
Guide for **Insulation co-ordination**

Part 2. Application guide

Guide sur la coordination de l'isolement
Partie 2. Guide d'application

Hinweisblatt über Isolierungskoordination
Teil 2. Anwendungshinweisblatt

National foreword

This Part of this British Standard is identical with IEC Publication 71-2 'Insulation co-ordination' Part 2 : 1976 'Application guide'. It is published under the direction of the General Electrotechnical Engineering Standards Committee. Other Parts of this British Standard are:

Part 1 : 1979 Terms, definitions, principles and rules (identical with IEC Publication 71-1 : 1976)

Part 3 Insulation co-ordination for Ranges A and B (still under development within the IEC).

This British Standard gives guidance to those concerned with the design and testing electrical apparatus. When designing for the UK market, insulation levels of Series I are required (see clause 41 of BS 5622 : Part 1 : 1979).

Terminology and conventions. The text of the international standard has been approved as suitable for publication, without deviation, as a British Standard. Some terminology and certain conventions are not identical with those used in British Standards; attention is especially drawn to the following.

The comma has been used as a decimal marker in some of the figures, e.g. figure 1. In British Standards it is current practice to use a full point on the baseline as the decimal marker.

Where the words 'this publication' appear, referring to this standard, they should be interpreted as 'this British Standard' or 'this Part of this British Standard' as appropriate.

Where the words 'apparatus committee' or 'apparatus committees' or 'Apparatus Committee' or 'Apparatus Technical Committee' appear, they should be interpreted as meaning technical committee(s) concerned with the requirements for apparatus. The reference in 13.2 to 'IEC Technical Committee No. 37, Lightning Arresters' should be interpreted as meaning the BSI Technical Committee concerned with surge diverters.

Where, as in 8.1, the words '50 % disruptive discharge voltage' appear, they should be interpreted as having the same sense as '50 % dielectric breakdown voltage' used in BS 923. Terms such as '50 % discharge voltage', as in 8.2, may be interpreted by analogy. Where, as in 8.1, the words 'disruptive discharge' appear, they should be interpreted as having the same sense as 'dielectric discharge' used in BS 923 or 'disruptive discharge' used in BS 2914.

Wherever the words 'surge arrester' or 'surge arresters' appear, they should be interpreted as having the same sense as 'surge diverter' or 'surge diverters', respectively, used in BS 2914.

Wherever page numbers are quoted in connection with references to tables and figures, they are IEC page numbers.

Cross references.

International standard*	Corresponding British Standard
IEC 60 : 1962	BS 923 : 1972
revised in Parts thus:	Guide on high-voltage testing techniques (related, see note 1)
60-1 : 1973	
60-2 : 1973	
60-3 : 1976	
60-4 : 1977	
IEC 71 : 1967 (4th edition)	No corresponding British Standard for this superseded publication (see note 2)
IEC 71-1 : 1976	BS 5622 Guide for insulation co-ordination Part 1 : 1979 Terms, definitions, principles and rules (Identical)
IEC 99-1 : 1970	BS 2914 : 1972 Surge diverters for alternating current power circuits (related, see note 3)
IEC 99-1A : 1965	Appendix C of BS 2914 : 1972 (title as above) is technically equivalent (see note 4)
IEC 99-2 : 1962	No corresponding British Standard (see note 5)
IEC 282-1 : 1974	BS 2692 Fuses for voltages exceeding 1000 V a.c. Part 1 : 1975 Current-limiting fuses (related, see note 6)

NOTE 1. As stated in its foreword, BS 923 : 1972 is based on IEC 60 : 1962 but 'also incorporates some information which will appear in the next revision of that publication'.

For the purposes of this standard and taking account of differing terminology as noted under 'Terminology and conventions' in this national foreword, BS 923 is technically equivalent to IEC 60.

Reference to IEC 60 appears only in clause 2 of this standard.

NOTE 2. The references (in B2 and in the explanatory text to figure 17 of this standard) to the 4th edition of IEC 71, for which there is no corresponding British Standard, constitute informative matter only and sufficiently detailed extracts are given in this standard. The 4th edition of IEC 71 has been superseded, firstly by the 5th edition in 1972 and then by IEC 71-1 : 1976 and IEC 71-2 : 1976.

NOTE 3. For the purposes of this standard and taking account of differing terminology as noted under 'Terminology and conventions' in this national foreword, BS 2914 : 1972 is technically equivalent to IEC 99-1 : 1970 except that in tables 6 and 7 it includes a diverter (arrester) rating of 132 kV (which is not in the corresponding tables in IEC 99-1) together with values corresponding to the interpolated values of the IEC 99-1 series, and excludes the arrester rating of 150 kV (which is in the corresponding tables in IEC 99-1) for which there was no demand in the UK.

6.3.5 of BS 2914 : 1972 corresponds to 61.4 of IEC 99-1 : 1970 (referred to in 13.2 of this standard).

NOTE 4. Appendix C of BS 2914 : 1972 is a reproduction of IEC 99-1A : 1965 except as noted under 'Terminology and conventions' in this national foreword; there are also some minor editorial and numbering changes.

*Undated in the text.

Amendment No. 1
published and effective from 15 March 1993
to BS 5622 : Part 2 : 1979
Guide for insulation co-ordination
Part 2. Application guide

NOTE. This amendment is issued to implement CENELEC
Harmonization Document HD 540.2 S1.

Revised text

AMD 7533
March 1993

Front cover

Immediately below the title of Part 2, insert the following.

‘Implementation of CENELEC HD 540.2 S1’

AMD 7533
March 1993

National foreword

Delete the existing national foreword and substitute the attached.

AMD 7533
March 1993

HD title page and foreword

Immediately after the national foreword insert the attached new HD title page
(foreword on reverse).

AMD 7533
March 1993

New annex ZA

Immediately after figure 20 insert the attached new annex ZA.

AMD 7533
March 1993

New annex ZB

Immediately after the new annex ZA insert the attached new annex ZB.

National foreword

This Part of this British Standard is identical with IEC Publication 71-2 'Insulation co-ordination' Part 2 : 1976 'Application guide' and implements CENELEC Harmonization Document (HD) 540.2 S1 : 1991. It is published under the direction of the General Electrotechnical Standards Policy Committee.

The IEC has published IEC 71-3 : 1982 'Phase-to-Phase insulation co-ordination principles, rules and application guide', but this has not been published as Part 3 of BS 5622.

This British Standard gives guidance to those concerned with the design and testing of electrical apparatus. When designing for the UK market, insulation levels of Series I are required (see clause 41 of BS 5622 : Part 1 : 1979).

Cross-references

International standard*	Corresponding British Standard
IEC 60	BS 923 Guide on high-voltage testing techniques
IEC 60-1 : 1989	Part 1 : 1990 General (Identical)
	Part 2 : 1980 Test procedures (Identical)
IEC 60-3 : 1976	Part 3 : 1980 Measuring devices (Identical)
IEC 60-4 : 1977	Part 4 : 1980 Application guide for measuring devices (Identical)
IEC 71-1 : 1976	BS 5622 Guide for insulation co-ordination Part 1 : 1979 Terms, definitions, principles and rules (Identical)
IEC 99-1 : 1970	BS 2914 : 1972 Specification for surge diverters for alternating current power circuits (see note 2)
IEC 99-1A : 1965	Appendix C of BS 2914 : 1972 is technically equivalent (see note 3)
IEC 99-2 : 1962	See note 4
*IEC 282-1 : 1985	BS 2692 Fuses for voltages exceeding 1000 V a.c. Part 1 : 1986 Specification for current-limiting fuses (Technically equivalent, see note 6)

NOTE 1. The references (in **B2** and in the explanatory text to figure 17 of this standard) to the 4th edition of IEC 71, for which there is no corresponding British Standard, constitute informative matter only and sufficiently detailed extracts are given in this standard. The 4th edition of IEC 71 has been superseded, firstly by the 5th edition in 1972 and then by IEC 71-1 : 1976 and IEC 71-2 : 1976.

NOTE 2. For the purposes of this standard and taking account of differing terminology, BS 2914 : 1972 is technically equivalent to IEC 99-1 : 1970, except that in tables 6 and 7 it includes a diverter (arrester) rating of 132 kV (which is not in the corresponding tables in IEC 99-1) together with values corresponding to the interpolated values of the IEC 99-1 series, and excludes the arrester rating of 150 kV (which is in the corresponding tables in IEC 99-1) for which there was no demand in the UK.

6.3.5 of BS 2914 : 1972 corresponds to 6.1.4 of IEC 99-1 : 1970 (referred to in 13.2 of this standard).

NOTE 3. Appendix C of BS 2914 : 1972 is a reproduction of IEC 99-1A : 1965 except that there are also some minor editorial and numbering changes.

NOTE 4. The references (in clauses 2 and 14 and in 16.2 of this standard) to IEC 99-2 : 1962, for which there is no corresponding British Standard, constitute informative matter only as they relate to expulsion-type lightning arresters, which are an alternative type not used in the UK. Since no requirements are involved, the validity of this British Standard is not affected.

NOTE 5. *Textual errors.* When adopting the text of the international standard, the errors listed below were noticed. They have been corrected in this British Standard and have been reported to the International Electrotechnical Commission in a proposal to amend the text of the international standard.

Subclause 7.3, paragraph 3, line 2 (IEC page 21). 'analisers' has been deleted and replaced by 'analysers'.

Clause 22, paragraph 2, line 1 (top of IEC page 53). 'one to three values' has been deleted and replaced by 'one to five values'.

Appendix B, clause B1, final paragraph, line 2 (IEC page 77). 'or than the probability' has been deleted and replaced by 'or that the probability'.

Appendix B, clause B2, first paragraph, line 1 (IEC page 77). 'basis limitations' has been deleted and replaced by 'basic limitations'.

Appendix C, note 1, line 1 (IEC page 83). 'Baussian' has been deleted and replaced by 'Gaussian'.

Appendix C, line 2 of paragraph before formula (18) (IEC page 85). 'Formula (1)' has been deleted and replaced by 'Formula (11)'.

Appendix D, first paragraph, line 1 (top of IEC page 89). 'Table III, page 98' has been deleted and replaced by 'Table III, page 99'.

Table 1, note 3 (bottom of IEC page 95). 'on the insulators may' has been deleted and replaced by 'on the insulators, may'.

Figure 12, block 6 (IEC page 119). 'rated-voltage' has been deleted and replaced by 'rated voltage'.

NOTE 6. BS 2692 : Part 1 implements CENELEC HD 492.1.S2 : 1989 and its Amendment 1 : 1990. HD 492.1.S2 consists of IEC 282-1 : 1985 edition 3, plus Amendment 1 (1988). Amendment 1 to HD 492.1.S2 consists of the following addition to clause 9.

‘Fuses within the scope of this standard are not sensitive to electromagnetic disturbances and therefore no immunity tests are necessary. Electromagnetic disturbance generated by a fuse is limited to the instant of its operation. Provided the switching voltage values during operation comply with those given in tables IX and IX A of this standard, no other tests for electromagnetic compatibility are required.’

Compliance with a British Standard does not of itself confer immunity from legal obligations.

UDC 621.316.13.052.3.048.1:621.3.053

Descriptors: Insulation coordination, a.c. high voltage network, voltage stress, insulation withstand, protective device, coordination between stresses and withstand

English version

Insulation coordination
Part 2: Application guide
(IEC 71-2 : 1976)

Coordination de l'isolement
Deuxième partie : Guide d'application
(CEI 71-2 : 1976)

Isolationskoordination
Teil 2 : Anwendungsrichtlinien
(IEC 71-2 : 1976)

This Harmonization Document was approved by CENELEC on 1990-03-05. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for implementation of this Harmonization Document on a national level.

Up-to-date lists and bibliographical references concerning national implementation may be obtained on application to the Central Secretariat or to any CENELEC member.

This Harmonization Document exists in three official versions (English, French, German).

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B-1050 Brussels

Foreword

The CENELEC questionnaire procedure, performed for finding out whether or not the international standard IEC 71-2 : 1976 could be accepted without textual changes, has shown that no CENELEC common modifications were necessary for the acceptance as Harmonization Document.

The reference document was submitted to the CENELEC members for formal vote and was approved by CENELEC as HD 540.2. S1 on 5 March 1990.

The following dates were fixed:

- latest date of announcement
of the HD at national level (doa) 1990-09-01
- latest date of publication of
a harmonized national standard (dop) 1992-04-01
- latest date of withdrawal of
conflicting national standards (dow) 1992-04-01

For products which have complied with the relevant national standard before 1992-04-01, as shown by the manufacturer or by a certification body, this previous standard may continue to apply for production until 1997-04-01.

Annexes designated 'normative' are part of the body of the standard. In this standard, annexes ZA and ZB are normative.

ANNEX ZA (normative)

SPECIAL NATIONAL CONDITIONS

Special national condition: National characteristic or practice that cannot be changed even over a long period, e.g. climatic conditions, electrical earthing conditions. If it affects harmonization, it forms part of the European Standard or Harmonization Document.

For the countries for which the relevant special national conditions apply these provisions are normative, for other countries they are informative.

BELGIUM

Two additional rated voltages 41,5 kV and 82,5 kV are authorized so as to take into account the special national condition for which variations between real network and immediately upper IEC voltages are important.

Consequently, in table VIA (page 105), the following values are to be added:

Rated lightning impulse withstand voltage (kV)	Minimum phase-to-earth air clearance (mm)
200	380
350	750

ANNEX ZB (normative)

OTHER INTERNATIONAL PUBLICATIONS QUOTED IN THIS STANDARD WITH THE REFERENCES OF THE RELEVANT EUROPEAN PUBLICATIONS

When the international publication has been modified by CENELEC common modifications, indicated by (mod), the relevant EN/HD applies.

IEC Publication	Date	Title	EN/HD	Date
60	—	High-voltage test techniques	—	—
71-1	—	Insulation co-ordination — Part 1 : Terms, definitions, principles and rules	—	—
99-1	—	Lightning arresters — Part 1 : Non-linear resistor type arresters for A.C. systems	—	—
99-1A	—	First supplement to Publication 99-1	—	—
99-2	—	Part 2: Expulsion-type lightning arresters	—	—
282-1 (mod)	—	High-voltage fuses Part 1: Current-limiting fuses	HD 492.1 S2* + A1	1989 1990

* Includes IEC 282-1 : 1985 + A1 : 1988.

NOTE 5. The references (in clauses 2 and 14 and in 16.2 of this standard) to IEC 99-2 : 1962, for which there is no corresponding British Standard, constitute informative matter only as they relate to expulsion-type lightning arresters, which are an alternative type not used in the UK. Since no mandatory requirements are involved, the validity of this British Standard is not affected.

NOTE 6. For the purposes of this standard, BS 2692 : Part 1 : 1975 is technically equivalent to IEC 282-1 : 1974 as column A of table 9 of 18.8 is identified by Appendix K as being equivalent to table IX of IEC 282-1, although containing only those values of rated voltage (and the corresponding maximum switching voltages) for which there is a need in the UK; table 9 of BS 2692 : Part 1 : 1975 includes all the rated voltages from IEC 282-1 : 1974 which appear in Part 1 of this British Standard (BS 5622 : Part 1 : 1979).

Reference to IEC 282-1 appears only in clause 2 of this standard.

NOTE 7. *Textual errors.* When adopting the text of the international standard, the errors listed below were noticed. They have been corrected in this British Standard and have been reported to the International Electrotechnical Commission in a proposal to amend the text of the international standard.

Subclause 7.3 paragraph 3, line 2 (IEC page 21). 'analysers' has been deleted and replaced by 'analysers'.

Clause 22, paragraph 2, line 1 (top of IEC page 53). 'one to three values' has been deleted and replaced by 'one to five values'.

Appendix B, clause B1, final paragraph, line 2 (IEC page 77). 'or than the probability' has been deleted and replaced by 'or that the probability'.

Appendix B, clause B2, first paragraph, line 1 (IEC page 77). 'basis limitations' has been deleted and replaced by 'basic limitations'.

Appendix C, note 1, line 1 (IEC page 83). 'Baussian' has been deleted and replaced by 'Gaussian'.

Appendix C, line 2 of paragraph before formula (18) (IEC page 85). 'Formula (1)' has been deleted and replaced by 'Formula (11)'.

Appendix D, first paragraph, line 1 (top of IEC page 89). 'Table III, page 98' has been deleted and replaced by 'Table III, page 99'.

Table 1, note 3 (bottom of IEC page 95). 'on the insulators may' has been deleted and replaced by 'on the insulators, may'.

Figure 12, block 6 (IEC page 119). 'rated-voltage' has been deleted and replaced by 'rated voltage'.

CONTENTS

	Page
National foreword	Inside front cover
Cooperating organizations	Back cover
 SECTION ONE — SCOPE AND REFERENCE TO EXISTING IEC PUBLICATIONS	
Clause	
1. Scope	3
2. Reference to existing IEC publications	3
 SECTION TWO — VOLTAGE STRESSES IN SERVICE	
3. General	4
4. Power-frequency voltages	5
5. Temporary overvoltages	5
6. Switching and lightning overvoltages	7
7. Determination of expected overvoltage levels	9
 SECTION THREE — INSULATION WITHSTAND	
8. General	11
9. Insulation behaviour at power-frequency voltages and temporary overvoltages	12
10. Probability of disruptive discharge of insulation under impulse voltages	12
11. Apparatus with windings	15
 SECTION FOUR — PROTECTIVE DEVICES	
12. General	15
13. Non-linear resistor-type surge arresters	15
14. Expulsion-type surge arresters	16
15. Spark gaps	17
16. Application of different protective devices	18
 SECTION FIVE — CO-ORDINATION BETWEEN STRESSES AND WITHSTAND CONSIDERATIONS COMMON TO RANGES A, B AND C	
17. Insulation design to power-frequency operating voltage and temporary overvoltages. Problems of pollution and ageing	19
18. Pollution	19
19. Ageing	20
 SECTION SIX — CO-ORDINATION BETWEEN STRESSES AND WITHSTAND IN VOLTAGE RANGE A	
20. Selection of the rated power-frequency withstand voltage	20
21. Selection of the rated lightning-impulse withstand voltage	20
 SECTION SEVEN — CO-ORDINATION BETWEEN STRESSES AND WITHSTAND IN VOLTAGE RANGE B	
22. Selection of the rated power-frequency withstand voltage and the rated lightning-impulse withstand voltage	25
 SECTION EIGHT — CO-ORDINATION BETWEEN STRESSES AND WITHSTAND IN VOLTAGE RANGE C	
23. Insulation design with respect to power-frequency voltage and temporary overvoltages	26
24. Insulation design with respect to switching and lightning overvoltages	26
25. Block-diagram of the insulation design and co-ordination of an electrical installation	30
 APPENDIX A — Surge transference through transformers	
APPENDIX B — Validity of the tests in Clauses 52, 53 and 54 of IEC Publication 71-1	
APPENDIX C — Statistical evaluation of the protective effect of spark gaps	
APPENDIX D — Examples of application	
APPENDIX E — Clearances in air between live conductive parts and earthed structures to secure a specified impulse withstand voltage for dry conditions	
TABLES	47
FIGURES	53

British Standard Guide for

Insulation co-ordination

Part 2. Application guide

SECTION ONE — SCOPE AND REFERENCE TO EXISTING IEC PUBLICATIONS

1. Scope

This publication provides some guidance on the selection of the electric strength of equipment, of surge arresters or protective spark gaps, and on the extent to which it will be useful to control switching overvoltages.

The object of this publication is not to give strict rules for insulation co-ordination and design, but to provide guidance toward rational and economical solutions.

Therefore it is intended to consider only a few basic cases in this publication, it being evident that installations constituting exceptions to normal design, or included within systems having exceptional characteristics, will require special study by experienced engineers.

This Application Guide is based on apparatus types and ratings in use at the time of publication. As new equipment and equipment characteristics are developed and proved, this guide should not be interpreted as a limit to their adoption.

Like Publication 71-1, Publication 71-2 covers only phase-to-earth insulation.

Like Publication 71-1, Publication 71-2 deals separately with the three following ranges of the highest voltage for equipment:

- range A: above 1 kV and less than 52 kV;
- range B: from 52 kV to less than 300 kV;
- range C: 300 kV and above.

It covers installations of all kinds and in all situations involving voltages higher than 1 kV, whether or not they are exposed to lightning, with the exception of overhead lines. However, the test procedures apply also to the latter.

2. Reference to existing IEC publications

Several IEC publications give standards which deal respectively with the withstand and protective levels considered separately. Thus:

- a)* IEC Publication 71-1, Insulation Co-ordination, Part 1: Terms, Definitions, Principles and Rules, contains the definitions of terms to be found here; it gives the series of standard values of the rated lightning and switching impulse withstand voltage, the rated withstand voltages of short duration at power frequency, as well as the tables of the recommended combinations between the highest voltage for equipment and these rated withstand voltages.
- b)* IEC Publication 99-1, Lightning Arresters, Part 1: Non-linear Resistor Type Arresters for A.C. Systems, gives the protective characteristics under lightning impulses of non-linear resistor type surge arresters for ratings up to 198 kV. Standard ratings above 198 kV are not included in IEC Publication 99-1. However, values for guidance are given up to 396 kV. Values for switching impulses are under consideration.

The characteristics given in IEC Publication 99-1 refer to surge arresters in general use. However, surge arresters with better protective characteristics are available and their standardization is at present under consideration. IEC Publication 99-1A, First Supplement to Publication 99-1, gives guidance on the selection of surge arresters.

c) IEC Publication 99-2, Lightning Arresters, Part 2: Expulsion-type Lightning Arresters, gives the impulse characteristics of expulsion-type surge arresters. No reference is made in IEC Publication 71-1 to this type of arrester, but it is still being used on some supply systems, particularly for voltages in range A.

d) IEC Publication 282-1, High-voltage Fuses, Part 1: Current-limiting Fuses, lists the maximum overvoltages permitted during the interruption of fault current by a high-voltage fuse.

e) IEC Publication 60, High-voltage Test Techniques, describes the methods for generation and measurement of test voltages and currents and the appropriate test procedures, and recommends methods for calibration and checking of measuring devices.

There is no IEC publication for the protective characteristics of spark-gaps.

SECTION TWO — VOLTAGE STRESSES IN SERVICE

3. General

Dielectric stresses on insulation may be classified as follows:

- power-frequency voltages, under normal operating conditions;
- temporary overvoltages;
- switching overvoltages;
- lightning overvoltages.

In IEC Publication 71-1, overvoltages are classified with reference to the shape of the voltage wave which determines their effect on insulation and on protective devices, without reference to the cause of the overvoltages.

The term “temporary overvoltages” refers to sustained overvoltages, or to overvoltages having several successive peaks, with a decrement of amplitude such as to be comparable with a sustained overvoltage at power frequency or at harmonic frequency.

The terms “switching overvoltages” or “lightning overvoltages” refer to overvoltages for which only the highest peak value has to be considered and which can be represented, with regard to their effects on insulation and protective devices, by the long-fronted standard switching impulses or short-fronted standard lightning impulses used for test purposes. The foregoing names have been chosen because such overvoltages often—but not always—originate from switching operations or lightning discharges.

For example, the energization of a transformer-terminated line gives rise to an overvoltage that may be regarded as a “switching” or temporary overvoltage depending on the decrement of the successive peaks (i.e. depending on the circuit parameters). As another example: a phase-to-earth fault, although actually a switching operation (the same phenomenon would arise if a phase conductor was connected to earth by a circuit-breaker operation), may give rise to steep-front overvoltages, similar to those due to lightning; on the other hand, a lightning surge transferred through a transformer by inductive coupling between windings may produce on the secondary side of the transformer long-fronted waves, similar to those due to switching operations.

4. Power-frequency voltages

In insulation co-ordination processes, since overvoltages and impulse voltages are defined in terms of their peak values to earth, it is also convenient to make use of the phase-to-earth peak value of the system voltage, which is $\sqrt{2}/\sqrt{3} = 0.816$ times the usual r.m.s. phase-to-phase voltage.

Under normal operating conditions, power-frequency voltage can be expected to vary somewhat in magnitude and may be described by means of a probability distribution about the average operating value. The parameters of this distribution will differ from one point of the system to another. For purposes of insulation design and co-ordination, power-frequency voltage should however be considered as constant and equal to the highest voltage for equipment, which in voltage range C does not materially differ from the highest system voltage, with a phase-to-earth peak value of $U_m \sqrt{2}/\sqrt{3}$.

In range A and in range B up to 72.5 kV, the highest voltage for equipment may be substantially higher than the highest system voltage, as indicated in the note under Clause 5 of IEC Publication 71-1. For the sake of standardization, it is however assumed that equipment insulation will always be able to operate satisfactorily at the highest voltage for equipment immediately above, if not equal to, the highest system voltage.

5. Temporary overvoltages

The severity of temporary overvoltages is mainly characterized both by their amplitude and duration.

The importance of temporary overvoltages in insulation co-ordination is twofold:

- on the one hand, the characteristics of temporary overvoltages at the surge arrester location are of great importance in surge arrester selection;
- on the other hand, the repetition of successive overvoltage peaks of opposite polarity, even if of lower amplitude than some other overvoltages, may determine the design of both the internal insulation of equipment as well as the external insulation (surfaces exposed to contamination).

Temporary overvoltages generally arise from:

- a) earth faults;
- b) sudden changes of load;
- c) resonance and ferro-resonance.

5.1 Earth faults

The overvoltage at power frequency on the sound phases when another phase is accidentally earthed depends, at a given point of the system, on the treatment of the system neutral with respect to earth, as characterized by its earth fault factor at that point.

Note. — In the evaluation of earth fault factors, the following remarks should be considered:

- In general, in order to evaluate this factor at a given location it is assumed, for simplicity, that the fault is located at the point for which the factor is desired; but, in some special cases, it may be desirable to investigate the effect of other fault locations on this factor.
- In principle, there are as many particular values of the earth fault factor at a given location as different possible configurations of the system. The factor which characterizes the location considered is the highest of the values that correspond to the different system configurations which may occur in practice.
- The system configurations which have to be considered are those which exist during a fault; thus one should take into consideration those changes in the system which may be produced by the fault itself, for example, on account of the operation of circuit-breakers.
- For many systems, it will be sufficient to consider only one value of the earth fault factor which covers all possible fault locations on the system.
- Attention is drawn to the fact that the highest voltage at power frequency which may appear on a sound phase during a particular earth fault does not depend only on the value of the earth fault factor, but also on the value of the phase-to-phase voltage at the time of the fault. This phase-to-phase voltage will generally be taken as the highest system voltage, as given in

Definition 4 of IEC Publication 71-1; but, in some cases, in order to predict the operation of protective devices and specify their characteristics, it is necessary to take into account the increased value of the phase-to-phase voltage that may appear at the selected location under abnormal operating conditions not covered by the definition referred to above.

Within range A and in some cases within range B, many systems or installations are operated with their neutral earthed through a high impedance, an arc-suppression coil or with their neutral isolated. For the purpose of insulation co-ordination, particular attention must therefore be paid in these cases to the earth fault factor.

Independently of the earth fault factor, particularly high overvoltages may arise in range A and range B systems in the case of:

- a) earth faults in a system the neutral of which is earthed through an arc-suppression coil when the circuit is under-compensated;
- b) arcing earth faults in a system the neutral of which is isolated and in some cases in a system the neutral of which is earthed through an arc-suppression coil.

5.2 *Sudden changes of load*

In usual conditions of operation, the phase-to-phase voltage does not exceed the value of the highest voltage of the system as given by Clause 4 concerning definitions of IEC Publication 71-1; but higher values may temporarily be reached in the case of sudden disconnection of large active and reactive loads; these values depend on the system layout after disconnection and on the characteristics of the sources (short-circuit power at the station, speed and voltage regulation of the generators, etc.).

This voltage rise may be especially important in the case of load rejection at the remote end of a long line (Ferranti effect). It affects mainly the apparatus at the station connected on the source side of the remote open circuit-breaker.

Note. — From the point of view of overvoltages, a distinction should be made between various types of system layouts. As extreme cases we can consider: those with relatively short lines and high values of the short-circuit power at the terminal stations; and those with long lines and low values of the short-circuit power at the generating site. With the latter layouts, as are usual in an extra-high-voltage system in its initial stage, much higher overvoltages at power frequency may result when a large load is suddenly disconnected.

Due to the characteristics of the systems, overvoltages of this kind are more severe in voltage range C than in voltage range B; overvoltages of this kind, in voltage range A, occur in generator-transformer circuits.

5.3 *Resonance and ferro-resonance*

Temporary overvoltages due to these causes generally arise when circuits with large capacitive elements (lines, cables, series-compensated lines) and inductive elements (transformers, shunt reactors) having non linear-magnetizing characteristics are energized, or as a result of sudden changes of load.

These situations are generally found for systems in ranges B and C in the following cases:

- a) A lightly loaded line, fed or terminated by a transformer, can show for example harmonic oscillations and pronounced overvoltages if the natural frequency of the linear part of the system corresponds to one of the harmonics of the transformer magnetizing current.
- b) Subharmonic oscillations and overvoltages can occur in systems compensated by series capacitors and terminated by lightly loaded power transformers or shunt reactors if the impressed voltage, the effective circuit resistance, which is strongly influenced by synchronous machines, and the circuit capacitance fall between certain limits.
- c) If harmonic filters are connected to a system containing saturable elements, oscillations due to resonances between these elements and the filter capacitors can develop.

These ferro-resonance effects following energization processes can either be sustained or last several cycles of the power frequency depending on the time constant of transformer inrush currents.

Causes of resonance and ferro-resonance in systems of range A are:

- d)* Resonance between inductive and capacitive components, e.g. when capacitors are used for power-factor correction.
- e)* Ferro-resonance which can occur in non-simultaneous closure or disconnection of the phases of a transformer the secondary of which is loaded by a small capacitance only.
- f)* Ferro-resonance occurring on a transformer having on the secondary side an iron-cored inductive load such as a voltage transformer, particularly when being switched in.
- g)* Ferro-resonance which can occur when one phase of a circuit supplying an unearthed primary transformer is opened particularly if the circuit is a cable. At the highest end of range A, transformer bushing capacitance may be sufficient to cause ferro-resonance under these conditions.

6. Switching and lightning overvoltages

For the purpose of this Guide, switching overvoltages are, as stated above, of a type which can be simulated by a standard switching impulse, i.e. an aperiodic wave with a front duration of the order of hundreds of microseconds and a tail duration of the order of thousands of microseconds. They stress the various parts of an insulation in about the same proportions as power-frequency voltages, but are not repetitive and only one peak of either polarity is normally significant.

Lightning overvoltages are those which can be simulated by a standard lightning impulse, i.e. an aperiodic wave with a front duration of the order of one microsecond and a tail duration of the order of several tens of microseconds. Due to the front steepness, they stress more than the former the longitudinal insulation of inductive windings, and because of their shorter duration, a generally somewhat higher stress at equal amplitude can be withstood by a given insulation. The magnitude of this effect depends on the type of insulation being considered.

These overvoltages generally arise from:

- a)* line energization and re-energization;
- b)* faults and fault clearing;
- c)* switching of capacitive currents and of small or moderate inductive currents;
- d)* load rejections;
- e)* lightning strokes (first or subsequent components of a lightning flash).

Note. — The overvoltages in cases *a)* to *d)* depend on the characteristics of the equipment, especially of the circuit breakers, transformers and shunt reactors. They may generally be reduced by suitable choice of these characteristics, i.e. in case *a)* by using pre-insertion resistors or shunt reactors, and in case *c)* by using surge arresters connected between the circuit-breaker and the transformer.

6.1 Switching overvoltages due to line energization and re-energization

Overvoltages due to closing and to single-phase and three-phase reclosing are of great importance in the selection of system insulation in range C.

These overvoltages, except in special cases, are not of particular importance in the other ranges of voltages.

6.2 Switching overvoltages due to faults and fault clearing

In range A and in relatively few cases in range B under the conditions listed in Items *a)* and *b)* of Sub-clause 5.1, high switching overvoltages can arise at the initiation of a fault.

In all the voltage ranges, high overvoltages may arise due to faults to earth in composite circuits including overhead lines and cable-connected transformers.

At the highest voltages of range C, a high degree of control of overvoltages caused by line energization and re-energization is normally attempted. For this reason, switching overvoltages due to faults and fault clearing (single and double phase-to-earth faults, and their clearance) need careful consideration.

6.3 *Switching overvoltages due to switching of inductive and capacitive currents*

In range A, the switching of inductive or capacitive currents can give rise to overvoltages, which may require attention, both in high-voltage distribution systems and in industrial installations and power stations. In the case of the former, high overvoltages may arise if the circuit breaker deionizes so rapidly as to force the current prematurely to zero, so-called current chopping.

In particular, the following switching operations should be taken into consideration:

- a) interruption of the starting currents of motors;
- b) interruption of inductive currents, e.g. when interrupting the magnetizing current of a transformer or reactor;
- c) switching and operation of arc furnaces and their transformers which may lead to current chopping;
- d) switching of unloaded cables and of capacitor banks;
- e) interruption of currents by high-voltage fuses.

In range B, overvoltages due to the interruption of capacitive currents (switching off unloaded lines, cables or capacitor banks) may be particularly dangerous since the use of restrike-free circuit-breakers cannot always be assumed.

6.4 *Switching overvoltages due to sudden changes of load*

Overvoltages due to sudden changes of load may start with a high switching surge followed by a temporary overvoltage.

Overvoltages of this kind are particularly important at the highest voltages in range C where a high degree of control of reclosing surges is attempted.

6.5 *Lightning overvoltages*

Lightning overvoltages are caused either by direct strokes to the phase conductors, back-flashovers, or as a result of strokes to earth very close to the line which produce induced lightning surges. The overvoltages by which substation insulation is stressed are a function of the line construction and the system configuration. The configuration of the station itself has a great influence if the travelling time of surges within the station is not negligible in relation to the front time of the surge.

Depending on the system configuration, overvoltages with time parameters in the range of switching surges may also arise as a result of lightning strokes.

Lightning discharges which produce significant overvoltages in ranges B and C are confined to direct strokes to phase conductors or strokes to towers or earth wires with subsequent back-flashovers.

In range A, induced lightning surges must also be considered. Furthermore, in this range, surges transferred through transformers from a higher voltage system need careful consideration.

7. Determination of expected overvoltage levels

7.1 Range A

For voltages of less than 52 kV, switching overvoltages do not generally constitute a serious problem for overhead supply systems and insulation co-ordination is based on lightning overvoltages.

Switching overvoltages transferred from an overhead line into a plant through transformers or lengths of cable can, in general, be ignored for the same reason. An exception is the case of an installation connected to the lower-voltage terminals of a high-voltage transformer feeder, particularly if resonance occurs between the two systems during one- or two-phase energizing.

In industrial plants and power stations, the amplitudes and waveshapes of switching overvoltages generated within the installation vary over a very wide range. In the great majority of cases they are innocuous; in some cases, serious overvoltage amplitudes and rates of change can occur. Thus sudden voltage swings can be caused when a switching device re-strikes; the resulting rate-of-change of voltage can equal that caused by a severe close lightning strike.

A very large amount of practical operational experience is available from different industrial plants and power stations, and the most severe overvoltages or voltage swings can usually be avoided by eliminating resonance and by correct choice of the switching device to be employed.

Detailed representation of the system under consideration on a digital computer or transient network analyser can only be economically justified in particular cases at these voltage levels since accurate representation is needed to obtain accurate results and a complex plant frequently consists of many pieces of equipment and electrical connections. Furthermore, the operation of some types of switching devices and arcing earths is difficult to simulate with a sufficient degree of accuracy. Experience is often the best guide and, in exceptional cases, deliberate switching tests with simultaneous recording (both high-speed and low-speed) will produce the most valuable information so that remedial measures can be taken as the result of subsequent calculations and confirmatory tests.

The amplitudes, waveshapes and frequency of occurrence of lightning overvoltages on systems in range A can be estimated with a reasonable degree of accuracy. As the impulse flashover voltage of insulators used on overhead lines in this range is quite low as compared with the voltage impressed on such a line by a direct lightning stroke, the stresses to which substation equipment is liable to be subjected are primarily determined by the type of line construction. Thus careful protection of substation equipment is required if it is connected to a wood-pole line with un-earthed cross-arms. Reduced protection is permissible where the lines are erected on steel masts, reinforced concrete poles or where metal cross-arms are otherwise earthed.

Amplitudes and waveshapes are also affected by the following factors which characterize the constitution of the system and arrangement of the station:

- a) Surge impedance of those lines or cables which are connected to the station. For example, when only one line is connected to a terminal transformer, the surge is reflected at the termination and is doubled in voltage amplitude; when n lines of the same surge impedance are connected to the busbars of a station, and if the lightning stroke to the line does not occur close to the station, the voltage at the busbars becomes $2u/n$, where u is the amplitude of the surge voltage transmitted along the line on which the lightning surge originated; in the case of lightning in the vicinity of the sub-station, wave reflection must be taken into account and calculation may prove to be necessary.
- b) Cables with an earthed metallic sheath which are in series with the line or connected between the station busbars and apparatus to be protected. Any cable tends to reduce the steepness of the waves entering the station, but the cable length must be at least 1 or 2 km long before it has a significant effect on the surge amplitude. In the case of a direct lightning stroke to the last span in front of a station, a cable section between overhead line and station affords practically no relief to the station equipment. More details are given in Sub-clause 21.4.

- c) Protective earth wires on the overhead lines extending up to a few kilometres from the station; these are effective against close lightning strikes to the line near the station which are the most dangerous. This presupposes

that shielding by the earth wires is sufficiently well designed to prevent direct strokes reaching the phase conductors, and that the earthing resistance of the tower is sufficiently low to reduce the risk of back flashover, as given in Item *e*) below.

d) Protective spark gaps or protective earth wires extending over one or two spans in front of the station; these can materially reduce the amplitudes of incoming surges on lines with high insulation to earth, e.g. on fully insulated wood-pole lines.

e) Earthing resistances and inductances of the down leads of towers, particularly close to the station. In the cases of high values of earthing resistance or the inductance of the down lead of the tower or pole, a lightning strike to such a tower or pole or to an earth wire may cause high overvoltages on the phase conductors by back flashover across the line insulators to one or more phase conductors.

In range A, lightning surges transferred through transformers are also important. Analytical expressions for the electrostatic and electromagnetic terms of the transferred voltages are derived in Appendix A.

7.2 Range B

In range B, as well as in range A, the insulation levels are generally such that switching overvoltages are seldom a major problem and that insulation co-ordination is still mainly based upon lightning overvoltages occurring in overhead line systems.

Furthermore, also in this voltage range, there is usually no decisive economic incentive towards a detailed study of overvoltage stresses.

Thus the considerations in Sub-clause 7.1 continue to apply.

7.3 Range C

For this voltage range, the importance of the switching overvoltages in insulation co-ordination becomes predominant, all the more so as the voltage level increases. This is what justifies the substitution of a switching impulse test, considered more representative, for the traditional 1-min power frequency test.

The high cost of equipment then compels consideration of more economical designs of insulation co-ordination, while, in turn, the serious consequences of a failure necessitate a more precise estimation of the overvoltages to be expected. These have to be evaluated for each type of significant overvoltage in the particular system considered.

Because of the extensive computational requirements, virtually all practical overvoltage predictions must be made using transient network analysers or digital computers.

Experience with studies of a wide variety of systems has shown that development of generalized formulae for overvoltages is difficult because of the large number of parameters affecting the overvoltage value.

Both analogue and digital techniques of transient solution require a high level of skill in problem-solving. These skills are principally useful in the selection of significant cases (it being impractical to study all possibilities), in the reduction of the system to a reasonable number of busbars and lines (it is not practical to represent the entire system on either TNA or digital solutions) and in the description of system constants and apparatus characteristics.

Whenever possible, field tests to check the validity of the parameters used are recommended.

In the sophisticated approaches to insulation co-ordination now becoming more and more usual for the highest values of voltage, the amplitudes of the overvoltages to be expected at a given location due to a given type of event cannot be defined by a single value (see Figure 1, see page 106). It is only possible to state the probability $f_0(U) dU$

that an overvoltage value comprised between U and $U + dU$ may occur, $f_o(U)$ being the overvoltage probability density. The probability $F_o(U')$ that the value U' may be exceeded is then given by:

$$F_o(U') = \int_{U'}^{\infty} f_o(U) dU \quad (1)$$

SECTION THREE — INSULATION WITHSTAND

8. General

8.1 *Self-restoring and non-self-restoring insulation*

Clauses 10 and 11, concerning definitions of IEC Publication 71-1, subdivide insulation into self-restoring and non-self-restoring insulation according to its behaviour in the case of occurrence of a disruptive discharge during a dielectric test. On the former kind of insulation, it is possible to carry out tests under conditions that imply an appreciable risk of such discharges, e.g. by applying a large number of impulses at the rated impulse withstand voltage, or even in conditions with deliberately applied discharges as in a 50% disruptive discharge test carried out at voltages above the rated impulse withstand level.

On non-self-restoring insulation, a disruptive discharge destroys the insulating property of the insulation and a large number of impulses at rated withstand voltage may result in a gradual deterioration of the insulation. Non-self-restoring insulation is for these reasons tested by application of a limited number of impulses at rated withstand voltage.

The degree of information on the dielectric strength of the equipment directly obtainable can thus be much higher for self-restoring insulation. However, in the case of non-self-restoring insulation, the economic importance for the manufacturer of the risk of having the equipment rejected tends to compel him to design the equipment for a very low probability of failure under test. Taking these two factors together, no difference is made in IEC Publication 71-1 between impulse withstand levels, in relation to the kind of insulation or the nature of the test.

While self-restoring insulation does not lose or modify its insulating ability following a disruptive discharge in a dielectric test, it should not be inferred that damage may not occur in service if the disruptive discharge is followed by an intense power arc.

Furthermore, possible damage to equipment is not the only consideration to be introduced in the selection of an acceptable risk of discharge in service, as the effect on continuity of supply also has to be considered. For example, a much lower probability of insulation failure is required in the case of busbars than on individual lines.

It must be emphasized that the insulating structures of a piece of equipment are always made up of self-restoring and non-self-restoring parts. Generally it cannot therefore be stated that the insulation of an apparatus is self-restoring or non-self-restoring. But the probability that discharges may occur across or through non-self-restoring parts in the presence of self-restoring parts can, for different types of equipment, be negligible or otherwise. Due to the different voltage-time sparkover characteristics of solid and air insulations, this probability tends to increase with increasing impulse voltage amplitudes; thus it may be negligible at the rated withstand voltage, but may become appreciable around the 50% disruptive discharge voltage.

8.2 *Selection of the type of test*

For some types of apparatus, within the range of overvoltages that tests have to simulate, the probability of a discharge occurring across a non-self-restoring part is negligible. In this case, the discharge probability coincides

with that of the self-restoring parts of the apparatus and its insulation may be called “essentially self-restoring” or, for the sake of simplicity, “self-restoring”. Disconnecting switches may be considered an example of this type; in fact, even when applying impulses well above the 50% discharge voltage during a 50% discharge test, sparkover takes place usually in air without any puncture of the porcelain. For this type of equipment, the test of Clause 52 of IEC Publication 71-1 is possible and recommended.

For types of apparatus with mainly or a large part of non-self-restoring insulation, the high cost of this part of insulation excludes tests of the complete apparatus at higher than rated withstand voltage. The test voltage is therefore limited to the rated withstand voltage as this already implies an overinsulation of the non-self-restoring parts so as to give negligible probability of discharge up to rated withstand voltage.

Such types of apparatus that also have a self-restoring part of insulation that cannot be tested separately from the non-self-restoring part, e.g. bushings and some types of instrument transformers, would require a large number of impulses to prove the adequacy of the self-restoring insulation. The number of impulses must however be restricted because of the possibility of gradual deterioration of the non-self-restoring parts of insulation. Insulation of this type of equipment, that can be called combined, should be tested according to Clause 53 of IEC Publication 71-1.

For some types of equipment with mainly non-self-restoring insulation, e.g. power transformers, the self-restoring insulation (e.g. bushings) can be tested separately according to Clause 52 of IEC Publication 71-1. This kind of equipment is called “essentially non-self-restoring” or, for the sake of simplicity “non-self-restoring”. Insulation of this kind is verified by means of the test in Clause 54 of IEC Publication 71-1.

Considerations on the validity of the tests in Clauses 52, 53 and 54 of IEC Publication 71-1 are given in Appendix B.

9. Insulation behaviour at power-frequency voltages and temporary overvoltages

In general, sparkover under power-frequency voltage in normal operating conditions and under temporary overvoltages will be caused by progressive deterioration of the insulating properties of the equipment or by exceptional reductions in insulation withstand due to severe ambient conditions.

In the latter case, the concept of probability is applicable to the degree of contamination (see Clause 4).

Because of the difficulties involved, no use of statistical concepts will be made in this Guide in respect of insulation behaviour at power-frequency voltages and temporary overvoltages (see also Clauses 17 and 18).

10. Probability of disruptive discharge of insulation under impulse voltages

The ability of a given insulation to withstand the dielectric stresses caused by the application of an impulse of given waveshape and peak value U is, in most cases, a random phenomenon, even if we consider a time interval so small (such as that needed to carry out a dielectric test on equipment) that the ambient and insulation conditions may be considered constant, at least with respect to parameters such as pressure, temperature, humidity, etc., which can be measured and which are used to define the ambient and insulation conditions during tests.

The disruptive discharge probability of insulation for an impulse of given waveshape and polarity, and for a peak value U in a short time interval as defined above (e.g. in a dielectric test) can be determined, if the insulation is self-restoring, by applying the impulse U N times successively within this time interval, and counting the number $N1$ of discharges. From the fraction $\frac{N1}{N}$ a numerical value can be obtained for this probability which will be the more accurate the greater is the value of N .

The discharge voltages of a population of non-self-restoring insulation can be described statistically by means of a distribution curve that gives the relation between the amplitude of the discharge voltage and the fraction of the population that will break down at that voltage amplitude. For the determination of this distribution curve, tests must be performed with voltage amplitudes increased up to breakdown on a sample of pieces from the population. The accuracy in the determination of the curve will be increased by increasing the number of pieces in the sample. Because a disruptive discharge normally results in the destruction of the test piece, the number of pieces in the sample must be limited for reasons of economy.

No method is at present known for the determination of the probability of disruptive discharge of a single piece of non-self-restoring insulation.

If we consider either switching or lightning impulses of different peak values U , we shall be able to associate with every possible value of U a discharge probability P_t , thus establishing a relationship $P_t(U)$ for a given insulation in a short time interval Δt or, for the sake of simplicity, at a time t (see Figure 2a, page 107).

The values of $P_t(U)$ increase from near 0 to near 100% probability in a more or less narrow band of voltage values. In general, the resulting curve can be defined by a biparametric law, one parameter being associated with the position of the voltage band and giving an indication of the withstand level, and the other associated with the bandwidth and giving an indication of the scattering of the voltage values which give appreciable proportions of both discharges and non-discharges.

Generally, in a laboratory, the parameter that defines the position of the probability curve is taken as the voltage $U_{t\ 50}$ which corresponds to the 50% discharge (or withstand) probability. The standard deviation of the distribution (σ_t), defined by the square root of the sum of the squares of the deviations with respect to the mean is usually taken as the parameter which expresses the scattering. For a Gaussian distribution, it corresponds to half the difference between the voltages that give discharge probabilities of 16% and 84%.

In service, the ambient and insulation conditions do not remain constant. Therefore the discharge probability curve of insulation, as defined above for the time t , is bound to change from one moment to another ($P_t, P_{t'}, \dots$) (see Figure 2a). The variations are determined, as regards external insulation, mainly by atmospheric conditions.

Taking the ambient and insulation conditions as random, it will be necessary to consider for each insulation, in addition to the discharge probability $P_t(U)$, as defined above, a discharge probability of insulation $P_T(U)$ to over-voltages of amplitude U liable to occur at any instant of a long time interval T of operation. For the purpose of insulation design, it is this second distribution which is of interest (see Figure 2c, page 107).

Similarly to $P_t(U)$, $P_T(U)$ can be defined by the voltage ($U_{T\ 50}$) which corresponds to the 50% discharge (or withstand) probability and by the standard deviation of the distribution σ_T .

The variations of $P_t(U)$ within the time interval ΔT may be conveniently defined by the probability density $P_n(U_{t\ 50})$ where $U_{t\ 50}$ is considered as a random variable (Figure 2b, page 107). This latter function in turn may be characterized by the 50% discharge voltage $U_{T\ 50}$ and by its standard deviation σ_n .

On the simplifying assumption that the standard deviation σ_t of $P_t(U)$ is constant within the time interval ΔT , the following relation holds:

$$\sigma_T = \sqrt{\sigma_t^2 + \sigma_n^2} \quad (2)$$

In IEC Publication 71-1, the parameter that defines the position of the probability curve $P(U)$ is taken as the voltage which corresponds to a withstand probability of 90% (see Clause 26 of IEC Publication 71-1), although the 50% discharge voltage which was referred to above is a convenient measure for pieces of insulation that can be submitted to a 50% disruptive discharge test.

The reason for this choice is that the 50% disruptive discharge test cannot be generally applied to all kinds of insulation. Thus, in order to have the same values of the rated impulse withstand voltages for all types of equipment, whatever its insulation, and to use these values directly in the definitions of statistical distributions, it has been deemed appropriate to refer to a higher value (90%) of the withstand probability, the rated impulse withstand voltage U_{RW} being identical with the lowest permissible value of the statistical impulse withstand voltage under specified test conditions $U_{t\ 90}$.

For risk-of-failure evaluations, it is however convenient to express the probability curves of insulation discharge in terms of their 50% discharge voltages and standard deviations.

Assuming for $P_t(U)$ a Gaussian distribution with standard deviation σ_t , the difference between the 50% discharge (or withstand) voltage and the statistical (or 90%) withstand voltage is given by:

$$U_{t\ 50} = \frac{U_{t\ 90}}{1 - 1.3 \sigma_t} \quad (3)$$

σ_t depends upon numerous parameters (waveshape, polarity, configuration of the object, dielectric nature, etc.). However, on present information, and for equipment of range C in air, σ_t is taken as 0.03 or 0.06 depending on the type of impulse, lightning or switching, unless another value has been specified by the relevant Apparatus Committee (see Clause 52 of IEC Publication 71-1).

The probability of discharge $P_t(U)$ of a piece of equipment which during the test conforms to what is specified in IEC Publication 71-1 can then be defined in terms of its 50% discharge voltage and its standard deviation, as follows:

$$U_{t\ 50} = \frac{U_{t\ 90}}{1 - 1.3 \sigma_t} \geq \frac{U_{RW}}{1 - 1.3 \sigma_t} \quad (4)$$

The probability of discharge $P_t(U)$, defined by the above parameters, refers to the most severe test conditions for the equipment, since U_{RW} is the rated switching or lightning impulse withstand voltage. Therefore, if impulse tests have to be made in both wet and dry conditions, the probability $P_t(U)$ refers generally to wet conditions.

The probability of discharge in service $P_T(U)$ of a given piece of equipment can only be deduced from field tests, depending on the site of installation.

However, as a broad indication, the probability $P_T(U)$ of a piece of equipment conforming to the specifications of IEC Publication 71-1 can be defined, recalling equation (2), in terms of its 50% discharge voltage and its standard deviation, as follows:

$$U_{T\ 50} \geq k \frac{U_{RW}}{1 - 1.3 \sigma_T} \quad (5)$$

$$\sigma_T = \sqrt{\sigma_t^2 + \sigma_n^2}$$

where k is the ratio between the 50% discharge voltage of a given equipment in service during a time interval ΔT and the 50% discharge voltage under the most severe impulse test for the equipment (wet or dry, positive or negative polarity).

For switching impulses U of positive polarity, the values of k and σ_n relevant to time intervals ΔT of fine dry weather or various bad weather conditions do not show appreciable differences. The same may be said concerning the degree of atmospheric pollution, at least in the range from clean conditions to lightly polluted conditions.

For switching impulses U of negative polarity, the values of k and σ_n are highly dependent on the type of weather within the time interval ΔT under consideration. Concomitance of bad weather (rain, snow, fog, mist, etc.) and not negligible pollution leads to a low value of k ; bad weather also increases the value of σ_n .

Values of $k = 1$ and $\sigma_n = 5\%$ are suggested in this Guide for normal conditions and a time interval ΔT equal to the seasonal cycle to cover the worse polarity impulse. This value of σ_n results in a value of σ_T a little lower than 8%.

The same values of k and σ_n are also suggested for lightning impulses. This gives a value of σ_T equal to 6% approximately.

The information given above is to be considered merely as broadly indicative and it is recommended that use should be made of more detailed data derived from field and laboratory tests, if available.