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OUTDOOR INSULATION IN POLLUTED CONDITIONS:

GUIDELINES FOR SELECTION AND DIMENSIONING

Part 1: General principles and the AC case

Working Group
C4.303

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Outdoor insulation in polluted conditions: Guidelines for selection and dimensioning

Part 1: General principles and the a.c. case

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Abbreviations

ALS Alternating Long/Short Sheds
DDDG Directional Dust Deposit Gauge
ESDD Equivalent Salt Deposit Density
NSDD Non Soluble Deposit Density
SDD Salt Deposit Density
SES Site Equivalent Salinity
SPS Site Pollution severity
U_m Highest voltage for equipment
USCD Unified Specific Creepage Distance

Definitions

Ceramic insulator:

An insulator with an insulating body that consists of either ceramic material, porcelain, toughened glass or annealed glass.

Polymeric insulator:

An insulator whose insulating body consists of at least one organic based material. Coupling devices may be attached to the ends of the insulating body.

Housing of a polymeric insulator:

The external insulating part of a polymeric insulator which provides the necessary creepage distance and protects (in the case of composite insulators) the core from the environment. Any intermediate sheath made of insulating material is a part of the housing.

Sheds:

Projections from the trunk of an insulator intended to increase the creepage distance.

Arcing distance:

The shortest distance in air external to the insulator between the metallic parts which normally have the operating voltage between them.

NOTE: The term "dry arcing distance" is also used.

Creepage distance:

The 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 high resistance coating 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.

Unified Specific Creepage Distance (USCD):

The creepage distance of an insulator divided by the maximum operating voltage across the insulator (for a.c. systems usually $U_m/\sqrt{3}$). It is generally expressed in mm/kV.

NOTE: This definition differs from that of Specific Creepage Distance where the phase-to-phase value of the highest voltage for the equipment is used. For phase 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 815 (1986).

Salt Deposit Density (SDD):

The amount of sodium chloride 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.

Equivalent Salt Deposit Density (ESDD)

The amount of sodium chloride that, when dissolved, gives the same conductance 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.

Non-Soluble Deposit Density (NSDD):

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

Site Equivalent Salinity (SES):

The salinity of a salt fog test according to IEC 60507 that would give comparable peaks of leakage current on the same insulator as produced at the same voltage by natural pollution at a site.

1 Introduction

As society has become increasingly dependent on a continuous supply of electrical energy, more attention has been given to the reliability and cost of each component in the electricity supply system, including the insulation of power lines and substations. The integrity of outdoor insulation is crucial in maintaining the reliability and cost-effectiveness of a modern electricity supply utility.

In service the outdoor insulation should withstand all voltage and environmental stresses that it may be subjected to. The pollution performance of the insulation is, therefore, one component of the overall insulation coordination design and the final solution will be chosen taking due cognisance of all the aspects of insulator performance.

For many years ceramic materials (glass and porcelain) dominated as the preferred materials for outdoor insulation on account of their tough and long lasting surface properties, their mechanical strength and their relatively low-cost. Service experience and intensive research led to a good understanding of the failure mechanisms involved and engineers were able to design insulation which gave satisfactory performance in the majority of situations.

However, there remained a significant number of environments, particularly where the severity of pollution was high or where there was a long-term pollution build-up over a period of years, that the reliability of insulation remained unacceptably low. As the development of polymer materials proceeded, rivals to glass and porcelain became available with the possibility of improved performance in these situations. Initially, design and selection of insulators made from these newer materials followed the practice for glass and porcelain insulators. But, it soon became apparent that the failure mechanisms, and the processes which led to them, were very different and so research and analysis of service experience was needed to equip engineers to design and select polymeric insulation with confidence.

In June 2000, Cigré published an important review [1] of current knowledge covering, in considerable depth, what is currently known of the performance of glass, porcelain and polymeric insulators. Against this background, it was feasible to produce a document that will provide engineers with the tools to select and dimension outdoor insulation that is most suited to a given environment, taking into account the wide variety of materials and insulator types that are currently available and the desired levels of performance. This work was started under the auspices of Cigré Study Committee 33 “Insulation coordination” and this task was taken over by Advisory Group 3 of Study Committee C4 in 2005.

Following considerable debate, it was agreed that this guideline should present a performance-based methodology motivated by information which emerged in the course of the literature search. It is acknowledged that this approach will need further investigation and refinement, but the working group is confident that when this has been accomplished, utility engineers will have a methodology for the selection of outdoor insulation which can be successfully applied in all environments and easily adapted to new situations.

The basis of the methodology is the use of performance as the fundamental system parameter for insulation specification. In the appendices, the methodology will be illustrated by examples with pointers to materials, profiles and physical dimensions. These are illustrations, limited by current knowledge.

In the process of compiling this document, close liaison has been maintained with the IEC working group responsible for the rewriting of IEC 60815, “Selection and dimensioning of high-voltage insulators for polluted conditions”. In keeping with the IEC approach on determining the fitness of a product for its intended application, their revision also stresses the need for evaluation, either by laboratory testing or by field trial.

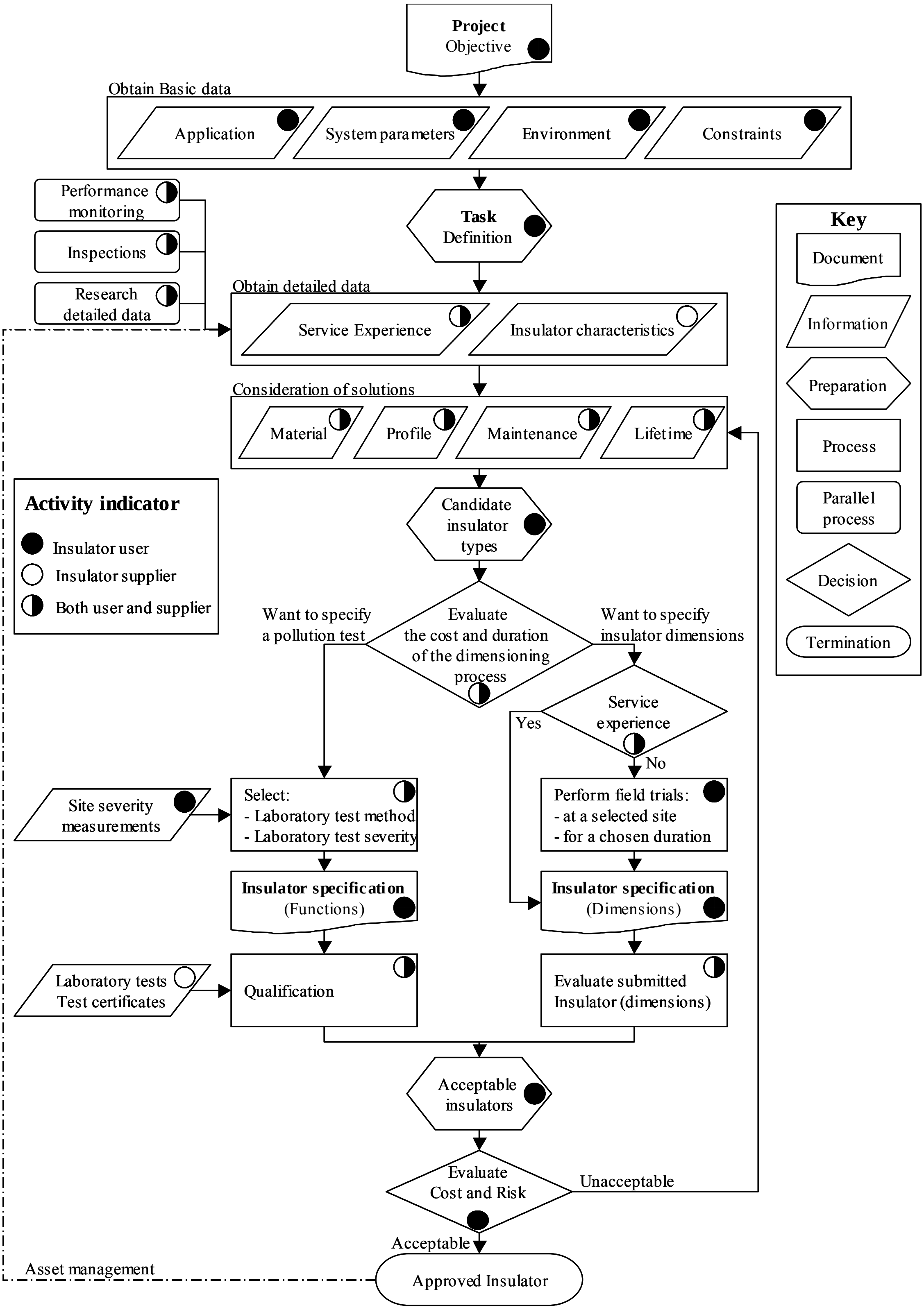
This document is based on a flowchart, which assumes that certain basic data regarding the application of the insulators, the environment and available insulator characteristics can be obtained and that the design and selection involves matching the application and environment to the characteristics of available insulators in an optimal way. Where good, relevant service experience is not available, or where new insulator types are being considered, field or laboratory testing is recommended and a sufficient lead-time must therefore be budgeted to allow the completion of this qualification phase.

The text of the document follows a flowchart and at the end of the document a few selected methods for site severity assessment are described as well as a proposal for a laboratory test method to determine the pollution performance of polymeric insulators. Details on where to find information in the review [1] on the aspects covered by this document are also provided.

In view of the need for refinement of the methodology and parameters used in this guideline, and to cater for the integration of new knowledge and experience, members of the working group will organise workshops and seminars in their own countries. These will serve to publicise the contents of the guidelines and to stimulate a discussion of the methodology introduced here and to obtain input for a future revision.

Please note that this document deals with general principles and details of the a.c. case. The complementary d.c. case is the subject of a further document, which is expected to be available in 2008/9.

2 Flowchart for the Selection and Dimensioning Process



3 Project objective

This is a brief, but important statement putting the project in its context. Representative statements could be:

a. Insulation is to be designed for a new 400kV a.c. line extending from locations **A** to **B** as well as for the substations at its terminals.

b. Insulation is to be designed to upgrade the existing 110kV a.c. line from locations **A** to **B** and its terminal substations, to 220kV a.c.

c. The existing insulation on the 220kV a.c. line from locations **A** to **B** is to be upgraded to improve the performance and reduce the number of pollution related flashovers.

d. Insulator maintenance procedures are to be designed to improve the pollution flashover performance of the 400kV substation at **A**.

4 Basic data

The basic data are the collection of information that is necessary to enable the selection and specification of insulators to meet the project objective. It describes the demands that are placed on the insulators. The basic data are made up of:

- The *application* of the insulators.
- The system parameters.
- A characterisation of the *environment*.
- The *constraints* placed on the insulator selection and design of the insulator.

In the following sections each of these items will be amplified.

4.1 Application

The applications considered in these guidelines are classified as follows:

- Overhead line insulation
- Substation insulation
- Apparatus insulation
- "Special" insulation

These main groups can be subdivided as per Table 4-1. It shows specific types of insulation for each application.

Table 4-1: Specific types of insulation for different applications.

Overhead line insulation	**Substation insulation**	**Apparatus insulation**	**"Special" Insulation**
Suspension insulators Jumper insulators	Solid core post insulators	Circuit breaker/isolator housing	Phase spacers
Tension insulators	Hollow or filled hollow core post insulators	Arresters Arrester housing	Booster sheds
Line post insulators		Equipment housing e.g. CT, VT etc.	Shield-wire insulation
Braced structures		Transformer bushing Cable terminations GIS entry bushings Through-wall bushings	Coatings
Multiple assemblies		Disconnecters Cut out fuses	Fibre optic feeds
Insulating cross-arms or structures Wooden structures		Capacitors Air core reactors	Guy/strain, railway insulators

In addition to these groups, the application of the insulation includes the angle of mounting of the insulation (horizontal, vertical or inclined) and its orientation with regard to the direction of the main source of pollution. It also includes the size of the insulator. All of these factors feature prominently in the dimensioning process.

The type of insulator chosen for the application is dictated by many factors, which are discussed later in these guidelines. However, it must be noted that the system parameter of voltage type (i.e. a.c. or d.c.) is of the utmost importance when defining the insulator application.

The application is further defined by type of system, maintenance and design constraints. Particular attention may need to be taken to deal with the following:

- Electric field grading along the insulator.
- The use of insulators in phase-to-phase applications.
- Mechanical requirements.
- Live working / washing.

4.2 System parameters

The following information is generally required on the system:

1. Voltage type, i.e. a.c. or d.c.
2. Highest voltage for equipment, U_m.
3. The required lightning impulse-withstand strength.
4. The required switching impulse-withstand strength.
5. The magnitude and duration of the maximum power arc that the insulators should be able to withstand.
6. The radio interference limit for system components.
7. Expected range of operating voltage in p.u. of nominal system voltage.
8. Total number of insulators exposed to the same conditions.
9. The anticipated use of multiple insulator strings.
10. Expected reliability for the total system (i.e. number of allowable flashovers in a given period).
11. Feasibility of periodic maintenance under live working or out-of-service conditions.
12. Constraints for cold switch-on; i.e. any time, or selectable such as in dry weather or particular time of day.
13. Technological preferences e.g. use of polymeric insulators, semi-conducting glaze, special profiles.
14. Maximum level in p.u. for switching overvoltages (p.u. of the peak phase-to-ground value of U_m).
15. Anticipated frequency distribution of switching overvoltages.
16. Maximum level for temporary overvoltages.
17. Anticipated frequency and duration of temporary overvoltages.

4.3 Environment

There are many factors that influence the performance of insulators in a particular environment. Information on the following aspects will be useful when assessing the environment:

1. Insulator pollution parameters
    - Severity of the area
    - Source of the pollution
    - Deposit-rate of the soluble pollution
    - Analysis of the chemical constituents in the pollution
    - Type of insoluble deposit
    - Deposit-rate of the insoluble pollution
    - Particle size distribution of the pollution
2. Meteorological parameters (See also Appendix B)
    - Prevailing wind speed and direction
    - Rainfall
- Frequency and duration of rainstorms
- Range of rainfall-rate
- Range rainfall conductivity
    - Likelihood and duration of extended dry periods
    - Prevalence of mist or fog
    - Snow and ice
    - Intensity of solar radiation
3. Local bird population
4. Biological growth
5. Animal encroachment
6. Likelihood of impact damage
7. Vandalism
8. Likelihood of fires under the overhead lines

4.3.1 General types of environment

For the purposes of these guidelines the five general types of environment are:

1. Inland/clean.
2. Agricultural.
3. Coastal.
4. Industrial.
5. Desert.

For details of these please refer to Appendix D.

4.3.2 General types of pollution

Pollution can generally be classified as one of two types:

A. Solid pollution is deposited by wind onto the insulator surface. This pollution becomes conductive when wetted. The deposited pollution generally consists of soluble and non-soluble components.

B. Liquid electrolytes are deposited onto the insulator surface. This type of pollution generally contains very little to no non-soluble pollutants.

Combinations of the above may occur.

4.3.3 Site severity estimation

The severity of a site can, generally, be determined with one or a combination of the following methods[2]:

1. ESDD and NSDD - adapted to environments where pollution accumulates on the insulator over time – i.e. solid pollution as per section 4.3.2.
2. Leakage current / conductance measurements - for areas where liquid pollutants are deposited – i.e. liquid pollution as per section 4.3.2 – or areas with frequent wetting.
3. Directional dust deposit gauges - For the measurement of the total amount of pollution in the air.

An overview of these, and other methods, that can be used to measure the amount of pollution at a site can be found in the Review[1] (pp 87 - 92). Precise definitions of the above mentioned methods will be included in the revised IEC 60815 document.

The Site Pollution Severity (SPS) can be determined from pollution measurements by using the following principles:

- The site pollution severity should, preferably, be based on site severity measurements made over an appreciable period of time i.e. one or more years. The period over which measurements are made should preferably be of the same order of length as that of the acceptable mean time between pollution flashovers of the installation.
- The SPS is described by the 2% level of pollution, i.e. the level that is exceeded for only 2% of the time. As an approximation, the SPS can be set equal to the highest value recorded.
- If several types of measurements are performed, the site severity is characterised by the maximum value recorded of each of the methods, whether these maximum values coincide in time or not.

For pollution measurements on actual insulators the following additional principles should be considered:

- The aim is to obtain an indication of the maximum amount of pollution that can collect on the insulators. This may necessitate the adjustment of the measurement interval according to the rainfall-pattern.
- The pollution severity on an insulator is characterised by the average value over the whole insulator.
  For example: if the ESDD is determined on a disc for the top and bottom surfaces separately, then the pollution severity on the complete disc is given by the weighted average of the measurements taken.

4.3.4 Ice and snow

The selection and testing of insulators with respect to ice and snow are covered by the report from Cigré Task Force 33.13.07[3] and are not considered further in this document.

4.4 Constraints

Constraints are the limitations placed on the selection and design of the insulator; especially those that relate to the geometry of the installation, cost, time frames and operational issues.

Under **installation geometry** falls any limitations placed on the length or diameter of the insulator. On transmission lines, the length of the insulator may be limited by the size of the tower window or the sag of the line conductors in the case of in insulator replacement projects. In substations the height of the insulators can be limited to obtain a low-profile structure. The diameter of the insulator, or its grading rings, can be limited in the case of ‘V’ strings or tension sets with parallel insulator strings. The accessibility of the site and how the insulators will be installed may also force a preference to a specific type of insulator.

Probably the most influential constraint is **cost**, and it provides a constant pressure to provide an optimal insulator-design with limited resources. Life cycle costing – i.e. cost of installation, maintenance, and subsequent costs if the insulator fails – is also an important consideration when selecting and dimensioning insulation.

In many projects the **time frame** does not allow for a thorough site assessment to provide comprehensive information for the selection and dimensioning of the insulation. The design must then be based on limited information that is available but nonetheless on sound assumptions. However, this is a situation that should, as far as possible, be avoided as it may result in either an over or an under design of the insulation and accordingly higher costs due to either having longer insulators or under performing insulation. Short cuts can lead to embarrassing and/or very costly failures.

Operational issues can come in various forms, like whether the insulators will be regularly accessible for maintenance or if live line maintenance will be performed. Cigré Taskforce C4.13.12 deals with live line working and its influence on the selection of insulators**.**

5 Definition of Task

The **“definition of task”** is an amplification of the “**Project Objective”** in the light of the information provided in “**Basic Data”** and is used to define the specific tasks that have to be addressed. This is an identification of the types of insulator that need to be considered, the performance specification that they must satisfy and a quantification of environments in which they must satisfy this performance.

In Appendix A worked examples are provided based on the task definitions for a coastal and desert type of environment.

6 Collection of Detailed Data

With the demands that will be placed on the insulator and with the task described, sufficient information is available to collect detailed data about the insulator characteristics and relevant service experience. This will, in turn, be used to select the candidate insulator types as is described in Section 7.

6.1 Insulator characteristics

In this document, the insulator characteristics relate specifically to the pollution flashover performance. The main parameters, other than the insulator length, that influence the flashover behaviour of the insulator are the:

- Type of housing material.
- Shed profile.
- Diameter of the insulator — this is especially of interest for equipment insulators
- Mounting angle and orientation of the insulator in the intended installation
- Presence of internal voltage grading

The Review[1] provides a general discussion of these factors and its influence on the pollution catch of the insulator (pp 29 – 33) and its pollution flashover performance (pp 38 - 57).

In addition, it could also be advisable to collect information on the long-term performance of the insulators due to the effects of ageing. Such information can be used to specify maintenance and/or palliatives that can be used to maintain a required performance.

Insulators may suffer ageing effects such as surface erosion, or corrosion of the metal parts, in conditions that cause significant levels of leakage current. In such cases it would be advisable to obtain from the manufacturer's information on the insulator's long-term characteristics.

The use of maintenance and palliatives is discussed in the Review (pp118-132 in [1]).

Obviously the user will also need to identify and specify other characteristics, such as the mechanical strength and the other parameters that define the electrical strength for the insulator to ensure its integration in the mechanical and electrical design of the apparatus or line. This information can normally be obtained from the insulator manufacturer, but some users may opt to obtain it through local field or laboratory tests specific to their conditions.

6.2 Service experience

It is recognised that service experience can be most useful in evaluating insulator designs. However, it must be borne in mind that an existing installation may have an excellent pollution flashover performance because it has been over designed - perhaps unwittingly so!

A wide variety of data from service experience may be used to design insulation in a polluted environment for new installations, to improve insulation performance in an existing installation, or to define tests necessary for either of these situations.

Since consideration may be given to utilize the same insulator or a different insulator, and the environment may either be the same or different. The four possible situations where service experience may be useful are broadly categorized as follows:

A. Same Insulator, Same Environment
B. Same Insulator, Different Environment
C. Different Insulator, Same Environment
D. Different Insulator, Different Environment

The following list describes different types of data and between brackets, the category to which it is most relevant.

1. Performance of lines or substations in the same area or with similar contamination conditions **(A,B,C,D)**.
2. Contamination severity (A,B,C,D).
3. Chemical analysis of contamination (B,C,D).
4. Weather conditions and type: short term, long term and historical (B,C,D).
5. Environmental changes, such as new industry, agricultural activity, etc. (B,D).
6. Performance of alternative insulator designs (C,D).

7. Type of insulator, e. g. station post, suspension, etc. (C,D).
8. Insulator details such as shed material, dimensions, etc. (C,D).
9. Number of flashovers that have occurred and time period over which record extends (A).
10. Maintenance records (A).

Alternatively, the four categories and the most relevant information from the list are:

SAME INSULATOR SAME ENVIRONMENT (A) 1, 2, 9, 10	DIFFERENT INSULATOR SAME ENVIRONMENT (C) 1, 2, 3, 4, 6, 7, 8
SAME INSULATOR DIFFERENT ENVIRONMENT (B) 1, 2, 3, 4, 5	DIFFERENT INSULATOR DIFFERENT ENVIRONMENT (D) 1, 2, 3, 4, 5, 6, 7, 8

Most of this information must be obtained from the operating departments in the utility, but the performance of alternative insulator designs could also be obtained from literature and from manufacturers.

7 Consideration of Solutions to identify the Candidate Insulator Types

7.1 Introduction

Once the task has been defined, the line or substation designer has the necessary information to study the different insulation solutions for the project. The choice of solutions will, in general, be limited - having only the following options:

- **Material**
  The insulation type dictates the materials available. For example, hollow insulators are generally only constructed in porcelain or composite materials. Additionally, national or company policy may further limit this choice.
- **Profile**
  The choice of insulator profile is based mainly on the type of environment. The freedom on the choice of profile is limited by the insulator type and, additionally, by the insulator material. The converse is also true, in that a preferred profile might not be available in certain materials.

At this stage in the process the line, or substation, designer has identified possible material/profile combinations as candidate solutions. This selection may be extended, or reduced, by two further considerations:

- **Maintenance and/or palliatives**
  The overall value of a solution may be modified by the necessity, or availability, of maintenance or palliative measures. For example, in an extreme case of pollution the most economical, or technically acceptable, solution may be to foresee regular washing or to pre-coat the insulation. Conversely, a higher investment cost solution may be acceptable because regular maintenance is logistically difficult or not economically viable.

- **Life-Cycle analysis**
  The prospective life of the insulation is important and can be a determining factor in the choice of an appropriate solution. Once again, the choice here is guided principally by economic factors. An acceptable balance should be found between initial investment, maintenance costs and replacement costs.

The investigation of the above considerations should have narrowed the field of possible solutions to a point where the designer can choose or request candidates from manufacturers. The next step is to define the method and criteria for testing or evaluating the suitability of each candidate solution.

The final choice or recommendation will be made after the subsequent evaluation of the candidates. Thereafter, more extensive cost and risk analysis may be made.

7.2 Insulation material

The selection of insulator material is often initially dictated by user policy and economics. For example, it may be the policy to use porcelain for post insulators, glass for suspension insulators and polymers for bushings. On the other hand, the choice of material may be dictated entirely by environmental or system constraints; for example, where only polymer material is light or compact enough to be integrated into switching apparatus.

Table 7-1 gives a general view of the applicability of different materials to different insulator technologies.

Table 7-1: General applicability of insulation materials to insulator technologies.

	Porcelain	Annealed glass	Toughened glass	Polymer rubbers (EPDM, SiR...) with fibre/resin core	Resins and other plastics or hybrids
Overhead lines	• cap and pin • longrod • line post • pin-type	• pin-type	• cap and pin • pin-type	• longrod • line post • phase spacers	• longrod for MV lines • pin-type • shield wire insulators
Station insulators	• solid core posts • hollow core posts • multi-cone posts • apparatus insulators	• apparatus insulators	• multi-cone posts • apparatus insulators	• solid core posts • hollow core posts • apparatus insulators	• apparatus insulators
Switchgear, Transformers, Measurement equipment	• bushings, cable terms • MV fuses cut-outs	• MV fuses cut-outs	• MV fuses cut-outs	• bushings, cable terms • MV fuses cut-outs	• MV bushings • MV fuses cut-outs
Surge arresters	• medium voltage • high voltage	Not used	Not Used	• medium voltage • high voltage	• medium voltage

As far as pollution performance is concerned, the following general considerations apply:

- **Ceramic insulating materials (i.e. porcelain and glass)**
  These "traditional" materials have a well-known pollution behaviour and have often been characterised by on-site and laboratory tests. However, the mechanical aspects of their design - and the production process - can mean that they are not suitable for certain applications or environments where dimensional constraints do not allow them to supply the necessary creepage distance with an appropriate profile.

- **Polymer rubber insulating materials**

  These "newer" materials present advantages from both a design and pollution performance aspect. In general, they are lighter and the housing profile is more compact; hence, they can supply more creepage distance for a given axial length than can ceramics while maintaining profile efficiency. For line insulation, their smaller overall diameter tends to reduce the leakage currents and enhance pollution flashover performance. For insulators of comparable average diameters, polymeric rubber insulators perform better than do ceramic ones.

  Certain polymers are hydrophobic and such materials present a clear advantage over ceramics as long as they maintain their hydrophobicity. However, this hydrophobicity may be lost under extreme or repeated service/environment stresses. In this case, their pollution behaviour becomes the same as that for hydrophilic polymer materials. This behaviour must be borne in mind when choosing polymer materials.

  As far as the minimum requirements for polymer rubbers are concerned, their mechanical strength (e.g. tear resistance) and electrical characteristics (resistance to arcing, tracking, UV etc.) should be such that they ensure a sufficient target-life.

  There is a tendency to group polymer rubber materials into simple classes (Silicone, EPDM, EPR etc.) and to consider all members of the class as being identical. This practice is fallacious. There can be vast differences in composition and consequently in long-term behaviour of different Silicone (or EPDM) rubbers which can affect both lifetime and pollution performance. Hence, a guide to minimum requirements of insulating materials for polymer insulators is being prepared by Cigré WG D1.14 that covers these points in detail[4].

- **Resin or plastic insulating materials**

  As a general rule, resin and plastic insulating materials for outdoor insulation applications do not have as long a lifetime as that of polymer rubbers. Moreover, their application is often limited by their mechanical strength for insulators without a FRP core. Nevertheless, recent improvements and new formulations make these materials a viable choice for some MV applications. These materials are economic and light so their use may be considered in situations where maintenance/replacement costs are lower or where a certain number of interruptions can be tolerated.

  As with polymer rubbers, their resistance to erosion, tracking, UV attack etc. are of primary importance and will also be dealt with by Cigré WG D1.14 publication[4]. Some resin or plastic materials are hydrophobic when new, but it would appear that this is always temporary (p 78 and 165 in [1]). Hence this must be borne in mind when using such materials.

- **Coatings and other palliative measures**

  As a general rule, coatings (RTV Silicone, greases etc.) are used as a palliative measure and are not to be considered as a candidate solution for new insulation projects. However, if their use is unavoidable it should be borne in mind that greases require regular replacement (sometimes very frequently) and that coatings may also require one or more replacements during the life of the insulation. See p 129-131 in the Review[1] for more information on these and other palliative measures.

7.3 Insulator profile

Many aspects that influence insulator behaviour need to be considered when selecting an insulator profile for a particular site (Section 7.2.1 of [1]). Different types of insulator and even different mounting angles and 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. Recommended profiles are different for a.c. applications than they are for d.c. ones. Also, they may be different for ceramic insulators than they are for polymeric ones or for hollow type insulators.

Because of these difficulties, the recommended practise when selecting profile is to rely heavily on local site experience. This may not always be possible however; for example, when the existing insulation at a site performs badly and other types of profile need to be considered. For the cases when service experience is lacking, general guidelines that could help in the selection of profile are provided in Appendix D.

A description of the characteristics of commonly used profiles, as are illustrated in Table 7-2 to Table 7-4, is as follows:

- Aerodynamic or open profiles prove to be beneficial in areas where the pollution is deposited on to the insulator by wind. Such areas are deserts, heavily polluted industrial areas or coastal ones which are not directly exposed to salt spray. This type of profile is especially effective in areas that are characterised by extended dry periods. Open profiles are also readily cleaned.
- The use of steep anti-fog profiles or sheds with 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 particulate pollution precipitation containing slow dissolving salts. These profiles provide a longer creepage and have a good heavy wetting performance.
- More recent flatter anti-fog profiles, with fewer or shallower under-ribs, can be beneficial in areas of heavy industrial pollution - notably where string length is limited. However deep under-ribs should be avoided on horizontal insulators. As for the steep anti-fog profiles, these provide also a longer creepage and a good heavy wetting performance.
- Alternating long and short sheds are beneficial in areas where heavy wetting can occur. These profiles allow easy cleaning under maintenance
- Standard profiles are effective for use in 'very light' to 'medium' polluted areas where a long creepage distance or aerodynamically effective profile is not required.

Table 7-2: Typical examples of a.c. cap and pin insulator profiles.

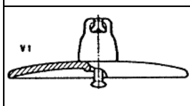
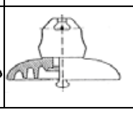
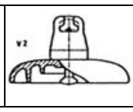
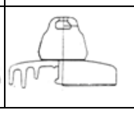
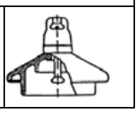
Open profile	Standard profiles		Anti-fog profiles	
				

Table 7-3:Typical examples of various types of ceramic a.c. longrod and post insulator profile.

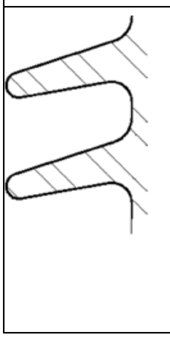
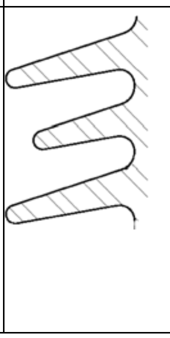
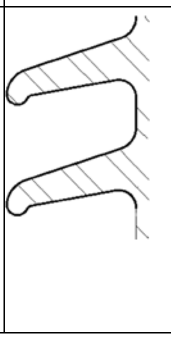
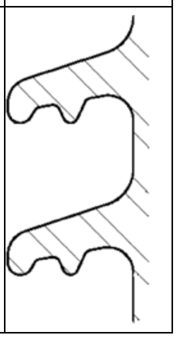
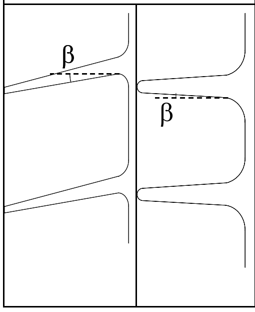
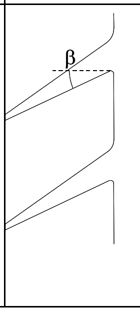
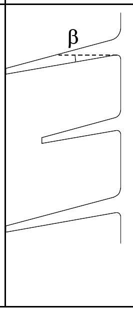
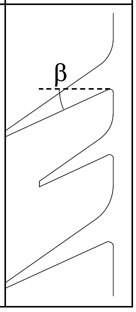
Plain shed	Alternating shed	DIN shed	Anti-fog shed
			

Table 7-4: Typical examples of polymeric insulator profiles

Flat shed [a]	Inclined shed [b]	Flat alternating shed [a]	Inclined alternating shed [b]
			

a: Flat sheds have an underside inclined between 7° below and 3° above the horizontal, i.e. angle β.

b: Inclined sheds have an underside inclined more than 10° below the horizontal, i.e. angle β.

7.4 Maintenance and palliatives

The maintenance requirements for in-service equipment depends largely on the following factors:

- **Site experience:** A site, circuit or particular item of equipment is considered to have good or poor experience based on the level of pollution activity and the propensity to flashover. With good experience there is no requirement for maintenance.
- **Site pollution severity:** The pollution severity of a site or installation is considered with reference to site pollution measurements as described in section 4.3.
- **Site commercial or strategic value:** The commercial and strategic value of a site, installation or piece of equipment is based upon both its location in the system, and the degree of importance of the connected clients. The value and the characterisation of the site may change from year to year and so it is advised that this assessment be performed in co-operation with the system operators.
- **Functional attributes:** The equipment insulation at a particular site is usually designed according to a specification, whether functional or prescriptive. Over time the criteria used in the specification may show to be unsuitable or outdated, as the system properties or the environment change. As a result, equipment may become under-dimensioned for the changed circumstances and, so a palliative may need to be considered.

The information obtained about the aforementioned factors are combined to form an action plan that is based on the risk posed by each condition together with the most cost effective solution to control or mitigate that risk. Such a plan can be individual to a particular site and may indicate the interval and type of maintenance for the various groups of equipment identified. A regular review of such a plan is necessary to keep abreast of changed circumstances. This action is especially required after a pollution-related incident that possibly indicates a weakness in the existing plan.

When reviewing the plan of action the following issues may be considered:

- The occurrence of pollution, or heavy wetting, incidents that were not reported during the previous review period.
- Changes to the site, circuits, or operating environment that may affect the performance of the equipment. For example: local civil works, a new industrial plant or a changed weather pattern.

- A review of the maintenance plan in place, with a view of identifying possibilities for saving money by adopting more cost-effective palliatives and extending the maintenance interval.
- The risks associated in adopting the modifications to the maintenance plan. The local maintenance staff may have valuable experience in this regard.

A schematic representation of the maintenance, or palliative options available, is presented in Figure 7-1. More information on a selection of these is as follows:

- **Cleaning:** The cleaning of insulators is a very labour intensive but effective method of removing pollutants from its surface. In most cases, it is only used when other methods are ineffective or impractical. Cleaning can be conducted by hand wiping, with or without the use of solvents, or by compressed air or dry abrasive cleaning. Typical abrasive cleaning compounds are ground corncob mixed with ground walnut or pecan shells, powdered silica, lime or combinations of these. Cleaning is conducted under de-energised conditions. The costs of cleaning are mostly related to the manpower used and the capital costs of the spray equipment if abrasive cleaning is used.

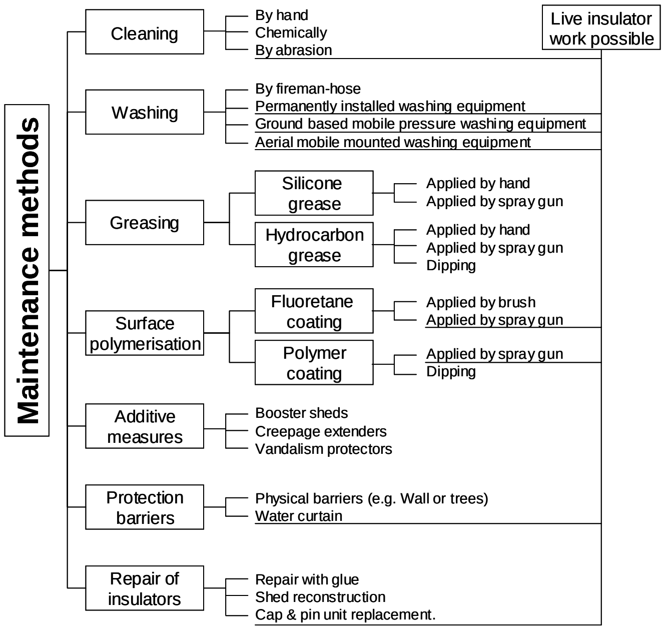


Figure 7-1: A schematic representation of the various insulator maintenance and palliative methods available.

- **Washing:** This is a relatively easy means of avoiding pollution-related outages. It can be performed on de-energised or on live equipment. Washing is usually conducted remotely by using a pressure washer but it can also be done by hand on de-energised equipment. For live washing, there are special requirements on the quality of the water and the minimum distances of the sprayer to the insulator. These aspects and other detailed information can be found in the Cigré review[1] (Section 8.2.1 for ceramic and section 8.2.2 for polymeric insulators). When live washing is carried out in a particular station, it is normally performed at regular time intervals to limit the build up of a latent surface pollution that can be activated during the washing process and thereby cause a flashover. The costs of washing are related to the manpower used and the capital cost of the water-sprayer.
- **Greasing:** Greasing is labour intensive and it requires a certain amount of experience to ensure that the grease coating is of the correct consistency and thickness. The two types of grease in general use (Section 8.3.2 of [1]) are silicone or hydrocarbon based. Both of these types can be applied by hand or by conventional air-less spraying equipment. When spraying, hydrocarbon grease needs to be heated before application while silicone grease is dispersed in a solvent. Grease must be sampled regularly to derive its condition and to

ascertain when it should be replaced or re-sampled. Tests to determine the condition of the grease may include: checking its hardness; its particle-load factor and its hydrophobicity. The frequency of the grease sampling will depend on the importance of the site, circuit or equipment and the level of risk that the local staff wishes to accept. Typically a 2-3 year sample interval is employed. The initial costs associated with greasing are related to the manpower, access equipment and the grease itself. There is also an ongoing cost associated with the regular inspection, which is due to the manpower, and the access equipment required.

- **Surface polymerisation:** The application of a polymeric insulator coating – such as a room temperature vulcanised (RTV) silicone rubber – to insulators is labour intensive. The application of the layer requires a certain amount of experience to ensure that it is of sufficient thickness and correct consistency. These coatings have, however, generally a longer life-span than that of a grease layer (Section 8.3.3 of [1]). Polymeric coatings can be applied by brush or by using air-less spraying equipment. An inspection programme is required to determine the condition of the coating and its need for replenishment or replacement. Such a programme normally comprises a visual inspection and a hydrophobicity measurement at an inspection interval of 5-6 years. The initial costs incurred with polymeric coatings are related to manpower, access equipment, the coating material itself and the application equipment. There is also an ongoing cost related to the manpower costs for inspection and maintenance of the coatings.
- **Additive measures:**
  The installation of creepage extenders are less labour intensive than greasing or the application of a polymeric insulator coating, but they do require the disconnection of the equipment from the electrical system so that the extenders can be slipped over the insulator. The type and number of creepage extenders used will depend on the dimensions of the equipment to which they will be fitted. Creepage extenders are made from a heat-shrink plastic and can be fitted by local staff following a basic training. A periodic visual inspection, e.g. at an interval of 5-6 years, is required to determine the condition of the creepage extenders (e.g. in terms of material erosion or puncture) and its need of replacement or maintenance. Creepage extenders can be used in combination with a polymeric coating or a regular washing programme. The cost of using creepage extenders is associated with the manpower for its installation, the extender itself and the hire of necessary access equipment. The ongoing costs of using creepage extenders are related to the manpower needed for the inspection.

  The installation of booster sheds (see section 8.4 in [1]) are even less labour intensive than that for creepage extenders as they do not require the disconnection of the equipment from the electrical system although it has, of course, to be de-energised. The type and number of booster sheds depend on the dimensions of the equipment to which it will be fitted. A booster shed is a fairly stiff sheet of shaped polymer, to which is moulded some small polymeric studs so that it stands a few millimetres above the surface of the insulator shed and its outer diameter is somewhat larger than that of the latter. It is tailored made and contains a radial joint to enable it to be easily fitted onto the insulator. Its can be installed by local staff by following simple instructions. A periodic visual inspection, e.g. at an interval of 5-6 years, is required to determine the condition of the booster sheds (e.g. in terms of material erosion or puncture) and their need of replacement or maintenance. Booster sheds may be used in combination with a regular washing programme. The cost of using booster sheds is associated with the manpower for it installation, the sheds themselves and the renting of necessary access equipment. The ongoing costs of using booster sheds are related to the manpower needed for the inspection.
- **Protection barriers:** Some network owners resort to natural or artificial barriers to protect installations from pollution. This measure could take the form of trees planted or walls

erected around the substation or line. These barriers may also fulfil other functions, such as the control of noise pollution emanating from the electrical installation. Some types of barriers are of temporary nature, such as a water curtain that is initiated around sensitive installations during salt storms[5]. The costs associated with barriers are related to their installation and maintenance. This is especially so in the case of a water curtain.

- **Repair of insulators:** Although insulators are fairly robust pieces of equipment, damages or defects sometimes do occur. Examples are: punctures, erosion, tracking cracks or shattering. On equipment insulators, damage can happen due to the explosion of nearby equipment or mishandling that lead to broken sheds. On cap and pin insulators, units can readily be replaced – even under live-line conditions if suitable procedures are in place. On equipment insulators, the damage is assessed and the equipment replaced if the damage is serious enough. On polymeric insulators, some manufacturers supply kits to repair torn sheds – either by using an adhesive or by shed reconstruction.

The choice of the palliative depends on the technical, practical and economic requirements. The technical one may relate to the particular application whereas the others are related to the ease and cost of the application as well as the effort and cost associated with managing the palliative for the duration of the service that is required from the equipment to which it is applied.

7.5 Lifetime of insulators

Deleterious changes, from the viewpoint of pollution flashover performance, can occur both on the surface and within the body of an insulator.

Roughening of the surface will increase the aerodynamic catch of pollutants. A reduction in the water-repellent property of the insulating material (i.e. a change from the hydrophobic state to the hydrophilic one) will result in an increase in leakage current.

Corrosion expansion of metal parts embedded in structural mortar or even the volumetric increase in that mortar can result in radial cracks in a porcelain shell. Such cracks cause a reduction in the leakage path of that part of the insulator. Incipient defects within the body of porcelain can sometimes increase in size with time which can also produce cracks, often in regions hidden from a visual inspection - e.g. within the head of a porcelain cap and pin insulator. Impurities within porcelain and in glass can also result in an increase in the expansive pressure within the body of such insulators, thereby possibly leading to the formation of cracks in porcelain and shattering of toughened glass.

Many forms of adverse changes over time, sometimes of short duration, have been noted with polymeric insulators. These have involved both the bulk of the material and the joints between the components. Fortunately, improvements in the design and the manufacturing process of such insulators have overcome most, if not all, of these earlier noted problems.

As improvements have come about due to the research effort - the findings of which are sometimes not released into the public domain for obvious commercial reason - the appearance of new products on the market need to be carefully assessed from the ageing viewpoint. Although this caution applies particularly to polymeric insulators, a prudent operator of a high-voltage power network should bear it in mind for all types of insulators.

8 Consideration of the Cost and Duration of the Dimensioning Process

Where there has been some good service experience in the same, or very similar, environment the task of insulator selection is considerably simplified and the steps suggested in Section 6.2 can then be followed. When this is not so, however, a testing programme may be required and so the following aspects need to be taken into consideration.

The flashover of a polluted insulator usually involves the elongation, alignment and conjoining of a number of surface arcs along its length. This process occurs more readily as the magnitude of the currents in these arcs increases.

Because the critical current is of quite a few amperes to cause such flashover, the test transformer and its regulator are costly pieces of equipment; especially as they need to have low voltage regulation at the high current-magnitudes. Under natural conditions, the critical level of pollution for the desired test of the insulator is not often reached; possibly happening only once in two years. Even in an artificial test of fixed and sustained pollution severity, an hour may elapse before the arcs are in their critical positions to produce the weakest electrical situation; the number of repeated tests depends upon the degree of confidence required from the results. To perform the conditioning of the insulator and to run an adequate number of identical tests – possibly three successes out of four attempts to obtain a Withstand Pollution Severity value for a particular voltage – may take the best part of a day in an artificial pollution chamber.

Although the artificial pollution test is obviously the quicker – and cheaper -- one to conduct, it is important to recognise that it determines only the ability of the insulator to cope electrically with a controlled severity of wetted pollution. In contrast, the natural pollution test fully replicates the service condition in that it shows both the extent to which an insulator collects pollution for a certain environment and the ability of this energised insulator to withstand this pollution deposit when wetted with fog, mist, drizzle etc. A combination of the findings from tests made at an appropriate outdoor facility and the complementary ones conducted in an artificial pollution chamber provides the most reliable results for predicting the pollution flashover performance of a candidate insulator under most conditions.

9 Qualification by Laboratory Testing

If there is no need or no possibility to perform field tests, artificial pollution tests – performed in a laboratory – may help the user to take decisions on the insulation. Also, the results of field tests may require additional laboratory tests. In general, laboratory tests can be completed in a much shorter period of time than that required for field tests.

9.1 Selection of the method

The two types of tests standardised by IEC are the Salt-Fog method and the Solid-Layer method, the latter now often referred to as the Clean-Fog test because of the technique used to wet the pollution layer. The former simulates coastal pollution where a thin conductive layer formed by the salt covers the insulator's surface. In practice, this layer contains little - if any - insoluble matter. The same test also applies to industrial pollution - principally gases - which result in the formation of acids when there is essentially no non-soluble material present on the surface. In contrast, the Solid Layer (Clean-Fog) method simulates the condition when there is an appreciable amount of non-soluble pollution in addition to that forming ions when wetted.

The current versions of these two methods - IEC documents 60507[6] and 61245[7] for a.c. and d.c. energization respectively - were developed for the testing of ceramic insulators. The major difficulty with the testing of polymeric insulators - especially those of the silicone rubber variety - is the temporary loss and subsequent recovery of the water-repellent properties of its polluted surface due to various phenomena. Because some people may wish to know the consequence to the pollution flashover performance of having various levels of this temporary reduction in the water-repellent property, it would be ideal to have a test which would create this situation in a controlled way to enable either the corresponding Flashover Voltage or Withstand Salinity to be determined. Unfortunately, this is no easy task. Further details and the currently assessed best method of overcoming this testing problem are dealt with in Appendix E.

For environments close to the coast, characterised by a rapid pollution build up and a low non-soluble content, no laboratory test method that is generally accepted is presently available for polymeric insulators. One option is to use the modified Clean-Fog method, described in Appendix E, but with a low non-soluble component in the contamination slurry, e.g. 10-20 g Kieselguhr per 1 000 g water. Another noteworthy test, but currently of non-standard status, is conducted using the Dry Salt Layer method[8]. This latter method is proposed as being representative of coastal and inland environments characterised by a pollution deposit on the insulators with a low non-soluble component. It can also be used to test both ceramic and polymeric types of insulator.

It is known that d.c. laboratory tests tend to provide conservative, i.e. lower, withstand values than is experienced for the same pollution level in service (see figure 6-5 in [1]). A design based on service experience, when possible, should, therefore, be preferred. If sufficient service information is not available, then the withstand severity required (see section 9.2) for the chosen laboratory test should be somewhat reduced to compensate for this effect.

9.2 Selection of the test severity

This section provides a simple method of how to calculate a withstand severity for laboratory pollution tests from site pollution severity measurements[9].

From the site pollution severity measurements the statistical severity, γ_{s2}, which is the level having a 2% probability of being exceeded, must be estimated. This can be done through a simple graphical method, of which an example is shown in Appendix A. Such a method gives acceptable results if at least 40-50 individual measurements are available. If this is not the case, more advanced statistical method, e.g. a maximum likelihood analysis[10], should be used to obtain the confidence interval, so that it can be included when estimating the statistical severity.

The strength of the insulation is characterised by the co-ordination withstand severity γ_{cw}. This is defined as the pollution severity that the insulator must be able to withstand (i.e. defined as a 10% flashover probability). The co-ordination withstand severity is calculated from the statistical severity γ_{s2} as:

$$\gamma_{cw} = K_{cs} \cdot \gamma_{s2}$$

Where K_{cs} is the statistical co-ordination factor, which can consist of several components such as:

$$K_{cs} = K_r \cdot K_s \cdot K_i \cdot K_p \cdot K_d \cdot K_m \cdot ...$$

Some are:

- A factor, K_r, which is based on a risk of flashover evaluation, to ensure the required performance is met. This statistical analysis should take into account the number of insulators that will be exposed to the same conditions as well as the regularity by which wetting events occur in service.
- The severity measurement needs to be corrected, by a factor K_s, if it was performed for a differently shaped and sized insulator than the one being specified for the installation.
- Insulator material also influences the amount of pollution deposit. This is corrected by factor K_i, which gives the ratio of pollution deposit on that material insulator relative to that of a ceramic insulator.
- The severity measurement also needs to be corrected with a factor, K_p, if the measurements were performed on non-energised insulators.

- It has been shown that insulators with a large diameter collect less pollution than those insulators with a small diameter. The diameter correction factor, K_d, can be calculated as follows (p. 31-32 of [1]):

$$K_d = 2{,}6 \cdot D^{-0{,}21}$$

Where D is the average diameter of the insulator expressed in mm.

- K_m corrects for the lack of precise data, but if sufficient severity measurements are deemed to have been taken – e.g. 50 measurements – then $K_m = 1$ can be assumed. However, it can be chosen higher to compensate for too few severity measurements.

Appendix D provides further information that could help with the selection of appropriate values for these correction factors.

Instead of adjusting the pollution severity at which the laboratory test is performed with the correction factors explained above, it is also possible to perform the test at the *site pollution severity*, but at a an increased voltage level. The test voltage can be calculated from the statistical co-ordination factor, K_{cs}, as follows.

$$U_{test} = K_{cs}^{\alpha} \cdot U_{service}$$

$U_{service}$ is the maximum operating voltage across the insulator (i.e. normally $U_m/\sqrt{3}$) and "α" is explained, with examples of typical values, in Appendix D.4.

Laboratory testing to qualify an insulator can either be a pollution withstand-test or a range of pollution tests to determine the insulator's flashover characteristic. The former is preferred as it requires only a maximum of four pollution tests to qualify the insulator and is better suited for polymeric insulators - especially silicone rubber ones as numerous flashovers are avoided that may reduce its hydrophobic properties.

A withstand pollution-test is used to "prove" that the insulator has an acceptable performance in a certain environment. Because a withstand test consists of only four pollution tests, the user has a risk that insulators with an unacceptable performance may pass this withstand test. This lack of discrimination may be overcome by performing more than the prescribed number of laboratory tests. On insulators without internal field grading another option is to perform flashover tests to determine the 50% flashover voltage, U_{50}, and to calculate the withstand voltage, U_{10}, by:

$$U_{10} = (1 - 1.28 \cdot c)U_{50}$$

where, c is the normalised standard deviation as determined form the test results (i.e. $c = \sigma/U_{50}$).

9.3 Areas located at a high altitude

Depending on how critical the selection of the insulators is, it may be necessary to adjust the flashover performance values that are available to take account of the altitude of the installation. This correction can be performed as described below.

Ceramic insulators:

Service voltage flashover is the important performance criterion to consider. The change of flashover voltage as a function of altitude (air density) is given in the Review (pp 68-69 in [1]):

For a.c: $$E = E_0(1 - 0{,}05h)$$

Where:

E_0 is the flashover voltage at sea level

h is the height above sea level in km

E is the flashover voltage at height h

The creepage length of the insulator must be increased in the ratio (E_0/E) as the altitude increases while at the same time preserving the profile. In addition, the minimum arcing distance must be increased to ensure that lightning and switching surge performance is maintained (see IEC 60070).

Polymeric insulators:

The dominant failure mode with polymeric insulators is mechanical and as altitude is increased steps must be taken to ensure that there is no aggravation of the mechanisms which cause degradation of the core sheath. Corona attacks polymeric materials[11] and, since the corona inception field is proportional to air density, the electric field grading must be designed so that there is a proportional decrease in the electric field to compensate for the increase in altitude (decrease in air density).

Although flashover is not the dominant failure mechanism with polymeric insulators – especially silicone rubber ones, it is advisable to increase the creepage length while retaining the profile.

10 Using Service Experience

Service experience, in the form of the flashover performance or the need for maintenance on insulators, can be used in several ways to select and dimension insulators:

- Insulators that perform well in a specific area can be selected again for new installations in that same or in similar areas.
- The flashover performance or maintenance requirements for insulators in a specific region can be plotted against the measured pollution severity to obtain an estimation of the required insulator length as a function of pollution severity. An example of such a graph is shown in Figure 10-1[12].

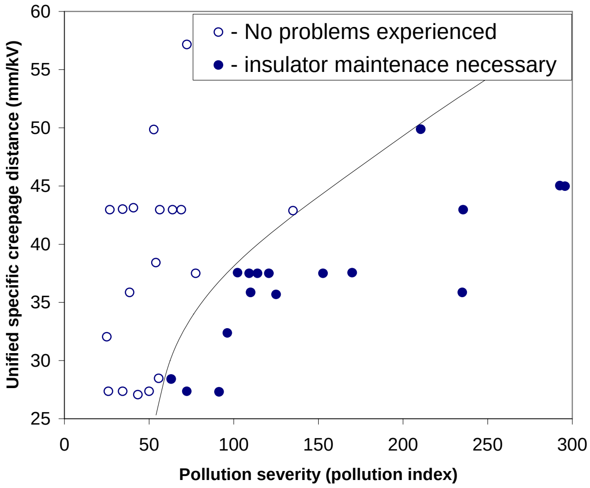


Figure 10-1: An example of how a creepage path requirement can be derived from site pollution severity measurements and the need of insulator maintenance[12].

- The flashover performance of insulators in service as a function of the measured pollution severity can be combined with flashover data from laboratory tests to obtain a simple relationship between the site pollution severity and laboratory severity[13]. This relationship can then be used to specify directly a required withstand severity for a specific area.
- The flashover performance of a reference insulator at a particular site can be used, in combination with its relative performance to that of other insulators as determined through laboratory testing, to dimension other insulator types for that particular site. If an insulator is known to flashover at a given rate per year at a site, then the equivalent pollution severity – in terms of the parameter used in an artificial pollution test – can be determined by establishing the flashover voltage versus the pollution severity characteristic of that insulator in that artificial pollution test. Of course, this equivalent pollution severity is

related both to the particular insulator type and its flashover-rate at that site. For example, tests conducted at Brighton Insulator Testing Station identified an insulator type that flashed over once per year. At the relevant voltage, flashover in the salt-fog test occurred, on that insulator, at a salinity of 60kg per cubic metre.

The relative flashover performance of an insulator can be expressed as the length of a standard insulator divided by the length of the candidate insulator for flashovers to occur across both of them under the same voltage and environmental conditions. Use of such a relative performance factor enables the flashover statistics -- i.e. number of flashovers per year at a site -- to be determined even though the data come from different insulator types. That is, the axial flashover stress of a test insulator is normalised to that of the standard insulator by dividing its stress by its relative performance. Therefore, if the relative performance factor of a candidate- insulator is known, the flashover probability of that insulator at that site can be determined. It seems possible, that this approach could be used to estimate the flashover probability at other sites by using the relationship between flashover stress and pollution severity that has been established in artificial pollution tests (See section 6.2.1.1 of [1]).

10.1 Field tests

If sufficient time is available, long-term testing under natural pollution conditions can be performed to get results of the actual service performance of insulators as well as of site severity data. The Review[1] provides information about typical field-test programmes as well as examples pertaining to some field-test stations (see section 6.2). The details of different techniques used in field-testing can be found in section 5 of the Review.

Such field trials offer the opportunity to obtain the insulator-flashover stress, e.g. by lengthening the insulator through explosive fuses[1] which may not otherwise be available from the system operational experience. An additional advantage is that the susceptibility of the insulator to ageing can also be evaluated[14].

The following parameters can provide useful information for the selection and dimensioning process:

- Site severity measurements: Regular site severity measurements conducted according to the recommendations given in Appendix C.
- Weather information: Precipitation, humidity, temperature and wind. Optionally, information about the intensity of the ultra-violet component of the sunlight may be useful in the estimation of ageing.
- Insulator-flashover performance: This can be done either through measuring the leakage current across the insulator or by determining the insulator flashover stress - see section 5.6 and 5.7 of the Review [1].
- Periodic visual inspections of the condition of the insulators under test.

11 Cost and Risk Analysis

Although insulators form a relatively small component of the total cost of a new project, the potential consequences of their bad performance can be costly. It is, therefore, important to consider this aspect when selecting insulators. One way of dealing with this aspect is to define an operational risk, which is the likelihood of failure (either flashover or mechanical breakage) multiplied by the severity of the consequences of failure.

Minimum technical requirements, and tests to verify these, are provided in a technical specification which ensures that the new equipment will have a sufficiently low likelihood of failure in the intended environment. These technical requirements are normally adopted from the available international or national standards, e.g. IEC or IEEE, but they may also include a company's specific requirements over and above those of the standards that relate to the operational experience of that utility. The technical specification is generally functional, e.g. citing a particular pollution level at which the equipment must operate. However, this approach may not always be the best one to adopt, especially for areas where sufficient service experience is available that allows the specification of the required insulation dimensions (e.g. leakage distance or axial length) to be stated which would provide reliable operation.

Another approach that has been followed as an extra insurance of good long-term performance is to get the supplier to demonstrate, in addition to the technical specification, that the equipment is fit for its purpose by the submission of suitably detailed in-service experience in a similar, or more onerous, operating environment (e.g. a natural pollution testing station). For example, a minimum period of 2 years incident-free pollution performance without the use of a palliative is required by some companies. The decision of whether or not to follow this approach is based on a risk assessment of equipment type, supplier knowledge, in-service experience and the proposed application.

Ordinarily, equipment that can be utilised without a palliative is preferred, because palliatives represents a maintenance cost that cannot be easily capitalised to the installed value. In cases were a palliative has to be used, additional information on the maintenance requirement for that palliative is requested from the suppliers of the equipment and palliative. In some circumstances, the utility may be better placed to advise on the best practice for sustaining an acceptable level of pollution performance. Before such measures are implemented it is advisable to clear the use of it with the equipment-supplier.

12 Asset Management

The subject of asset management has now become very topical in many industries - especially those that have been de-regulated - and are now subjected to increased commercial pressures. Therefore, it is timely that a paper [15] was prepared for the 2002 Cigré conference that deals with a survey conducted by the joint taskforce C1/B2/B3-01: "Asset Management" and to note that this group of experts propose to publish a Cigré brochure for the publication of their guidelines in the near future.

In the meantime, it is worth stressing with regard to polluted insulators that prudent managers of high-voltage power systems will probably conduct inspections, possibly supported with sample tests, of its outdoor insulators over their anticipated long lifetime - e.g. fifty years. From United Kingdom experience, it is concluded that it is unwise to assume that the electrical and mechanical condition of insulators is the same for all types in a given general location. This caution applies even though the insulators are of the same generic design (e.g. cap and pin) and material (e.g. porcelain) when only the operating voltage (and hence, probably, size) is different.

Cracking of porcelain insulators can occur due to a number of causes and some cracks are hidden from view. Often, cracks will reduce the pollution flashover performance of the insulator; the seriousness depends on the consequential reduction of the leakage path. Numerous methods for identifying cracked porcelain have been investigated.

Toughened glass has the advantage of being readily seen when faulty because shattering occurs. However, such an occurrence also has the disadvantage of being promoted by vandals and so such insulators, at certain trouble locations (possibly after the end of school holidays!), need to be inspected to assess their need of replacement to restore the Pollution Withstand Strength.

Polymeric insulators need to be inspected from a number of different viewpoints. In particular, the hydrophobicity of silicone rubber needs to be checked to ensure that permanent loss has not occurred to any appreciable extent because, if so, the pollution flashover performance will be greatly impaired. Also, it is vital that the structural member of resin bonded glass fibre has not become exposed to the elements. In some cases, this defect can result in the rod becoming burnt through discharge attack. Another, point of concern is the risk of promoting a brittle fracture of the glass component of the rod.

Insulators on d.c. systems possibly need to be inspected more frequently than do those on corresponding a.c. ones. Some points of concern are due to enhanced corrosion processes and the importance of the purity of the ceramic, especially that of glass.

13 References

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Appendix A: Worked examples for some typical cases

A.1 Introduction

Two worked examples are presented, which are based on site- severity information of actual sites. These are selected to illustrate the process to be followed when selecting insulators. The sites are as follows:

1. Coastal site
2. Desert coastal site

The aim of these examples is to show how the data, relevant to the insulator selection and dimensioning process, are extracted from the available site characteristics.

A.2 Example 1: Coastal

The proposed route for this line is situated between 5 and 50 km from the coast. This area experiences rain throughout the year resulting in very little dust in the air. Table A-1 presents the basic data collected for this project.

Table 13-1: A summary of relevant data to be considered for the definition of the task.

		Example 1
Application	Transmission line	
	Insulator Type	Suspension & Tension
	Numbers required	1020 (≈ 100 units located in the polluted sector)
System parameters	Voltage Type	a.c.
	Um	420 kV
	Wet P.F. Withstand	650 kV
	SIWL	1050 kV
	LIWL	1425 kV
	Other	Fault current 40 kA 3 sec.
Environment	Pollution type	Coastal
	Site severity estimation	ESDD measurements
	Ice and snow	Rarely
	Other	Negligible NSDD
Constraints	Installation geometry	Axial length<3,2 m
	Cost	--
	Time-frame	--
	Operational issues	Live-line work

A.2.1 Site severity estimation

ESDD measurements were performed on a standard shape glass disc insulator string during a period of three and a half years. The raw data are presented in Figure A-1.

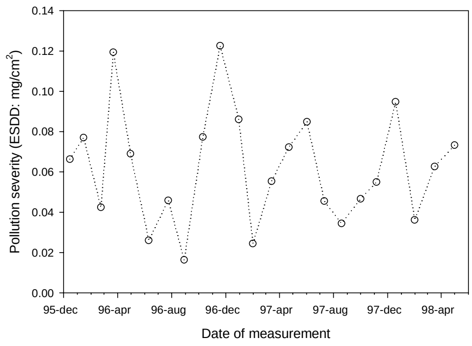

Figure 13-1: ESDD measurements at a coastal site.

These values are then sorted and plotted on Log-Normal probability paper -- see Figure A-2. A straight line can now be fitted visually through the measurement to determine an estimate of the 50% value and the standard deviation of ln(ESDD). In Figure A-2 these are 0,057 mg/cm^2 and 0,57 respectively. This curve can also be used to obtain an estimate of the statistical severity, i.e. 2% value, which is in this case 0,18 mg/cm^2.

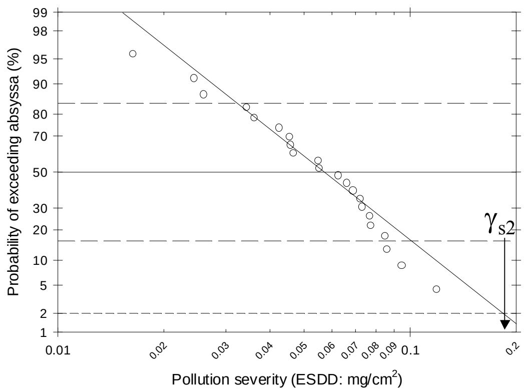

Figure 13-2: Graphical estimation of the distribution function describing the pollution severity at Dungeness. The statistical severity, γ_{s2}, is indicated.

A more rigorous method for fitting the distribution function can also be employed. For comparison, the method of maximum likelihood has been used to fit a Log-Normal distribution function to the same coastal site ESDD measurements[A-1]. The results are given graphically in Figure A-3, which shows that the fitted curve has a 50% value of 0,056 mg/cm^2 and a standard deviation of ln(ESDD) equal to 0,51. In this case, the statistical severity (i.e. the 2% value) is 0,16 mg/cm^2. Furthermore, the 95% confidence intervals are also determined and indicated in Figure A-3 as dotted lines.

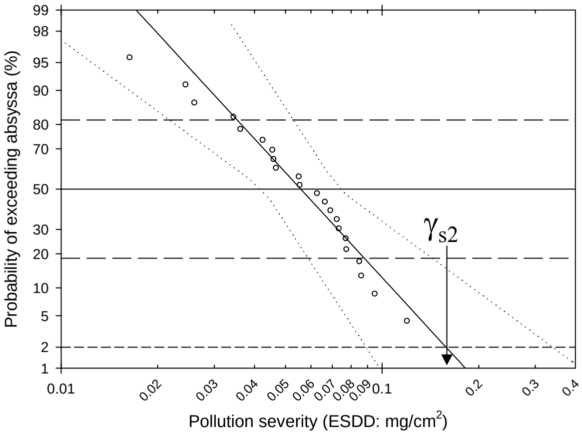

Figure 13-3: Maximum likelihood estimation of the distribution function and 95% confidence interval based on site severity measurements [A-1]. The statistical severity, γ_{s2}, is indicated.

A.2.2 Selection of a suitable profile and material

The pollution in this site comprises sea salt, which is fast dissolving. Wind is the main carrier to transport the contaminants to the insulators since they are not subjected to direct sea spray. An open profile will have in this case an advantage since it has a low pollution catch and is easily accessible to natural cleaning. Both polymer and ceramic are acceptable insulator types.

A.2.3 Specification of a standard withstand pollution test

The required pollution severity withstand level can be calculated for the pollution severity shown in Figure A-3. The figure shows that the statistical severity, γ_{s2}, corresponds to an ESDD level of 0,16 mg/cm^2.

The correction factors were selected as follows:

- K_r: 1,4 (Based on the number of insulators and a test standard deviation of 8% - See Figure D-13)
- K_s: 0,8 (Select an open profile – See Table D-1)
- K_i: 1 (Material glass – See Table D-2)
- K_p: 1,0 (Effect of energisation – See Table D-3)
- K_d: 1,0 (Diameters same)
- K_m: 1,0 (A sufficient number of measurements are available to estimate the 2% value)

Thus the statistical co-ordination factor K_{cs} = 1,12.

The co-ordination withstand required withstand severity can then be calculated as 0,18 mg/cm^2.

For glass line insulators it is possible to perform flashover tests. The 50% flashover voltage should not be less than:

$$U_{50} = \frac{U_m}{\sqrt{3} \cdot (1 - 1.28 \cdot c)}$$

where "c" is the normalised standard deviation which can be taken as 0,08. Inserting these values into the equation above results in a requirement that the U_{50} should not be less than 270 kV at a test severity of 0,18 mg/cm^2.

A.3 Example 2: Desert Coastal

The second example regards the re-insulation of an existing line due to the high number of pollution flashovers it has experienced since it was commissioned. This line, with a length of about 70 km, experiences an average of 8 flashovers per year due to contamination.

The transmission line is situated on a coastal plane less than 5 km from the sea. This area is very dry with a rainfall of less than 200 mm per year. However, for 6 months of the year the relative humidity is very high leading to a early morning occurrence of dew. The prevailing wind direction is from the coast, which carries a mixture of salt and dust particles quite far inland. Table A-1 presents the basic data collected for this project.

Table 13-2: A summary of relevant data to be considered for the definition of the task.

		Example 2
Application	Transmission line	
	Insulator Type	Suspension & Tension
	Numbers required	450

System parameters	Voltage Type	a.c.
	Um	132 kV
	Wet P.F. Withstand	400 kV
	SIWL	--
	LIWL	795 kV
	Other	Fault current 10 kA 3 sec.
Environment	Pollution type	Coastal high inert content
	Site severity estimation	None
	Ice and snow	Never
	Other	Dry and Humid
Constraints	Installation geometry	Axial length≈ 1,66 m
	Cost	--
	Time-frame	--
	Operational issues	Live washing system

The line is presently insulated with porcelain longrod insulators with a creepage distance of 71 mm. The line suffers frequent flashovers in spite of being washed on average twice per year.

A.3.1 Site severity estimation

No ESDD, NSDD or any other site-assessment measurements have been performed at this site. A visual inspection of the presently installed insulators revealed that the humid conditions in combination with high winds from the sea create ideal conditions for a quick build-up of pollution on the insulators. This is because the combination of salt and dust carried by the wind absorbs moisture if the relative humidity is above 75%. This makes it damp enough to stick to the insulator surface on contact.

The lack of severity measurements is a serious drawback but the service experience can be used in combination with published flashover results from other desert areas to estimate an approximate severity level. From the literature, it can be noted that a desert environment typically has a high NSDD level. In Saudi Arabia a ratio of 5-6 mg/cm^2 has been recorded[A-2], while in Iran levels of 7-10 mg/cm^2 have been measured[A-3] and in Tunisia typical levels have been between 0.5 and 2 mg/cm^2[A-4].

Standard laboratory tests on a longrod insulator of similar design to that used on the transmission line resulted in a 50% flashover level (U_{50}: kV) versus pollution level (γ in ESDD: mg/cm^2) described by the following equation for tests done with an NSDD level of 0,2 mg/cm^2[A-2]:

$$\frac{U_{50}}{l} = 45{,}311\gamma^{-0{,}1810}$$

Where l is the length of the insulator in m.

The calculated design values, after correction for the high level of NSDD, are presented in Figure A-4.

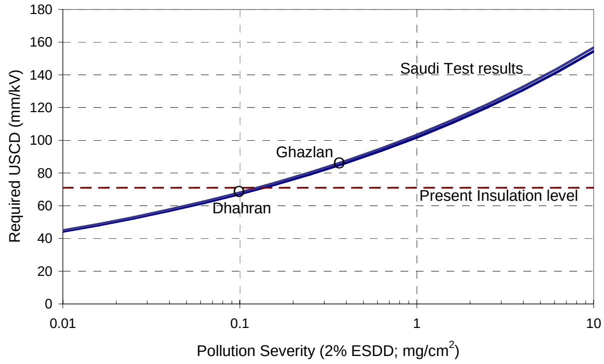

Figure 13-4: Design curve from Saudi Arabia[A-2].

Since the line is under performing the lowest limit of the pollution level at this site is 0,2 mg/cm^2. A more realistic estimation of pollution level would be a 2% level of about 0,5 mg/cm^2.

A.3.2 Selection of a suitable profile and material

Since this is a re-insulation project, there is a severe constraint on the length of the insulators. Figure A-4 shows that, for the estimated pollution level, an increase of at least 30% in the creepage distance is necessary. It is deemed that it is impractical to achieve this increase with ceramic or glass insulators as it may lead to a very high creepage distance to length ratio of such insulators, thereby risking inter-shed breakdown.

Based on the data presented in the Review (Section 3.3.2) it was decided to specify silicone rubber insulators to utilise its hydrophobic properties to obtain a better flashover performance for the given section length.

A.3.3 Specification of a standard withstand pollution test

Most of the correction factors are not used in this case since the selected ESDD level is based only on a rough estimation of the site severity. The statistical severity, γ_{s2}, is therefore taken as an ESDD = 0,5 mg/cm^2. However, it is still necessary to select a value for K_r from Figure D-13 based on the number of insulators exposed to the polluted conditions.

- K_r: 1,5
  (Based on the number of insulators and a test standard deviation of 8% - See Figure D-13)

Desert environments often have frequent wetting events, in the form of early morning dew, due to the large diurnal temperature variations. If this is the case, a complete statistical analysis is advisable.

The co-ordination withstand severity is, therefore, selected to be 0,75 mg/cm^2. A withstand test is specified according to Appendix E of this document with a resting time for the polymer insulators of one week. The NSDD level for this test is specified as being 5 mg/cm^2.

A.4 References

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Appendix B: General descriptions of types of environment

The general types of environment are classified according to the sources of pollution, what it consists of and how it gets on or off the insulator. Descriptions of typical polluted environments follow. It should, however, be noted that these descriptions are rather simplistic and that actual environments are more complex as they may have characteristics of several of the environmental types described below.

B.1 Inland

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

B.2 Agricultural

Often these will be areas subjected to ploughing or crop spraying. The pollution layer on the insulators consists mostly of fast or slow dissolving salts such as crop-spraying chemicals, products of burning, salts present in the soil, or bird droppings. The pollution layer will normally have a medium to high non-soluble component (NSDD). Natural cleaning of the insulators can be quite effective depending on the type of salt deposited. The pollution often comprises heavy particles which settle on horizontal surfaces, but it may also be wind borne pollution.

B.3 Indirect Coastal

These areas are in the vicinity of the coast which, in some cases, can be as far as 10-20 km inland. The pollution layer on the insulators consists of quick dissolving salts with a low non-soluble component -- i.e. low to very low NSDD. The build-up of pollution occurs over a relatively long term through a deposit of wind-borne salt particles. Natural cleaning of the insulators is effective as the pollution consists mainly of fast dissolving salts which are not very adhesive.

B.4 Direct coastal

These areas are in the direct vicinity of the coast, which in most cases is less than 5 km away. As occurs in indirect costal areas, the pollution layer on the insulators consists of quick dissolving salts with a low non-soluble component – i.e. low to very low NSDD. The pollution build-up is generally rapid, especially during conductive fog conditions, and the insulator may be exposed to a direct salt-spray. Pollution is deposited onto the insulators mainly by precipitation. Natural cleaning of the insulators is effective as the pollution consists mainly of fast dissolving salts which are not very adhesive.

B.5 “Liquid” industrial

These are areas located in close proximity to an industrial pollution source, and it may affect only a few installations. The pollution layer constitutes mainly of dissolved gasses -- such as NO_x, SO_x. The pollution layer may have a medium to high non-soluble component (medium to high NSDD). The pollution is deposited onto the insulators mainly by wind. The effectiveness of natural cleaning in industrial areas can vary greatly depending on the type of pollution present.

B.6 Particulate industrial

These are areas located in close proximity to an industrial pollution source, and it may affect only a few installations. The pollution layer may constitute conductive particulate pollution -- such as coal, metallic deposits or pollution that dissolves slowly -- such as cement and gypsum. The pollution layer may have a medium to high non-soluble component (medium to high NSDD). The pollution is often heavy particles which settle on horizontal surfaces. The effectiveness of natural cleaning in industrial areas can vary greatly depending on the type of pollution present.

B.7 Inland Desert

These are areas that are characterised by sandy soils with extended periods of dry conditions. Such areas can be extensive. The pollution comes entirely from the soil. It normally comprises salts that dissolve slowly in combination with a high NSDD level. 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. The infrequency of rain together with the type of pollution (slow dissolving salts) causes natural cleaning to be not very effective. Critical wetting, which poses a risk for insulator flashover, can occur relatively frequently in the form of dew on the insulators.

B.8 Coastal Desert

These areas are characterised by sandy soils with extended periods of dry conditions. They can be extensive. The pollution layer in such areas arises from both the sea and the soil. It normally comprises salts that dissolve slowly in combination with a high NSDD level. 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. The infrequency of rain together with the type of pollution (slow dissolving salts) causes natural cleaning to be not very effective. Critical wetting, which poses a risk for insulator flashover, can occur relatively frequently in the form of dew on the insulators.

Appendix C Site pollution severity assessment

C.1 General principles

When performing a site severity assessment it is important to consider the following points so that this assessment truly reflects the actual conditions at the site (Refer to chapters 2 and 5 of the Review [C-1]):

a. The aerodynamic catch from air is the principal process by which the insulators are contaminated.

b. Although wind-borne pollution can be collected in the Directional Deposit Gauge, this value has to be correlated with that collected on an insulator before it can be used for the aforementioned task.

c. NSDD, in addition to ESDD, affects the flashover strength.

d. Obviously the most accurate measurement of ESDD and NSDD, or leakage current, is made on the candidate-insulators that are being considered for installation at that site. However, this is not always possible and so a short string of cap and pin units, or a porcelain longrod, can be employed as a substitute insulator[C-2].

e. For the purpose of comparison between different sites, standard insulators should be employed for this substitute insulator[C-2]. If applied extensively, the results can be used to produce a pollution map.

f. The pollution collected on the insulator is affected not only by the shape, size and material of the insulator but also by its mounting position, i.e. its angle to the vertical and its orientation (i.e. direction of the insulator's axis with regard to the compass, prevailing wind or main source of pollution).

g. An equilibrium deposit is reached when rates of catch and natural purging - due to airflow, rain or leaching during high humidity conditions - are equal. The times to reach equilibrium may vary from days to years.

h. Measurements must be repeated at intervals frequent enough to find the maximum levels between periods of natural washing[C-2].

i. When there is no natural washing, ESDD (and NSDD) can be expressed as a function of logarithm of time - from which a maximum value can be estimated.

j. To a first approximation, a.c. energisation does not affect the amount of pollution collected. In contrast, d.c. energisation substantially increases the pollution-catch.

k. In coastal areas characterised by rapid build up of pollution, hereafter called "rapid pollution", leakage current or surface conductivity measurements are better suited than ESDD and NSDD measurements to determine the SPS. It is advisable that these measurements should be made frequently. A typical interval of time between measurements should be one hour or less, as the duration of this type of pollution event could be less than 24 hours or even as short as one hour.

Point "h" above highlights the necessity of determining the interval for ESDD and NSDD measurements that will lead to the highest ESDD and NSDD values. One method of achieving this is described in section C.2. With this method several insulators are exposed to the same environment, but are measured at different time intervals. This detailed approach may not always be practical and a more pragmatic approach, such as ESDD measurements on single insulator disc, could be adopted. In this case, the sampling interval should be adjusted according to the type of environment. Table C-1 presents rough estimates for the different types of environment to help the user to choose a optimal measurement interval when this latter approach is followed.

Table 13-3: Typical measuring intervals to determine maximum ESDD values.

Type of Environment	ESDD measurement interval
Desert	From 12 to longer than 24 months
Coastal	1-6 months depending upon the length of dry season, or just after a rapid pollution event
Industrial	12-24 months
Agriculture	3-6 months
Inland (Low pollution)	3-6 months

For coastal areas with rapid pollution, when leakage current measurements are used in the site assessment, it is necessary to determine the equivalent severity of the Salt-Fog test that will produce leakage currents of a similar magnitude on the same insulator type and at the same voltage stress. The Salt-Fog tests are made with increasing salinity from test-to-test until $I_{highest}$-values comparable to those from the site measurement occur. The resulting test salinity is defined as the Site Equivalent Salinity (SES).

When using SPS -- or SES in the case of rapid pollution -- either to define a test or to dimension candidate-insulators, its value must - of course - be multiplied by appropriate factors to take account of the points mentioned earlier (i.e. material, shape, size, mounting-angle, orientation of the candidate-insulator and the type of energisation). Guidelines on the use and selection of these factors are provided in section 9.2 of this document.

In cases where a Pollution Severity Monitor is used, it needs to be calibrated against the pollution collected by insulators intended for that site. Although such instruments can also be calibrated in an artificial pollution test - thereby enabling the site's reading to be expressed in terms of the test's severity - correlation with the corresponding values for a candidate-insulator is still necessary.

This same argument also applies when using flashover statistics for insulators that are not the candidate-ones. That is, a site can be specified in terms of the withstand severity of the standard insulator in the artificial salt-fog test when that insulator has a certain flashover probability at the site for the same test-voltage. However, the Figure of Merit (FOM) – that is performance of the candidate-insulator relative to that of the standard one – still needs to be known.

The following test protocol has been developed by Cigré Taskforce 33.13.03, Pollution Monitors, to evaluate those instruments that are available to utilities and manufacturers. This protocol describes the measurements and the reporting method for various types of site pollution severity measurements. Additional information about site pollution severity measurements can be found in the Review (section 5 of [C-1]).

C.2 ESDD measurement

ESDD is given by the equivalent deposit of Sodium Chloride - in mg/cm^2 - on the surface area of an insulator, which has the same conductivity as that of the actual deposit dissolved in the same volume of water.

The ESDD is determined by removing a pollution sample from the surface of a chosen insulator and dissolving it in a known quantity of water. The conductivity of the resulting solution, its volume and temperature - together with the insulator surface area - are utilised to calculate the Equivalent Salt Deposit Density. Detailed instructions on how to perform this measurement will be provided in the forthcoming revision of IEC 60815.

C.2.1 Sample insulators and installation

For standardised site pollution severity measurements, a string of 7-reference cap and pin insulators – or reference longrod – with at least seven sheds, could be used. Two examples of a typical reference disc insulators are illustrated in Figure C-1. However, for a detailed assessment of a particular site the most accurate results are obtained if the measurements are made on the candidate-insulators that are being considered for installation at that location.

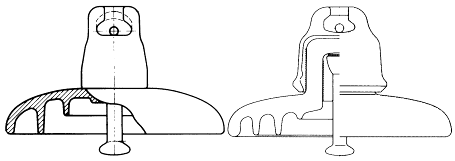

Figure 13-5: Details of two typical reference disc insulators
e.g. 120 kN disc with a spacing of 146 mm and a 305-320 mm creepage distance.

The insulator string is located at a height as close as possible to that of the line or busbar insulators. Each disc or shed of the insulator is monitored at a defined interval. In most cases, it is not necessary that the insulators be energised for the monitoring period. In special cases, such as pollution assessment for a d.c. installation, energisation of the sample insulators should, however, seriously be considered. A representation of the reference insulator for ESDD measurements is shown in Figure C-2.

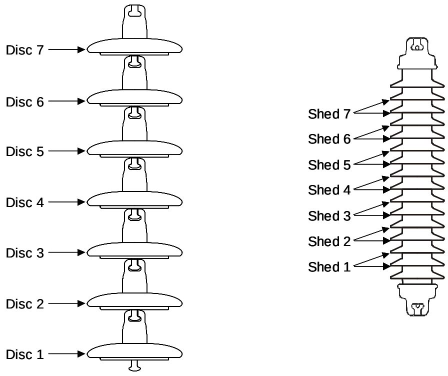

Figure 13-6: Identification of insulators, or sheds, for ESDD measurements

C.2.2 Sampling frequency

ESDD measurements are performed on the insulators shown in Figure C-2 at the following intervals:

Insulator or shed	2 - every month
	3 - every 3 months
	4 - every 6 months
	5 - every 12 months
	6 - at the end (24 months)

Obviously, the insulators should be de-energised before sampling takes place.

C.2.3 Duration

A typical site severity assessment will continue for at least 24 months in order to cover each season twice. The study can be started in any season, but at sites with extended dry periods it is advantageous to commence measurements at the start of that dry season.

C.2.4 Additional measurements

It is advisable to complement the ESDD measurements with one or more of the following:

- NSDD (see Section C.3)
- Leakage current (see Section C.5)

- Deposit Gauge (see Section C.6)
- IEC probe (see Section C.7)

C.3 NSDD measurements

The non-soluble deposit density (NSDD) is sometimes measured in conjunction with the ESDD and it characterises the content of the non-soluble contaminants in a pollution layer. It is normally expressed as mg deposit per cm^2 of insulator surface area. NSDD measurements can also be coupled with a chemical / physical analysis of the deposit layer. This information may indicate the source of the pollution. Also, the type and density of these contaminants could be important to the hydrophobicity feature of silicone rubber insulation [E1].

The non-soluble deposit density is an important measurement to take in combination with the ESDD measurement - as the electrical strength of an insulator is affected by the amount of inert material present (Section 2.3.2.2. of [C-1]).

The NSDD can be measured by filtering the wash-water used for ESDD measurement through filter papers that are pre-dried in an oven and re-dried after the solution has drained through the filters. The weight of the non-soluble component is determined by subtracting the weight of dried paper from that of the re-dried paper. A more detailed description of this method will be provided in the forthcoming version of the IEC 60815-1.

C.4 Chemical analysis

The constituents of the pollution can be determined by performing a chemical analysis of the deposit from the bottom surface of the top dummy insulator (i.e. disc 7 or shed 7).

C.5 Leakage current measurement

The leakage current across an insulator surface depends upon the service voltage and the conductance of the surface layer. It is possible to estimate the insulator flashover performance from the leakage current measurement. The aim is, therefore, to obtain the level of leakage current during exceptional pollution events. There are two methods of measuring the current collected at the grounded end of the insulator. These methods are discussed separately as:

- Surge counting.
- $I_{highest}$ measurement.

The surge count is the number of leakage current pulses above a specific amplitude that flowed across the test insulator, which is energised at its service voltage, in a given period of time.

$I_{highest}$ is the highest peak of leakage current that is recorded during a given time period on an insulator continuously energised at its service voltage. It has been considered as a suitable parameter to indicate how close a glass or porcelain insulator is to flashover.

Leakage current measurements should preferably be performed on the candidate insulator or, if that is not practical, the reference insulator used for the ESDD measurements. The insulator is normally mounted in a vertical position and at the same height as the line or busbar insulators. The length of the insulator is selected so that flashovers are unlikely.

The test insulator string is isolated from earth by a stand-off insulator which could be a short polymeric insulator or a greased ceramic one.

C.6 Directional Dust Deposit Gauge (DDDG)

The directional deposit gauge consists of four collectors into each of which are blown both rain and pollution through a vertical slot on the side open to the North, South, East or West respectively (see Figure C-3). The gauge is designed primarily to collect wind-borne pollution since it is the main contributor to pollution on vertical insulator strings.

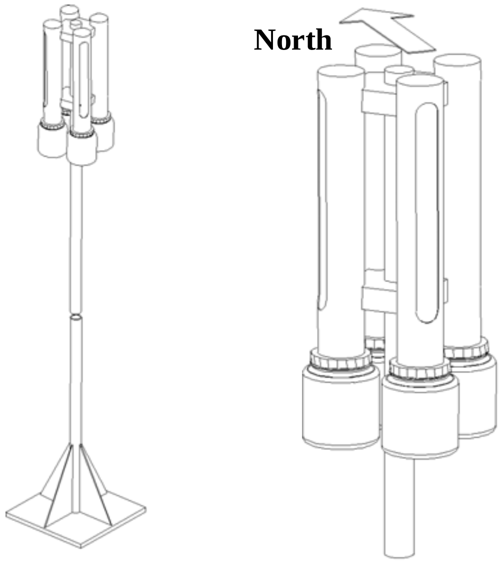

Figure 13-7: Directional Dust Deposit Gauges

With the DDDG the site severity is expressed in terms of the pollution index which is the conductivity of dissolved deposits from each collector of the deposit gauge, normalised to 500 ml of solution and a 30-day collection period. Also this method will be fully described in the forthcoming version of the IEC 60815-1.

C.7 IEC hand probe

The IEC hand probe[C-3] provides a means of measuring the surface conductivity of the wetted pollution layer. As for ESDD measurement, this method requires that a string of insulators be exposed to the environment. In most cases, it is not necessary for the insulators to be energised for the exposure period. However, in special cases, such as a pollution assessment for a d.c. installation, energisation of the sample insulators should be seriously considered.

The measurements are usually performed every month and are carried out on the de-energised insulator. The wetting of the pollution layer should be achieved a spray-bottle containing distilled water. Before making the surface conductivity measurement, the surface temperature of the insulator (or ambient temperature) should be measured.

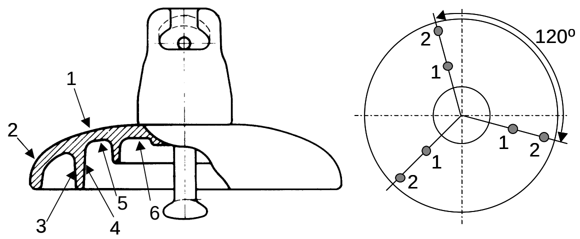

Figure 13-8: Measurement points for disc insulators

a) Positions of measurement on a seven-disc reference string:

The measurements should be carried out on three insulators (2nd, 4th, 6th) of a seven-disc reference insulator string (not the same string that is employed for determining the ESDD) at points shown in Figure C-4, i.e. 18 points per insulator.

b) Positions of measurement on a longrod or post insulator:

Measurements on longrod or post insulators should be carried out on three sheds (i.e. the second, middle, and penultimate shed) and at the points shown in Figure C-5, i.e. at 36 points.

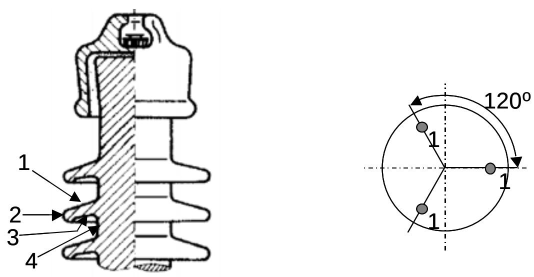

Figure 13-9: Measurement points for longrod and post insulators

C.8 Additional information

When performing a site assessment via detailed measurements as described in the previous sections it is worthwhile to complement these measurements with the information about the weather at the site and details of any flashovers that had occurred.

C.8.1 Meteorological data:

The following meteorological parameters can be monitored:

- Temperature
- Relative humidity
- Atmospheric precipitation
- Direction and speed of wind
- It is useful if these measurements are summarized every three months in the following form (table or record):
- Temperature: daily average
- Relative humidity: daily maximum
- Atmospheric precipitation: daily total
- Wind: wind rose

In many counties, such information may be available from the local weather office.

C.8.2 Information on flashovers:

In the case that an insulator flashover occurs in the vicinity of the test site, it is advisable to collect the following data:

- Time of the flashover
- Insulator type
- Insulator position (horizontal, vertical)
- Unified Specific Creepage distance
- Duration of the insulator exposure on site (without cleaning)
- Surface conductivity (measured by IEC probe) of the insulator that flashed over.
- Instantaneous data from all pollution monitors present.
- Meteorological data, previous to and at time of flashover (temperature, humidity, rain, fog etc.)

C.9 References

[C-1] Cigré Taskforce 33.04.01: "Polluted insulators: a review of current knowledge", Cigré technical publication 158, June 2000.

[C-2] Cigré Working Group 33.04, Study Committee 33, "The measurement of site pollution severity and its application to insulator dimensioning," Electra, no. 64, Jan 1979, pp 101-116.

[C-3] IEC: "Artificial pollution tests on high voltage insulators to be used on a.c. systems". Standard 60507, 2nd ed. 1991.

Appendix D :Insulator characteristics

D.1 General conclusions from the review

Traditionally the selection and dimensioning of insulation for outdoor use has largely been based on creepage distance alone. With the aim of applying the information contained in the Review to produce these guidelines, the main conclusions of Section 3 of that substantial document[1] are as follows:

1. Pollution flashover performance is determined by many factors other than axial length or creepage length. The nature and accumulation of the contaminants, the effect of natural washing and the physical characteristics of the surface discharges all play a part.
2. For all insulators, the specific length needs to be increased as the pollution severity increases following a power law.

D.1.1 Ceramic insulators

1. The most common mechanism for failure of ceramic insulators is pollution flashover. The processes leading to this flashover have been extensively researched and are fairly well understood.
2. Although the pollution flashover performance of porcelain and glass insulators is generally good, inadequate performance has occurred in situations where the pollution severity is high or where there is a long-term build-up of pollution over a period of years.
3. For vertically mounted post and barrel insulators, there is a general trend relating specific length to average diameter for a given voltage and pollution severity.
4. Under a.c. stressing, the pollution flashover performance of suspension insulators is essentially linear with string length for voltages up to 700 kV and is only moderately non-linear for higher voltages. Post insulators seem to be more non-linear than the corresponding case for cap and pin ones. Although the situation for d.c. is less clear, there are some indications that at voltages around 800 kV the non-linearity effect is more pronounced than the corresponding situation for a.c. energization.
5. The effect of mounting angle to the vertical depends upon the type of insulator. For suspension insulators, improvement occurs as this angle increases. When large diameter insulators are horizontally mounted the performance is much inferior to those for corresponding vertical cases.
6. The flashover strength at cold switch-on can be at least 40% less than that for continuous energization.
7. In desert regions, flashover can be a problem even for USCD values of 90mm/kV.
8. Snow and ice can substantially decrease the flashover performance when icicles or snow span most of the insulator. The probability of flashover at operating voltage is very high during the melting stage.
9. Non-uniform wetting and/or pollution coverage can have an adverse effect on flashover performance, especially under d.c. stressing.
10. Hollow insulators or shells may have a lower flashover performance than that of comparable solid insulators; this is due to the influence of both the electric field and heat from internal components. It is thought essential to design the structure to achieve a uniform axial-voltage distribution on the outer surface of the shell.
11. At a given surface stress at flashover, the critical pollution severity under d.c. energization is much less (maybe a factor 10) than that under a.c. stressing.
12. By using semi-conducting glaze to achieve a continuous leakage current of about 1 mA, sufficient heating of the insulator surface is achieved to keep it essentially dry in dew or fog - thereby greatly increasing the pollution flashover performance compared with that of a

normally glazed insulator. However, cold switch-on remains a problem with insulators designed in this way. Although such a glaze has been found to have a long and effective life on post insulators, rapid deterioration may take place around the pin cavity of disc insulators in severe marine pollution. Semi-conducting glaze is not recommended for d.c. insulators.

D.1.2 Polymeric insulators

1. Service experience has demonstrated that the performance of polymeric insulators is excellent if they have been properly dimensioned and the correct materials are used.
2. Failure of polymeric insulators using silicone rubber for the sheath and shed material is usually mechanical as a result of damage to the reinforced glass fibre core. It is important, therefore, to design the insulator so that the integrity of the material covering the core is maintained under all operating conditions.
3. The pollution flashover performance of some polymeric materials - especially silicone rubber - is generally superior to that of glass or porcelain. In contrast, epoxy resin rapidly degrades from its new - hydrophobic - condition such that its flashover strength can be somewhat inferior to that of ceramic materials.
4. Some types of discharge activity (e.g. corona or sparking) at or near the surface may cause severe degradation of the material, thereby exposing the core to mechanical degradation and also reducing the flashover performance. Such discharges may be minimised or prevented by having the correct design of stress ring.

D.2 Selection of profile

In order to give general guidelines for the selection of profile it is necessary to make a classification of both the insulator shapes available and the various types of environment. Neither of these classifications is easy to make. For insulators there are a host of shapes produced that include common types such as standard, open and anti-fog profiles, as well as more unusual ones such as the outer-rib type, bell-type, alternate-rib type. Pollution conditions at the site where the insulators are to be installed can actually consist of combinations of classified pollution; such as coastal and desert, or desert and industrial. Moreover, there can be great variations between sites which fall in the same type of environment. For example, industrial sites may be dominated by thick particulate pollution such as cement, coal or gypsum, while other industrial sites may be exposed to already dissolved chemicals such as NOx or SOx.

In spite of these variations, rough generalisations have been made to provide some general guidelines for the selection of profile for five different types of environment that can be used during the preliminary selection of insulator profiles when service experience is lacking. Descriptions of the different kinds of environment can be found in Appendix B. These guidelines also focus only on the profiles most commonly in use. Some examples are shown for a.c. cap and pin, ceramic longrod and post insulators as well as polymeric longrod insulators. The illustrations shown in the figures and tables are intended to be generic examples of what each type of insulator may look like.

Three aspects should be considered when selecting profile:

- Pollution catch
- Creepage distance per unit axial length
- Efficiency of this creepage during the flashover process

The selection is a balance between the axial length of creepage distance per unit length provided by the insulator versus the pollution catch.

D.2.1 Profile and creepage distance

The Guidelines of this section cover the first two points while the latter is generally determined during laboratory testing.

Figure D-1 shows the relationship between profile complexity and creepage distance per unit axial length for ceramic line insulators. It can be seen that this relationship is U-shaped with the minimum creepage per unit axial length occurs for standard profiles. As expected, complex profiles, such as the anti-fog type, exhibit a higher creepage to length ratio due to the increasing number and deepness of the under-ribs. Also open profiles exhibit a higher ratio but in this case it is due to the larger diameter of the insulator disc.

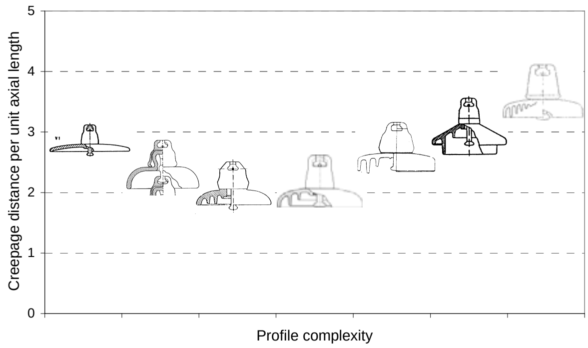

Figure 13-10: Creepage per unit axial length for various a.c. cap and pin insulator profiles.

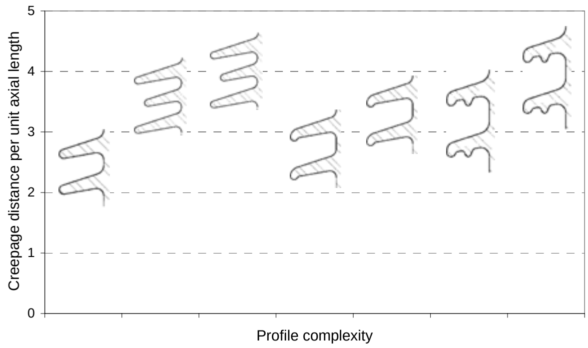

Figure 13-11: Creepage per unit axial length for various a.c. post and longrod insulator profiles.

With reference to Figure D-2, it can be seen that both of the insulators with and without alternating sheds show an increasing creepage distance per unit axial length increases as the profile becomes more complex.

D.2.2 Profile and environment

Inland: In these areas the insulator length, and not the creepage distance, is the main parameter that determines the pollution flashover value. As a result, insulators that offer a long creepage length per unit axial length do not offer a significant advantage. On the contrary, in areas with extended dry periods complex profiles may suffer from a long-term pollution build-up which may be detrimental to their performance.

Agricultural: The pollution in these areas is deposited mainly by precipitation, thus large upper insulator surfaces should be avoided. Wind borne deposits may also occur which may lead to a long-term build-up on convoluted under surfaces; however, the additional creepage offered by the profile may outweigh the disadvantage of the higher deposit. The protected creepage of complex profiles may prevent the efficient wetting of the insulator under surface during critical wetting conditions, which is typically light rain.

Indirect coastal: Pollution is brought onto the insulators by wind in these areas. Insulators with aerodynamic profiles show, therefore, a distinct advantage because it collects less pollution and the whole surface is accessible for natural cleaning. Complex profiles tend to collect more pollution and experience a long-term pollution build-up as the protected creepage is not accessible for natural cleaning, i.e. rain. All types of profile are effectively wetted during the critical wetting conditions, which are fog or mist.

Direct coastal: Pollution is brought onto the insulators by salt-fog or direct sea-spay during storm conditions. Insulators with a substantial amount of protected creepage have, therefore, a distinct advantage because it prevents the whole surface from being covered. Open profiles tend to be more exposed and have, as a result, a lower flashover voltage.

Liquid industrial: Pollution is brought onto the insulators by acid rain or conductive mists conditions. Insulators with a substantial amount of protected creepage have an advantage because it prevents the whole surface from being wetted. Open profiles tend to be more exposed and have as a result a lower flashover voltage.

Particulate industrial: The pollution in these areas is deposited mainly by precipitation. Large upper insulator surfaces should thus be avoided. Complex profiles have the advantage that their protected creepage prevents the whole insulator from becoming damp during critical wetting conditions, which is typically rain.

Inland Desert: Good aerodynamic properties of the open profiles are beneficial in these areas as they lead to both a low pollution deposit and effective self-cleaning by wind. Although complex profiles may initially offer better flashover voltages, they suffer from a long-term pollution accumulation that ultimately reduces their performance to below that of the open profiles.

Marine Desert: Good aerodynamic properties of the open profiles are beneficial in these areas as they lead to both a low pollution deposit and effective self-cleaning by wind. Complex profiles may suffer from a long-term pollution accumulation but the additional creepage per unit length may outweigh the disadvantage of a higher pollution deposit.

D.2.3 Guidelines for a.c. disc insulators

The guidelines presented in Section D.2.2 for the selection of profile apply for a.c. disc insulators. Figure D-3 shows examples for vertically installed insulators in Inland, Agricultural and Coastal areas and Figure D-4 shows examples for Industrial and Desert environments. For horizontally mounted insulators, the corresponding figures are Figure D-5 and Figure D-6.

The Y-axis of all these figures gives an indication of the benefit of using a profile indicated on the X-axis. A "+" means the profile is regarded as good while a "-" means that the profile should be avoided. The "O" indicates that a profile does not have a specific advantage or particular disadvantage.

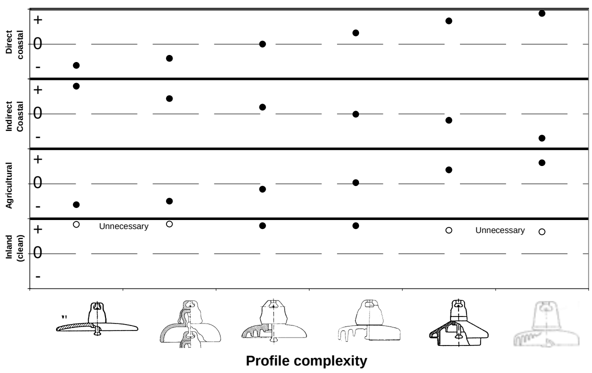

Figure 13-12: Vertical ceramic a.c. disc insulators: profile efficiency vs. profile complexity – I.

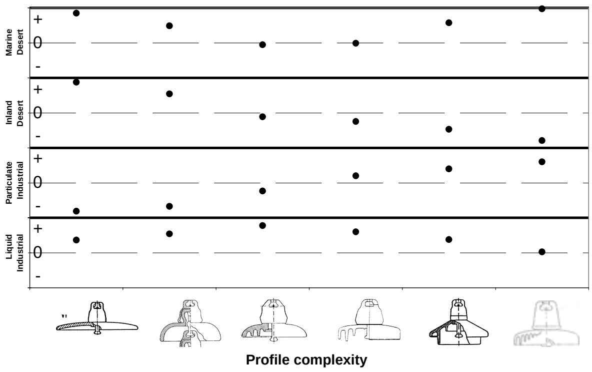

Figure 13-13: Vertical ceramic a.c. disc insulators: profile efficiency vs. profile complexity–II.

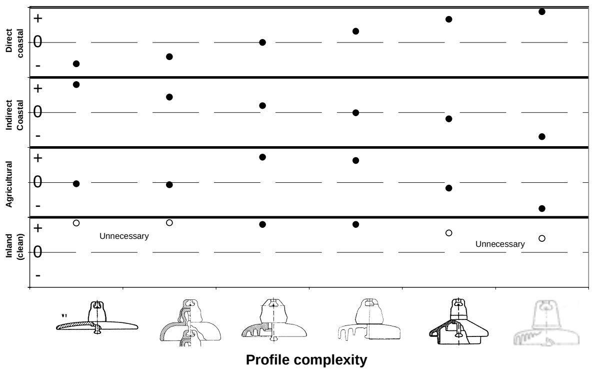

Figure 13-14: Horizontal ceramic a.c. disc insulators: profile efficiency vs. profile complexity–I.

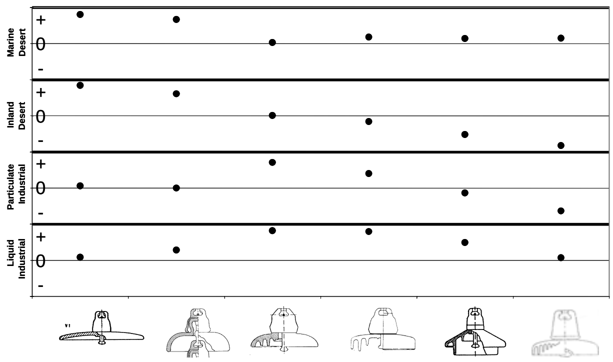

Figure 13-15: Horizontal ceramic a.c. disc insulators: profile efficiency vs. profile complexity–II.

D.2.4 Post, Longrod and Hollow insulators

The guidelines presented in Section D.2.2 apply to the selection of profile for vertically or horizontally installed a.c. post insulators. These examples are shown in Figure D-7 for Inland, Agricultural and Coastal areas and in Figure D-8 for Industrial and Desert environments. The corresponding information is presented for hollow insulators in Figure D-9 and Figure D-10 respectively. The following points should be noted when choosing post or hollow insulators:

- An alternating shed profile might have an advantage under heavy wetting conditions.
- The pollution deposit on hollow and post insulators reduces with increasing diameter. However, the flashover voltage at a given pollution level reduces with increasing diameter.
- It is assumed that the shed profile parameters are according to IEC 60815:1985.

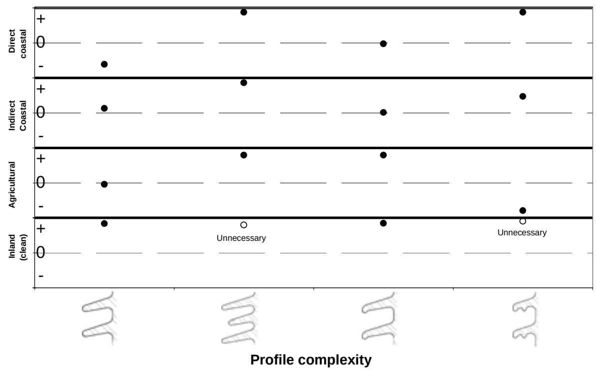

Figure 13-16: Vertical and horizontal ceramic a.c. post and longrod insulators: profile efficiency versus profile complexity –I.

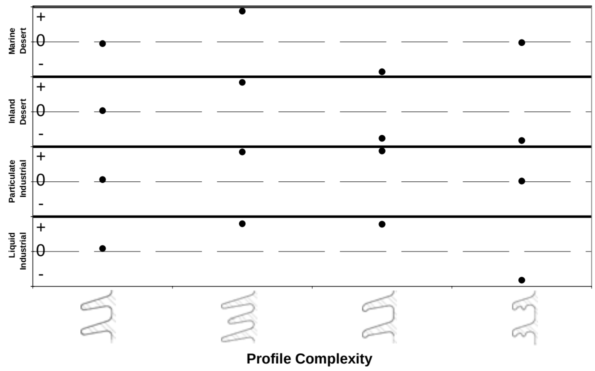

Figure 13-17: Vertical and horizontal ceramic a.c. post and longrod insulators: profile efficiency versus profile complexity –II.

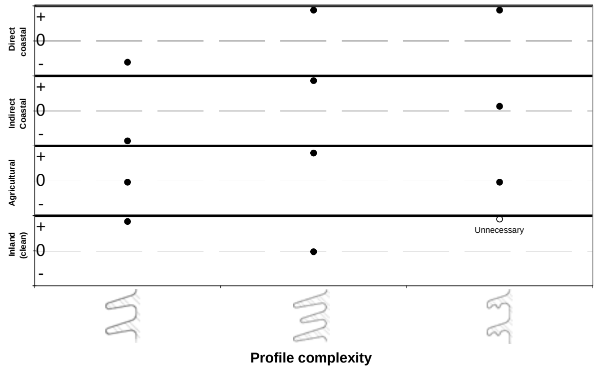

Figure 13-18: Vertical ceramic a.c. hollow insulators: profile efficiency versus profile complexity –I.

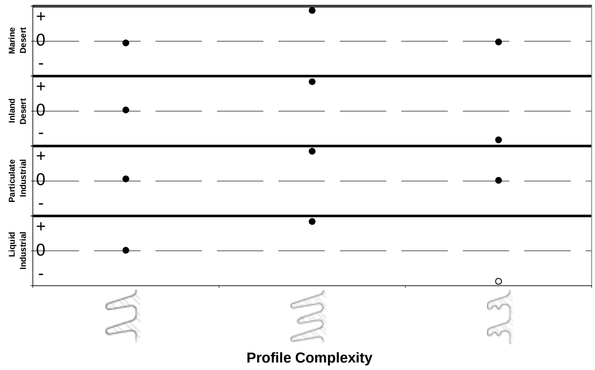

Figure 13-19: Vertical ceramic a.c. hollow insulators: profile efficiency versus profile complexity –II.

D.2.5 Polymeric insulators

The guidelines presented in Section D.2.2 apply to the selection of profile for polymeric a.c. post insulators – i.e. both vertically and horizontally installed cases. These examples are shown in Figure D-11 for Inland, Agricultural and Coastal areas and in Figure D-12 for Industrial and Desert environments.

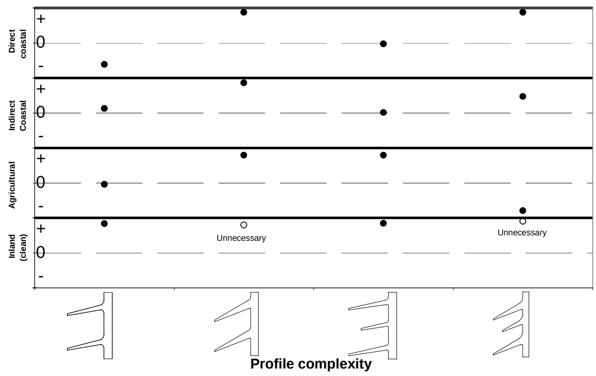

Figure 13-20: Vertical and horizontal polymeric a.c. insulators: profile efficiency versus profile complexity –I.

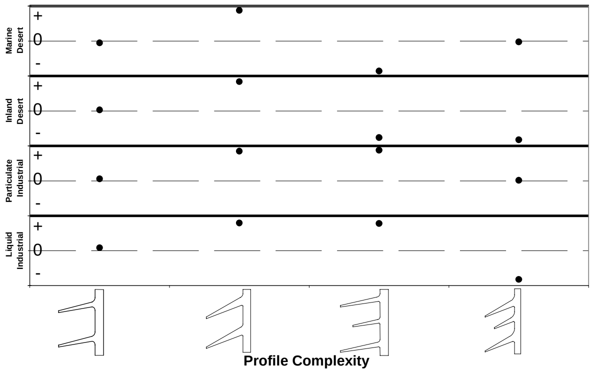

Figure 13-21: Vertical and horizontal polymeric a.c. insulators: profile efficiency versus profile complexity –II.

D.3 Correction factors

In Section 9.2, a set of correction factors is introduced to compensate site severity measurements. They are based on the performance required as well as for differences in profile, material, energization, diameter and finally the number of measurements performed. In this section, tables are provided that give typical values for such factors. These values are approximate and so they should be treated as indicative only.

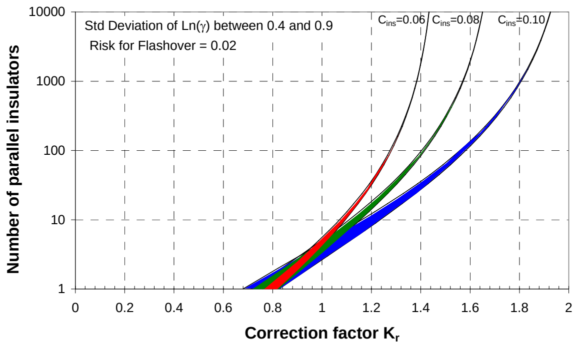

Figure 13-22: Typical range for the correction factor K_r depending on the number of insulators that are exposed to the same environment[D-1].

It should be noted that the curves in Figure D-13 are calculated for a risk of flashover per pollution event of 0,02, or on average one flashover in 50 events[D-1]. The risk for flashover per year is obtained by multiplying this risk for flashover by the number of pollution events expected each year. It should, however, be recognized that there may be sites, with a very high number of pollution events, where the resulting risk for flashover per year would become unacceptably high. These cases require a detailed statistical analysis to obtain a suitable value for K_r.

Table 13-4: Correction factor, Ks, is the ratio between the pollution level on a standard profile and that on other profiles for vertically a installed disc insulators.

Profile type	Desert	Coastal[b]	Industrial/ Agricultural	Inland
Open	0,4 ±0,3	0,6 ±0,3	0,7 ±0,3	0,6 ±0,2
Standard	1,0	1,0	1,0	1,0
Anti-fog	0,8 ±0,3	0,8 ±0,3	0,85 ±0,3	1,08 ±0,2
longrod (open profile)	0,4 ± 0,3	1,6±0,4	0,4 ± 0,3	0,4 ± 0,3

Note a: Information is provided only for vertical insulators. Presently, correction factors cannot be supplied for horizontally installed insulators due to the lack of data. Horizontally installed insulators will generally collect less than vertically installed ones, except on complex profiles with large shed under-ribs – refer to Tables D-5 and D-6

Note b: During rapid pollution conditions (e.g. typhoon or strong wind from sea)

Table 13-5: Correction factor, K_i, is the ratio between pollution level for polymeric insulators relative to that of ceramic ones.

K_i	Insulator material
1,0	Glass and Porcelain
1 – 1,5	Silicone rubber (0,001 < ESDD < 0,1 mg/cm^2)
1 – 1,2	Silicone rubber (ESDD > 0,1 mg/cm^2; Section 2.3.7.4 of[C-1])
1	EPDM

Table 13-6: Correction factor, K_p, is the ratio between pollution level for insulators energised with a.c. voltage and those that are not energized.

K_p	Site conditions
1,0	All inland areas
1 – 1,2	Areas where insulators may be directly exposed to liquid pollution

D.4 A summary of laboratory test results

In this section a summary of the available laboratory test results are presented. These general values could be used for the selection of the required withstand severity (see Section 9.2) when pollution performance characteristics of the candidate insulator are not available. The pollution withstand performance of insulators can be expressed by:

$$USCD = A \cdot \gamma^{\alpha}$$

Where USCD is the Unified Specific Creepage Distance, defined in mm per kVrms of the *withstand* voltage across the insulator at a given pollution severity, γ. *A* is an experimental constant and α is the slope parameter. Both A and α can be estimated from published laboratory data, of which a summary is provided in Table D-4 through Table D–7.

Table 13-7: Disc insulators, solid layer method (i.e. Clean Fog) procedure B[D-8]

Source	**Insulator configuration**	**Range of γ SDD; mg/cm^2**	**A**	α
IEEE [D-9]	I-string	0,02-0,1	86,5	0,374
IEEE [D-9]	I-string	0,1-0,3	51,4	0,158
IEEE [D-9]	V-string	0,02-0,1	52,9	0,274
IEEE [D-9]	V-string	0,1-0,3	37,1	0,122
Cigré [D-10]	I-string	0,02-0,4	66	0,223
CESI [D-11]	I-string	0,02-0,4	48	0,220
NGK[D-12]	I-string	0,02-0,4	54,4	0,232

Table 13-8: Post insulators, solid layer method (i.e. Clean Fog) procedure B[D-8]

Source	**Insulator average diameter, mm**	**Range of γ SDD; mg/cm^2**	**A**	α
NGK [D-12]	200	0,01-0,1	63,0	0,220
NGK [D-12]	300	0,01-0,1	75,8	0,226
NGK [D-12]	400	0,01-0,1	87,4	0,229
NGK [D-12]	500	0,01-0,1	103,2	0,240
NGK [D-12]	600	0,01-0,1	115,6	0,240

Table 13-9: Disc insulators, solid layer method (i.e. Clean Fog) procedure A[D-8]

Source	**Insulator configuration**	**Range of γ Layer conductivity; µS**	**A**	α
Cigré [D-10]	I-string	2,5-80	14,2	0,387
CESI [D-11]	I-string	2,5-80	14,2	0,28

In the literature the normalised standard deviation, σ, is quoted when reporting on laboratory pollution flashover tests. The corresponding normalised standard deviation, *c*, is given by:

$$c = \sigma / U_{50}$$

Where: U_{50} is the voltage with a 50% flashover probability

A summary list is presented in Table D–7.

Table 13-10: Reported standard deviations for solid layer (i.e. Clean Fog) tests

Source	**Type of insulator**	**Norm. standard deviation (c)**
[D-1]	Standard shape disc	0,10
[D-3]	Anti-fog disc	0,088
[D-4]	Porcelain post insulators	0,084
[D-5]	Post insulators	0,06
[D-6]	IEEE disc anti-fog disc	0,01-0,11 0,04-0,15
[D-7]	Standard shape disc	0,06

D.5 References

[D-1] Engelbrecht CS, Gutman I, Hartings R, "A Practical Implementation of Statistical Principles to Select Insulators with Respect to Polluted Conditions on Overhead A.C. Lines", PowerTech'2005, St Petersburg, Russia, Paper 129.

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Appendix E A laboratory test method for polymeric insulators

E.1 Introduction

There are presently no standardised methods available for the testing of polymeric insulators.

The difficulty with performing the Salt-Fog test lies with the temporary loss of hydrophobicity under discharge activity. It can, of course, be used to establish the "worst" case - i.e. a loss of hydrophobicity to the extent that the insulator behaves as a hydrophilic one – but it is not obvious how the realistic "best" case and the "intermediate" cases can be readily achieved. Nonetheless, some people advocate that the "worst" case should be used for dimensioning purposes -- and may, for some insulators, be the only test that can be conducted at an acceptable cost.

The non-soluble component of pollution masks the water-repellent properties of silicone rubber. Although it is recognized that these properties are eventually transferred to the outer layer of the pollution, a complicating factor is that this transfer-time is a function of both the type and the density of the non-soluble component.

From some published proposals and information[E-1][E-2][E-3][E-4][E-5], a recommended modified version of the Clean-Fog Test is outlined below in which the various cases -- from "worst" through "intermediate" to "best" -- can be determined by increasing the elapsed time between the insulator being polluted to it being tested.

Based on these principles, modifications are proposed in this appendix to the standard "Solid Layer Method" of the IEC 60507:1991-04: "Artificial pollution tests on high-voltage insulators to be used on a.c. systems".

E.2 Composition of the contaminating suspension

For both application procedures "I" and "II", a suspension shall be prepared with the following ingredients:

- 100 g Kieselguhr according to clause 14 of IEC 60507:1991.
- 1 000 g tap water
- a suitable amount of NaCl of commercial purity

The criteria for the tap water conductivity and reference degree of pollution are as specified in clause 13.1 of IEC 60507:1991.

If application procedure "II" is used, then a wetting agent according to the following prescription shall be added:

- 0,5 g Triton X-100, as is used in the Inclined Plane Test (IEC 60587), for each 1 000 g of water in the suspension.

E.3 Main characteristics of non-soluble materials

The characteristics of the non-soluble materials shall comply with clause 14 of IEC 60507:1991.

E.4 Application of the pollution layer

There is a choice of two methods for the application of the pollution layer:

E.4.1 Application procedure I

11. Dry Kieselguhr (300 mesh) is applied to the insulator housing using sponge, cotton wool or a brush.

18. The surplus Kieselguhr is blown off with an electric blower to leave a thin, uniform layer covering the insulator housing.
19. After about 30 min, when the housing surface is wettable, the suspension as specified in section E-2 can be applied using the method described in clause 15 of IEC 60507:1991.

E.4.2 Application procedure II

The suspension with wetting agent, described in section E-2, is applied to the insulator using the method described in clause 15 of IEC 60507:1991.

E.5 Determination of the degree of pollution of the tested insulator

The degree of pollution of the tested insulator is expressed in the Salt Deposit Density or the layer conductivity.

The Salt Deposit Density, performed according to IEC 60507, should be performed as soon as the pollution layer has dried, i.e. before the insulator has regained its hydrophobicity.

Layer conductivity measurements, made according to IEC 60507, can be performed at any time during the test to obtain information on the encapsulation effect of the insulator housing.

E.6 Variation of hydrophobic state

The hydrophobic state of the insulator is varied by waiting a predetermined time before the test is performed. The waiting times for the different hydrophobic states are defined as follows for the pollution application procedure I:

Worst hydrophobicity case:

The test is performed as soon as the pollution layer is completely dry, but the elapsed time before the test is performed should not exceed 5 hours since the end of the pollution application.

Best hydrophobicity case:

The test is performed one week after the pollution was applied

Intermediate hydrophobicity cases:

Optionally, tests can be performed at various intermediate hydrophobicity states to obtain more information on the recovery of the insulator. The preferred waiting times are: 25, 50, 75 and 100 hours after the end of the pollution application.

The waiting times for the pollution application procedure “II” is not finalised yet. It is, however, recommended that for now be used as those adopted for the procedure “I”.

E.7 Determination of hydrophobic state

Hydrophobicity measurements are optional, but if performed they should be done in accordance with the IEC 62073 Standard.

E.8 General requirements for the wetting of the pollution layer

The wetting requirements are as described in clause 17 of IEC 60507:1991.

E.9 Test procedures

Both test procedures described in clause 18 of IEC 60507:1991 are acceptable for use with this method.

E.10 Withstand test and acceptance criterion

The withstand test is performed according to the requirements of clause 19 of IEC 60507:1991.

E.11 References

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