

TECHNICAL SPECIFICATION

**Selection and dimensioning of high-voltage insulators intended for use in
polluted conditions –
Part 1: Definitions, information and general principles**

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**Selection and dimensioning of high-voltage insulators intended for use in
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Part 1: Definitions, information and general principles

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SELECTION AND DIMENSIONING OF HIGH-VOLTAGE INSULATORS
INTENDED FOR USE IN POLLUTED CONDITIONS –****Part 1: Definitions, information and general principles**

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC/TS 60815-1, which is a technical specification, has been prepared by IEC technical committee 36: Insulators.

This first edition of IEC/TS 60815-1 cancels and replaces IEC/TR 60815, which was issued as a technical report in 1986. It constitutes a technical revision and now has the status of a technical specification.

The following major changes have been made with respect to IEC/TR 60815:

- Encouragement of the use of site pollution severity measurements, preferably over at least a year, in order to classify a site instead of the previous qualitative assessment (see below).
- Recognition that “solid” pollution on insulators has two components, one soluble quantified by ESDD, the other insoluble quantified by NSDD.
- Recognition that in some cases measurement of layer conductivity should be used for SPS determination.
- Use of the results of natural and artificial pollution tests to help with dimensioning and to gain more experience in order to promote future studies to establish a correlation between site and laboratory severities.
- Recognition that creepage length is not always the sole determining parameter.
- Recognition of the influence other geometry parameters and of the varying importance of parameters according to the size, type and material of insulators.
- Recognition of the varying importance of parameters according to the type of pollution.
- The adoption of correction factors to attempt to take into account the influence of the above pollution and insulator parameters.

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

Enquiry draft	Report on voting
36/264/DTS	36/270/RVC

Full information on the voting for the approval of this technical specification 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 the parts in the future IEC 60815 series, under the general title *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

SELECTION AND DIMENSIONING OF HIGH-VOLTAGE INSULATORS INTENDED FOR USE IN POLLUTED CONDITIONS –

Part 1: Definitions, information and general principles

1 Scope and object

IEC/TS 60815-1, which is a technical specification, is applicable to the selection of insulators, and the determination of their relevant dimensions, to be used in high-voltage systems with respect to pollution. For the purposes of this technical specification, the insulators are divided into the following broad categories, each dealt with in a specific part as follows:

- IEC/TS 60815-2 – Ceramic and glass insulators for a.c. systems;
- IEC/TS 60815-3 – Polymeric insulators for a.c. systems;
- IEC/TS 60815-4 – *equivalent to 60815-2 for d.c. systems*¹;
- IEC/TS 60815-5 – *equivalent to 60815-3 for d.c. systems*¹.

This part of IEC 60815 gives general definitions, methods for the evaluation of pollution site severity (SPS) and outlines the principles to arrive at an informed judgement on the probable behaviour of a given insulator in certain pollution environments.

This technical specification is generally applicable to all types of external insulation, including insulation forming part of other apparatus. The term “insulator” is used hereafter to refer to any type of insulator.

CIGRE C4 documents [1], [2], [3]², form a useful complement to this technical specification for those wishing to study in greater depth the performance of insulators under pollution.

This technical specification does not deal with the effects of snow, ice or altitude on polluted insulators. Although this subject is dealt with by CIGRE [1], [4], current knowledge is very limited and practice is too diverse.

The object of this technical specification is to

- understand and identify parameters of the system, application, equipment and site influencing the pollution behaviour of insulators,
- understand and choose the appropriate approach to the design and selection of the insulator solution, based on available data, time and resources,
- characterize the type of pollution at a site and determine the site pollution severity (SPS),
- determine the reference unified specific creepage distance (USCD) from the SPS,
- determine the corrections to the “reference” USCD to take into account the specific properties (notably insulator profile) of the “candidate” insulators for the site, application and system type,
- determine the relative advantages and disadvantages of the possible solutions,
- assess the need and merits of “hybrid” solutions or palliative measures,
- if required, determine the appropriate test methods and parameters to verify the performance of the selected insulators.

¹ At the time of writing these projects have yet to be initiated.

² References in square brackets refer to the bibliography.

2 Normative references

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

IEC 60038, *IEC standard voltages*

IEC 60050-471, *International Electrotechnical Vocabulary – Part 471: Insulators*

IEC 60305, *Insulators for overhead lines with a nominal voltage above 1 000 V – Ceramic or glass insulator units for a.c. systems – Characteristics of insulator units of the cap and pin type*

IEC 60433, *Insulators for overhead lines with a nominal voltage above 1 000 V – Ceramic insulators for a.c. systems – Characteristics of insulator units of the long rod type*

IEC 60507:1991, *Artificial pollution tests on high-voltage insulators to be used on a.c. systems*

IEC/TR 61245, *Artificial pollution tests on high-voltage insulators to be used on d.c. systems*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms, definitions and abbreviations apply. The definitions given below are those which either do not appear in IEC 60050-471 or differ from those given in IEC 60050-471.

3.1.1

reference cap and pin insulator

U120B or U160B cap and pin insulator (according to IEC 60305) normally used in strings of 7 to 9 units to measure site pollution severity

3.1.2

reference long rod insulator

L100 long rod insulator (according to IEC 60433) with plain sheds without ribs used to measure site pollution severity having a top angle of the shed between 14° and 24° and a bottom angle between 8° and 16° and at least 14 sheds

3.1.3

insulator trunk

central insulating part of an insulator from which the sheds project

NOTE Also known as shank on smaller diameter insulators.

3.1.4

shed

projection from the trunk of an insulator intended to increase the creepage distance

NOTE Some typical shed profiles are illustrated in 9.3.

3.1.5

creepage distance

shortest distance, or the sum of the shortest distances, along the insulating parts of the insulator between those parts which normally have the operating voltage between them

NOTE 1 The surface of cement or of any other non-insulating jointing material is not considered as forming part of the creepage distance.

NOTE 2 If a high resistance coating, e.g. semi-conductive glaze, is applied to parts of the insulating part of an insulator, such parts are considered to be effective insulating surfaces and the distance over them is included in the creepage distance.

[IEV 471-01-04, modified]

3.1.6

unified specific creepage distance

USCD

creepage distance of an insulator divided by the r.m.s. value of the highest operating voltage across the insulator

NOTE 1 This definition differs from that of specific creepage distance where the line-to-line value of the highest voltage for the equipment is used (for a.c. systems usually $U_m/\sqrt{3}$). For line-to-earth insulation, this definition will result in a value that is $\sqrt{3}$ times that given by the definition of specific creepage distance in IEC/TR 60815 (1986).

NOTE 2 For ' U_m ' see IEC 604-03-01 [5].

NOTE 3 It is generally expressed in mm/kV and usually expressed as a minimum.

3.1.7

insulator profile parameters

set of geometrical parameters that have an influence on pollution performance

3.1.8

salt deposit density

SDD

amount of sodium chloride (NaCl) in an artificial deposit on a given surface of the insulator (metal parts and assembling materials are not included in this surface) divided by the area of this surface, generally expressed in mg/cm^2

3.1.9

equivalent salt deposit density

ESDD

amount of sodium chloride (NaCl) that, when dissolved in demineralized water, gives the same volume conductivity as that of the natural deposit removed from a given surface of the insulator divided by the area of this surface, generally expressed in mg/cm^2

3.1.10

non soluble deposit density

NSDD

amount of non-soluble residue removed from a given surface of the insulator divided by the area of this surface, generally expressed in mg/cm^2

3.1.11

site equivalent salinity

SES

salinity of a salt fog test according to IEC 60507 that would give comparable peak values of leakage current on the same insulator as produced at the same voltage by natural pollution at a site, generally expressed in kg/m^3

3.1.12

dust deposit gauge index – soluble

DDGI-S

volume conductivity, generally expressed in $\mu\text{S}/\text{cm}$, of the pollutants collected by a dust deposit gauge over a given period of time when dissolved in a given quantity of demineralized water

3.1.13**dust deposit gauge index – non-soluble****DDGI-N**

mass of non-soluble residue collected by a dust deposit gauge over a given period of time, generally expressed in mg

3.1.14**site pollution severity****SPS**

maximum value of either ESDD/NSDD, SES or DDGIS/DDGIN, recorded over an appropriate period of time

3.1.15**site pollution severity class**

classification of pollution severity at a site, from very light to very heavy, as a function of the SPS.

3.2 Abbreviations

DDDG directional dust deposit gauge

DDGI-S dust deposit gauge index – soluble

DDGI-N dust deposit gauge index – non-soluble

D_m dry months (for DDDG)

ESDD equivalent salt deposit density

F_d fog days (for DDDG)

F_f form factor

NSD non soluble deposit

NSDD non soluble deposit density

PI pollution index (for DDDG)

SDD salt deposit density

SES site equivalent salinity

SPS site pollution severity

TOV temporary overvoltage

USCD unified specific creepage distance

4 Proposed approaches for the selection and dimensioning of an insulator**4.1 Introductory remark**

To select suitable insulators from catalogues based on system requirements and environmental conditions, three approaches (1, 2 and 3, in Table 1 below) are recommended. These approaches are also shown in flowchart form in Annex A.

Table 1 shows the data and decisions needed within each approach. The applicability of each approach depends on available data, time and economics involved in the project. The degree of confidence that the correct type and size of insulator has been selected varies also according to the decisions taken during the process. It is intended that if “shortcuts” have been taken in the selection process, then the resulting solution will represent over-design rather than one with a high failure risk in service.

In reality, the pollution performance of the insulator is determined by complicated and dynamic interactions between the environment and the insulator. Annex B gives a brief summary of the pollution flashover mechanism.

4.2 Approach 1

In Approach 1, such interactions are well represented on an operating line, or substation, and can also be represented in a test station.

4.3 Approach 2

In Approach 2, these interactions cannot be fully represented by laboratory tests, e.g. the tests specified in IEC 60507 and IEC/TR 61245.

4.4 Approach 3

In Approach 3, such interactions can only be represented and catered for to a limited degree by the correction factors. Approach 3 can be rapid and economical for the selection and dimensioning process but may lead to under-estimation of the SPS or to a less economical solution due to over-design. The overall costs, including imposed performance requirements, have to be considered when choosing from the three approaches. Whenever circumstances permit, Approaches 1 or 2 should be adopted.

The time-scales involved in the three approaches are as follows:

- For service experience (Approach 1), a period of satisfactory operation of five to ten years can be considered as acceptable. This period may be longer or shorter according to the frequency and severity of climatic and pollution events.
- For test station experience (Approach 1), a period of investigation of two to five years can be considered as typical. This period may be longer or shorter according to the test protocol and severity.
- For measurement of site severity (Approaches 2 and 3), a period of at least one year is necessary (see 8.2).
- For estimation of site severity (Approaches 2 and 3), it is necessary to carry out research into the climate and the environment and to identify and analyse all possible pollution sources. Hence, estimation is not necessarily an immediate process and may require several weeks or months.
- For laboratory testing (Approach 2), the necessary time is a matter of weeks or months depending on the type and scale of tests.

Table 1 – The three approaches to insulator selection and dimensioning

	APPROACH 1 (Use past experience)		APPROACH 2 (Measure and test)		APPROACH 3 (Measure and design)	
Method	Use existing field or test station experience for the same site, a nearby site or a site with similar conditions		- Measure or estimate site pollution severity - Select candidate insulators using profile and creepage guidance hereafter - Choose applicable laboratory test and test criteria - Verify/adjust candidates		- Measure or estimate site pollution severity - Use these data to choose type and size of insulation based on profile and creepage guidance hereafter	
Input data	- System requirements - Environmental conditions - Insulator parameters - Performance history		- System requirements - Environmental conditions - Insulator parameters - Time and resources available		- System requirement - Environmental conditions - Insulator parameters - Time and resources available	
Decisions	Does the existing insulation satisfy the project requirements and is it intended to use the same insulation design ?		Is there time to measure site pollution severity?		Is there time to measure site pollution severity?	
	YES Use the same insulation design	NO Use different insulation design, materials or size. Use experience to pre-select the new solution or size	YES Measure	NO Estimate	YES Measure	NO Estimate
			- Type of pollution determines the laboratory test method to be used - Site severity determines the test values			
Selection process	If necessary, use the profile and creepage guidance hereafter to adapt the parameters of the existing insulation to the new choice using Approach 2 or 3		- Select candidates - Test if pollution performance data is not available for candidates - If necessary, adjust selection/size according to the test results		- Use the type of pollution and climate to select appropriate profiles using the guidance hereafter - Use the pollution level and correction factors for profile design and material to size the insulation using the guidance hereafter	
Accuracy	A selection with a good accuracy		A selection with an accuracy varying according to the degree of errors and/or shortcuts in the site severity evaluation and with the assumptions and/or limitations of the chosen laboratory test		- A possibly over or under-dimensioned solution compared with approaches 1 or 2 - A selection with an accuracy varying according to the degree of errors and/or shortcuts in the site severity evaluation and the applicability of the selected correction factors	

The following clauses give more information on system requirements, environment and site pollution severity determination.

An example of a questionnaire that can be used in Approach 1 to obtain operational experience from an existing line or substation is given in Annex H.

Guidelines for using laboratory tests in Approach 2 are described in general terms in Annex F. Both deterministic and statistical design methods are available to design and select

appropriate insulator solutions based on SPS and laboratory test results; a short description of these two methods is given in Annex G.

For Approach 3, required minimum unified specific creepage distance and correction factors are given in the relevant parts of this publication.

5 Input parameters for the selection and dimensioning of insulators

The selection and dimensioning of outdoor insulators is an involved process; a large number of parameters have to be considered for a successful result to be obtained. For a given site or project, the required inputs are considered under three categories: system requirements, environmental conditions of the site and insulator parameters from manufacturer's catalogues. Each of these three categories contains a number of parameters as indicated in Table 2 below. These parameters are further discussed in later clauses.

Table 2 – Input parameters for insulator selection and dimensioning

System requirements	Environmental conditions	Insulator parameters
Type of system:	Pollution types and levels:	Overall length:
Maximum operating voltage across the insulation	Rain, fog, dew, <i>snow and ice</i> ^a	Type
Insulation co-ordination parameters	Wind, storms	Material
	Temperature, humidity	Profile
Imposed performance requirements	Altitude	Creepage distance
Clearances, imposed geometry, dimensions	<i>Lightning, earthquakes</i>	Diameters
	<i>Vandalism, animals</i>	Arcing distance
Live line working and maintenance practice	<i>Biological growths</i>	<i>Mechanical and electrical design</i>
^a Non pollution related parameters are given in <i>italics</i> and are not dealt with in this technical specification; however, they may influence or limit the choice of the type of insulator to be used.		

6 System requirements

System requirements shall be taken into account for the selection and dimensioning of outdoor insulation. The following points may strongly influence insulator dimensioning and therefore need to be considered.

- *Type of system (a.c. or d.c.)*

It is well known from service and from laboratory test results that, for the same pollution conditions, some d.c. insulation may require a somewhat higher value of unified specific creepage distance compared to a.c. insulation. This effect will be dealt with in detail in future parts of IEC 60815 dealing with d.c. systems.

- *Maximum operating voltage across the insulation*

Usually an a.c. system is characterized by the highest voltage for equipment U_m (see IEC 60038).

Phase-to-earth insulation is stressed with the phase-to-earth voltage $U_{ph-e} = U_m/\sqrt{3}$.

Phase-to-phase insulation is stressed with the phase-to-phase voltage $U_{ph-ph} = U_m$.

In the case of a d.c. system, usually the maximum system voltage is equal to the maximum line-to-earth voltage. In the case of mixed voltage waveforms, the r.m.s. value of the voltage may need to be used.

- *Overvoltages*

The effects of transient overvoltages need not be considered due to their short duration..

Temporary overvoltages (TOV) may occur due to a sudden load release of generators and lines or line-to-earth faults and cannot always be ignored.

NOTE The duration of the TOV depends on the structure of the system and can last for up to 30 min or even longer in the case of an isolated neutral system. Depending on the duration of the TOV and its probability of occurrence, the combined effect of TOV and insulator pollution may have to be considered. CIGRE 158 [1] gives information on this subject and on other risks such as cold switch-on.

- *Imposed performance requirements*

Longitudinal insulation used for synchronization can be stressed up to a value of 2,5 times the phase-to-earth voltage.

Some customers may require performance levels for outdoor insulation with regard to availability, maintainability and reliability. This may be specified, for example, as the maximum number of pollution flashovers allowed per station, or per 100 km line length, over a given time. Such requirements may also include a maximum outage time after a flashover.

In addition to the insulator dimensioning according to the site conditions, imposed requirements could become the controlling factor for the insulator parameters.

- *Clearances, imposed geometry and dimensions*

There could be several cases, or a combination thereof, where special solutions for insulation types and dimensions are required.

Examples include:

- compact lines and substations;
- unusual position of an insulator;
- unusual design of towers and substations;
- insulated conductors;
- lines or substations with a low visual impact.

7 Environmental conditions

7.1 Identification of types of pollution

There are two main basic types of insulator pollution that can lead to flashover:

Type A: where solid pollution with a non-soluble component is deposited onto the insulator surface. This deposit becomes conductive when wetted. This type of pollution can be best characterized by ESDD/NSDD and DDGIS/DDGIN measurements. The ESDD of a solid pollution layer may also be evaluated by surface conductivity under controlled wetting conditions.

Type B: where liquid electrolytes are deposited on the insulator with very little or no non-soluble components. This type of pollution can be best characterized by conductance or leakage current measurements.

Combinations of the two types can arise.

Annex A gives a short description of the pollution flashover mechanisms for type A and type B pollution.

7.1.1 Type A pollution

Type A pollution is most often associated with inland, desert or industrially polluted areas (see 7.2). Type A pollution can also arise in coastal areas in cases where a dry salt layer builds up and then rapidly becomes wetted by dew, mist, fog or drizzle.

Type A pollution has two main components, namely soluble pollution that forms a conductive layer when wetted, and non-soluble pollution that forms a binding layer for soluble pollution. These are described below.

- *Soluble pollution:*

Soluble pollution is subdivided into high solubility salts (e.g. salts that dissolve readily into water), and low solubility salts (e.g. salts that hardly dissolve). Soluble pollution is measured in terms of an equivalent salt deposit density (ESDD) in mg/cm².

- *Non-soluble pollution*

Examples of non-soluble pollution are dust, sand, clay, oils, etc. Non-soluble pollution is measured in terms of non-soluble deposit density (NSDD) in mg/cm².

NOTE The influence of the solubility of salts on the pollution withstand voltage is not taken into account in this technical specification and is currently under consideration. Similarly, the influence of the type of non-soluble pollution is not taken into account. Furthermore, the non-soluble component may contain conductive pollution (e.g. pollution with metallic conductive particles).

Reference [1] gives more information on the influence of types of pollutant materials.

7.1.2 Type B pollution

Type B pollution is most often associated with coastal areas where salt water or conductive fog is deposited onto the insulator surface. Other sources of type B pollutions are, for example, crop spraying, chemical mists and acid rain.

7.2 General types of environments

For the purposes of this technical specification, environments are described by the following five types. These types describe the typical pollution characteristics for a region. Examples of the type of pollution (A or B according to 7.1) are shown in the text. In practice, most polluted environments comprise more than one of these types, for example coastal regions with sandy beaches; in such cases it is important to determine which pollution type (A or B) is dominant.

- “Desert” type environments

These are areas which are characterized by sandy soils with extended periods of dry conditions. These areas can be extensive. The pollution layer in these areas normally comprises salts that dissolve slowly in combination with a high NSDD level (type A). The insulators are polluted mainly by wind borne pollution. Natural cleaning can occur under the infrequent periods of rain or by “sand blasting” during strong wind conditions. Infrequent rain, combined with the slow dissolving salts in this type of pollution, causes natural cleaning to be less effective. Critical wetting, which poses a risk for insulator flashover, can occur relatively frequently in the form of dew on the insulators.

- “Coastal” type environments

These areas are typically in the direct vicinity of the coast, but in some cases, depending on topography, they can be as far as 50 km inland. Pollution is deposited onto the insulators mainly by spray, wind and fog. The pollution build-up is generally rapid, especially during spray or conductive fog conditions (type B). A build-up of pollution over a longer term can also occur through a deposit of wind-borne particles, where the pollution layer on the insulators consists of quick dissolving salts with a degree of inert component (type A) which depends on the local ground characteristics. Natural cleaning of the insulators is typically effective as the active pollution consists mainly of fast dissolving salts

- “Industrial” type environments

These are areas located in close proximity to an industrial pollution source, and may affect only a few installations. The pollution layer may constitute conductive particulate pollution, such as coal, metallic deposits; or dissolved gasses, such as NO_x, SO_x (type B); or pollution that dissolves slowly, such as cement, gypsum (type A). The pollution layer may have a medium to high inert component (medium to high NSDD) (type A). The effectiveness of

natural cleaning in industrial areas can vary greatly depending on the type of pollution present. The pollution is often heavy particles which settle on horizontal surfaces.

- “Agricultural” type environments

These are areas which are situated in the vicinity of agricultural activity. Typically this will be areas subjected to ploughing (type A) or crop spraying (type B). The pollution layer on the insulators consist mostly of fast or slow dissolving salts such as chemicals, bird droppings or salts present in the soil. The pollution layer will normally have a medium to high inert component (medium to high NSDD). Natural cleaning of the insulators can be quite effective depending on the type of salt deposited. The pollution is often heavy particles which settle on horizontal surfaces, but it may also be wind borne pollution.

- “Inland” type environments

These are areas with a low level of pollution without any clearly identifiable sources of pollution.

7.3 Pollution severity

Pollution severity measurements at a site (e.g. by gauges, dummy insulators, current monitors etc) are generally expressed in terms of

- ESDD and NSDD for type A pollution,
- site equivalent salinity (SES) for type B pollution,
- DDGIS and DDGIN for both types.

Pollution severity measurements on naturally polluted insulators are generally expressed in terms of

- ESDD and NSDD for type A pollution,
- surface conductivity for type B pollution.

NOTE In some cases, ESDD measurements can be used for type B pollution.,

Pollution severity in artificial pollution tests on insulators is generally specified in terms of

- SDD and NSDD for solid layer methods,
- Fog salinity (kg/m^3) for salt-fog methods.

8 Evaluation of site pollution severity (SPS)

8.1 Site pollution severity

The site pollution severity (SPS) is the maximum value(s) of either ESDD and NSDD (in the case of cap and pin insulators, average ESDD/NSDD for top and bottom surfaces), or SES, or DDGIS and DDGIN, measured according to the methods given in this technical specification and recorded over an appreciable period of time, i.e. one or more years, and with a certain measurement interval. The measurement interval (continuous, every month, three months, six months, every year, etc. – see Annexes C and D) may be chosen according to knowledge of local climate and environmental conditions.

If rain occurs during this measuring period, the measurements should be repeated at appropriate intervals to determine the effect of natural washing; SPS is then the largest value recorded during this series of measurements.

NOTE 1 Even if the highest values of ESDD and NSDD (or DDGIS and DDGIN) do not occur at the same time, then SPS is, nonetheless, taken as the combination of these highest values.

NOTE 2 When there is no natural washing during the measuring period, the maximum value of ESDD and NSDD can be estimated from the plot of deposit density as a function of the logarithm of time, taking a time value in relation with the expected rainfall frequency.

NOTE 3 When sufficient data are available, the maxima may be replaced by statistical values (e.g. 1 %, 2 %, 5 %).

8.2 Site pollution severity evaluation methods

The evaluation of the pollution severity can be made with a decreasing degree of confidence:

- 1) from measurements in situ;
- 2) from information on the behaviour of insulators from lines and substations already in service on or close to the site (see Annex H);
- 3) from simulations that calculate the pollution level from weather and other environmental parameters (see CIGRE 158 [1]);
- 4) If not otherwise possible, qualitatively from indications given in Table 5.

For measurements in situ, different measurement methods are generally used. They are

- either
 - ESDD and NSDD on the insulator surface of reference insulators (see Annex C) for type A pollution sites,
 - or
 - SES from on-site leakage current or conductance measurements on reference insulators or a monitor (see Annex D) for type B pollution sites,
 - or
 - DDGIS, DDGIN of the pollutant collected by means of a DDDG (see Annex E) for type A or B pollution sites,
- total number of flashovers of insulators of various lengths;
- leakage current or conductance of sample insulators.

NOTE 1 Reference [6] gives examples of site pollution severity monitoring solutions.

The first three measurement methods above (ESDD, SES or DDGIS) do not require expensive equipment and can be easily performed. The ESDD/NSDD and SES methods characterize the pollution severity of the site with respect to a reference insulator. The DDDG method gives the measure of the amount of the ambient pollution. In all cases, information on rainfall and wetting should be separately obtained using appropriate meteorological equipment.

The accuracy of all these methods depends upon the frequency of measurement and the duration of the study. Accuracy may be improved by using two or more methods in combination.

The method based on total flashovers needs expensive test facilities. Reliable information can be obtained from test insulators having a length close to the projected length and flashing over at a voltage near the actual operating voltage.

The last two methods, which need a power source and special recording equipment, have the advantage that the effects of pollution are continuously monitored. They have been developed to assess the rate of pollution build-up. When related to test data, they can be used to indicate that the pollution is still at a safe level or to signal that washing or another palliative is required. These two methods allow direct determination of the minimum USCD necessary for the tested insulators at the site.

When measurements are carried out on reference insulators it can be very useful to include insulators with other profiles and orientations in order to study the deposit and self-cleaning

mechanisms for the site. This information can then be used to refine the choice of an appropriate profile.

Pollution events are often seasonal and related to the climate; therefore a measurement period of at least one year is necessary to take into account any seasonal effects. Longer periods may be necessary to take exceptional pollution events into account or to identify trends. Equally it may be necessary to measure over at least three years for arid areas (see 9.5.2).

NOTE 2 Future industrial development, transport networks, etc. should be taken into account. It is advisable to continue monitoring pollution severity after installation.

8.3 Site pollution severity (SPS) classes

For the purposes of standardization, five classes of pollution characterizing site severity are qualitatively defined, from very light pollution to very heavy pollution as follows:

- a – Very light;
- b – Light;
- c – Medium;
- d – Heavy;
- e – Very heavy.

NOTE 1 These letter classes do not correspond directly to the previous number classes of IEC/TR 60815:1986.

NOTE 2 In nature, the change from one class to another is gradual; hence if measurements are available, the actual SPS value, rather than the class, can be taken into account when determining insulator dimensions.

For type A pollution, Figures 1 and 2 show the ranges of ESDD/NSDD values corresponding to each SPS class for the reference cap and pin, and long rod insulators, respectively. These values are deduced from field measurements, experience and pollution tests. The values are the maximum values that can be found from regular measurements taken over a minimum one year period. These figures are only applicable to the reference insulators and take into account their specific pollution accumulation properties.

If sufficient local or national information is available (e.g. regional pollution maps associated with line performance data, monitoring based on surface conductivity, ESDD, DDGIS, etc.), specific classes adapted to this information may be overlaid on Figures 1 and 2.

For extreme site pollution severities in the shaded areas to the top right-hand side of Figures 1 and 2, and to the right-hand side of Figure 3, simple rules can no longer be used to ensure satisfactory pollution performance. Furthermore, for very high values of NSDD relative to ESDD (shaded area to the top left-hand side of Figures 1 and 2), there is very limited data available. These areas require a careful study and a combination of insulating solutions and palliative measures are necessary (see 9.5.5).

NOTE 3 Separate figures are given for the two types of reference insulator, since in the same environment they do not accumulate the same quantity of pollution. Generally, the long rod reference insulator accumulates less pollution than the cap and pin reference. However, it is to be noted that in some conditions of rapid pollution deposit (e.g. coastal storms, typhoons), the accumulation ratio between the two types may be temporarily reversed.

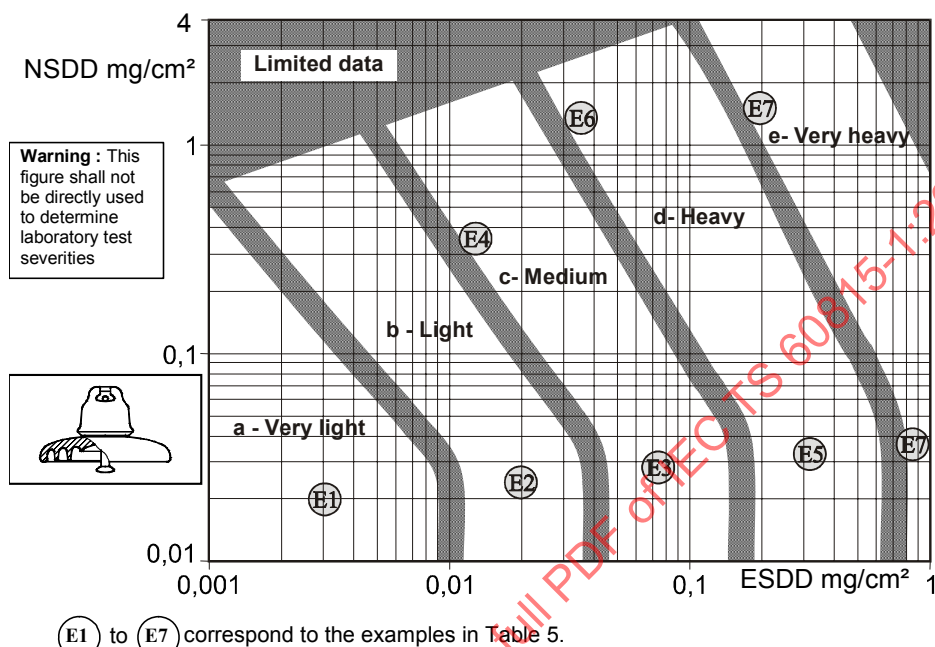
For type B pollution, Figure 3 shows the correspondence between SES measurements and SPS class for both types of reference insulator.

The correspondence between DDDG measurements and SPS class relevant to both type A and type B pollution is shown in Tables 3 and 4.

The values in Figures 1 to 3 are based on natural pollution deposited on reference insulators.

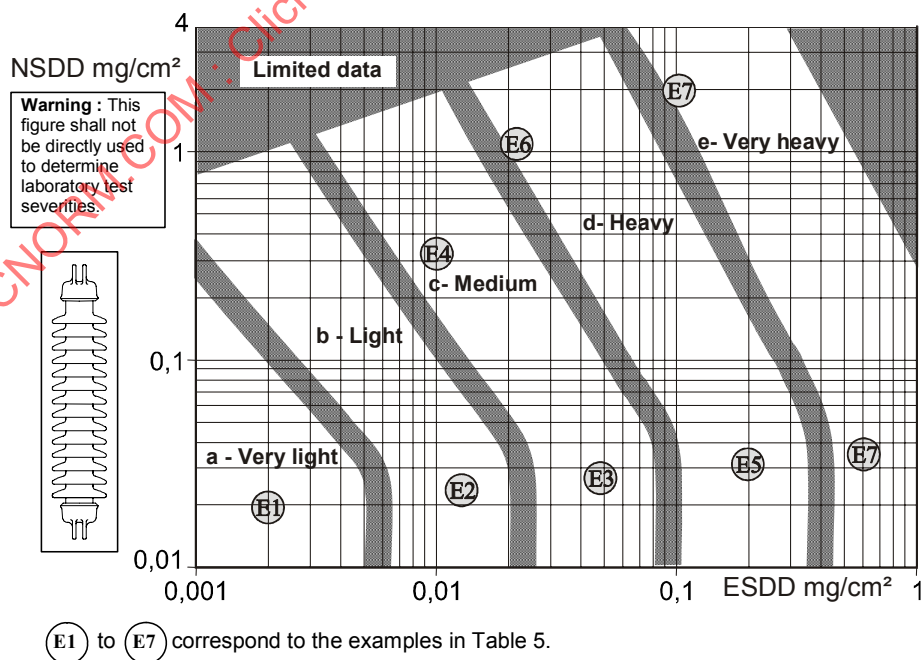
These figures shall not be directly used to determine laboratory test severities. Corrections are necessary for the difference between natural and test conditions as well as for the difference between types of insulators (see Annex F and [1]).

The transition from one SPS class to another is not abrupt; hence the boundary between each class in Figures 1 to 3 is shaded (see Note 2 above).



IEC 1954/08

Figure 1 – Type A site pollution severity – Relation between ESDD/NSDD and SPS for the reference cap and pin insulator



IEC 1955/08

Figure 2 – Type A site pollution severity – Relation between ESDD/NSDD and SPS for the reference long rod insulator

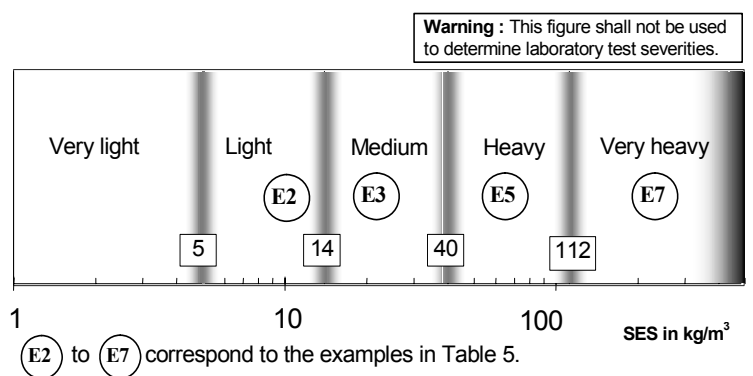


Figure 3 – Type B site pollution severity – Relation between SES and SPS for reference insulators or a monitor

Table 3 – Directional dust deposit gauge pollution index in relation to SPS class

Directional dust deposit gauge pollution index, PI (μS/cm) (take whichever is the highest) ^a		Site pollution severity class	
Average monthly value over one year	Monthly maximum over one year		
< 25	< 50	a	Very light
25 to 75	50 to 175	b	Light
76 to 200	176 to 500	c	Medium
201 to 350	501 to 850	d	Heavy
> 350	> 850	e	Very heavy

^a If weather data for the site in question is available, then the directional dust deposit gauge pollution index can be adjusted to take into account climatic influences – see Annex E.

Table 4 – Correction of site pollution severity class as a function of DDDG NSD levels

Directional dust deposit gauge NSD (grams) (take whichever is the highest)		Site pollution severity class correction
Average monthly value over one year	Monthly maximum over one year	
< 0,5	< 1,5	None
0,5 to 1,0	1,5 to 2,5	Increase by one class
> 1,0	> 2,5	Increase by one or two classes and consider mitigation (see 9.5.5)

Table 5 gives, for each level of pollution, an example and approximate description of some typical corresponding environments. The list of environments is not exhaustive and the descriptions should preferably not be used alone to determine the severity level of a site. The examples E1 to E7 in Table 5 are reproduced in Figures 1, 2 and 3 to show typical SPS levels. Some insulator characteristics, for example profile, have an important influence on the pollution quantity deposited on insulators themselves; therefore, these typical values are only available for the reference cap and pin and long rod insulators.

Table 5 – Examples of typical environments

Example	Description of typical environments
E1	> 50 km^a from any sea, desert, or open dry land > 10 km from man-made pollution sources^b Within a shorter distance than mentioned above of pollution sources, but: • prevailing wind not directly from these pollution sources • and/or with regular monthly rain washing
E2	10-50 km^a from the sea, a desert, or open dry land 5-10 km from man-made pollution sources^b Within a shorter distance than E1 from pollution sources, but: • prevailing wind not directly from these pollution sources • and/or with regular monthly rain washing
E3	3-10 km^c from the sea, a desert, or open dry land 1-5 km from man-made pollution sources^b Within a shorter distance than mentioned above of pollution sources, but: • prevailing wind not directly from these pollution sources • and/or with regular monthly rain washing
E4	Further away from pollution sources than mentioned in E3, but: • dense fog (or drizzle) often occurs after a long (several weeks or months) dry pollution accumulation season • and/or heavy, high conductivity rain occurs • and/or there is a high NSDD level, between 5 and 10 times the ESDD
E5	Within 3 km^c of the sea, a desert, or open dry land Within 1 km of man-made pollution sources^b
E6	With a greater distance from pollution sources than mentioned in E5, but: • dense fog (or drizzle) often occurs after a long (several weeks or months) dry pollution accumulation season • and/or there is a high NSDD level, between 5 and 10 times the ESDD
E7	Within the same distance of pollution sources as specified for “heavy” areas and: • directly subjected to sea spray or dense saline fog • or directly subjected to contaminants with high conductivity, or cement type dust with high density, and with frequent wetting by fog or drizzle • desert areas with fast accumulation of sand and salt, and regular condensation
^a During a storm, the ESDD level at such a distance from the sea may reach a much higher level. ^b The presence of a major city will have an influence over a longer distance, i.e. the distance specified for sea, desert and dry land. ^c Depending on the topography of the coastal area and the wind intensity.	

9 Insulation selection and dimensioning

9.1 General description of the process

The overall process of insulation selection and dimensioning can be summarized as follows:

- determination of the appropriate Approach 1, 2 or 3 as a function of available knowledge, time and resources;
- collection of the necessary input data, notably whether a.c. or d.c. energisation, system voltage, insulation application type (line, post, bushing, etc.);
- collection of the necessary environmental data, notably site pollution severity and class.

At this stage a preliminary choice of possible candidate insulators suitable for the applications and environment may be made (see 9.2 to 9.4).

- determination of the reference unified specific creepage distance for the insulator types and materials, either using the indications in the relevant parts 2 and onwards of IEC 60815 or from service or test station experience in the case of Approach 1;
- modification, where necessary, of the reference USCD by factors depending on the size, profile, orientation, etc. of the candidate insulators;
- verification that the resulting candidate insulators satisfy the other system and line requirements in Table 2 (e.g. imposed geometry, dimensions, economics), change solution or requirements if no satisfactory candidate is available;
- verification of the dimensioning, in the case of Approach 2, by laboratory tests (see Annex E).

NOTE The specific guidelines for each of the types of insulator mentioned above are given in the relevant parts 2 and onwards of IEC 60815.

9.2 General guidance on materials

The choice of material may be dictated entirely by environmental or system constraints. On the other hand, the selection of insulator material may be dictated solely by user policy and economics. The traditional materials used for outdoor insulation are glazed porcelain and glass. The use of polymers, either for a complete insulator or as a housing in combination with a glass fibre core, is an alternative to glass and porcelain. The various profiles and material technologies associated with polymer insulators mean that pollution behaviour does not necessarily follow the same parameters as for traditional insulation.

IEC/TS 60815-2 deals with choice and dimensioning of insulators made with traditional materials. IEC/TS 60815-3 deals with polymer insulators. See also references [2], [3] for more details of CIGRE work on this subject and references [7], [8] for information on polymeric materials and wettability.

NOTE Further equivalent parts of IEC/TS 60815 are envisaged to deal with d.c. systems.

9.3 General guidance on profiles

Different types of insulator and even different orientations of the same insulator type may accumulate pollution at different rates in the same environment. In addition, variations in the nature of the pollutant may make some shapes of insulator more effective than others. Condensed guidance on the selection of profile is provided in the following. It shall be borne in mind that the minimum or maximum overall length of the insulation is an important imposed parameter, e.g. for insulation coordination or tower height. Table 6 summarizes the main characteristics of each type of profile.

More advice on profiles is given in the relevant parts of IEC 60815.

Table 6 – Typical profiles and their main characteristics

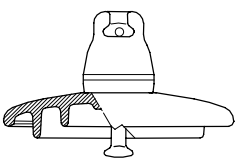
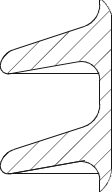
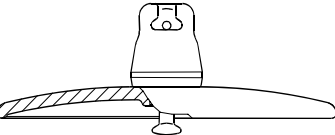
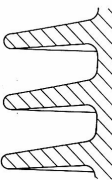
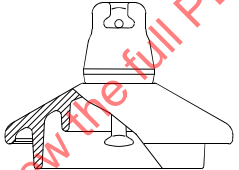
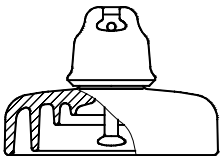
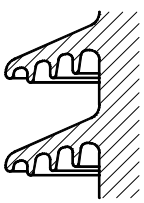
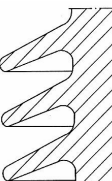
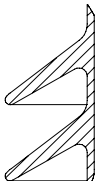
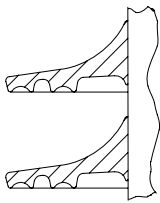
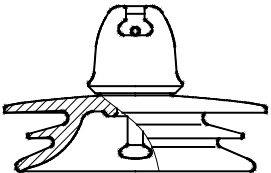
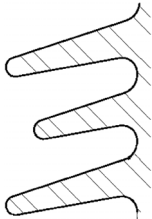
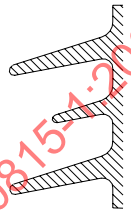
Standard profiles Standard profiles are effective for use in “very light” to “medium” polluted areas where a long creepage distance or an aerodynamically effective profile is not required	 Cap and pin standard disc insulators	 Porcelain standard profile, long rod insulators, post insulators, hollow insulators
Aerodynamic or open profiles Aerodynamic or open profiles prove to be beneficial in areas where the pollution is deposited onto the insulator by wind, such as deserts, heavily polluted industrial areas or coastal areas which are not directly exposed to salt spray. This type of profile is especially effective in areas that are characterized by extended dry periods. Open profiles have good self-cleaning properties and are also more easily cleaned under maintenance	 Aerodynamic disc insulators  Porcelain long rod insulators, post insulators, hollow insulators	 Polymeric long rod insulators, post insulators, hollow insulators
Anti fog profiles The use of anti fog profiles with steep sheds or deep under-ribs are beneficial in areas exposed to a salt water fog or spray, or to other pollutants in the dissolved state. These profiles may also be effective in areas with a particulate pollution precipitation containing slow dissolving salts They can also be effective in areas with low NSDD and slow dissolving salts	 Steep anti-fog disc insulators  Deep under-ribs disc insulators  Deep under-ribs on porcelain long rod insulators, post insulators, hollow insulators	 Steep porcelain long rod insulators, hollow insulators, post insulators  Steep polymeric long rod insulators, hollow insulators, post insulators  Under-ribs on polymeric long rod insulators, hollow insulators, post insulators

Table 6 (continued)

Alternating shed profiles	 Alternating shed disc insulators	 Porcelain long-rod insulators, post insulators, hollow insulators  Polymeric long rod insulators, post insulators, hollow insulators
Alternating shed arrangements are in general feasible for all profiles, although steep sheds are less beneficial. They offer increased creepage distance per unit length without penalising performance in heavy rain or icing. Similar benefits to open profiles are also provided by simple alternating profiles		

9.4 Considerations on creepage distance and insulator length

The choice and performance of insulators for polluted environments is very often expressed solely in terms of the creepage distance necessary to withstand the polluted conditions under the system voltage. This may lead to the comparison of insulators in terms of necessary creepage distance per unit voltage. However the use of creepage distance alone to establish orders of merit does not take into account other factors which depend on the creepage distance available per unit length of the insulator. For example, a string of standard cap and pin insulators with 146 mm spacing may have similar pollution performance as an equivalent string, of the same length, of high creepage distance insulators with 170 mm spacing due to the increased number of insulators in the string. This point is worth being borne in mind when choosing insulators, notably for applications where insulator length is a minor constraint.

Conversely, if insulator length or height is a major constraint, increasing the creepage distance in the available space may not give the full improvement in performance expected, due to reduced profile efficiency. Additionally, for polymer materials, such an increase of creepage or reduction of shed spacing may result in aggravated ageing effects.

9.5 Considerations for exceptional or specific applications or environments

9.5.1 Hollow insulators

Polymeric and porcelain hollow insulators are used for apparatus insulators, bushings and also as station posts. They are used, for example, as housings for capacitors, surge arresters, circuit breaker chambers and supports, cable terminations, wall bushings, transformer bushings, instrument transformers and other measuring devices.

The pollution performance of complete hollow insulators is not only a function of profile, leakage distance and diameter, but also function of uniformity of voltage distribution. Two major parameters that affect voltage distribution are internal and external components and uneven wetting (see 9.5.1.1 and 9.5.1.2). Care should be taken to design accordingly, especially at lower pollution levels where the effect of non-uniformity is more critical and can reduce flashover performance and also increase the risk of puncture.

9.5.1.1 Internal and external components

The presence of a conductor, shielding or grading devices within or outside the insulator housing can greatly affect the electrical performance of the assembly. In addition to the known behaviour difference found between empty housings and assembled apparatus with the same housing during impulse, dry or wet flashover tests, there are similar electrical behaviour differences when subjecting empty housings and assembled housings to pollution tests.

The effect of non-uniformity of voltage distribution is more evident at lower pollution levels (ESDD 0,01 to 0,03 mg/cm²) because the weaker resistive leakage currents cannot compensate for, correct or rectify sufficiently the non-uniformity of voltage distribution.

For higher pollution levels, the resistive surface currents become dominant and therefore reduce the effect of non-uniformity of voltage distribution. This effect is observed during laboratory tests, where similar results are obtained on both empty hollow insulators and on ones with internal equipment.

The best performance (high flashover voltage and low risk of puncture) is generally obtained on an insulation system with a uniform axial and radial voltage distribution, such as devices with capacitive grading. An insulator design that first helps to even out the total voltage distribution and then takes into account the inner associated components is therefore advantageous.

9.5.1.2 Non-uniform wetting and uneven pollution deposit

Protection by buildings or other equipment from rain can cause uneven wetting of bushings and housings. In some positions, the operating temperature of bushings can induce uneven wetting of the insulator by simple drying. Furthermore, uneven pollution deposits can occur in natural conditions. Therefore, even at higher pollution levels, the cancellation of the non-uniform voltage distribution effect might not be as effective on apparatus such as horizontally mounted wall bushings.

9.5.2 Arid areas

Arid areas pose particular difficulties when selecting and dimensioning insulators. The long dry spells may lead to extreme ESDD and NSDD levels even in areas that are not in the direct vicinity of the coast. This is because the surrounding sand may have a high salt content.

The use of aerodynamic "self-cleaning" profiles can help reduce the impact of the pollution deposition in such cases, as can the use of polymeric insulators. Equally, a semi-conducting glaze on porcelain insulators provides a continuous flow of current of about 1 mA, which helps to avoid dew formation.

9.5.3 Proximity effects

Any insulators that are in close axial proximity, e.g. live-tank circuit-breaker interrupters and grading capacitors, some disconnectors and multiple-string line insulators, can have an adverse effect on pollution performance. This is caused by voltage gradients arising from different field distributions during pollution induced discharge activity.

9.5.4 Orientation

The effect of the orientation of insulation on its flashover performance is not generally subject to simple rules. The insulator type and the size directly affect the performance of the polluted insulation in different orientations. In addition, the pollution severity at a site and the time taken for maximum pollution levels to build up may determine the effect of orientation. The nature of the wetting process and the flashover mechanism (e.g. surface flashover or inter-shed breakdown) are also important factors affecting the influence of orientation and size.

Hence, the flashover strength of different insulator types and orientation is a balance between the various processes that directly influence such performance.

The information in this technical specification principally concerns vertical insulation. More information on the effect of orientation can be found in [1].

9.5.5 Maintenance and palliative methods

In exceptional cases, pollution problems cannot be solved economically by a good choice of insulator. For instance, in areas having very severe pollution or low annual rainfall, insulator maintenance may be required. This can also occur when the environment of an already built substation (or line) changes due to new pollution sources.

Maintenance and palliative methods may take one or more of the following forms:

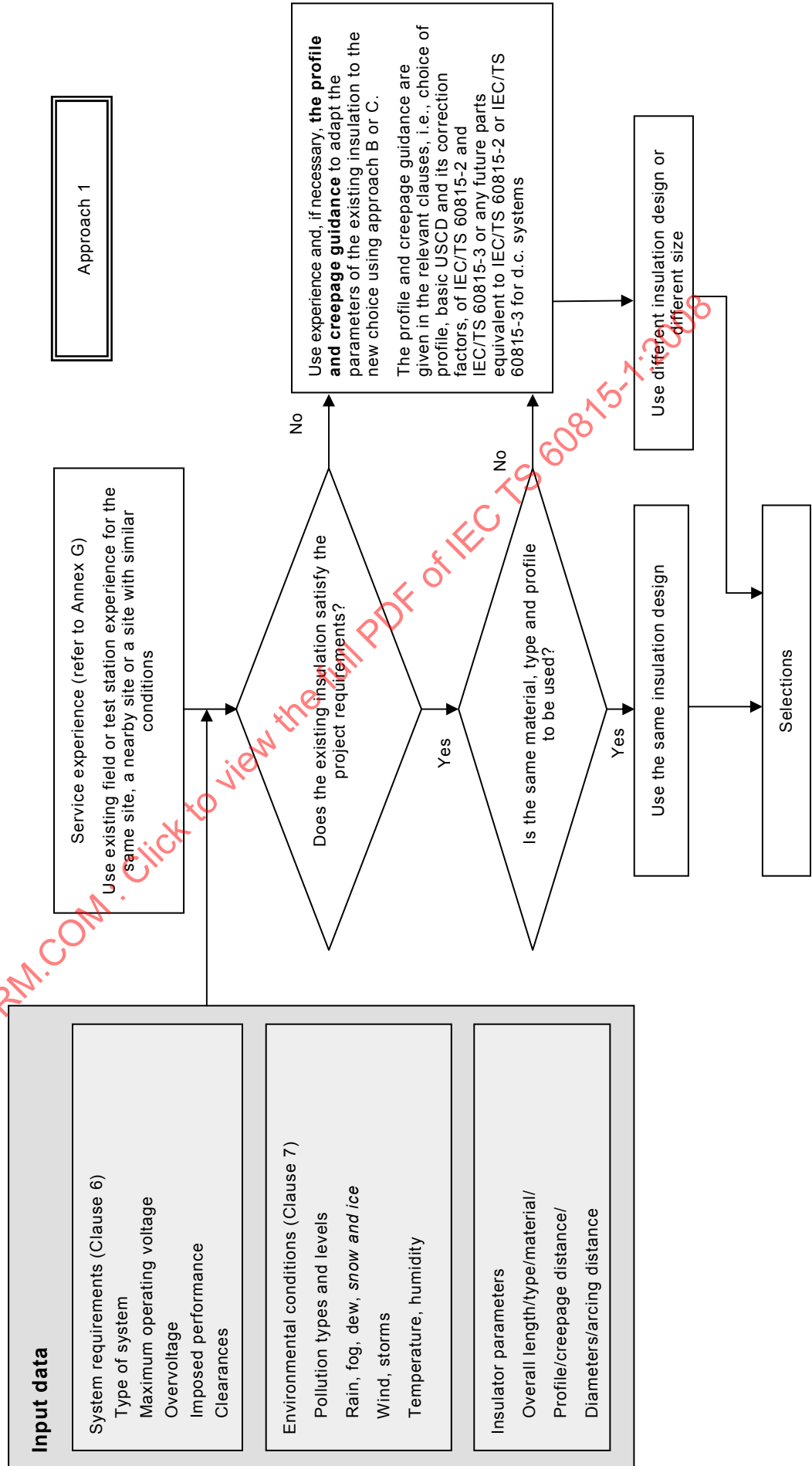
- *Cleaning or washing.* These methods may be applied manually or automatically. Some automatic washing methods may be used on energized insulators. These methods can reduce the pollution accumulated on the insulator.
- *Application of hydrophobic coatings,* e.g. silicone rubber or grease. The hydrophobic property of these coatings improves the pollution performance of the insulator.
- *Installation of additive components,* e.g. booster sheds or creepage extenders. Booster sheds improve the performance of the insulator mainly through barrier effects and the reduction of shed bridging by water drops. Creepage extenders increase the creepage distance of the insulator.

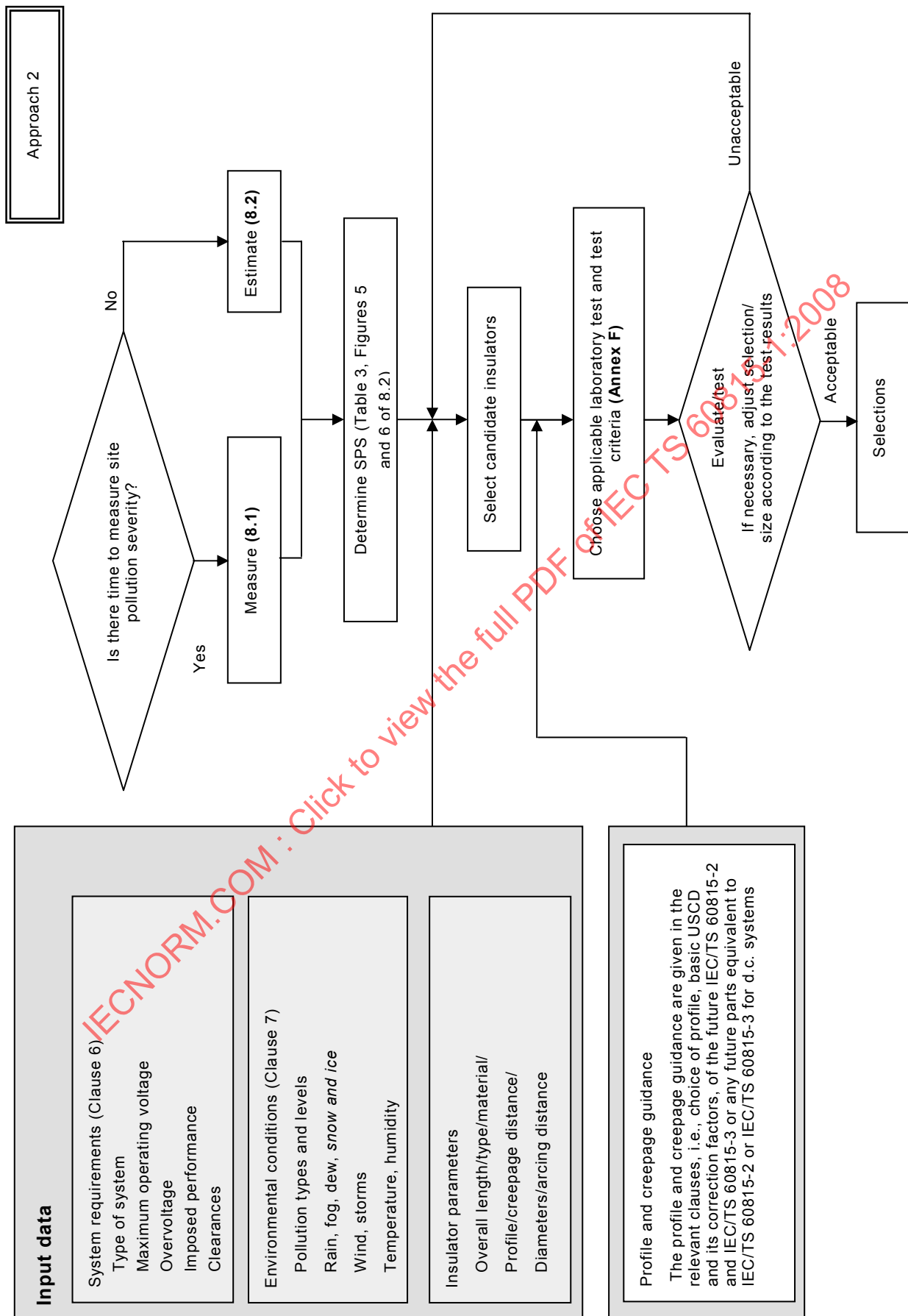
These methods have been widely used with good experience. The choice of the maintenance and palliative methods depends on the site conditions, type of insulators, practicality and economical requirements. More information can be found in [1] and [2].

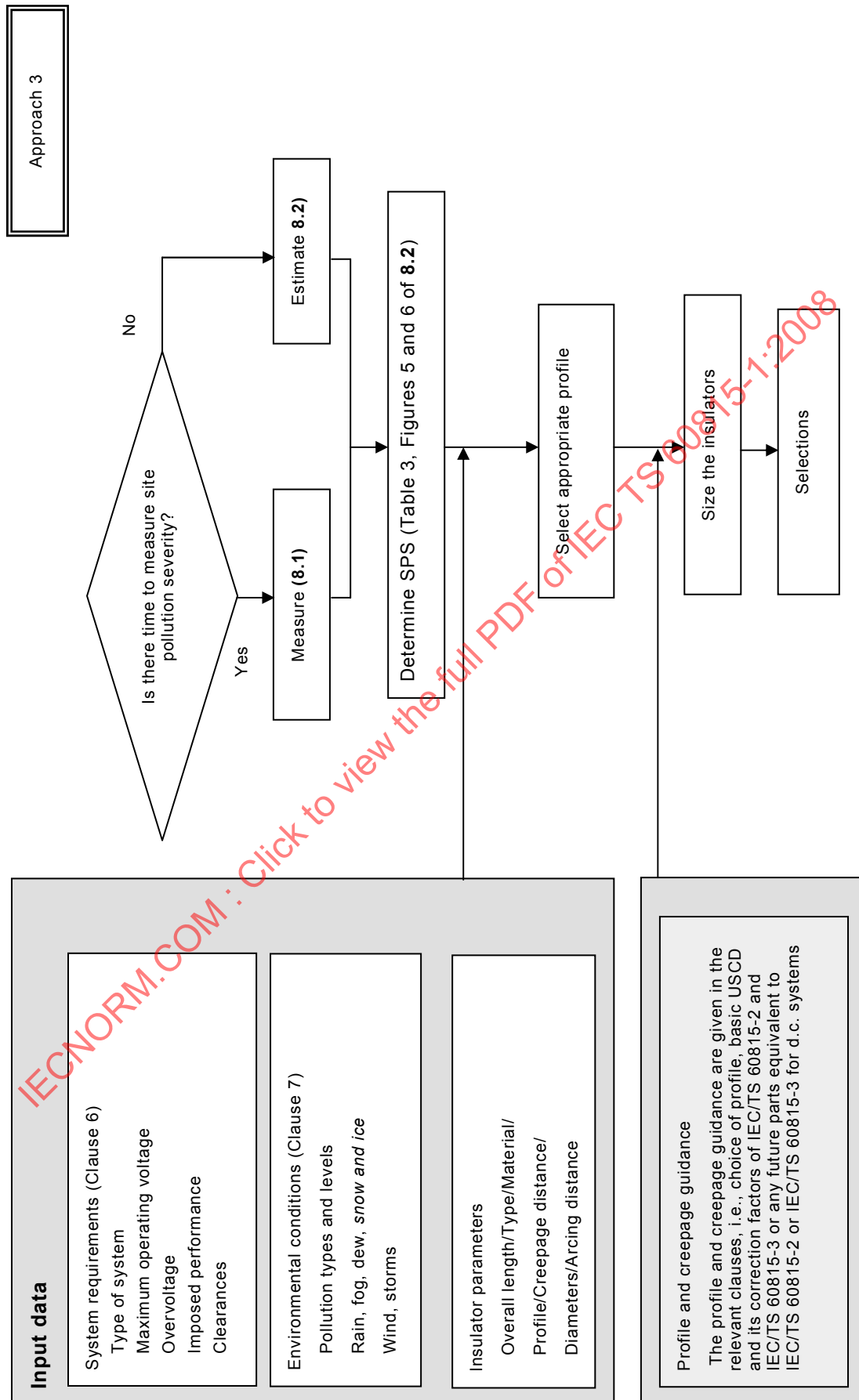
Annex A (informative)

Flowchart representation of the design approaches

The following flowcharts show the Approaches 1, 2 and 3 from 5 in graphical form.







Annex B (informative)

Pollution flashover mechanisms

B.1 Description of the pollution flashover mechanism under type A pollution

For ease of understanding the pre-deposit pollution (type A) flashover process, it is divided into six phases described separately below. In nature, these phases are not distinct but may tend to merge.

The pollution flashover process of insulators is greatly affected by the insulator's surface properties. Two surface conditions are recognized: either hydrophilic or hydrophobic. A hydrophilic surface is generally associated with glass and ceramic insulators whereas a hydrophobic surface is generally associated with polymeric insulators, especially silicone rubber. Under wetting conditions, such as rain, mist, etc., hydrophilic surfaces will wet out completely so that an electrolyte film covers the insulator. In contrast, water beads into distinct droplets on a hydrophobic surface under such wetting conditions.

The pollution flashover process is also significantly affected by the voltage waveform, a.c. or d.c. Under a.c. arc-propagation across the insulator surface can take several cycles and, therefore, the arc is subject to an extinction and re-ignition process at around current zero.

A complicating feature is the breakdown of the air between neighbouring points of the insulator profile (e.g. between ribs or sheds) which reduces the flashover performance by shorting out some of the insulator surface. In addition, drops or streams of water may facilitate this reduction in performance.

The process is described below as encountered on hydrophilic surfaces, such as ceramic materials.

Phase 1: The insulator becomes coated with a layer of pollution. If the pollution is non-conductive (high resistance) when dry, some wetting process (phase 2) is necessary before flashover will occur.

Phase 2: The surface of the polluted insulator becomes wetted. The wetting of an insulator can occur in the following ways: by moisture absorption, condensation and precipitation. Heavy rain (precipitation) may wash away the electrolytic components of part or the entire pollution layer without initiating other phases in the breakdown process, or it may promote flashover by bridging the gaps between sheds. Moisture absorption occurs during periods of high relative humidity (>75 % RH) when the temperature of the insulator and ambient air are the same. Condensation occurs when the moisture in the air condenses on a surface whose temperature is lower than the dew point. This condition usually occurs at sunrise or just before.

Phase 3: Once an energized insulator is covered with a conducting pollution layer, surface leakage currents flow and their heating effect starts within a few power-frequency cycles to dry out parts of the pollution layer. This occurs where the current density is highest, i.e. where the insulator is at its narrowest. These result in the formation of what are known as dry bands.

Phase 4: The pollution layer never dries uniformly, and in places the conducting path becomes broken by dry bands which interrupt the flow of leakage current.

Phase 5: The line-to-earth voltage appearing across multiple dry bands (which may be only a few millimetres wide) causes air breakdown and the dry bands are bridged by arcs which are electrically in series with the resistance of the still wet and conductive portion of the pollution layer. This causes a surge of leakage current each time the dry bands on an insulator spark over.

Phase 6: If the resistance of the still wet and conductive part of the pollution layer is low enough, the arcs bridging the dry bands are sustained and may finally continue to extend along the insulator, bridging more and more of its surface. This in turn decreases the resistance in series with the arcs, increasing the current and permitting them to bridge even more of the insulator surface. Ultimately, it is completely bridged and a line-to-earth fault (flashover) is established.

One can summarize the whole process as an interaction between the insulator, pollutants, wetting conditions, and applied voltage (and source impedance in laboratory conditions).

The likelihood of flashover increases with higher leakage current, and it is mainly the surface layer resistance that determines the current magnitude. It can therefore be concluded that the surface layer resistance is the underlying factor determining whether an insulator will flash over or not, in terms of the above model. Surface layer resistance may be calculated – assuming uniform pollution distribution and wetting – using the form factor (see Annex H).

Pollution flashover can be a problem in very dry areas such as deserts. The explanation often lies with the “thermal lag” at sunrise between the temperature of the surface of the insulator and the rapidly rising temperature of the ambient air. This difference in temperature need only be a few degrees centigrade for substantial condensation to take place, even at fairly low values of relative humidity. The thermal capacity and thermal conductivity of the insulating material control the rate at which its surface warms up.

More information on pollution flashover processes and models is available in CIGRE 158 [1].

B.2 Description of the pollution flashover mechanism under type B pollution

B.2.1 Conductive fog

Type B “instantaneous pollution” refers to a contamination of high conductivity which quickly deposits on insulator surfaces, resulting in the condition where the insulator changes from an acceptably clean, low conductive state to flashover in a short (<1 h) time and then returns to a low conductive state when the event has passed.

For ease of understanding the instantaneous pollution flashover, the same process as described in Clause B.1 applies. However, the instantaneous pollution is normally deposited as a highly conductive layer of liquid electrolyte, e.g. salt spray, salt fog or industrial acid fog, thus the process begins at phase 3 above and can progress rapidly to phase 6. In nature, these phases are not distinct but they do merge. These only refer to hydrophilic surfaces. Areas most at risk are those situated close chemical plants, or areas close to the coast with a known history of temperature inversions.

B.2.2 Bird streamers

A particular case of type B pollution is a bird streamer. This is a type of bird excrement, which, on release, forms a continuous, highly (20-40 kΩ/m) conductive stream of such length that the air gap is sufficiently reduced to cause flashover. In this case, the insulator geometry and characteristics play little or no role and the best solution may be to fit dissuasive devices or alternate perches, appropriate to the local fauna and structure design.

B.3 The pollution flashover mechanism on hydrophobic surfaces

Due to the dynamic nature of a hydrophobic surface and the resulting complex interaction with pollutants – both conducting and non-conducting – and wetting agents, there exists today no generally adopted model of pollution flashover for hydrophobic insulator surfaces. However, a qualitative picture for the pollution flashover mechanism is emerging which involves such elements as the migration of salt into water drops, water drop instability, formation of surface liquid filaments and discharge development between filaments or drops when the electric field is sufficiently high.

However, in service the hydrophobic materials are submitted to a dynamic process of pollution deposition, wetting, localized discharges or high electric field which can combine to cause parts or the entire surface to become temporarily more hydrophilic. Thus much of the physics of the flashover process of hydrophilic surfaces also applies, albeit locally or for limited periods of time, to nominally "hydrophobic" materials or surfaces.

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Annex C (normative)

Measurement of ESDD and NSDD

C.1 Introductory remark

The site pollution severity can be determined by measuring both equivalent salt deposit density (ESDD) and non-soluble material deposit density (NSDD) on reference insulators which come from existing installations and/or are installed in field testing stations. In addition, if possible, the measurement of ESDD and NSDD on the exact insulator to be selected will provide direct information to determine the required creepage distance of the insulator. Also chemical analysis of the pollutants is sometimes useful. This annex describes how to measure ESDD and NSDD, and how to make chemical analysis of the pollutants.

For site pollution severity measurement purposes, the measurements are standardized by using a string of 7 reference cap and pin insulators (preferably 9 discs to avoid end effect) or a reference long rod insulator with at least 14 sheds. The unenergized insulator string shall be located at a height as close as possible to that of the line or bus bar insulators. Each disc or shed area of the insulator string is shall be monitored at defined appropriate intervals e.g. every month (disc 2 / area 1), every three months (disc 3,4,5 / area 2,3,4), every six months (disc 5 / area 6), every year (disc 7 / area 6), after two years (disc 8 / area 7), etc. before anticipating rainfall, dew and so on.

NOTE For d.c. applications, it may be useful to measure top and bottom surface ESDD and NSDD separately.

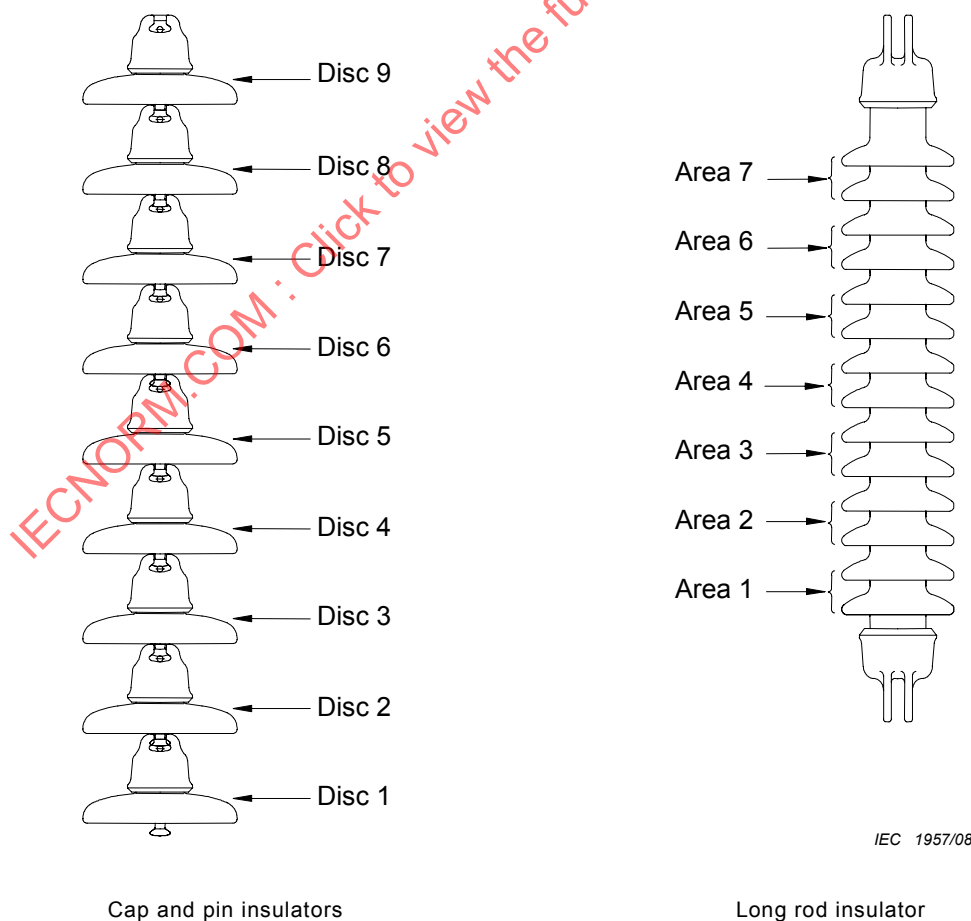


Figure C.1 – Insulator strings for measuring ESDD and NSDD

C.2 Necessary equipment to measure pollution degree

The following equipment is necessary for the measurement of both ESDD and NSDD.

- Distilled water/demineralized water
- Measuring cylinder
- Surgical gloves
- Plastic cling wrap
- Labelled container
- Washing bowl
- Absorbent cotton/brush/sponge
- Conductivity meter
- Temperature probe
- Filter paper
- Funnel
- Desiccator/drying oven
- Balance scale

C.3 Pollution collection methods for ESDD and NSDD measurement

C.3.1 General remark

The surfaces of the insulator should not be touched to avoid any loss of pollution.

Wear clean surgical gloves.

A container, a measuring cylinder, etc. shall be washed well enough to remove any electrolytes prior to the measurement.

C.3.2 Procedure using a swab technique

- Distilled water of 100–300 cm³ (or more if required) shall be put into containers and absorbent cotton shall be immersed into the water (other tools such as a brush or a sponge may be used). The conductivity of the water with the immersed cotton shall be less than 0,001 S/m.
- The pollutants shall be wiped off from the area of the insulator surface, excluding any metal parts or assembly materials, with the squeezed cotton. In the case of cap and pin type insulator, the top and bottom surfaces may be measured separately, if necessary, in order to obtain useful information for evaluation as shown in Figure C.2. In the case of a long-rod or a post insulator, pollutants shall usually be collected from a part of the shed.
- The cotton with pollutants shall be put back into the containers. The pollutants are then dissolved into the water by shaking and squeezing the cotton in the water.
- Wiping shall be repeated until no further pollutants remain on the insulator surface. If pollutants remain, even after wiping several times, the pollutants shall be removed by a spatula and be put into the water containing the pollutants.
- Attention should be taken not to lose any water. That is, the quantity shall not be changed very much before and after collecting pollutants.

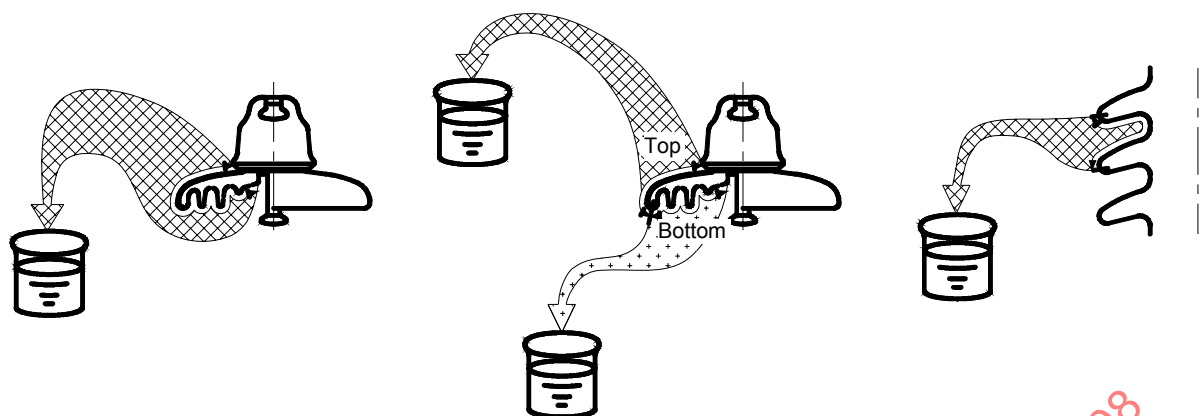


Figure C.2 – Wiping of pollutants on insulator surface

C.3.3 Procedure using washing technique (cap and pin insulators)

The following procedure shall be followed:

- Cover the cap and pin respectively with plastic cling wrap without covering the insulator surface.
- Ensure that the bowl in which the discs are to be washed in is clean.
- Measure 500–1 000 cm³ (or more if required) of distilled water ($\sigma < 0,001$ S/m) and pour into the bowl.
- Place the test insulator on its cap in the water and wash the surface facing the water with gentle hand strokes up to the rim.
- Place the same insulator on its pin in the bowl and gently wash the pollution off the under surface with gentle hand strokes.
- Pour the water into a container taking care again that no deposits remain in the bowl.

The above procedure can be used to collect top and bottom deposits separately.

C.4 Determination of ESDD and NSDD

C.4.1 ESDD calculations

The conductivity and the temperature of the water containing the pollutants shall be measured. The measurements shall be made after enough stirring of the water. A short stirring time, e.g. a few minutes, is required for high solubility pollutants. The low solubility pollutants generally require longer stirring time, e.g. 30–40 min.

The conductivity correction shall be made using Equation (C.1). This calculation is based on 16.2 and Clause 7 of IEC 60507:1991.

$$\sigma_{20} = \sigma_{\theta} [1 - b(\theta - 20)] \quad (\text{C.1})$$

where

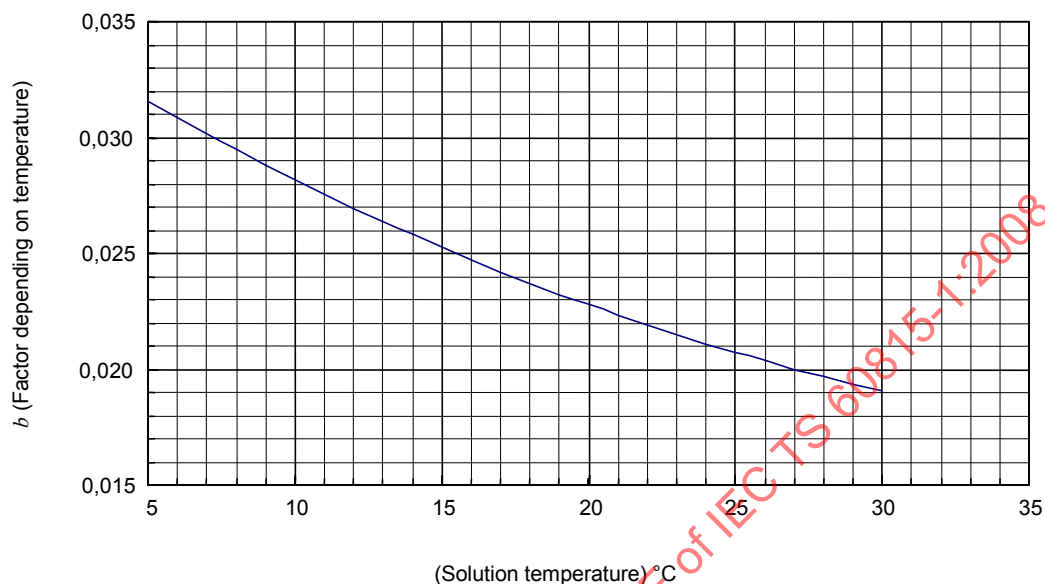
θ is the solution temperature (°C);

σ_{θ} is the volume conductivity at temperature of θ °C (S/m);

σ_{20} is the volume conductivity at temperature of 20 °C (S/m);

b is the factor depending on temperature of θ , as obtained by Equation (C.2), and as shown in Figure C.3.

$$b = -3,200 \times 10^{-8} \theta^3 + 1,032 \times 10^{-5} \theta^2 - 8,272 \times 10^{-4} \theta + 3,544 \times 10^{-2} \quad (\text{C.2})$$



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Figure C.3 – Value of b

The ESDD on the insulator surface shall be calculated by Equations (C.3) and (C.4). This calculation is based on 16.2 of IEC 60507:1991. The relation between σ_{20} and Sa (salinity, kg/m³) is shown in Figure C.4.

$$Sa = (5,7 \sigma_{20})^{1,03} \quad (\text{C.3})$$

$$\text{ESDD} = Sa \bullet V/A \quad (\text{C.4})$$

where

σ_{20} is the volume conductivity at a temperature of 20 °C (S/m);

ESDD is the equivalent salt deposit density (mg/ cm²);

V is the volume of distilled water (cm³);

A is the area of the insulator surface for collecting pollutants (cm²).

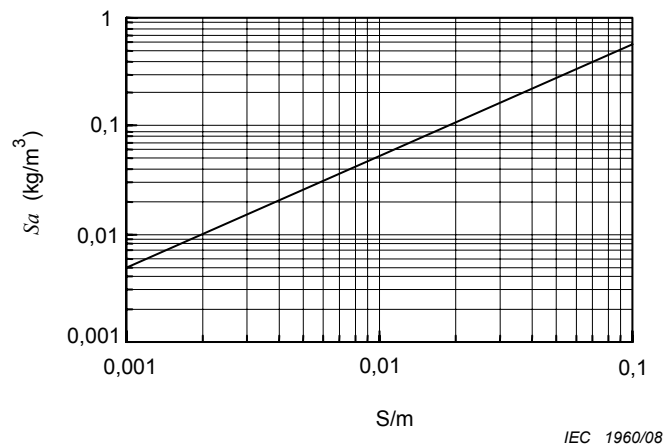


Figure C.4 – Relation between σ_{20} and S_a

If separate top and bottom ESDD measurements have been made, the average ESDD can be calculated as follows (Equation (C.5) can also be used for average NSDD) :

$$\text{Average ESDD} = (\text{ESDD}_t \times A_t + \text{ESDD}_b \times A_b) / A \quad (\text{C.5})$$

where

- ESDD_t is the ESDD on the top area (mg/cm²);
- ESDD_b is the ESDD on the bottom area (mg/cm²);
- A_t is the top area of the insulator surface (cm²).
- A_b is the bottom area of the insulator surface (cm²).
- A is the total area of the insulator surface (cm²).

NOTE 1 For low ESDD measurements in the range of 0,001 mg/cm², it is recommended to use very low conductivity water, e.g. less than a few 10⁻⁴ S/m. Normal distilled or demineralized water less than 0,001 S/m also can be used for this purpose by subtracting the equivalent salt amount of the water itself from the measured equivalent salt amount of the water containing pollutants.

NOTE 2 The quantity of the distilled or demineralized water depends on kind and amount of pollutants. A large quantity of water is recommended for measurements of very heavy pollution or low solubility pollutants. In practice, 2-10 l (litres) of water per m² of the cleaned surface can be used. In order to avoid underestimating the amount of pollutants, the quantity of the water would be so increased to have the conductivity less than around 0,2 S/m. If very high conductivity is measured, there might be some doubt of remaining pollutants not dissolved due to small amount of water.

NOTE 3 The stirring time before conductivity measurement depends on kind of pollutants. For low solubility pollutants, conductivity is measured at some interval with time up to about 30–40 min and is determined when the measured values level off. To dissolve pollutants quickly, special methods such as boiling method and ultrasonic method can also be used.

C.4.2 NSDD calculations

The water containing pollutants, after measuring ESDD, shall be filtered out by using a funnel and pre-dried and weighed filter paper (grade GF/A 1,6 µm or similar).

The filter paper containing pollutants (residuum) shall be dried, and then weighed as shown in Figure C.5.

The NSDD shall be calculated by Equation (C.6).

$$\text{NSDD} = 1\,000 (W_f - W_i) / A \quad (\text{C.6})$$

where

NSDD is the non-soluble material deposit density (mg/cm^2);

W_f is the weight of the filter paper containing pollutants under dry conditions (g);

W_i is the initial weight of the filter paper under dry conditions (g);

A is the area of the insulator surface for collecting pollutants (cm^2).

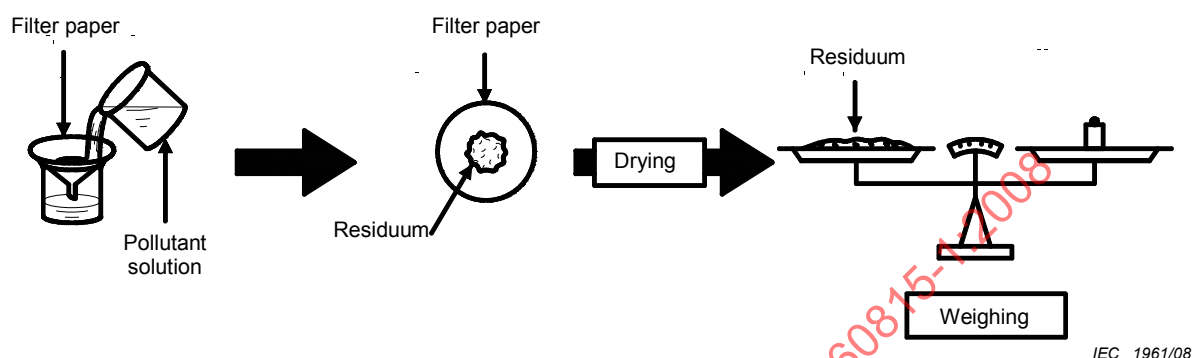


Figure C.5 – Procedure for measuring NSDD

C.5 Chemical analysis of pollutants

Quantitative chemical analysis can be made on pollutants for close examination of pollution conditions. The analysis can be useful to identify chemical components of soluble salts. Chemical analysis of soluble salts is made by using solution after ESDD measurement by means of ion-exchange chromatography (IC), inductive coupled plasma-optical emission analytical spectrometry (ICP), etc. The analysis results can show amounts of positive ions, e.g. Na^+ , Ca^{2+} , K^+ , Mg^{2+} , and negative ions, e.g. Cl^- , SO_4^{2-} , NO_3^- .

Annex D (normative)

Evaluation of type B pollution severity

D.1 Introductory remark

Marine site contamination often belongs to the type of instantaneous pollution occurring close to the coast. The duration of a pollution event may last from less than 1 h to more than 24 h. To determine the pollution severity in such a case a periodical measurement (for example every 30 min to 1 h) or a continuous measurement of surface currents on an insulator can be used. Alternatively, measurement of insulator flashover stress can be adopted (see Clause D.3). For all these cases, the measurements obtained are compared with values obtained in an artificial salt fog test to determine the site equivalent salinity (SES).

In some cases, notably where dry salt build-up is expected, the methods for evaluation of SPS for type A pollution are used for type B pollution. Clause D.4 gives some guidance on this method.

D.2 Evaluation of SES for type B pollution by leakage current measurement

D.2.1 Measurement of conductance

This periodical measurement is performed at a low voltage on an insulator with a simple shed shape or a reference cap and pin or long rod insulator. The applied voltage (2 min interval) shall be low enough (for example 700 V_{rms} per metre of creepage distance) to avoid dry band arcing. The current values shall be recorded in a suitable way.

NOTE The conductance is not a comparable parameter for different insulators. The conductance of a given insulator can be converted into surface conductivity with the help of the form factor (see Annex I).

D.2.2 Measurement of surface leakage currents

This continuous measurement is performed on a string of reference cap and pin insulators or a reference long-rod insulator. The electrical stress used should maintain the insulator in a withstand condition for the expected site pollution severity class, e.g. no pollution flashover should occur during the test period. The current values shall be recorded in a suitable way.

D.2.3 Calibration by a salt-fog test

In both the above cases, the calibration for the current values is made by a salt fog test according to IEC 60507 on the same insulator and at the same voltage stress. The tests are made with increasing salinity from test to test, until peak values of leakage current (i_{highest}) comparable to those from the site measurement occur. The corresponding salinity is the SES.

NOTE 1 i_{highest} is the highest peak value of the leakage current measured on an insulator at withstand conditions during a sufficient test period (i.e. one or more years in the case of an outdoor test station, or 1 h in the case of salt fog tests according to IEC 60507).

NOTE 2 If polymeric insulators are used for SES evaluation instead of the reference insulators defined in this technical specification, it is to be noted that hydrophobic insulators submitted to the IEC 60507 salt-fog test can exhibit lower performance than can be expected in service due to the temporary loss of hydrophobicity caused by the pre-conditioning process.

D.3 Evaluation of SES for type B pollution by measurement of insulator flashover stress

This continuous measurement is performed on a string of reference cap and pin insulators or a reference long-rod insulator at an outdoor testing station and provides results that are closest to service experience. The insulator flashover stress is the flashover voltage divided by either the insulator length or the insulator creepage length. Results over a period of time can be presented as either the minimum flashover stress, or as a relationship between flashover stress and frequency of flashover. The test procedure usually involves bridging out some insulators in a string with explosive fuses, so that after flashover the string is automatically lengthened (for more information, see CIGRE 158 [1]). The minimum flashover stress can then be directly calibrated against salt fog test results according to IEC 60507 on the same reference insulator to obtain the SES for the outdoor testing station. In this way, site pollution severity (SPS) can be correlated against SES for the reference insulator (see Figure 3), where flashover, rather than leakage current is the criteria of performance. In addition, other pollution severity measurements (e.g. DDDG, surface conductance, surface leakage currents) can also be correlated against SPS for the reference insulator at the test site.

NOTE The SES represents an appropriate IEC 60507 salt fog withstand test for the reference insulator and should not be used directly to determine the severity of an artificial pollution test for other insulator designs (see [2] for more information).

D.4 How to estimate SPS for type B pollution

The flowchart in Annex A represents the general approach for estimating the SPS for a site with type B pollution. Analysis of potential contamination sources and frequency of wetting is important in assessing the SPS. Data from a number of pollution severity measurements will also help in determining the correct SPS for a location. For example, SPS for a coastal location, where salt water or conductive fog is deposited onto the insulator surface and non-soluble deposits may or may not be important, can be obtained from service experience, ESDD, DDDG, surface conductivity or leakage current results. The strengths and weaknesses of each method need to be considered when interpreting results (see CIGRE 158 [1] for more information).

Therefore, in the above coastal example where non-soluble deposits are negligible and regular wetting of the reference insulator occurs, ESDD measurements are likely to be low due to regular cleaning of the insulator surface. Under such circumstances, a statistical approach is required to analyse collected data, and a maximum likelihood estimation of the distribution function should be used. The upper 2 % value at 95 % confidence level, for example, can then be used as the SPS dimensioning parameter to compensate for too low, or too few measurement values (see [2] for more information). This approach would be particularly important when designing insulation for critical installations.

Annex E (normative)

Directional dust deposit gauge measurements

E.1 Introductory remark

The dust gauge, as shown in Figure E.1, consists of four vertical tubes each with a slot milled in the side, these being so arranged as to face North, South, East and West. A removable container which collects the deposits blown into the slots is attached to the bottom of each tube.

To facilitate international comparison of results, the slot size, as shown in Figure D.1, shall be used. The nominal dimensions are a 40 mm wide slot with 20 mm radii at each end. The distance between the centres of the radii is 351 mm (the overall slot length thus being 391 mm). The tube is at least 500 mm long with 75 mm outside diameter. The distance from the top of the tube to the top of the slot is 30 mm. The tubes are mounted with the bottom of the slot approximately 3 m from the ground; this keeps the gauge out of reach of casual tampering but the jars can be easily and safely changed. The gauges may be mounted lower if ground conditions allow.

These containers are removed at monthly intervals, their contents mixed with 500 ml of demineralized water, any obvious macroscopic debris (leaves, insects, etc.) removed and the conductivities of the solutions measured. The pollution index is defined as the average of the conductivities of the four directions, expressed in $\mu\text{S}/\text{cm}$, and normalized to a 30-day interval.

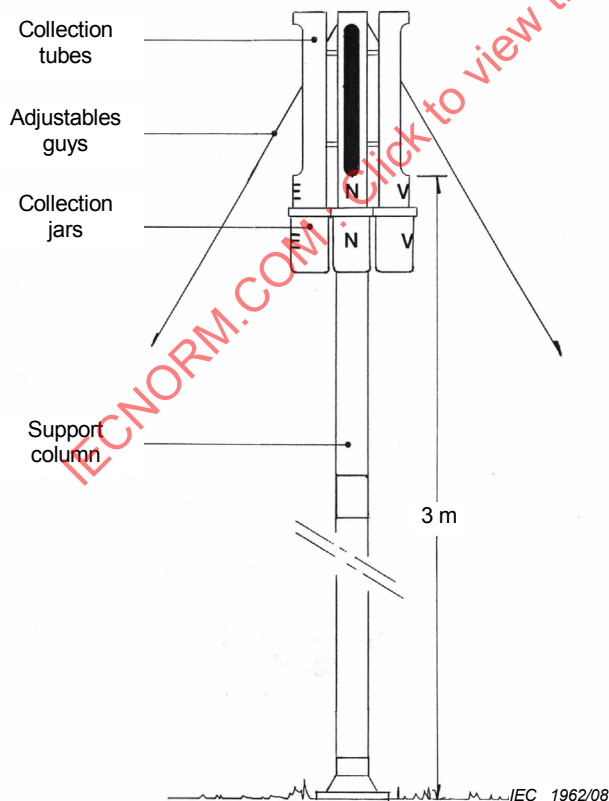


Figure E.1a – Installed

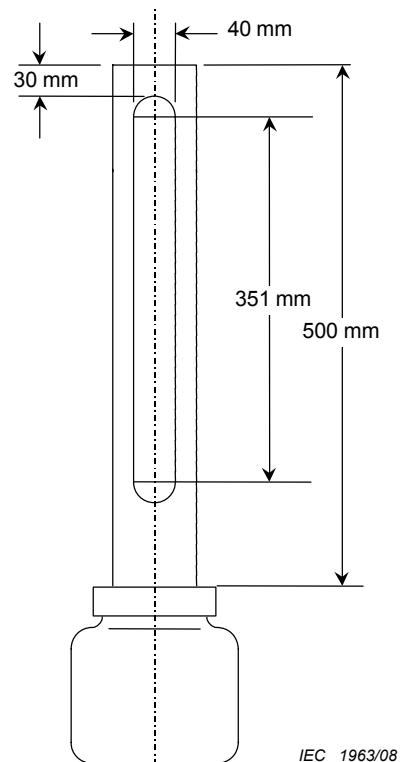


Figure E.1b – Slot dimensions

Figure E.1 – Directional dust deposit gauges

The advantage of this technique is its simplicity and the fact that it can be used at an un-energized site without insulators or facilities other than those required for the mounting of the gauges.

The major disadvantage with the dust gauge is that actual insulators are not used and therefore it is not possible to assess the self-cleaning properties of insulators and the effect of the shed profile on the deposition process on the insulator surface. In areas of high rainfall, a higher index can be tolerated, whereas in areas of low rainfall but with a high occurrence of fog, the actual severity is higher than that indicated by the gauges. The climatic factor for the area is thus used to help correct for this phenomena.

E.2 Measurement procedure

The monthly measurement procedure is as follows:

On site:

- 1) Remove the four collection jars from the tube ends and close with the lids provided.
- 2) Record the date of removal on the jar label.
- 3) Attach four clean jars to the tubes, having completed the label on each jar to indicate the site, the direction and the date of installation.

At the measurement location:

- 1) Add 500 ml of demineralized water to each collection jar. The conductivity of the water must be less than 5 $\mu\text{S}/\text{cm}$. Should the vessel contain rain water, add demineralized water to make up the volume to 500 ml. If, owing to heavy rainfalls, there is more than 500 ml in the jar, no additional water is required.
- 2) Swirl or stir the contents until all the soluble salts are dissolved.
- 3) Measure the conductivity of the solution, preferably with a conductivity meter, which automatically corrects the reading to 20 °C. If the meter is not compensated to 20 °C, then measure the temperature of the solution as well.
- 4) If the volume of the solution is not 500 ml, for example in the case of excessive rain having accumulated in the jar, measure the actual volume.
- 5) Calculate the corrected conductivity for each direction, this being the conductivity at 20 °C expressed in $\mu\text{S}/\text{cm}$, and normalized to a volume of 500 ml and a 30-day month. The normalized DDDG value is calculated using the following equation:

$$\text{DDDG} = \sigma_{20} \times \frac{V_d}{500} \times \frac{30}{D} \quad (\text{E.1})$$

where

DDDG is the directional deposit gauge conductivity, in $\mu\text{S}/\text{cm}$;

D is the number of days that DDG has been installed.

If the conductivity reading is not compensated for temperature by the measuring instrument, the value can be corrected to 20 °C using Equations (C.1) and (C.2).

- 6) Calculate the pollution index (PI) for the month by taking the average of the four corrected directional conductivities, expressed in $\mu\text{S}/\text{cm}$, i.e.

$$\text{PI} = \frac{(\text{DDDG}_{\text{North}} + \text{DDDG}_{\text{South}} + \text{DDDG}_{\text{East}} + \text{DDDG}_{\text{West}})}{4} \quad (\text{E.2})$$

NOTE 1 Some contamination can collect on the inside of the tubes and will be washed into the collection jars when it rains. The pollution indices for the wet months may therefore show slightly higher values than those when there was no precipitation. If the readings are averaged over a period then this makes no difference. However, if

very accurate monthly figures are required, then the internal walls of the tube can be rinsed off using a squeeze bottle of demineralized water before the collecting jars are removed for analysis.

NOTE 2 For more detailed information on the nature and/or source of the pollution, the gauge contents may be sent to a laboratory for comprehensive chemical analysis.

If an assessment of the non-soluble deposit is required, following the conductivity measurements, the solutions shall be filtered using a funnel and pre-dried and weighed filter paper of grade GF/A 1,6 mm or similar. The paper shall then be dried and weighed again. The weight difference in grams then represents the non-soluble deposit (NSD).

E.3 Determination of the SPS class from the DDDG measurements

The relationship between the site pollution severity (SPS) class and the pollution index, preferably measured over a period of at least one year, is provided in Table D.1. Table D.2 gives information on correction for NSD levels measured with the DDDG.

Table E.1 – Directional dust deposit gauge pollution index in relation to site pollution severity class

Directional dust deposit gauge pollution index, PI ($\mu\text{S}/\text{cm}$) (take whichever is the highest)		Site pollution severity class	
Average monthly value over one year	Monthly maximum over one year		
< 25	< 50	a	Very light
25 to 75	50 to 175	b	Light
76 to 200	176 to 500	c	Medium
201 to 350	501 to 850	d	Heavy
> 350	> 850	e	Very heavy

Table E.2 – Correction of site pollution severity class as a function of DDDG NSD levels

Directional dust deposit gauge NSD (grams) (take whichever is the highest)		Site pollution severity class correction
Average monthly value over one year	Monthly maximum over one year	
< 0,5	< 1,5	None
0,5 to 1,0	1,5 to 2,5	Increase by one class
> 1,0	> 2,5	Increase by one or two classes and consider mitigation (e.g. washing)

E.4 Correction for climatic influences

If weather data for the site in question is available, then the directional dust deposit gauge pollution index can be adjusted to take into account climatic influences. This is done by multiplying the pollution index value (PI), as determined above, by the climatic factor (C_f).

The climatic factor is given by:

$$C_f = \sqrt{\frac{\frac{F_d}{20} + \frac{D_m}{3}}{2}} \quad (\text{E.3})$$

where

F_d is the number of fog days ($\leq 1\,000$ m of horizontal visibility) per year;

D_m is the number of dry months (< 20 mm of precipitation) per year.

NOTE The relationship shown in Equation (E.3) is based on findings in South Africa measured at 80 sites for more than 4 years.

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Annex F (normative)

Use of laboratory test methods

The relevant test method to be used is selected according to the type of pollution at the site, the type of insulator and the type of voltage. The tests given in IEC 60507 and IEC/TR 61245 are directly applicable to ceramic and glass insulators. Up to now, there has been no standard test directly applicable to polymeric insulators. As a general rule, the solid layer test is recommended for type A pollution and the salt-fog test for type B pollution.

The pollution severity used in the laboratory test is determined in three steps:

- 1) The *pollution type* present and the *site pollution severity* are determined by assessing the pollution at a site, as described in Clause 8 and in Annexes C, D and E.
- 2) The site pollution severity level is corrected for any deficiency or inaccuracy in the determination of the SPS. The correction factors shall compensate for:
 - differences in pollution catch of the insulator used for the site pollution severity measurement and the insulator to be tested, e.g. the influence of shed profiles and diameters;
 - differences in types of voltage applied on the insulator used for the site pollution severity measurement and the insulator to be tested, e.g. d.c. or a.c. voltage;
 - other influences of importance.
- 3) The *required pollution severity* at which the laboratory test is performed is derived from the SPS to compensate for the differences between the actual in-service conditions of the insulation and those in the standard tests. These severity correction factors shall compensate for:
 - difference in pollution type of the pollution deposit at site and in the test;
 - differences in the uniformity of the pollution deposit at site and in the test;
 - differences in the wetting conditions in service and those during the test;
 - the differences in the equipment assembly.

Other influences of importance may include:

- the effect of ageing on the pollution catch and wettability of the insulation during the expected lifetime;
- the statistical uncertainty of performing a limited number of tests to verify the required pollution severity withstand level.

These are the general principles of this process. The choice of values for the correction factors is dependent on the site conditions and on service experience. Correction factors are known for certain types of insulators and more are becoming available as experience is being gained. Whenever possible, typical values of the factors are given in the relevant parts of IEC 60815.

The use of non-standard, or customized, laboratory pollution test methods may be considered, if agreed between the suppliers and customers. More information on such methods can be found in CIGRÉ 158 [1].