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TECHNICAL REPORT

colour inside

Guidance on clearances and creepage distances in particular for distances equal to or less than 2 mm – Test results of research on influencing parameters

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GUIDANCE ON CLEARANCES AND CREEPAGE DISTANCES IN PARTICULAR FOR DISTANCES EQUAL TO OR LESS THAN 2 mm – TEST RESULTS OF RESEARCH ON INFLUENCING PARAMETERS

FOREWORD

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IEC TR 63040, which is a Technical Report, has been prepared by IEC technical committee 109: Insulation co-ordination for low-voltage equipment.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
109/140/DTR	109/144/RVC

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

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

INTRODUCTION

This document provides information on printed board assemblies and other equivalent plane arrangements of insulation, where the clearance and the creepage distance follows the same path along the surface of solid insulation.

This document is based on German research data published in May 1989 [9], [10][1]. SC 28A, the predecessor of TC 109, began analysing this research data in November 1990.

The following points provide background information to the research.

- The research was carried out on test samples that were manufactured with the same technology being used for printed circuit boards (PCBs) with selected spacing of circuit patterns from 0,16 mm to 6,3 mm.
- Ten types of materials were used for the test samples. The influence of manufacturing operations on the surface of a material, for example moulding or machining, was not part of this research project.
- The test samples were placed in different locations, such as large city, rural, industrial, desert, sea side, and periodically exposed to a voltage stress and the data was accumulated over a long period of time.

1 Numbers in square brackets refer to the bibliography.

GUIDANCE ON CLEARANCES AND CREEPAGE DISTANCES IN PARTICULAR FOR DISTANCES EQUAL TO OR LESS THAN 2 mm – TEST RESULTS OF RESEARCH ON INFLUENCING PARAMETERS

1 Scope

This document describes test results of research on dimensioning of clearances and creepage distances, for spacing equal to or less than 2 mm for printed wiring material and other equivalent arrangements of insulation, where the clearance and the creepage distance follows the same path along the surface of solid insulation.

The information contained in this document is the result of research only and cannot be used for dimensioning the clearances and creepage distances for equipment within low-voltage systems, where IEC 60664-1 applies. However distances can be taken into account for functional reasons.

This document provides results of research related to the following criteria:

1) clearances independent from the micro-environment;
2) creepage distances for pollution degree 1, 2 and 3 which extends the use of smaller distances to products having design features similar to printed circuit boards;
3) creepage distances to avoid flashover of the insulating surface;
4) information on minimum creepage distances to maintain minimum insulation resistance.

A test method for the evaluation of the relevant water adsorption group for the surface of any insulating material which has not yet been classified is described.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60664-1:2007, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60664-1 and the following apply.

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

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

3.1
inhomogeneous field
non-uniform field
electric field which does not have an essentially constant voltage gradient between electrodes

Note 1 to entry: The inhomogeneous field condition of a point-plane electrode configuration is the worst case with regard to voltage withstand capability and is referred to as case A. It is represented by a point electrode having a 30 μm radius and a plane of 1 m × 1 m.

3.2
homogeneous field
uniform field
electric field which has an essentially constant voltage gradient between electrodes

Note 1 to entry: The electric field between two spheres where the radius of each sphere is greater than the distance between them is an example of a homogeneous field (case B).

3.3
electrical breakdown
failure of insulation under electric stress when the discharge completely bridges the insulation, thus reducing the voltage between the electrodes almost to zero

Note 1 to entry: For the purposes of this document the above definition is used, as the definition in IEC 60050-212:2010, 212-11-33 [1] is broader than the scope of this document.

3.4
flashover
electrical breakdown along a surface of solid insulation located in a gaseous or liquid medium

Note 1 to entry: For the purposes of this document the above definition is used, as the definition in IEC 60050-212, 212-11-47 is broader than the scope of this document.

3.5
humidity level
HL
level defining the expected humidity influences in the micro-environment and expressed numerically

3.6
water adsorption
capability of an insulating material to adsorb water on its surface

3.7
critical relative humidity
value of the relative humidity when the impulse withstand voltage of a creepage distance has dropped to 95 % of the value which was measured at 70 % humidity

3.8
water adsorption group
group characterizing the extent of the dependence of the critical relative humidity upon the creepage distance

3.9
working voltage
highest r.m.s. value of the AC or DC voltage across any particular insulation which can occur when the equipment is supplied at rated voltage

Note 1 to entry: Transients are disregarded.

Note 2 to entry: Both open-circuit conditions and normal operating conditions are taken into account.

3.10
rated insulation voltage
r.m.s. withstand voltage value assigned by the manufacturer to the equipment or to a part of it, characterizing the specified (long-term) withstand capability of its insulation

Note 1 to entry: The rated insulation voltage is not necessarily equal to the rated voltage of equipment which is primarily related to functional performance.

3.11
rated voltage
value of voltage assigned by the manufacturer, to a component, device or equipment and to which operation and performance characteristics are referred

Note 1 to entry: Equipment may have more than one rated voltage value or may have a rated voltage range.

4 Fundamental aspects and phenomena of clearance and creepage distances

4.1 Mutual correlation of insulation characteristics with regard to environmental conditions

The micro-environmental conditions for the insulation depend primarily on the macro-environmental conditions in which the equipment is located and in many cases the environments are identical. However the micro-environment can be better or worse than the macro-environment where, for example, enclosures, heating, ventilation or dust influence the micro-environment.

NOTE Protection by enclosures provided according to the degrees of protection specified in IEC 60529 [4] can increase or decrease the humidity of the micro-environment.

The most important environmental parameters are the following.

– For clearances:
  - air pressure;
  - temperature, if it has a wide variation.
– For creepage distances:
  - pollution;
  - relative humidity;
  - condensation.
– For solid insulation:
  - temperature;
  - relative humidity.

4.2 Pollution

4.2.1 General

Pollution does not only impair insulation with regard to long-term r.m.s voltage stress causing tracking but also impairs it with regard to peak voltages and water adsorption, causing reduced impulse withstand capability in case of short distances and thus flashover may occur along the insulation surface.

The influence of humidity on the surface of insulation is identified by the humidity levels. These levels also apply to a macro-environment having the same humidity as the micro-environment.

The influence of the water adsorption characteristics on the surface of insulation is identified by the water adsorption categories.

4.2.2 Humidity level (HL)

For the purpose of evaluating creepage distances with regard to flashover along the surface, respectively minimum insulation resistance, the following three levels in the micro-environment are established.

- Humidity level 1 (HL 1):

  The relative humidity at the insulation never reaches a level where condensation occurs on the insulation.

  Therefore, the flashover is not influenced by humidity. Humidity Level HL 1 is considered to be pollution degree 1.

- Humidity level 2 (HL 2):

  The relative humidity at the insulation is such that condensation on the insulation occurs only occasionally during transient changes in the micro-environment.

  Therefore, the flashover is influenced by humidity.

- Humidity level 3 (HL 3):

  The relative humidity at the insulation is such that condensation on the insulation may occur frequently.

  Therefore, the flashover is strongly influenced by humidity.

4.2.3 Relation of humidity levels to macro-environment

Macro-environmental conditions are specified in IEC 60364-5-51, in IEC 60721-3-3, IEC 60721-3-7, and IEC 60721-3-9. The relation of humidity levels to defined macro-environmental classes is shown in Table 1.

Table 1 – Relation of the humidity levels to macro-environments

Standard specifying climatic classes	**Climatic (macro-environmental) classes**			**Humidity levels**
IEC 60721-3-9 --------------------- IEC 60721-3-3 --------------------- IEC 60721-3-7 --------------------- IEC 60364-5-51	Y2 ----------- 3K1 ----------- ----------- ↓	Y3 ----------- 3K3 ----------- 7K1 ----------- AB5 ↓	Y4 ----------- 3K6 ----------- 7K3 ----------- AB7 ↓	
	=	(–)	(–)	→ HL 1
	(+)	=	(–)	→ HL 2
	(+)	(+)	=	→ HL 3
Key = micro-environment has the same humidity as the macro-environment (–) micro-environment is less humid than the macro-environment (+) micro-environment is more humid than the macro-environment				
NOTE In IEC 60721-3-9 different expressions of climatic classes are used.				

4.2.4 Comparative tracking index (CTI)

With regard to tracking, an insulating material can be roughly characterized according to the damage it suffers from the concentrated release of energy during scintillations when a surface leakage current is interrupted due to the drying-out of the contaminated surface. The following behaviour of an insulating material in the presence of scintillations can occur:

- no decomposition of the insulating material;
- the wearing of insulating material by action of electrical discharges (electrical erosion);
- the progressive formation of conductive paths which are produced on the surface of insulating material due to the combined effects of electric stress and electrolytically conductive contamination on the surface (tracking).

NOTE Tracking or erosion will occur when

- a liquid film carrying the surface leakage current breaks,
- the applied voltage is sufficient to break down the small gap formed when the film breaks, and
- the current is above a limiting value which is necessary to provide sufficient energy locally to thermally decompose the insulating material beneath the film. Deterioration increases with the time for which the current flows.

The behaviour of the insulating material under various contaminants and voltages is extremely complex. Under these conditions many materials may exhibit two or even all three of the characteristics stated. However, it has been found by experience and tests that insulating materials having a higher relative performance also have approximately the same relative ranking according to the comparative tracking index (CTI). Therefore, this document uses the CTI values to categorize insulating materials.

Materials are classified into four groups (MG) according to their CTI values. These values are determined in accordance with IEC 60112 using solution A. The groups are:

Material Group I	$600 \leq CTI$
Material Group II	$400 \leq CTI < 600$
Material Group IIIa	$175 \leq CTI < 400$
Material Group IIIb	$100 \leq CTI < 175$

The proof tracking index (PTI) is used to verify the tracking characteristics of materials. A material may be included in one of these four groups on the basis that the PTI, verified by the method of IEC 60112 using solution A, is not less than the lower value specified for the group.

The test for comparative tracking index (CTI) in accordance with IEC 60112 is designed to compare the performance of various insulating materials under test conditions. It gives a qualitative comparison and in the case of insulating materials having a tendency to form tracks it also gives a quantitative comparison.

For glass, ceramics or other inorganic insulating materials which do not track, creepage distances need not be greater than their associated clearance for the purpose of mutual correlation of insulation characteristics. The dimensions for inhomogeneous field conditions are appropriate. However, the behaviour with regard to flashover is important.

4.2.5 Flashover characteristics

Electric strength, thermal, mechanical and chemical characteristics of insulating material can be considered, taking into account the stresses likely to occur during the lifetime of the equipment.

Water adsorption is a surface-related phenomenon which depends on the characteristics of the insulating material. With regard to the effect of water adsorption on flashover behaviour, insulating materials are allocated to a water adsorption group according to the test procedure in Clause 7:

- Water adsorption group W1 (negligible influence)
- Water adsorption group W2 (weak influence)
- Water adsorption group W3 (medium influence)
- Water adsorption group W4 (strong influence)

NOTE Classification of materials with respect to water adsorption groups can be different if caused by fillers, additives, moulding method, surface tooling etc.

5 Clearances and creepage distances

5.1 General

Clearances need to withstand transient overvoltages and steady state voltages. The dimensioning of the associated creepage distance avoids failure due to tracking and flashover under humid conditions.

5.2 Clearances

5.2.1 Influencing criteria

5.2.1.1 Influencing factors on clearance dimensions

Selected clearance dimensions take into account the following influencing factors:

- impulse overvoltages;
- steady-state voltages and temporary overvoltages;
- recurring peak voltages;
- electric field conditions;
- altitude.

NOTE 1 The clearance dimensions given in Table 2 have sufficient impulse withstand capability for equipment for use at altitudes up to 2 000 m. For equipment for use at higher altitudes, see 5.2.2.

NOTE 2 Mechanical influences such as vibration and the effects of applied forces can require larger clearances.

5.2.1.2 Clearances to withstand transient overvoltages

Clearance dimensions according Table 2 can withstand impulse overvoltages with distances equal to or less than 2 mm.

For equipment directly connected to the supply mains, the required impulse withstand voltage is the rated impulse voltage (see IEC 60664-1:2007, Table F.1).

Table 2 – Clearances for mutual correlation of insulation characteristics to withstand transient overvoltages

	Minimum clearances up to 2 000 m above sea level	
Impulse withstand voltage[a] kV	Case A[c] inhomogeneous field conditions (see IEC 60664-1) mm	Case B[c] homogeneous field conditions (see IEC 60664-1) mm
0,33[b]	0,01	0,01
0,40	0,02	0,02
0,50[b]	0,04	0,04
0,60	0,06	0,06
0,80[b]	0,10	0,10
1,0	0,15	0,15
1,2	0,25	0,2
1,5[b]	0,5	0,3
2,0	1,0	0,45
2,5[b]	1,5	0,6
3,0	2,0	0,8
4,0[b]		1,2
5,0		1,5
6,0[b]		2,0

[a] This voltage is
– for functional insulation:
the maximum impulse voltage expected to occur across the clearance, see IEC 60664-1;
the rated impulse voltage of the equipment; see Table F.1 of IEC 60664-1:2007.

[b] Preferred values specified in IEC 60664-1.

[c] The values given in case A and case B are informative and cannot replace the values given in IEC 60664-1.

5.2.1.3 Inhomogeneous field conditions (case A of Table 2)

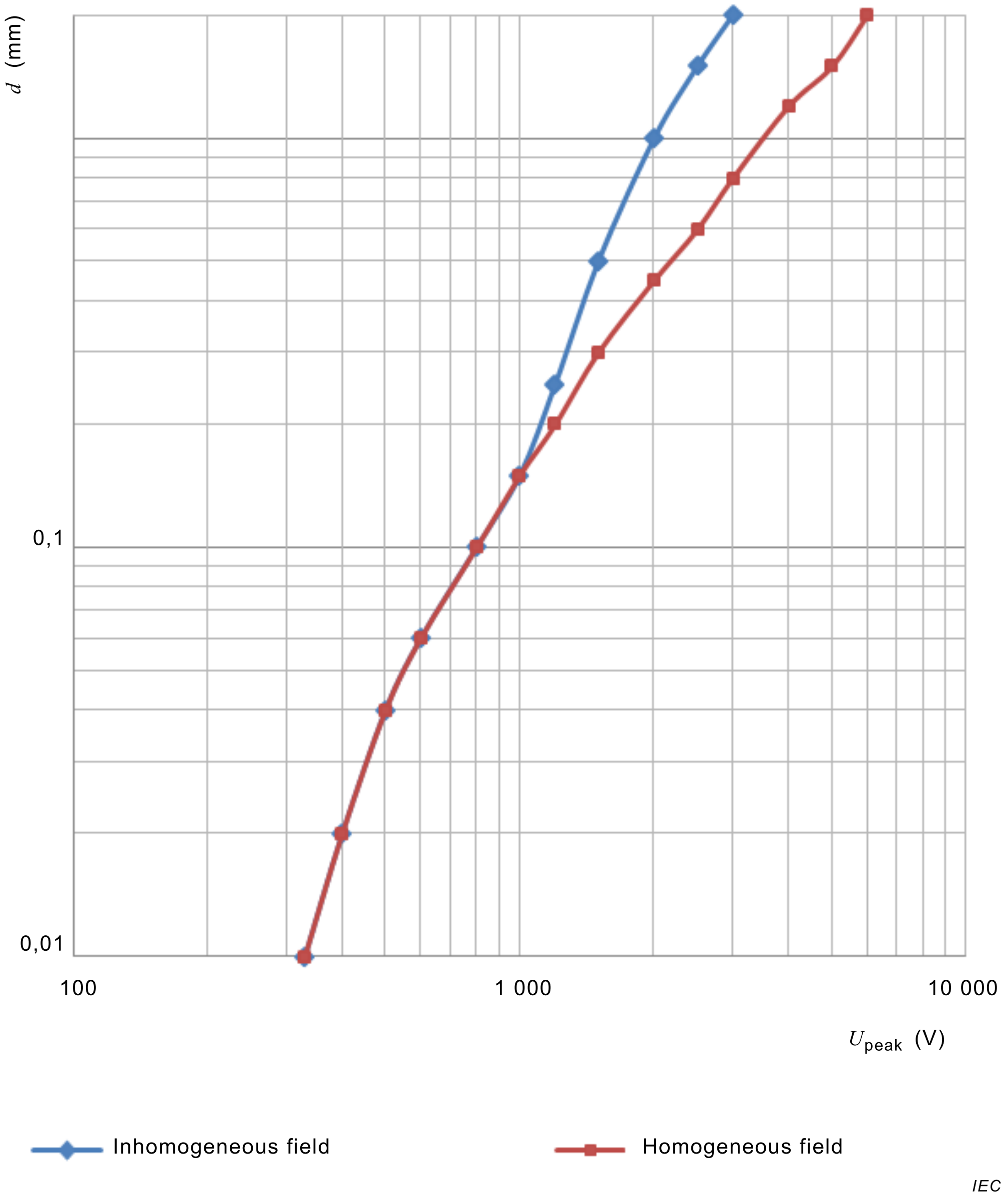
Clearances not less than those specified in Table 2 for inhomogeneous field conditions can be used irrespective of the shape and arrangement of the conductive parts and without verification by a voltage withstand test.

It is advisable that clearances through openings in enclosures of insulating material are not less than those specified for inhomogeneous field conditions since the configuration is not controlled. This can have an adverse effect on the homogeneity of the electric field.

5.2.1.4 Homogeneous field conditions (case B of Table 2)

Values for clearances in Table 2 for case B are only for homogeneous fields. They may only be used where the shape and arrangement of the conductive parts is designed to achieve an electric field having an essentially constant voltage gradient.

Clearances smaller than those specified in Table 2 for inhomogeneous field condition (case A) need verification by a voltage withstand test. Figure 1 illustrates Table 2.



NOTE See also Table 2 from which the figure is derived.

Figure 1 – Clearances in air for mutual correlation of insulation characteristics to withstand transient overvoltages up to 2 000 m above sea level

5.2.2 Altitude

5.2.2.1 General

As the values in Table 2 and Table 3 are valid for altitudes up to and including 2 000 m above sea level, clearances for altitudes above 2 000 m need to be multiplied by the altitude correction factor specified in IEC 60664-1:2007, Table A.2.

The dimensions in Table 5 are valid for altitudes up to and including 2 000 m above sea level, creepage dimensions to avoid flashover for altitudes above 2 000 m need to be multiplied by the altitude correction factor specified in IEC 60664-1:2007, Table A.2.

NOTE The breakdown voltage of a clearance in air for a homogeneous field is, according to Paschen's Law, proportional to the product of the distance between electrodes and the atmospheric pressure. Therefore experimental data recorded at approximately sea level is corrected according to the difference in atmospheric pressure between 2 000 m and sea level. The same correction is made for inhomogeneous fields and for creepage distances with respect to flashover.

5.2.2.2 Steady-state voltages, temporary overvoltages or recurring peak voltages

Clearances dimensioned according to Table 3 withstand the peak value of the steady-state (direct current or 50/60 Hz voltage) temporary overvoltage or recurring peak voltage.

The larger clearance of the dimensioning in Table 2 and Table 3 is applicable.

NOTE Dimensioning requirements for frequencies higher than 30 kHz are specified in IEC 60664-4.

Table 3 – Clearances to withstand steady-state voltages, temporary overvoltages or recurring peak voltages

Voltage[a] (peak value)[b] kV	Minimum clearances in air up to 2 000 m above sea level[e]	
	Case A Inhomogeneous field conditions (see 3.1) mm	Case B Homogeneous field conditions (see 3.2) mm
0,04	0,001[c]	0,001[c]
0,06	0,002[c]	0,002[c]
0,10	0,003[c]	0,003[c]
0,12	0,004[c]	0,004)
0,15	0,005[c]	0,005[c]
0,20	0,006[c]	0,006[c]
0,25	0,008[c]	0,008[c]
0,33	0,01	0,01
0,4	0,02	0,02
0,5	0,04	0,04
0,6	0,06	0,06
0,8	0,13	0,10
1,0	0,26	0,15
1,2	0,42	0,20
1,5	0,76	0,30
2,0	1,27	0,45
2,5	1,8	0,6
3,0	2,4[d]	0,8
4,0		1,2
5,0		1,5
6,0		2,0

[a] The clearances for other voltages are obtained by interpolation.

[b] See Figure 1 of IEC 60664-1:2007 for recurring peak voltage.

[c] These values are based on experimental data obtained at atmospheric pressure.

[d] This value is only given to allow interpolation of the peak voltage from one step lower to a value corresponding to 2 mm (maximum value according to this document).

[e] The values given in this table are informative and cannot replace the values given in IEC 60664-1.

If clearances are stressed with steady-state voltages of 2,5 kV (peak) and above, dimensioning according to the breakdown values in Table 3 may not provide operation without corona (partial discharges), especially for inhomogeneous fields. In order to provide corona-free operation, it is either necessary to use larger clearances as given in IEC 60664-1:2007, Table F.7b or to improve the field distribution.

5.2.2.3 Clearances

Clearances are dimensioned as specified in Table 2 corresponding to

- the rated impulse voltage, according Table F.1 of IEC 60664-1:2007, or
- the required impulse withstand voltage

and as specified in Table 3 corresponding to peak value of the

- the steady-state voltage,
- the recurring peak voltage, and
- the temporary overvoltage.

In a coordinated system, clearances above the minimum required are unnecessary for a required impulse withstand voltage. However, it may be necessary, for reasons other than mutual correlation of insulation characteristics, to increase clearances (for example due to mechanical influences). In such instances, the test voltage is to remain based on the rated impulse voltage of the equipment, otherwise undue stress of associated solid insulation can occur.

5.3 Creepage distances

5.3.1 General

Creepage distances equal to or less than 2 mm are dimensioned taking into account 5.3.2. The distance values obtained from the tables applying to the relevant stresses and conditions are compared and the largest is chosen. (see dimensioning diagrams in Clause 8).

5.3.2 Influencing factors

5.3.2.1 General

Creepage distances selected from Table 4 together with Table 5, take into account the tracking phenomema and the influence of humidity on flashover. The larger value from Table 4 and Table 5 is applicable.

The following influencing factors are taken into account in Table 4:

- voltage (r.m.s. or DC) with regard to tracking;
- pollution degrees (PD) within the micro-environment;
- insulating materials.

The following influencing factors are taken into account in Table 5:

- voltage (peak value) with regard to flashover along the surface of the insulating material;
- humidity levels (HL) within the micro-environment;
- insulating materials;
- altitude.

The dimensions in Table 5 are valid for altitudes up to and including 2 000 m above sea level, creepage distances to avoid flashover for altitudes above 2 000 m are to be multiplied by the altitude correction factor specified in Table A.2 of IEC 60664-1:2007.

5.3.2.2 Voltage

The basis for the determination of a creepage distance with regard to tracking is the long-term r.m.s. value of the voltage existing across this creepage distance. This voltage is the working voltage, the rated insulation voltage or the rated voltage.

With regard to flashover, however, the basis for the determination of a creepage distance is the peak value of the relevant voltage according to Table 5. The relevant peak voltage is the maximum value of any voltage expected to occur across the creepage distance under rated conditions.

5.3.2.3 Climatic conditions

5.3.2.3.1 General

For dimensioning of creepage distances, the influence of the climatic conditions in the micro-environment, in terms of the humidity levels (HL), is taken into account in Table 5. The following criteria can be considered for dimensioning:

- minimum insulation resistance;
- failure due to tracking;
- flashover;
- continuous paths of conductive pollution.

NOTE In equipment, different micro-environmental conditions can exist.

5.3.2.3.2 Minimum insulation resistance

A minimum insulation resistance applies when a maximum leakage current between live parts or between live parts and an accessible surface of equipment is specified by technical committees. The same applies for functional insulation when insufficient insulation resistance could lead to excessive leakage current impairing proper functioning of the equipment.

5.3.2.3.3 Failure due to tracking

In order to avoid failure due to tracking, creepage distances are dimensioned as specified in Table 4.

5.3.2.3.4 Flashover

In order to comply with the requirement to avoid flashover along the surface insulating material, the values according to Table 5 are considered. Table 5 covers humidity levels HL 2 and HL 3. For HL 1, flashover is not influenced by humidity. Dimensioning according to the clearances of Table 2 and Table 3 is applicable.

NOTE 1 The influence of the water adsorption characteristics on the surface flashover withstand capability is strongly dependent on the distance. For distances larger than 2 mm this influence is rather small. For distances equal to or less than 2 mm this influence is of very high significance.

NOTE 2 There is no physical relationship between the minimum clearance in air and the minimum acceptable creepage distance, except for dimensioning to avoid flashover.

If creepage distances according to Table 5 are stressed with steady-state voltages in excess of approximately 500 V (peak), partial discharges (corona) can be expected. Also with respect to this effect, the ranking of the insulating materials is according to the relevant adsorption characteristics (see Clause 7).

NOTE 3 As partial discharges at the polluted insulator surface are caused by local micro-disturbances of the field distribution in the surface layer, the shape of the electrodes is of secondary influence on this phenomenon.

Table 4 – Creepage distances for mutual correlation of insulation characteristics in equipment to avoid failure due to tracking

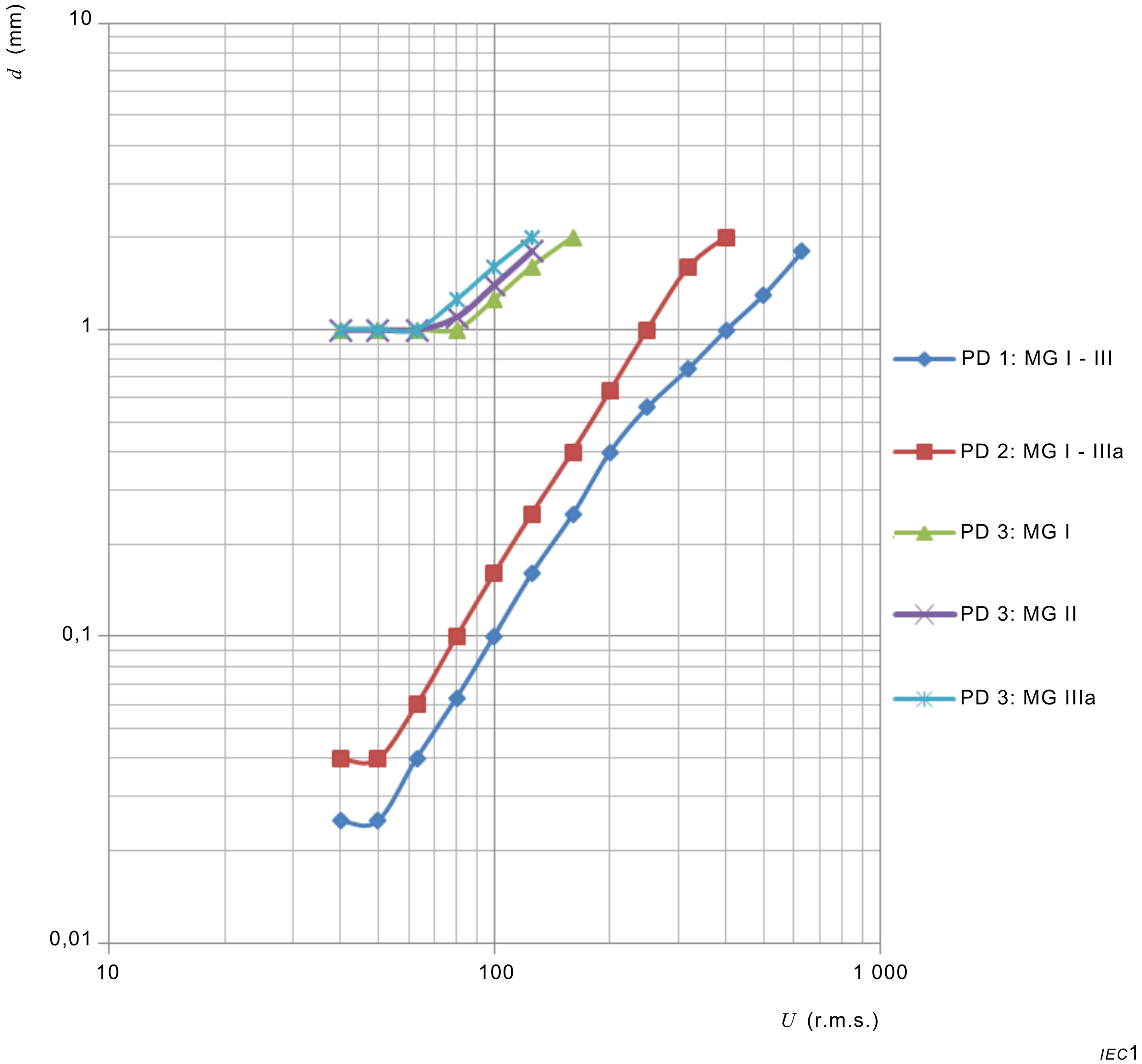
			Minimum creepage distances in millimetres[b c]		
Voltage[a] r.m.s	**Pollution degree 1**	**Pollution degree 2**	**Pollution degree 3**		
	MG I, II, IIIa and IIIb	MG I, II and IIIa	MG I	MG II	MG IIIa
V	mm	mm	mm	mm	mm
≤ 40	0,025	0,04	1,0	1,0	1,0
50	0,025	0,04	1,0	1,0	1,0
63	0,04	0,06	1,0	1,0	1,0
80	0,063	0,10	1,0	1,1	1,25
100	0,1	0,16	1,25	1,4	1,6
125	0,16	0,25	1,6	1,8	2,0
160	0,25	0,40	2,0	see IEC 60664-1	see IEC 60664-1
200	0,4	0,63	see IEC 60664-1		
250	0,56	1,0			
320	0,75	1,6			
400	1	2			
500	1,3	see the column for printed wiring material in IEC 60664-1			
630	1,8				
800	see the column for printed wiring material in IEC 60664-1				

[a] For functional insulation, this voltage is the working voltage.

[b] For glass, ceramics or other inorganic insulating materials which do not track, creepage distances need not be greater than their associated clearance for the purpose of mutual correlation of insulation characteristics. The dimensions of Table 2 or Table 3 for inhomogeneous field conditions are appropriate. However, the behaviour with regard to flashover according to Table 5 is taken into account.

[c] The values given in this table are informative and cannot replace the values given in IEC 60664-1.

Figure 2 illustrates Table 4.



NOTE See also Table 4 from which the figure is derived.

Figure 2 – Creepage distances for mutual correlation of insulation characteristics to avoid failure due to tracking

Table 5 – Creepage distances for mutual correlation of insulation characteristics to avoid flashover

	Minimum creepage distances, up to 2 000 m above sea level, to avoid flashover[d]							
Peak voltage[a]	HL 2[b]				HL 3[b]			
	W1 materials C,H[c]	W2 materials D,K[c]	W3 materials B,E,F,I[c]	W4 materials A,G[c]	W1 materials C,H[c]	W2 materials D,K[c]	W3 materials B,E,F,I[c]	W4 materials A,G[c]
kV	mm	mm	mm	mm	mm	mm	mm	mm
0,10					0,03	0,042	0,055	0,095
0,12	0,02	0,022	0,024	0,025	0,037	0,053	0,07	0,115
0,15	0,028	0,029	0,032	0,035	0,05	0,07	0,09	0,15
0,20	0,043	0,046	0,049	0,052	0,075	0,105	0,13	0,20
0,25	0,06	0,065	0,07	0,075	0,10	0,14	0,17	0,26
0,33	0,09	0,09	0,1	0,11	0,14	0,19	0,23	0,34
0,40	0,12	0,13	0,14	0,15	0,19	0,24	0,30	0,44
0,50	0,17	0,18	0,20	0,22	0,26	0,32	0,39	0,56
0,60	0,23	0,26	0,29	0,32	0,33	0,41	0,50	0,70
0,80	0,35	0,41	0,47	0,54	0,47	0,58	0,69	0,95
1,0	0,50	0,57	0,64	0,72	0,63	0,76	0,90	1,2
1,2	0,68	0,76	0,84	0,93	0,82	0,96	1,1	1,5
1,5	0,93	1,02	1,11	1,2	1,1	1,3	1,5	2,0
2,0	1,4	1,53	1,66	1,8	1,6	1,8	2,0	2,7
2,5	1,9	2,1	2,25	2,4	2,1	2,4	2,7	3,4
3,0	2,5	2,7	2,9	3,1	2,7	3,0	3,4	4,2

[a] For functional insulation, this voltage is the maximum peak value of any voltage expected to occur across the creepage distance, under rated conditions of the equipment.

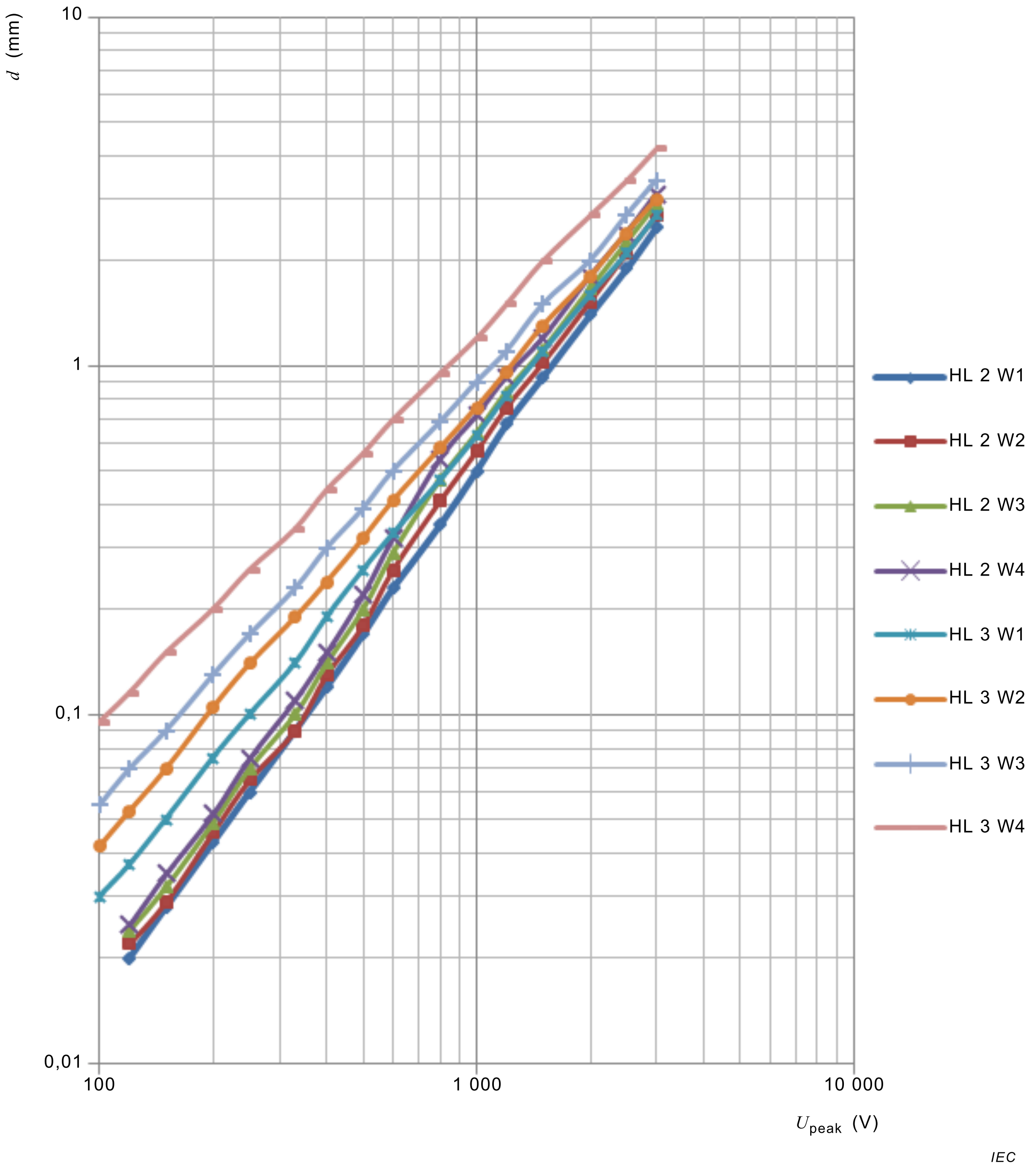
[b] HL: humidity level

[c] List of materials investigated so far:

A – Ceramic (unglazed);
B – Glass-epoxy laminate FR4;
C – Polyester resin (thermoset), type 802;
D – Phenolic resin, type 31.5;
E – Polyimide film laminated to glass-epoxy laminate FR4;
F – Phenolic resin paper laminate FR2;
G – Polyester laminate GPO III;
H – Melamine resin, type 150;
I – Polybutylenterephthalate;
K – Polycarbonate.

For the classification of materials with regard to the water adsorption characteristics, see 7.2.

Figure 3 illustrates Table 5.



Key

W: water adsorption group

HL: humidity level

NOTE For materials: see Table 5 from which the figure is derived.

Figure 3 – Creepage distances for mutual correlation of insulation characteristics to avoid flashover

5.3.2.3.5 Design to avoid a continuous path of conductive pollution

For micro-environmental conditions worse than pollution degree 3 and/or HL 3, the insulating surface can be shaped in a way appropriate to break the continuity of the path of conductive pollution. The remaining path(s) free of conductive pollution is subjected to micro-environmental conditions not worse than pollution degree 3 and/or HL 3, and (the sum of) its length(s) form the effective creepage distance which need to comply with the dimensioning for their humidity level achieved.

5.3.2.4 Relationship to clearance

Creepage distances less than the clearances required by Tables 2 or 3 for inhomogeneous field conditions may only be used under conditions of HL 1 and HL 2 when the creepage distance can withstand the impulse withstand voltage required for the associated clearance. However, attention is drawn to 5.3.2.3.4. For application in HL 2 conditions, the impulse withstand test is to be conducted under humidity conditions.

A creepage distance cannot be less than the associated clearance so that the shortest creepage distance possible is equal to the required clearance.

NOTE Clause 9 shows an example of a test procedure for testing under humidity conditions.

5.3.3 Dimensioning of creepage distances of functional insulation

Creepage distances of functional insulation can be dimensioned as specified in Table 4 corresponding to the working voltage across the creepage distance considered.

Dimensioning to avoid flashover may require larger creepage distances according to Table 5 than what is required in Table 4.

NOTE When the working voltage is used for dimensioning, it can be appropriate to interpolate values for intermediate voltages.

6 Additional information regarding creepage distance characteristics – surface current over a creepage distance (minimum insulation resistance)

In equipment design, compliance with specified maximum leakage current or minimum insulation resistance requirements can be checked using resistance values of Table 6, taking into account the maximum relative humidity to be expected at the surface of the insulating material. The values of Table 6 are based on research data and are given for creepage distances of Table 6 between conductors running in parallel over a length of 50 mm. For other longitudinal dimensions, the insulation resistance can be calculated as inversely proportional. When more electrically parallel creepage distances exist, their added-up leakage current is the appropriate value to be compared with specified data.

The values of Table 6 are valid in so far as no condensation on the surface of the insulation prevails. Otherwise, information about minimum insulation resistance cannot be given.

Table 6 – Minimum insulation resistance

HL	Relative humidity		Minimum insulation
	Continuously %	Short time %	Resistance Ω
2[a]	≤ 75	≤ 75	> 10^6
2[a]	≤ 75	≤ 85	> 10^5
3	≤ 95	≤ 95	> 10^4 [b]

[a] The conditions of HL 2 include both entry lines. Only when the maximum humidity is limited to a maximum value of 75 % even for short times, a minimum insulation resistance of > 10^6 Ω can be maintained.

[b] Humidity can lead to a further reduction of the insulation resistance, especially under the conditions of pollution degree 3 during extended periods of operation. In general, however, the insulation resistance will remain above 10^3 Ω.

NOTE 1 The values for the minimum insulation resistance apply to worst case conditions. The average minimum values are at least one order of magnitude higher.

NOTE 2 Test results show that it can be anticipated that the insulation resistance of creepage distances will be reduced by about two decades if the relative humidity in the micro-environment is increased from 50 % to 75 %. Increasing the relative humidity from 75 % to 95 % will further reduce the insulation resistance by about two decades.

The dimensioning data in Table 5 and Table 7 can be used for the maximum humidity specified in Table 6. Humidity above 95 % or condensation while voltage is applied across the creepage distance will lead to a permanently decreased insulation resistance.

NOTE 3 Figure 4 shows that the same insulation resistance necessitates increasing creepage distances with increasing voltage.

The minimum dimensions for creepage distances in Table 7 have been assessed by evaluation of systematically collected data and are recalculated for an anticipated lifetime of equipment of at least 15 years under continuous stress.

Table 7 – Creepage distances to maintain minimum insulation resistance (without condensation)

Voltage[a] r.m.s.	Minimum creepage distances to maintain minimum insulation resistance[g]			
V	HL 2[b] DC[c] mm	HL 2[b] AC[d] mm	HL 3[b] DC[c] mm	HL 3[b] AC[d e] mm
≤ 40			1	1
50			1	1,25
63	0,16	0,16	1	1,6
80	0,19	0,19	1,2	2
100	0,22	0,22	1,4	2,5
125	0,25	0,27	1,6	3,1
160	0,3	0,42	1,9	4
200	0,35	0,66	2,2	5
250	0,4	1	2,5	6,3
320	0,63	1,6	3,2	8[f]
400	1	2,5	4	10
500	1,5	4	5	12,5
630	2,5	6,3	6,3	16

[a] For functional insulation, this voltage is the working voltage.

[b] HL: humidity level.

[c] DC: Direct current voltage stress.

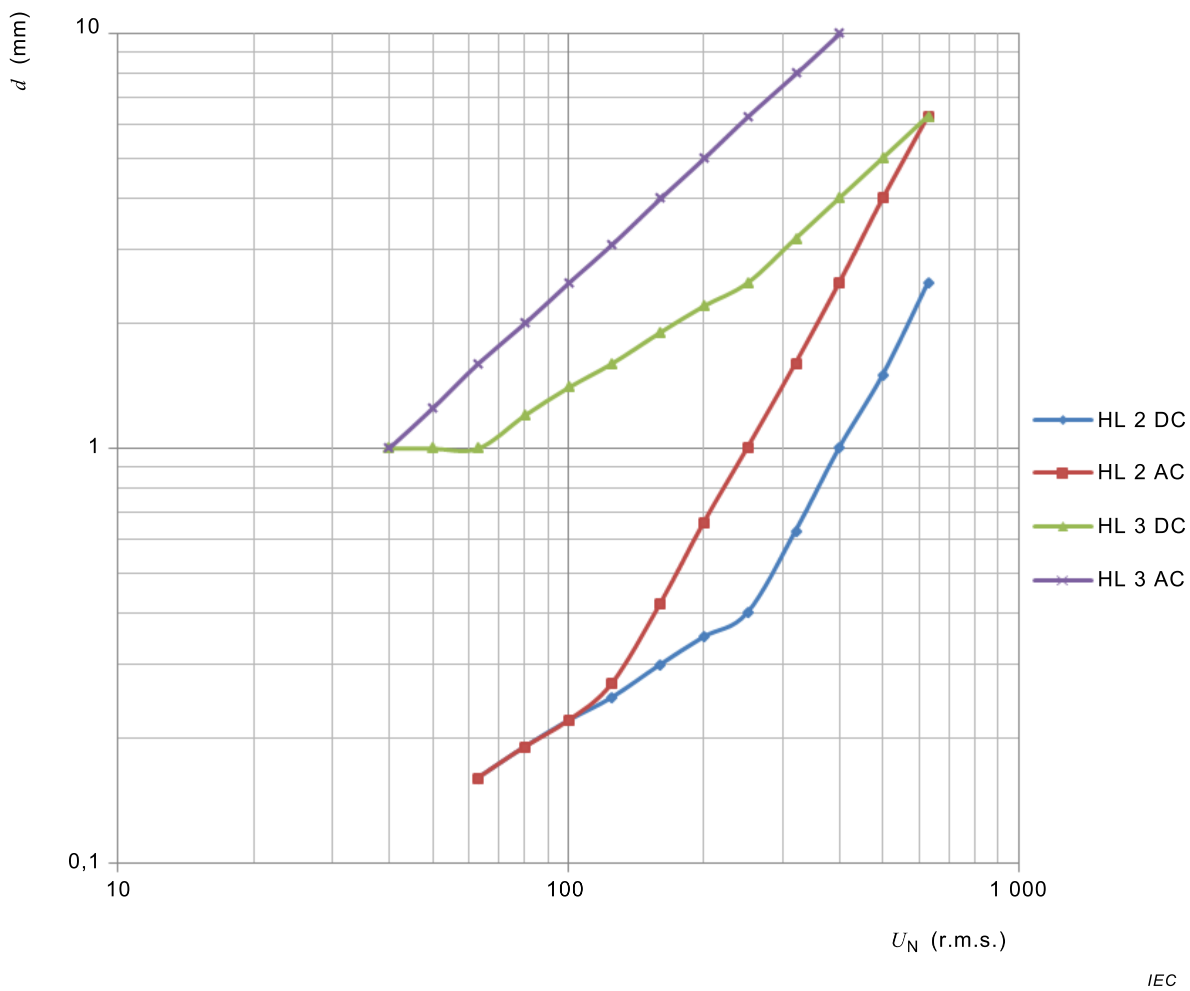
[d] AC: Alternating current voltage stress.

[e] The materials glass-epoxy laminate, FR4 and polycarbonate can, with regard to surface leakage current, not be used under these conditions.

[f] These values and those for higher voltages have been determined by linear extrapolation of research data.

[g] The values given in this table are informative and cannot replace the values given in IEC 60664-1.

Dimensioning data are only available for HL 2 and HL 3. For HL 2 and HL 3, dimensioning to avoid flashover needs also to be checked, in particular when peak voltages (recurring or transient) have a greater influence than the r.m.s. value of voltage. For conditions worse than HL 3, only design to avoid a continuous path of conductive pollution (5.3.2.3.5) is possible.



NOTE See also Table 7 from which the figure is derived.

Figure 4 – Creepage distances required to maintain minimum insulation resistance

7 Water adsorption test

7.1 Object

For dimensioning of creepage distances with respect to flashover, the water adsorption characteristics of any surface of the insulating material are of importance. According to the impulse withstand capability of the surfaces of the various insulating materials under humidity, the water adsorption groups W1, W2, W3 and W4 have been established. The object of this test is the evaluation of the relevant water adsorption group for the surface of any insulating material which has not yet been classified.

7.2 Withstand characteristics of creepage distances under high humidity

The voltage withstand capability of creepage distances may be significantly reduced by high humidity. On these conditions water may be adsorbed on the surface of the insulating material. This phenomenon has the more influence on the withstand capability the smaller the creepage distance is.

7.3 Recommended test method

7.3.1 Test specimen

A new test specimen of the insulating material with a thickness of approximately 1,5 mm having dimensions and electrode configuration according to Figure 5 is used. The test results for all measuring points need to be included in the evaluation of the test. It can be prepared by printed circuit board processing methods. In that case, however, careful cleaning of the test specimen is essential, as production residues can significantly influence the test results.

If the proposed test specimen cannot be used, a piece of material with a flat surface may be used with the plane electrodes similar to Figure 5 pressed on the surface. A minimum of 10 tests is advisable to be carried out at different places of the same test specimen in order to take into account the scattering of the critical relative humidity caused by inhomogeneous structures of filled materials. After that, the average value and the scattering of the test results can be evaluated.

7.3.2 Measurement of the impulse withstand voltage

A test circuit is shown in Figure 6. The test voltage of negative polarity is provided by an impulse test generator (1) with the voltage waveform of 1,2/50 µs and an output impedance between 50 Ω and 500 Ω. The relative humidity is adjusted within a climatic cabinet (2). The test specimen (3) is energized by the impulse generator. The statistical scatter of the impulse withstand voltage can be reduced by UV illumination (6) provided for instance by a mercury vapour lamp. There is no need for UV illumination if 10 to 20 successive flashover tests are conducted, preferably on the same specimen. The withstand voltage in this case is the lower limit (3σ – value) of the statistically scattering flashover voltages. The actual test voltage can be measured by a high voltage probe (7) and a digital storage oscilloscope (4). For more convenience the procedure may be controlled by a computer (5) if the test equipment is provided with adequate interfaces.

7.3.3 Procedure for characterization of the insulating materials

Specimens are prepared with electrode spacings of 6,3 mm, 2,5 mm, 1 mm, 0,4 mm and 0,16 mm. The surface of each specimen can be prepared in order to take into account the influence of manufacturing operations on the surface of the material, for example moulding, machining, or other preparation.

For the evaluation of the critical humidity for any of the electrode spacing of the test specimen, the impulse withstand voltage is measured at different values of relative humidity.

The test starts at 70 % relative humidity, which is increased in steps of 5 %. At each step the impulse withstand voltage is measured. The critical humidity is reached when the impulse withstand voltage has dropped to 95 % of its value at 70 % relative humidity.

For further simplification the following procedure is proposed.

During a waiting period of at least four hours, the specimen is subjected at a temperature between 20 °C and 25 °C and at 70 % humidity ± 3 %. Voltage impulses with increasing amplitudes are applied across each electrode spacing until flashover occurs. With a minimum of five tests the average value of the impulse voltage which leads to flashover can be calculated. The critical humidity is reached when the impulse withstand voltage has dropped to 95 % of its value at 70 % relative humidity. The corresponding voltage is called the critical humidity voltage U_c.

The relative humidity can be increased by steps of 5 %. At each step 10 voltage impulses with a peak value of 95 % U_c are applied. Humidity level is recorded until a flashover occurs across the spacing.

The results are represented in Figure 7 and compared to the definitions given in 7.4 in order to allocate the insulating material to a water adsorption group.

NOTE Figure 7 is based on smaller humidity steps of 1 %.

7.4 Definitions of the water adsorption groups

In Figure 7 the critical relative humidity of the insulating materials which have been investigated until now are plotted. According to behaviour shown, the investigated materials are allocated to the water adsorption groups as follows:

- Group 1 (W1): Water adsorption group for those materials which have not shown a reduction of the critical relative humidity with the creepage distance.
- Group 2 (W2): Water adsorption group for those materials which have not shown a reduction of the critical relative humidity for creepage distances of 1 mm and above.
- Group 3 (W3): Water adsorption group for those materials which have not shown a reduction of the critical relative humidity for creepage distances of 2,5 mm and above.
- Group 4 (W4): Water adsorption group for those materials which have not shown a reduction of the critical relative humidity for creepage distances of 6,3 mm and above.

The following insulating materials have been considered until now:

Water adsorption group W1 – negligible influence:

C – Polyester resin (thermoset), type 802;

H – Melamine resin, type 150;

Water adsorption group W2 – weak influence:

D – Phenolic resin, type 31.5;

K – Polycarbonate;

Water adsorption group W3 – medium influence:

B – Glass-epoxy laminate FR4;

E – Polyimide film laminated to glass-epoxy laminate FR4;

F – Phenolic resin paper laminate FR2;

I – Polybutylenterephthalate;

Water adsorption group W4 – strong influence:

A – Ceramic (unglazed);

G – Polyester laminate GPO III.

Dimensions in millimetres

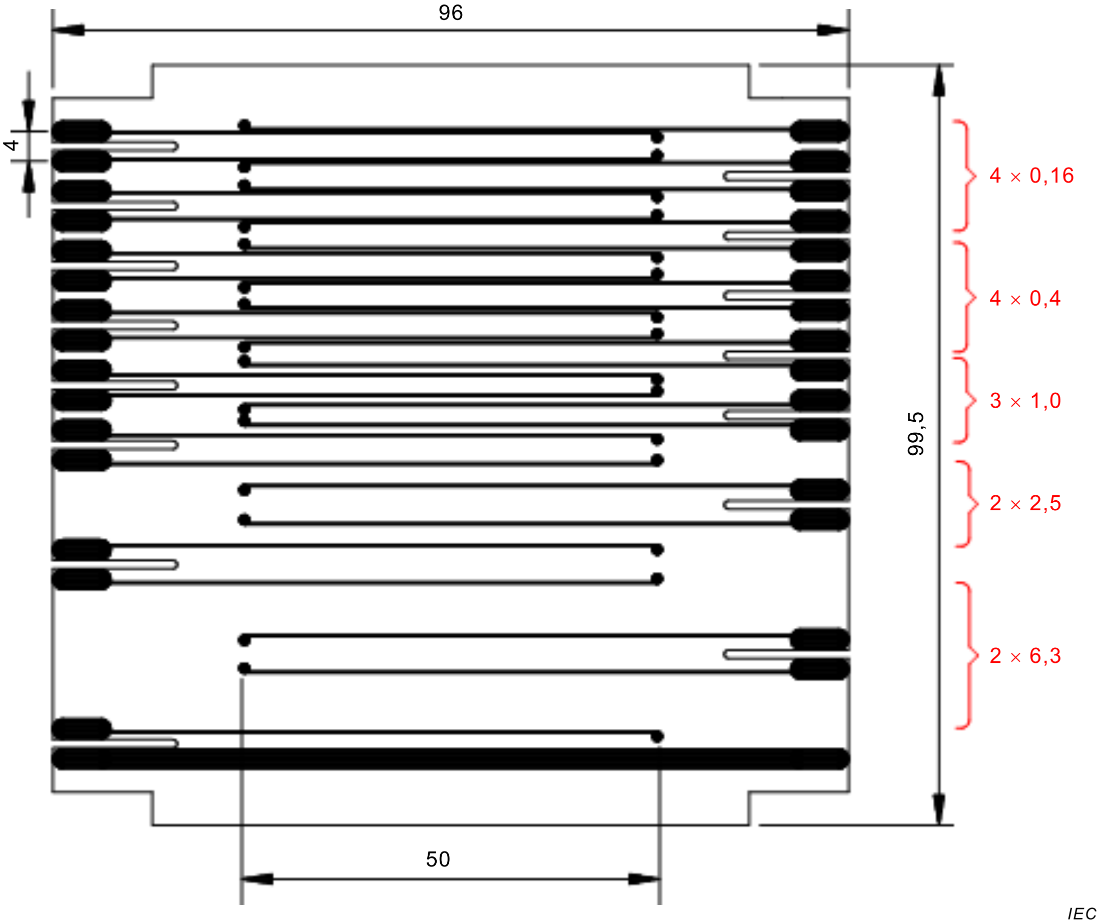
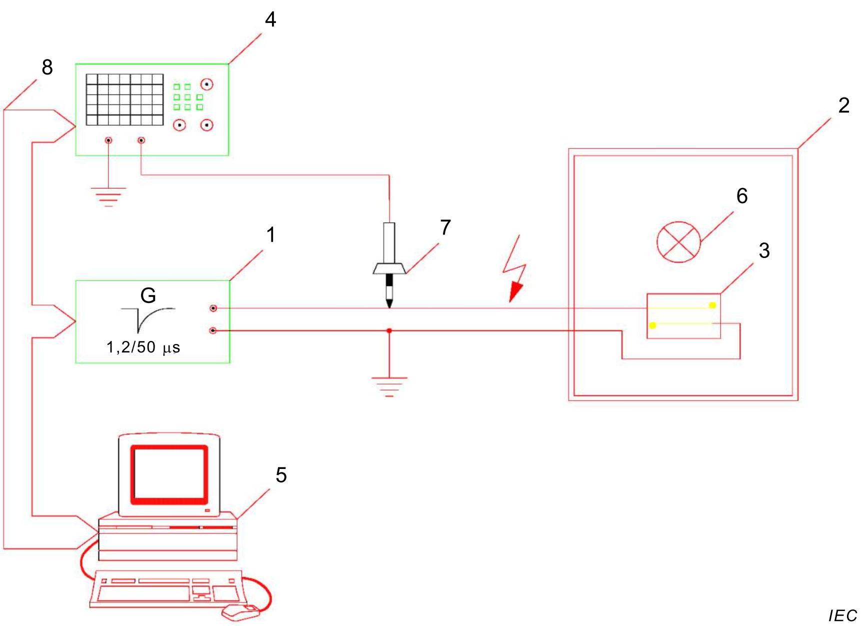
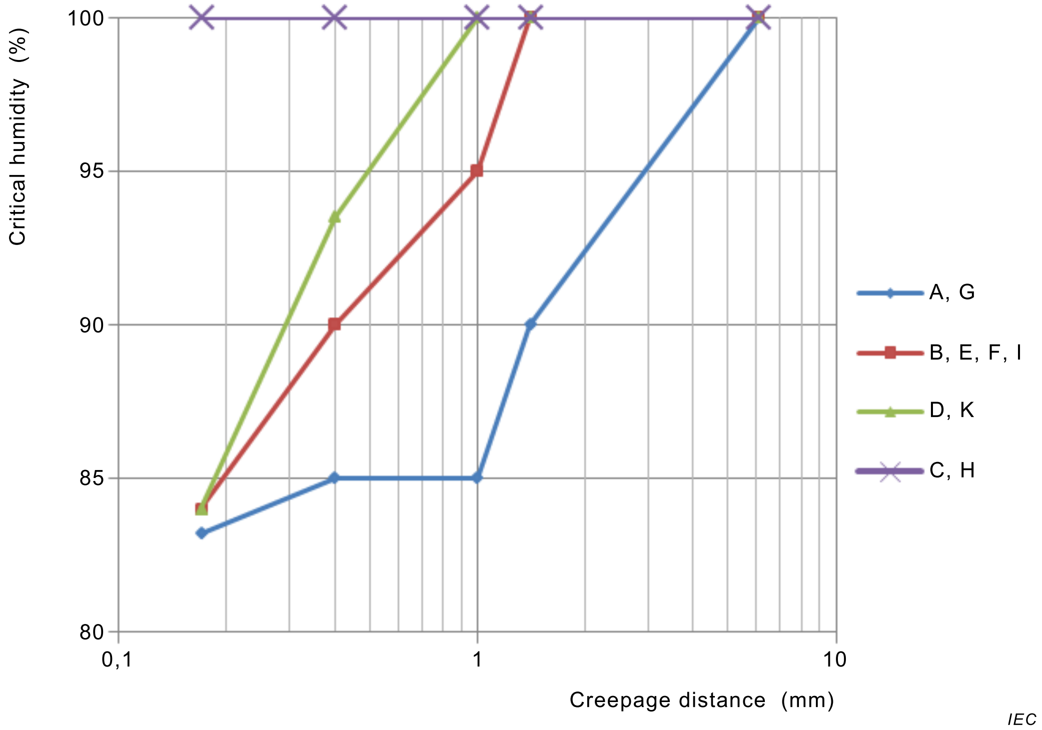


Figure 5 – Layout of the test specimen



1 - Impulse generator
2 - Climatic cabinet
3 - Test specimen
4 - Digital storage oscilloscope
5 - Computer
6 - UV illumination (see 7.3.2
7 - High voltage probe
8 - Data-bus

Figure 6 – Test circuit



Key

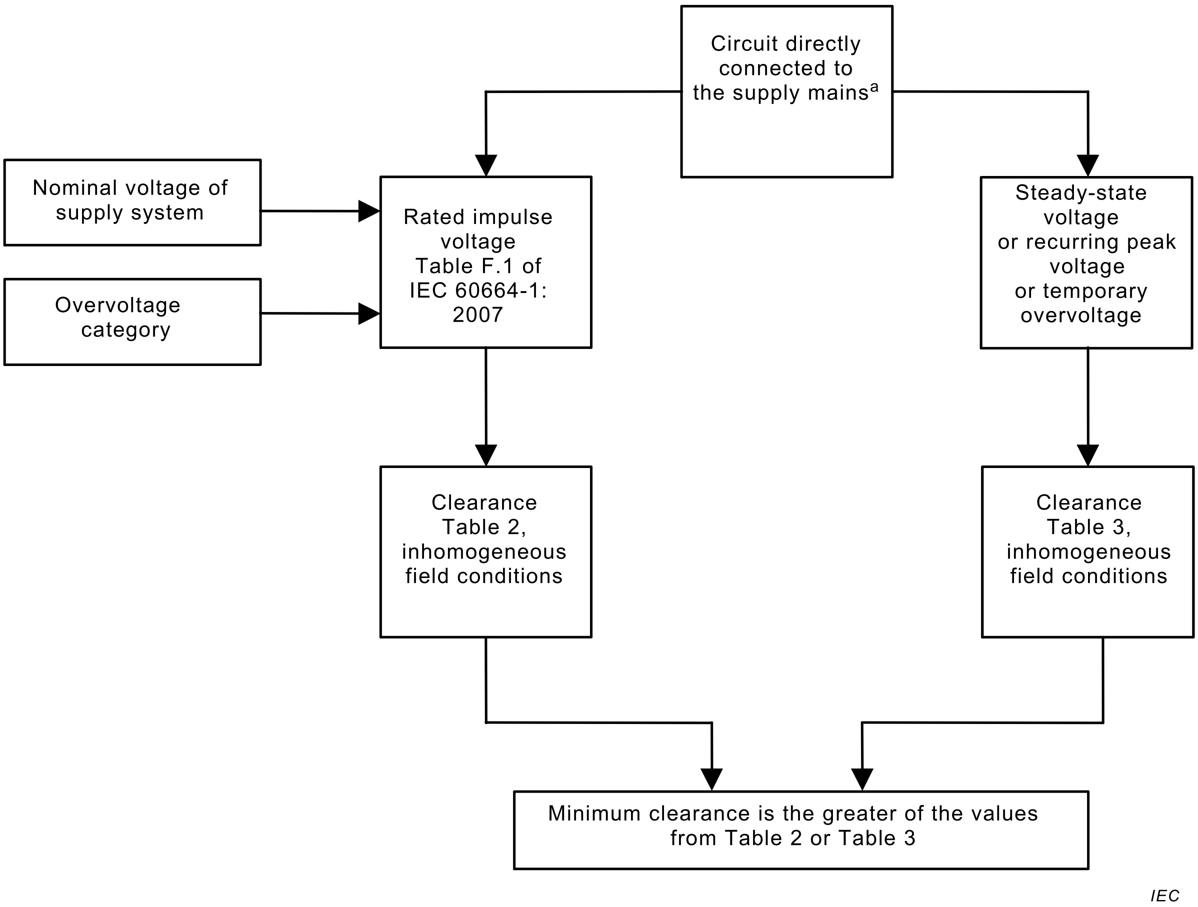
A Ceramic (unglazed)
B Glass-epoxy laminate FR4
C Polyester resin (thermoset), type 802
D Phenolic resin, type 31.5
E Polyimide film laminated to glass-epoxy laminate FR4
F Phenolic resin paper laminate FR2
G Polyester laminate GPO III
H Melamine resin, type 150
I Polybutylenterephthalate
K Polycarbonate

Figure 7 – Critical relative humidity of insulating materials

8 Dimensioning diagrams

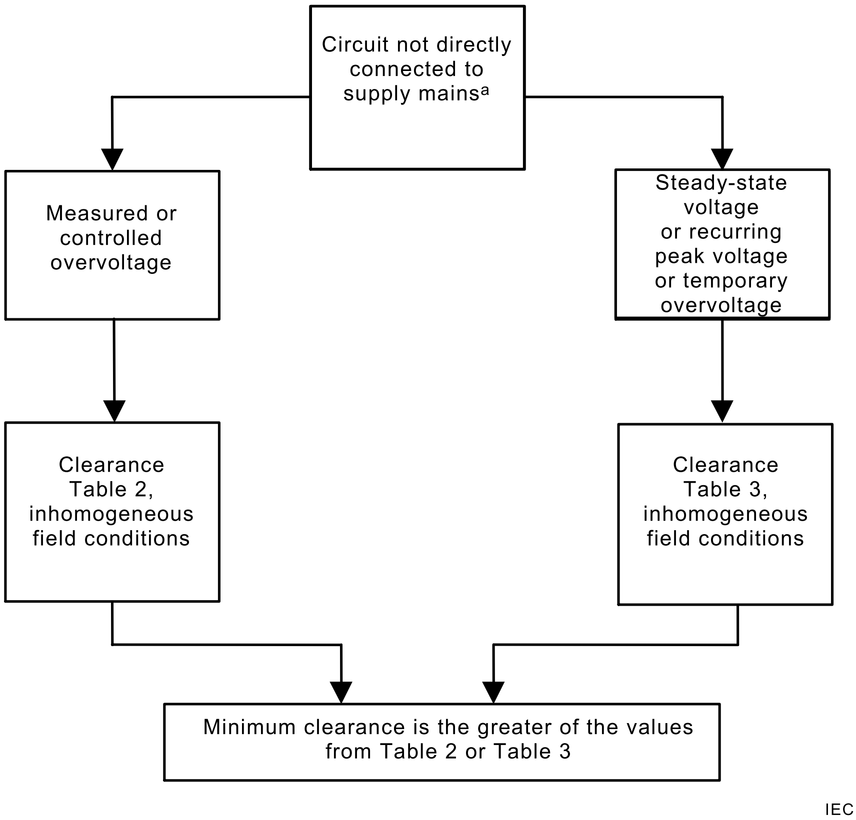
The diagrams given in Figure 8, Figure 9 and Figure 10 show the relationships between the factors influencing the dimensioning of clearances and creepage distances for mutual correlation of insulation characteristics. The diagrams highlight the major factors and are not intended to substitute a full review of the relevant subclauses.

It is to be noted that the dimensioning of clearances and creepage are independent functions. Therefore, where a clearance and a creepage distance are coincidental over the same insulating surface, the larger of the clearance or the creepage distance is to be used.



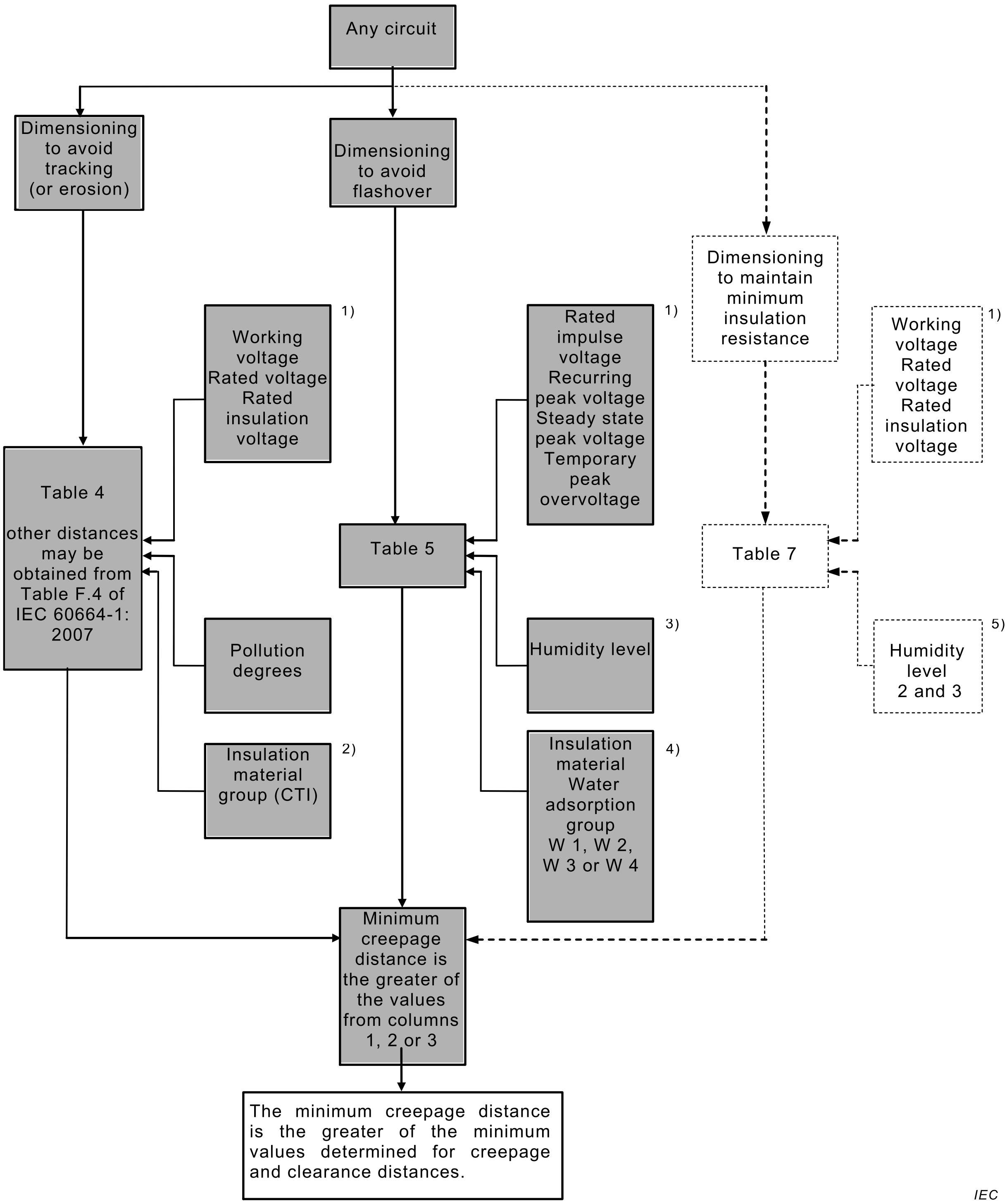
[a] Includes all circuits affected by external voltages.

Figure 8 – Diagram for dimensioning of clearances ≤ 2 mm for circuits directly connected to the supply mains (for low-voltage equipment up to 2 000 m)



[a] Includes all circuits not significantly affected by external transient voltages.

Figure 9 – Diagram for dimensioning of clearances ≤ 2 mm for circuits not directly connected to the supply mains (for low-voltage equipment up to 2 000 m)



Key

1) Use largest value of voltage.
2) For glass, ceramics or other inorganic insulating materials which do not track, creepage distances need not be greater than their associated clearance for the purpose of mutual correlation of insulation characteristics. The dimensions of Table 2 or Table 3 for inhomogeneous field conditions are appropriate. However, the behaviour with regard to flashover is taken into account according to Table 5.
3) If HL 1, the related clearance value is permitted. If HL 2 or HL 3, use Table 5.
4) The water adsorption group, if not already established, may be determined by the test of Clause 7.
5) If HL 1, the related clearance value is permitted. If HL 2 or HL 3, use Table 7.

NOTE 1) to 5) refer to steps for dimensioning the minimum creepage distance.

Figure 10 – Diagram for dimensioning of creepage distances ≤ 2 mm (for low-voltage equipment up to 2 000 m)

9 Withstand voltage test for creepage distance under humidity conditions

The appropriate test for testing the creepage distances with respect to their withstand capability under humidity conditions is basically the impulse voltage test. Although it is not difficult to apply this test for an isolated creepage distance, it is not practical to use the impulse test for a complete piece of equipment since it is not always possible to isolate creepage distances.

The following test procedure introduces an alternating current or direct current which may replace the impulse test for an equipment subjected to humidity conditions. This test also covers the withstand requirements with respect to short term temporary overvoltages.

For equipment connected to the mains the following test is applicable. The equipment is prepared by disconnection of SPDs.

The humidity conditions can be chosen in accordance with the intended HL. The following levels of relative humidity are recommended: HL 2, (85 ± 3) % and HL 3, (95 ± 3) %. The equipment under test is kept at the corresponding level of humidity at a temperature between 20 °C and 25 °C during at least four hours before testing.

The input terminals connected to the mains of the equipment (all phases and neutral terminals) are connected together according to Figure 11. Between these terminals and earth the test generator is connected. The test voltage is an AC voltage of 50/60 Hz. If required it may be replaced by a DC voltage source of equal peak value. The amplitude of the test voltage is 1 200 V + U_n (which is 2 050 V peak for U_n = 250 V) or the required impulse withstand voltage according to Table F.1 of IEC 60664-1:2007 (which is 2 500 V peak for overvoltage category 2), whichever is the higher value. The voltage is applied for a duration of 60 s.

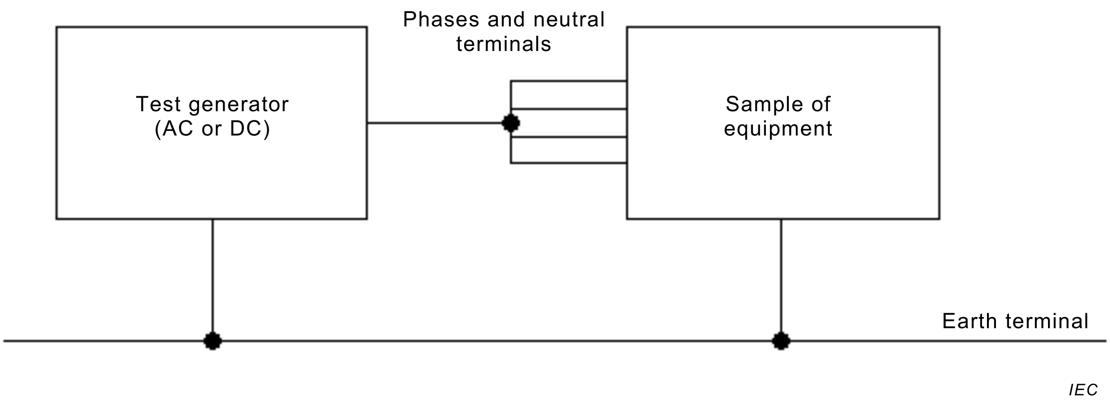


Figure 11 – Withstand voltage test for creepage distance under humidity conditions

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[5] IEC 60664-5:2007 (withdrawn), *Insulation coordination for equipment within low-voltage systems – Part 5: Comprehensive method for determining clearances and creepage distances equal to or less than 2 mm*

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