

Insulation coordination for equipment within low-voltage systems —

Part 4: Consideration of high-frequency voltage stress

The European Standard EN 60664-4:2006 has the status of a
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National foreword

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

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English version

Insulation coordination for equipment within low-voltage systems
Part 4: Consideration of high-frequency voltage stress
(IEC 60664-4:2005)

Coordination de l'isolement des matériels
dans les systèmes (réseaux)
à basse tension
Partie 4: Considérations
sur les contraintes de tension
à haute fréquence
(CEI 60664-4:2005)

Isolationskoordination für elektrische
Betriebsmittel in Niederspannungsanlagen
Teil 4: Berücksichtigung von
hochfrequenten
Spannungsbeanspruchungen
(IEC 60664-4:2005)

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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 text of document 109/51/FDIS, future edition 2 of IEC 60664-4, prepared by IEC TC 109, Insulation co-ordination for low-voltage equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60664-4 on 2005-10-01.

This European Standard is to be used in conjunction with EN 60664-1 or EN 60664-5.

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- | | | |
|--|-------|------------|
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Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60664-4:2005 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

High electrical stress also occurs in low-voltage equipment. The frequency is usually 50/60 Hz, but in some applications a higher frequency (400 Hz) or a lower frequency (16 2/3 Hz) or d.c. can occur. A particular situation exists in high-power RF transmitters. The development of such equipment had motivated earlier research on the withstand capability of insulation at radio frequencies. Since that time, the aspect of high-frequency voltage stress had not been pursued with much effort.

At present, high-frequency working voltages exceeding 30 kHz are often used in low-voltage equipment, and the use of frequencies in the MHz range is likely in the future. Many of the voltage shapes are non sinusoidal. Small dimensions are necessary for miniaturization and for high efficiency, for instance in high-frequency transformers. Consequently, very high stresses are common in solid insulation.

By increasing the frequency the deteriorating effect of partial discharges is also increased roughly proportionally to the frequency, so that the impact of partial discharges on dimensioning is much higher compared to power frequency.

As dimensions are likely to decrease further and frequencies increase, this situation will be aggravated in the future. Therefore, with respect to safety of personnel and reliability of equipment, the stress due to high frequencies up to 100 MHz has to be considered for insulation coordination of low-voltage equipment, (see note 2 in the Scope of Part 1).

This standard summarizes the most important available data concerning high-frequency stress of insulation, and identifies how materials and their dimensioning are influenced. Data for dimensioning of clearances, creepage distances and solid insulation are specified. This standard also describes how tests can be performed with respect to this stress.

INSULATION COORDINATION FOR EQUIPMENT WITHIN LOW-VOLTAGE SYSTEMS –

Part 4: Consideration of high-frequency voltage stress

1 Scope and object

This part of IEC 60664 deals with basic, supplementary and reinforced insulation subjected to high-frequency voltage stress within low-voltage equipment. The dimensioning values directly apply for basic insulation; for reinforced insulation additional requirements apply according to Part 1. It is applicable for the dimensioning of clearances, creepage distances and solid insulation stressed by any type of periodic voltages with a fundamental frequency above 30 kHz and up to 10 MHz.

This part of IEC 60664 can only be used together with IEC 60664-1 or with IEC 60664-5 (in this standard called Part 1 or Part 5). By using Part 1 or Part 5 together with this part the frequency limit of Part 1 or Part 5 is extended to frequencies higher than 30 kHz.

This part also applies to Part 3 for frequencies greater than 30 kHz and protection of type 1. For type 2 protection this question is under consideration.

NOTE 1 Dimensioning values for frequencies above 10 MHz are under consideration.

NOTE 2 This standard does not consider the high-frequency emission to the mains. In normal use of equipment, it is assumed that the interference of high-frequency voltages emitted to the mains is negligible with respect to insulation stress. Therefore it is not necessary to take it into account.

It applies to equipment for use up to 2 000 m above sea level having a rated voltage up to a.c. 1 000 V.

It specifies the requirements for clearances, creepage distances and solid insulation for equipment based upon their performance criteria. It includes methods of electric testing with respect to insulation coordination.

The minimum clearances specified in this part do not apply where ionized gases occur. Special requirements for such situations may be specified at the discretion of the relevant technical committee.

This part does not deal with distances

- through liquid insulation,
- through gases other than air,
- through compressed air.

NOTE 3 Higher voltages may exist in internal circuits of the equipment.

NOTE 4 Requirements for altitudes exceeding 2 000 m can be derived from Table A.2 of Annex A of Part 1.

The object of this standard is to guide technical committees responsible for different equipment in order to rationalise their requirements so that insulation coordination is achieved when specifying clearances in air, creepage distances and solid insulation for equipment.

2 Normative references

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

IEC 60112:2003, *Method for determining the comparative and the proof tracking indices of solid insulating materials under moist conditions*

IEC 60664-1:1992, *Insulation coordination for equipment within low-voltage systems: Part 1: Principles, requirements and tests*

Amendment 1 (2000)

Amendment 2 (2002)

IEC 60664-5:2003, *Insulation coordination for equipment within low-voltage systems: A comprehensive method for determining clearances and creepage distances equal to or less than 2 mm*

IEC Guide 104:1997, *The preparation of safety publications and the use of basic safety publications and group safety publications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in Part 1, as well as the following terms and definitions, apply.

3.1

approximately homogeneous field

for frequencies exceeding 30 kHz, the field is considered to be approximately homogeneous when the radius of curvature of the conductive parts is equal or greater than 20 % of the clearance

3.2

inhomogeneous field

for frequencies exceeding 30 kHz the field is considered to be inhomogeneous when the radius of curvature of the conductive parts is less than 20 % of the clearance

3.3

U_{peak}

peak value of any type of periodic peak voltage across the insulation

3.4

f_{crit}

critical frequency at which the reduction of the breakdown voltage of a clearance occurs

3.5

f_{min}

frequency at which the maximum reduction of the breakdown voltage of a clearance occurs

3.6**PD-voltage**

generic term for both partial discharge inception voltage U_i and partial discharge extinction voltage U_e

3.7**electrical field strength E**

voltage gradient per unit length usually expressed in kV/mm

4 Clearances**4.1 General conditions**

This clause is applicable to clearances in air. The dimensioning data are valid for a maximum altitude of 2 000 m above sea level. For higher altitudes, the altitude correction factors of Table A.2 of Part 1 are applicable.

4.2 Basic information

According to the basic information given in Clause A.1 the withstand capability of clearances can only be influenced by the frequency of the voltage if periodic voltages are relevant (see 3.1.1.2 of Part 1 or Part 5). For transient overvoltages dimensioning according to 3.1.1.1 of Part 1 or Part 5 is sufficient.

4.3 Homogeneous and approximately homogeneous fields**4.3.1 Conditions for approximately homogeneous field**

For frequencies exceeding 30 kHz, an approximately homogeneous field is considered to exist when the radius of curvature of the conductive parts is equal or greater than 20 % of the clearance.

4.3.2 Experimental data of breakdown characteristics

As a conclusion from A.2.1, the critical frequency f_{crit} , at which the reduction of the breakdown voltage occurs, depends upon the value of the clearance as follows:

$$f_{\text{crit}} \approx \frac{0,2}{d / \text{mm}} \text{ MHz} \quad (1)$$

where

d is the clearance.

The experimental data, presented in A.2.1 for homogeneous field conditions, shows a maximum reduction of the breakdown voltage with frequency of 20 % compared to the 50/60 Hz-values. The frequency, at which the maximum reduction occurs, is called f_{min} .

NOTE For the purposes of this standard, f_{min} as illustrated in Figure A.1 is accepted as 3 MHz.

4.3.3 Dimensioning of clearances for homogeneous and approximately homogeneous field conditions

The insulating characteristics of homogeneous field clearances in air at atmospheric pressure with respect to frequency can be summarized by the following statements.

- Above f_{crit} the breakdown voltage is reduced with increasing frequency. The maximum reduction of the breakdown voltage is about 20 %.
- The breakdown voltage reaches a minimum at a frequency f_{min} . For higher frequencies, the breakdown voltage is increased and can exceed the value at power frequency.

It is assumed that these characteristics are also applicable for approximately homogeneous field conditions.

Dimensioning for homogeneous fields is based upon Case B values of Table 7 of Part 1 or Table 3 of Part 5. The use of these values requires a withstand test according to 4.1.1 of Part 1 or Part 5.

Dimensioning for approximately homogeneous fields is based on Case A values of Table 7 of Part 1 or Table 3 of Part 5. No withstand test is required. However the radius of curvature of the conductive parts shall be equal or greater than 20 % of the clearance.

There are two methods for dimensioning:

1. If no detailed evaluation is intended, the clearance shall be designed within the frequency-scope of this standard for 125 % of the required withstand voltage according to Table 7 of Part 1 or Table 3 of Part 5.
2. If a detailed evaluation is intended, the following applies:
 - a) For frequencies below f_{crit} (see Equation (1)) the clearance shall be designed for 100 % of the required withstand voltage according to Table 7 of Part 1 or Table 3 of Part 5.
 - b) For frequencies above f_{min} the clearance shall be designed for 125 % of the required withstand voltage according to Table 7 of Part 1 or Table 3 of Part 5.
 - c) For frequencies between f_{crit} and f_{min} the clearance shall be designed for

$$100 \% + \frac{f - f_{\text{crit}}}{f_{\text{min}} - f_{\text{crit}}} \times 25 \% \quad (2)$$

of the required withstand voltage according to Table 7 of Part 1 or Table 3 of Part 5.

In order to obtain the critical frequency, in a first step the clearance is assumed for 100 % of the required withstand voltage according to Table 7 of Part 1 or Table 3 of Part 5. Then it has to be decided, if condition 2a, 2b or 2c is applicable. As this evaluation can be influenced by the result obtained (clearance), a second iteration can be required.

NOTE Further information about dimensioning is given in Annex F.

4.4 Inhomogeneous fields

4.4.1 Conditions for inhomogeneous field

For frequencies exceeding 30 kHz, an inhomogeneous field is considered to exist when the radius of curvature of the conductive parts is less than 20 % of the clearance.

4.4.2 Experimental data of partial discharge and breakdown characteristics

For inhomogeneous field conditions, f_{crit} can still be approximated from Equation (1). Above f_{crit} , the influence of frequency on the breakdown voltage is much more significant compared to homogeneous field conditions. The reduction of the breakdown voltage with respect to that at power frequency can be more than 50 %.

For inhomogeneous field conditions partial discharges (corona) must be expected at voltages below the breakdown voltage. Due to the high risk of deterioration caused by these discharges with high repetition frequency dimensioning shall be sufficient to avoid the occurrence of partial discharges (PD).

The experimental data are presented in A.2.2.

4.4.3 Dimensioning of clearances for inhomogeneous field conditions

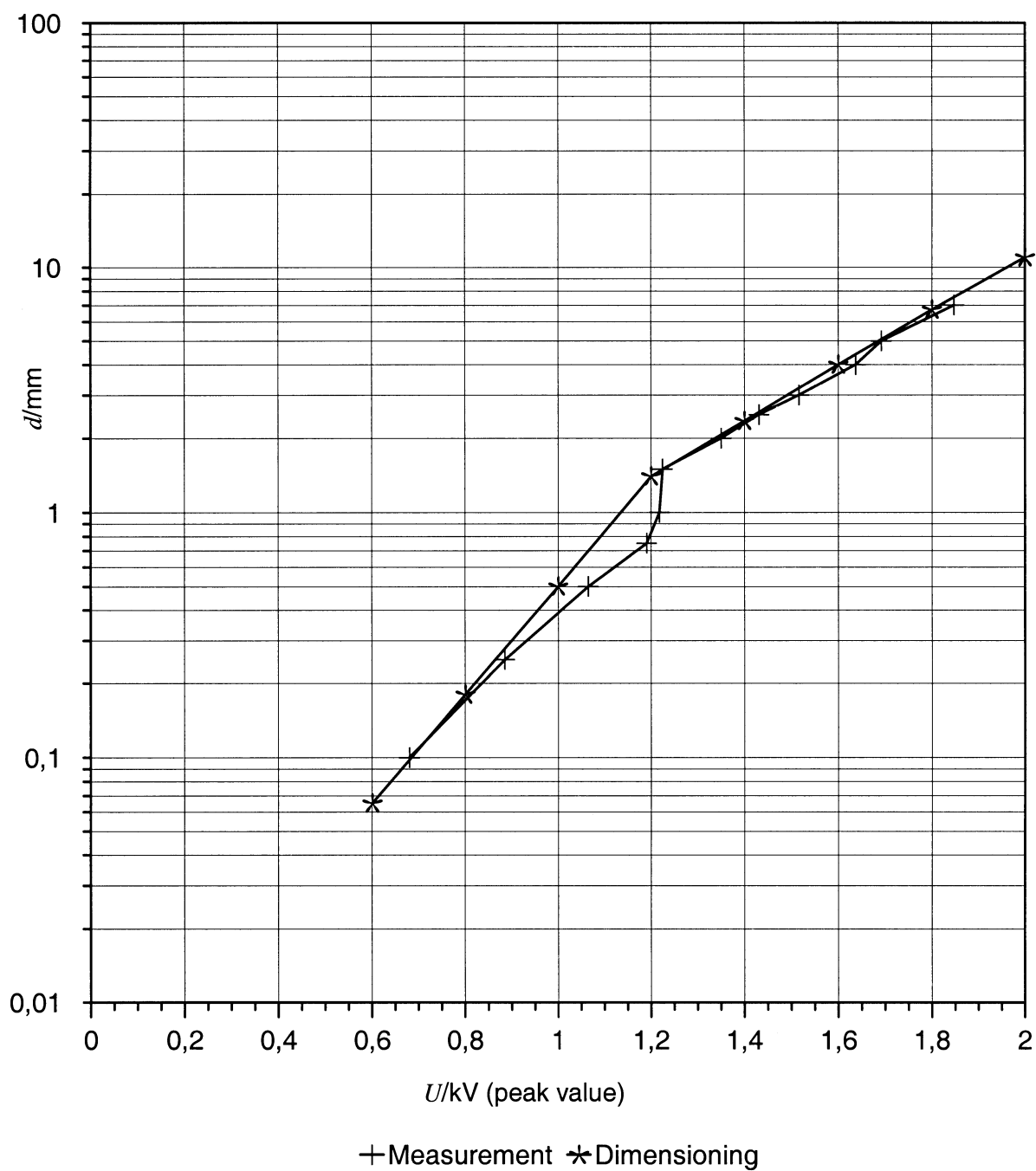
For frequencies below f_{crit} (see Equation (1)) the clearance shall be designed for 100 % of the required withstand voltage according to Table 7 of Part 1 or Table 3 of Part 5.

The frequency of the voltage shall be taken into account for dimensioning for frequencies equal to or greater than f_{crit} . As PD can be started by transient overvoltages and shall not be maintained by any steady state voltage (see 4.1.2.4 of Part 1), the PD-extinction voltage shall be used for dimensioning. The relevant data (see the note) is shown in Figure 1 (measurement) together with a limiting curve (dimensioning).

NOTE 1 For dimensioning, data from A.2.2 are applicable, obtained for clearances up to 0,75 mm from the breakdown voltages and above from the PD-extinction voltages at 1 MHz.

The dimensioning data for inhomogeneous fields are summarized in Table 1. These values are applicable if a small radius of curvature of the conductive parts occurs. In practice this condition is fulfilled if the radius of curvature of the conductive parts is smaller than 20 % of the clearance.

NOTE 2 Further information about dimensioning is given in Annex F.



IEC 1345/05

Key

d clearance

Figure 1 – Dimensioning of inhomogeneous clearances in air at atmospheric pressure (point-plane-electrodes, 5 μ m radius) to avoid PD (clearance ≥ 1 mm) or breakdown (clearance < 1 mm)

Table 1 – Minimum values of clearances in air at atmospheric pressure for inhomogeneous field conditions

Voltage U_{peak} kV	Clearance mm
Up to 0,6 a) b)	0,065
0,8 a)	0,18
1,0 a)	0,5
1,2 a)	1,4
1,4 a)	2,35
1,6 a)	4,0
1,8 a)	6,7
2,0 a)	11,0
a) For voltages between the values stated in this table, interpolation is permitted.	
b) No data is available for voltages U_{peak} of less than 0,6 kV.	

5 Creepage distances

5.1 Experimental data

The influence of frequency on the breakdown voltages of creepage distances is taken into account according to the data given in Annex B.

The experimental conditions for the investigations being performed and the materials being included in the experiments are described in Clause B.2.

The experimental data are shown in Clause B.3. Both the PD-voltages and the breakdown voltages are significantly influenced by the frequency of the voltage.

5.2 Dimensioning of creepage distances

Measuring data for three different frequency ranges up to 100 kHz, up to 1 MHz and up to 3 MHz are shown in Figure 2 (measurement) together with limiting curves (dimensioning). The dimensioning data for creepage distances are summarized in Table 2. The data for the additional frequency ranges have been obtained by linear interpolation. These data are valid for pollution degree 1.

NOTE 1 For dimensioning of creepage distances the data from Clause B.3 for the PD-extinction voltage are applicable as PD at high-frequency voltage will have a destructive effect on the base material, if it occurs during a longer period of time.

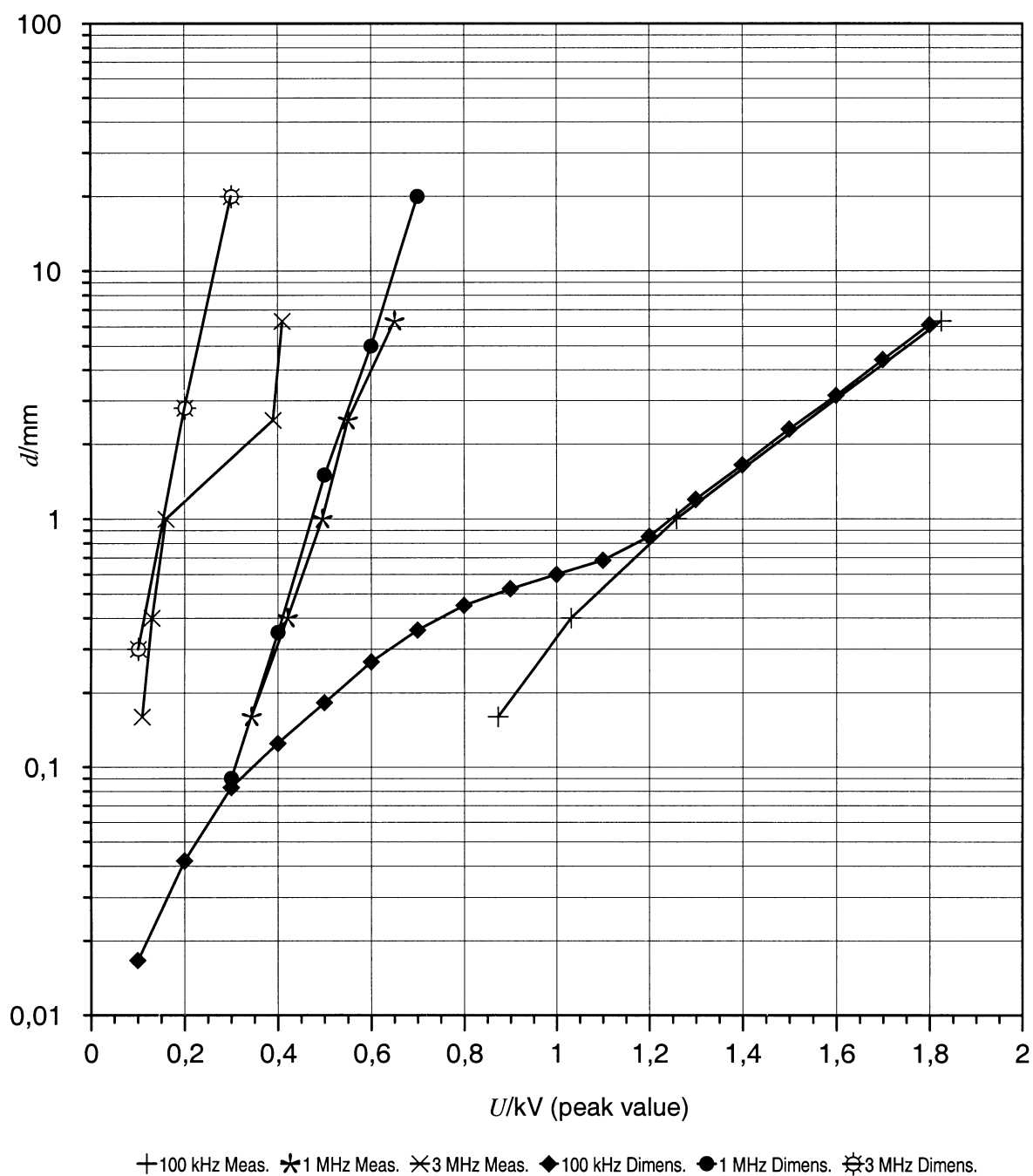
Experiments [5]¹ have shown that creepage distances for pollution degree 2 and 3 can be derived from the distances determined for pollution degree 1 by application of a multiplication factor. For pollution degree 2, the multiplication factor 1,2 and for pollution degree 3 the multiplication factor 1,4 are applicable.

¹ Figures in square brackets refer to the bibliography.

The data given in Table 2 do not take into account the influence of tracking phenomena. For that purpose Part 1 or Part 5 of IEC 60664 have to be taken into account. Therefore if the values from Table 2 of this standard are smaller than the relevant values from Table 4 of Part 1 or Part 5, the latter are applicable.

These dimensioning data are applicable for all materials that can be deteriorated by thermal effects. For materials where such deterioration is not likely to occur (for example ceramics) dimensioning for clearances according to Clause 4 of this standard is sufficient.

NOTE 2 Further information about dimensioning is given in Annex F.



Key

 d creepage distance

**Figure 2 – Dimensioning of creepage distances to avoid partial discharge
(creepage distance ≥ 1 mm)
or breakdown (creepage distance < 1 mm)**

Table 2 – Minimum values of creepage distances for different frequency ranges

Voltage U_{peak} kV	Creepage distance ^{a)} mm						
	for $30 \text{ kHz} < f \leq 100 \text{ kHz}$	for $f \leq 0,2 \text{ MHz}^{\text{b}}$	for $f \leq 0,4 \text{ MHz}^{\text{b}}$	for $f \leq 0,7 \text{ MHz}^{\text{b}}$	for $f \leq 1 \text{ MHz}^{\text{b}}$	for $f \leq 2 \text{ MHz}^{\text{b}}$	for $f \leq 3 \text{ MHz}^{\text{b}}$
0,1	0,0167						0,3
0,2	0,042					0,15	2,8
0,3	0,083	0,09	0,09	0,09	0,09	0,8	20
0,4	0,125	0,13	0,15	0,19	0,35	4,5	
0,5	0,183	0,19	0,25	0,4	1,5	20	
0,6	0,267	0,27	0,4	0,85	5		
0,7	0,358	0,38	0,68	1,9	20		
0,8	0,45	0,55	1,1	3,8			
0,9	0,525	0,82	1,9	8,7			
1	0,6	1,15	3	18			
1,1	0,683	1,7	5				
1,2	0,85	2,4	8,2				
1,3	1,2	3,5					
1,4	1,65	5					
1,5	2,3	7,3					
1,6	3,15						
1,7	4,4						
1,8	6,1						

^{a)} The values for the creepage distances in the table apply for pollution degree 1. For pollution degree 2 a multiplication factor of 1,2 and for pollution degree 3 a multiplication factor 1,4 shall be used.

^{b)} Interpolation between columns is allowed.

6 Solid insulation

6.1 General consideration

Compared to clearances in air, solid insulation can provide a breakdown field strength that is at least one order of magnitude higher. However in practical use the high breakdown field strength of solid insulation is of little use.

NOTE The mechanisms that are responsible for degradation and finally breakdown at much lower field strengths than expected are described in detail in Clause C.1.

6.2 Influencing factors

For a frequency of 1 MHz, the short-time breakdown field strength can be as low as 10 % of the power-frequency value. The breakdown field strength does not seem to reach a lower limit even at frequencies as high as 100 MHz.

NOTE High-frequency breakdown characteristics are shown in Clause C.2.

The dielectric strength of solid insulation in general, and especially at high-frequency voltage, can be further reduced by the influence of humidity and temperature. This influence is taken into account by conditioning before testing according to 7.3.

According to these characteristics solid insulation, which is intended for use in high-frequency applications, shall not be exposed for long period of time to humidity conditions higher than 92 % of relative humidity. Some materials e. g. glass and some ceramics are not influenced by humidity and therefore are not restricted by this limit of 92 %.

The breakdown field strength of solid insulation is a function of the thickness of the material. Very thin films can have a breakdown field strength that can be up to one order of magnitude higher than that of the test specimen with 0,75 mm thickness. So any dimensioning according to thickness of solid insulation shall take into account this dependency of the breakdown field strength upon the thickness of the insulation.

The influence of the temperature on the breakdown voltage can be seen in Clause C.2. Therefore the temperature is an important influencing factor, which shall be taken into account for dimensioning and testing.

Partial discharges at high-frequency voltages will have a high PD-impulse repetition frequency corresponding to the frequency of the voltage. Therefore no reasonable lifetime of solid insulation can be expected when partial discharges occur.

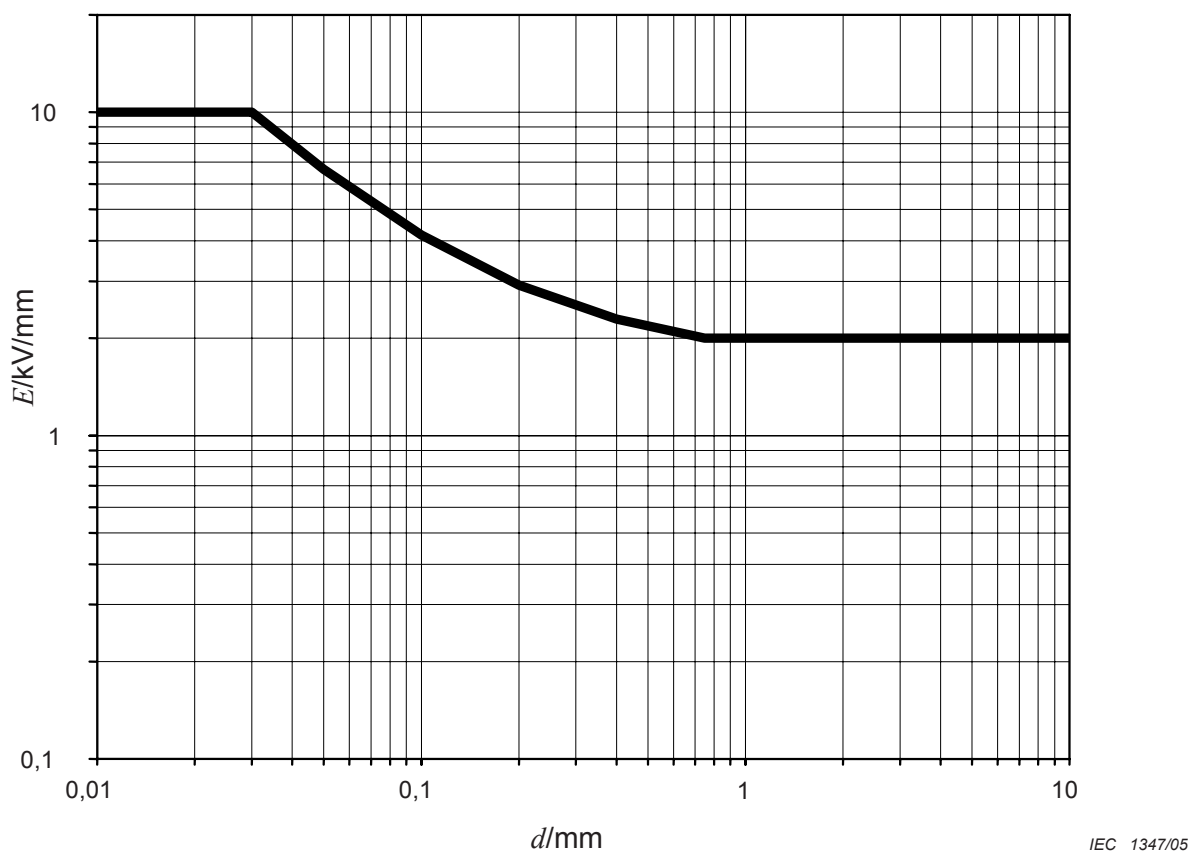
6.3 Dimensioning of solid insulation

The following method of dimensioning can be used instead of high-frequency testing according to Clause 7. It applies for a maximum frequency of the voltage 10 MHz, if the field strength is approximately uniform, not exceeding the specified values according to Equation (3) or Figure 3 respectively and no voids or air gaps are present in between the solid insulation. If these conditions cannot be fulfilled, high-frequency testing according to Clause 7 is required.

Dimensioning can be used if the electric field is approximately uniform (see the note). For thick layers of solid insulation of $d_1 \geq 0,75$ mm the peak value of the field strength E shall be equal or less than 2 kV/mm. For thin layers of solid insulation of $d_2 \leq 30$ µm the peak value of the field strength shall be equal or less than 10 kV/mm. For $d_1 > d > d_2$ Equation (3) shall be used for interpolation for a certain thickness d (see also Figure 3):

$$E = \left(\frac{0,25}{d} + 1,667 \right) \frac{\text{kV}}{\text{mm}} \quad (3)$$

NOTE In this context, the electric field is considered to be approximately uniform if the deviations are less than ± 20 % from the average value of the field strength.



Key
 E field strength

Figure 3 – Permissible field strength for dimensioning of solid insulation according to Equation (3)

The use of the field strength for dimensioning of solid insulation requires an approximately uniform field distribution with no voids or air gaps in between. If the field strength cannot be calculated (because the field is not uniform) or if the peak value is higher than given from Equation (3) or Figure 3 respectively or if the presence of voids or air gaps cannot be excluded or for higher frequencies than 10 MHz, a withstand test or a PD-test with high-frequency voltage is required. The first applies to short time stresses the second applies to long time stresses according to 3.3.3.2.2 of Part 1.

7 High-frequency testing

7.1 Basic requirements

The following tests are conducted at the frequency of the applied voltage:

- verification of the short-time dielectric strength for clearances and for solid insulation through use of a high-frequency a.c. voltage test;
- verification that no partial discharges occur under steady-state conditions of high-frequency voltage application.

Due to the large capacitive load at high-frequency, high-frequency testing is primarily applicable to components and subassemblies. If an additional high-voltage test on complete equipment is required, this test can be performed according to 4.1.2 of Part 1 with power-frequency voltage.

7.2 Test voltage source

Test voltage sources are given in Clause D.1.

7.3 Conditioning

If not otherwise specified by technical committees, the test shall be performed with a new test specimen. Conditioning of the specimen by temperature and humidity treatment is intended to

- represent the most severe normal service conditions,
- expose possible weaknesses that are not present in the new condition.

The conditioning methods described in 4.1.2.1 of Part 1 also apply for high-frequency testing.

7.4 High-frequency breakdown test

This test is similar to the high-voltage test at power-frequency (see 4.1.2.3 of Part 1).

7.4.1 Test method

High-frequency withstand capability is influenced by equipment temperature and environmental conditions. Therefore the test shall be performed under the most severe conditions that can be encountered in service, including the temperature rise caused by normal operation of the equipment. The test duration is 1 min.

7.4.2 Test result

No breakdown shall occur during the test duration. After the test, no visible damage (burning, melting etc.) shall occur.

7.5 High-frequency partial discharge test

7.5.1 General considerations

The general methods for partial discharge testing are described in IEC 60270. For PD-testing of low-voltage equipment 4.1.2.4 of Part 1 and Annex C of Part 1 are applicable, but for a test with high-frequency voltage changes are required in the test equipment and methods that are specified in this standard.

In order to minimize the risk of test sample degradation, a PD-testing should be performed with precise procedures and measurements and with test voltages in the range of the PD-inception voltage. For the failure criterion, low PD-levels have to be specified, normally below 10 pC. As the specified PD-extinction voltage can be determined with limited accuracy and is influenced by additional parameters such as temperature and humidity which are not usually