs of lines within these ranges, it is found that only a small error is introduced if only the conductor producing the highest noise at the measuring point of a three-phase line is considered; usually this is the nearest conductor but not necessarily so in all cases.

The formula is

$$E = 3{,}5\ g_{max} + 12\ r - 30, \qquad \text{in dB}(\mu\text{V/m})$$

where

E is the level of the radio noise field strength in dB(μV/m) at a direct distance D_0 of 20 m from nearest conductor of proposed AC line;

g_{max} is the maximum gradient of the RMS voltage at the conductor surface, in kV/cm;

r is the radius of conductor or sub-conductor, in cm.

This matter is considered in more detail in Annex A.

5.4 Determination of 80 % level

The 80 % level for a line may be predicted by calculation [2, 3][18] or, if the line exists, the 80 % level may be determined with a high degree of confidence, by measurement. Methods of determining the 80 % level are as follows:

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

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

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

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1) for an existing line, the 80 % level may be determined, with a high degree of confidence, from the all-weather distribution curve obtained by measurements made over a period of one year;
2) if the all-weather distribution curve is not available, or in the case of a proposed line, the results of measurements made one line of similar design in a similar climate and pollution environment could be used;
3) from the figures mentioned in 4.3.4 of CISPR TR 18-1:__[19] it is seen that, on average, the 80 % level for a line is 10 dB greater than the 50 % level. Therefore, if the 50 % level is known, the 80 % level may be estimated;
4) the 80 % level may be predicted by adding 5 dB to 15 dB, depending on the climate, to the fair-weather level estimated from the simple formula given in 5.3.

5.5 Conclusions

The particular method of prediction to use in the case of a particular proposed line will depend on whether the interest is in conductor corona or noise due to insulators and/or hardware that is whether the conductors are to operate at a voltage gradient greater than about 14 kV/cm or less than about 12 kV/cm. For voltage gradients in between these values, both the conductors and the insulators may contribute to the noise level of the proposed line.

The simple comparative formula referred to in item a) of 5.2, the catalogue of radio noise field strength profiles referred to also in item a) of 5.2 and the CIGRÉ formula given in 5.3 are all simple to use and, provided they are used within their inherent limitations, they should give reasonably accurate indications of the reference level to be expected from the conductors of a proposed line. It should be borne in mind that owing to the variable nature of radio noise and its dependency on the effects of weather, atmospheric conditions, pollution, etc., it is often difficult to measure the reference level of a line with any high degree of accuracy and reproducibility.

The method referred to in item b) of 5.2 relating to noise from insulators and/or hardware has not, as yet, become established practice for the case of specially polluted test insulators but the method would appear to have promise for this case. If a test line, referred to in item c) of 5.2, is available, together with the time required to carry out experimental work, the likely reference level from a proposed line may be obtained with a good degree of accuracy for the particular conductor, insulators and hardware proposed.

6 Preventive and remedial measures to minimize radio noise generated by bad contacts and their detection and location

6.1 General

Radio noise generated by sparking at bad, that is loose or imperfect, contacts occurs mainly in dry weather since in wet weather the comparatively small gaps involved usually became bridged with moisture.

6.2 Preventive and remedial measures

When constructing high voltage equipment it is important

1) to ensure that all fixing bolts are securely tightened, and
2) to bond conducting elements, as far as is possible, either to earth or conductor potential.

On distribution lines, bonding adjacent metal surfaces is important but bonding to earth or conductor potential is not required for spark suppression. If bonding to one side is not possible (for example at the pin and clevis, or ball and socket, couplings of an insulator string),

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the adjacent conducting elements should have good metal-to-metal contact and the whole assembly should be well insulated from other metallic parts of the equipment. It should be borne in mind that even when equipment is new, galvanized metallic parts can have a corrosion coating of zinc carbonate. When the surfaces have weathered, additional oxides and sulphides may be present and an imperfect contact may result leading to the possibility of gap-type discharges. The phenomenon may occur when suspension insulator strings have inadequate mechanical loading.

The following preventive and remedial measures have been found to be effective:

a) Conductive grease and paste

A quick and economical method is the application of conductive grease to the socket or clevis area of insulators. This is a temporary cure, however, and it is necessary to re-apply the grease at a later date. The use of a copper paste, instead of conductive grease, promises to be a more lasting remedy but care shall be taken to ensure that the grease or paste does not find its way on to an insulating surface.

Ordinary, non-conductive grease applied to freshly galvanized surfaces will inhibit corrosion.

b) Bonding brush

The application of a bonding brush, with stainless steel bristles, is a temporary cure, lasting for some three to five years, by providing metal-to-metal contact in the pin and clevis, or ball and socket, area.

c) Bonding clip

Where pin and clevis type insulators are used, bonding clips can easily be installed in the pin and clevis area. It is especially important that these be installed in the conductor clamp connection with the line end insulator. There are several types of clip suitable for insertion between ball and socket which maintain sufficient pressure to break down the oxide film.

d) Permanent bonding

The best results are likely to be obtained with a permanent flexible bond across each individual metallic link of the insulator string, together with bonds from the earth end insulator to the cross-arm and from the conductor clamp to the line end insulator. The bonds should consist of stranded stainless steel or copper cable and can either be welded or fastened by screws. The cable should have a plastic covering to prevent bird caging of broken strands.

e) Metal weights for insulator strings with inadequate mechanical loading

In order to ensure good contact between the caps and pins of adjacent insulator units, the strings should be loaded with metal weights which are well-rounded to prevent corona discharges.

f) Spring and plastic washers

If a wooden construction is used, there is some merit in using spring or plastic washers. The spring washers are capable of preventing loose hardware on poles and cross-arms due to wood shrinkage. A plastic washer of acetate or nylon also improves tightness of the nuts. Where these "shake-proof"-type nuts or plastic washers are used, care should be taken to ensure that there are no insulating gaps between metallic parts. Such a washer is generally used only between a nut and a wood pole or arm.

g) Single insulator

The use of a single insulator has the advantage of having fewer possible radio noise sources.

h) Pin-type insulators with conducting glaze

With pin-type insulators, sparking may occur on the surface where the conductor rests in the top groove and at the tie-wire or stirrups in the side groove of the insulator. This problem may be overcome by using conductive paints or metallization of the insulator surface in the area of contact. These metallizing agents are effective only if applied

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together with the glaze during manufacture of the insulator. In the case of pin-type insulators, if the pin screws directly into a threaded hole in the porcelain, the porcelain threads should be treated with conductive paint. As an alternative, a threaded metal insert can be cemented into the pin-hole; although the best solution is to purchase insulators with the pin-hole glazed during manufacture.

If a PVC insulated conductor is used, there is a possibility of local discharges occurring at the supporting insulators. These discharges can be avoided by wrapping the PVC with semi-conducting tape. For an 11 kV line, the tape should extend for 600 mm on either side of the insulator.

i) Plastic fasteners and insulated staples

The use of plastic fasteners or insulated staples to secure the earth wire to a wood pole will avoid sparking between the earth wire and its fasteners, particularly if the fasteners became loose or corrosion is present.

6.3 Methods of detecting and locating bad contacts

When bad contacts are present in a power line or substation, the detection and exact location of the radio noise source(s) are more important than the measurement of the resulting field strength. Practical methods for the detection and location of these bad contacts are described below. Measurements and observations should normally be made in fair weather.

Since a high voltage power line and associated equipment is often the source of different radio frequency fields, it is necessary to trace the radio noise by starting at the disturbed receiver. The first step in the investigation is to obtain an aural and/or visual indication of the radio noise, by using a loudspeaker or headphones and an oscilloscope or television receiver.

When tracing the source(s) of radio noise due to bad contacts it is better to observe the noise at the highest frequency perceptible because of the more rapid attenuation along the line. Whilst it is preferable that the apparatus used for tracing should cover the whole radio noise frequency range, few instruments are available that cover this spectrum. Few have been designed specifically for the location of sources of radio noise and, accordingly, it may be necessary to modify commercial apparatus to make it suitable.

The following apparatus will be found useful for locating bad contacts: a) to g) are conventional instruments and h) is a modern instrument employing recent digital signal processing techniques, which can estimate the Direction of Arrival (DOA) with high directional resolution.

a) A general coverage receiver (a.m.) tuneable from at least 500 kHz to 18 MHz.

b) A VHF field strength measuring instrumentation fitted with a two-element broadband antenna and a VHF pre-amplifier: The audio output should be amplified sufficiently to feed a loudspeaker and an oscilloscope.

c) An oscilloscope with sufficient intensity for use in full daylight, when used with a viewing hood, and a sweep frequency of approximately 500 Hz.

d) An UHF field strength measuring instrumentation fitted with two interchangeable Yagi antennas (one array for 500 MHz and the other for 800 MHz): A moderate level audio output is required for a loudspeaker. RF pre-amplification is required and IF gain control is desirable. The whole assembly should be able to be carried by one man.

e) A small radio frequency detector covering the frequency range MF to VHF but without automatic gain control.

f) A small a.m. broadcast radio receiver without manual or automatic gain control and enclosed in a metal box: The receiver antenna can either be telescopic, to allow for variation in RF sensitivity, that is to adjust the RF gain, or, preferably, a ferrite rod mounted inside the metal box opposite a slot of similar length in the box side. The box is mounted at one end of an insulating tube, a few metres in length and having a diameter of approximately 3 cm to 6 cm. The output of the receiver loudspeaker is directed into the bore of the tube while, at the other end, a microphone is arranged to pick up the noise signal. The microphone output is then fed into an amplifier feeding the headphones or a

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