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Part 2-1: Application guide - Explanation of the application of the IEC 60664 series, dimensioning examples and dielectric testing

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Insulation coordination for equipment within low-voltage systems - Part 2-1: Application guide - Explanation of the application of the IEC 60664 series, dimensioning examples and dielectric testing

FOREWORD

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IEC/TR 60664-2-1 has been prepared by IEC technical committee 109: Insulation coordination for low-voltage equipment. It is a Technical Report and serves as an application guide for the IEC 60664 series [1].

This third edition cancels and replaces the second edition, published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

– the third edition of this technical report is reconstructed to align with the structure of IEC 60664-1:2020 [2] and IEC 60664-1:2020/AMD1:2025 [3];
– reference numbers indicated in this technical report are updated in line with the changes to clause and table numbers in IEC 60664-1:2020 [2] and IEC 60664-1:2020/AMD1:2025 [3];

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– references to IEC 60664-5:2007 [4], withdrawn in 2014, are deleted, and replaced, where applicable, to reference to IEC TR 63040 [5];
– explanations of the principles of IEC 60664 series [1] and examples of practical application are improved;
– Table A.1, Table A.2, and Table A.3 are combined into one table;
– Annex B, Annex C, and Annex D are deleted.

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

Draft	Report on voting
109/254/DTR	109/255/RVDTR

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

The language used for the development of this Technical Report is English.

This publication has been drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

It has the status of a basic safety publication in accordance with IEC GUIDE 104 [6].

This document is to be read in conjunction with IEC 60664-1:2020 [2], IEC 60664-1:2020/AMD1:2025 [3], IEC 60664-3:2016 [7] and IEC 60664-4:2005 [8].

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A list of all the parts in the IEC 60664 series [1], published under the general title *Insulation coordination for equipment within low-voltage systems*, can be found on the IEC website.

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The committee has decided that the contents of this amendment and the base 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

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INTRODUCTION

This application guide provides information relating to insulation coordination, as described in the IEC 60664 series [1], for the benefit of IEC technical committees and manufacturers of electrical equipment and components for use within low-voltage systems. It covers general information for the dimensioning of clearances, creepage distances and solid insulation for equipment within low-voltage systems.

It aims to highlight the use and understanding of the IEC 60664 series [1] when applied by technical committees and manufacturers. For the IEC 60664 series [1], the following parts are published:

a) IEC 60664-1 [9]: Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests.

b) IEC TR 60664-2-1 [10]: Insulation coordination for equipment within low-voltage systems - Part 2-1: Application guide - Explanation of the application of the IEC 60664 series, dimensioning examples and dielectric testing.

c) IEC 60664-3 [11]: Insulation coordination for equipment within low-voltage systems - Part 3: Use of coating, potting or moulding for protection against pollution.

d) IEC 60664-4 [12]: Insulation coordination for equipment within low-voltage systems - Part 4: Consideration of high-frequency voltage stress.

Insulation coordination for equipment implies the assessment of the minimum necessary dimensioning for clearances, creepage distances and solid insulation in order to allow safe use of the equipment during its lifetime, taking into consideration the foreseeable environmental conditions.

The main parameters to be taken into account for understanding of the IEC 60664 series [1] include:

– the maximum voltage stress to be withstood in order to avoid flashover across clearances;

– the characteristics of the solid insulating material and the environmental conditions regarding tracking. IEC 60664-3 [11] provides methods for improving the micro-environment at the creepage distance;

– the electric field stress through solid insulation as it relates to the risk of partial discharge and dielectric loss causing a risk of breakdown due to excessive heating. Due to the fact that both partial discharge phenomena and dielectric losses increase in importance with voltage frequency, a dedicated standard, IEC 60664-4 [12], applies for frequencies higher than 30 kHz;

– the long-term maximum voltage stress on creepage distances to be withstood in order to avoid tracking over the surface of the insulating material;

– flashover; besides tracking, this is increasingly important with reduction of creepage distance in the presence of high humidity. IEC TR 63040 [5] provides information of humidity levels classifying the effects of humidity on creepage distances equal to or less than 2 mm.

Other stresses such as heat, vibration, mechanical shocks, radiation (thermal, X-rays, microwave, ultraviolet, etc.) can influence the performance of solid insulating materials in service. Technical committees and manufacturers are expected to consider the impacts to the solid insulation materials resulting from these other stresses following tests on equipment under particular situations.

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1 Scope

This document serves as an application guide, when using the IEC 60664 series [1] for the design and verification of an insulation system of electrical equipment within low-voltage systems, in order to provide better understanding related to the:

– basic technical characteristics relevant for the design of clearances, creepage distances, and solid insulation,
– design for insulation coordination to clearances, creepage distances, and solid insulation and combinations of such,
– test and measurement of clearances, creepage distances, and solid insulation for electrical equipment and their components,
– practical examples for dimensioning of clearances, creepage distances and solid insulation.

This document is informative only and does not provide any additional requirements beyond the IEC 60664 series [1]. It provides guidance to assist better understanding of the insulation coordination requirements and avoids repeating the content of the individual parts of IEC 60664 documents. In case of conflict between this document and documents mentioned above, requirements in these documents prevail over this technical report.

This document provides a summary for technical committees in the preparation of their standards, and for manufacturers of electrical equipment and components, on specific topics, activities and options which are considered when using the IEC 60664 series [1] in their specific equipment or application. See Annex A.

This basic safety publication focusing on safety guidance related to IEC 60664 series [1] is primarily intended for use by technical committees in the preparation of safety publications in accordance with the principles laid down in IEC GUIDE 104 [6] and ISO/IEC Guide 51 [13].

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One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications.

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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 60664-1:2020, *Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests*

IEC 60664-1:2020/AMD1:2025, *Amendment 1 - Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests*

IEC 60664-3:2016, *Insulation coordination for equipment within low-voltage systems - Part 3: Use of coating, potting or moulding for protection against pollution*

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

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60664-1:2020 , IEC 60664-1:2020/AMD1:2025 , IEC 60664-3:2016 , and IEC 60664-4:2005 apply.

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

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

3.2 Abbreviated terms

In addition to abbreviated terms given in IEC 60664-1:2020, IEC 60664-1:2020/AMD1:2025, the following abbreviations are used in this document.

SPD	Surge protective device connected to low-voltage power systems described in the IEC 61643-x1 series [14]
SPC	Surge protective component for low-voltage surge protective devices described in the IEC 61643-3x1 series [15]
OVC	Overvoltage category. See IEC 60664-1:2020 [2], 3.1.20.
TOV	Temporary overvoltage. See IEC 60664-1:2020 [2], 3.1.12.

4 Basic technical characteristics for insulation coordination

4.1 General

Designing each insulation part of an insulation system for electrical equipment according to the IEC 60664 series [1] is essential but it also involves careful considerations. It is important that insulation coordination is considered in the correct context.

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Important parts of this consideration are:

– the purpose of insulation coordination,
– the characteristics influencing the insulation system,
– the consequences of a failure of a specific insulation within the system.

For the design of insulation coordination different parameters are considered:

a) Limits for the equipment considering the intended use:
   1) Voltages characteristics present in the intended installation or application (see IEC 60664-1:2020 [2] and IEC 60664-1:2020/AMD1:2025 [3], 4.2 to 4.4).
   2) Macro-environmental and micro-environmental conditions (humidity, temperature, altitude, pollution etc.) and their impacts on the insulation coordination including consideration about the materials used as insulators (see IEC 60664-1:2020 [2], 4.5 to 4.7).
   3) Life time consideration about conditions and duration of voltage stress (see IEC 60664-1:2020 [2], 4.6 and 4.8).
b) Operation mode of the equipment considering:

   Voltage characteristics generated by the equipment itself considering normal operating conditions, abnormal operating conditions and single fault condition (see IEC 60664-1:2020 [2] and IEC 60664-1:2020/AMD1:2025 [3], 4.2).
c) Identification of the purpose of the insulation coordination:
   1) Insulation for the purpose of the primary function of the equipment not related to any risk or increased reliability.
   2) Risk mitigation for safety aspects (for example protection against electric shock, functional safety, explosive atmosphere, fire, energy hazards).
   3) For increased reliability, for example, taking into account an effect of ageing considering the pollution degree or group of material. See 4.6.2.
   4) Insulation for the purpose of a safe function of a specific functionality inside the equipment.

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NOTE 1 Examples of risks are taken from IEC GUIDE 116:2018 [16] where also the 3-step risk mitigation method is described.

While the IEC 60664 series [1] provides information about how to deal with a) and b), the purposes of the insulation as listed under c) implies further consideration by technical committees.

IEC 60664-1 [9] uses many concepts from the risk mitigation measures related to the protection against electric shock from IEC 61140 [17], which can mislead the user to think that the IEC 60664 series [1] primarily covers protection against electric shock and this is not the case. The IEC 60664 series [1] primarily describes the physics behind the insulation coordination for both design and verification considering many different aspects as those described in points a) and b) above.

NOTE 2 Examples of these concepts are insulation types such as basic insulation, supplementary insulation, double insulation and reinforced insulation.

As a general statement, according to IEC 60664-1 [9], the user is to consider the context where the insulation is used as described in c) above.

Good engineering practice, as described in many safety standards, considers that the protection against hazards is maintained under normal, abnormal and single fault conditions. This is well described in the context of protection against electric shock in IEC 61140 [17] by use of basic insulation for the basic protection and supplementary insulation as fault protection (see examples of insulation coordination dimensioning for protection against electric shock in Clause 7).

NOTE 3 Basic protection is intended to prevent contact with live parts and generally corresponds to protection against direct contact. See IEC 61140:2016 [18], 5.2.

The use of insulation coordination alone is not sufficient to address the risk associated with the following examples:

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– functional safety aspects,
– explosive atmosphere conditions,
– internal working voltages not critical to electric shock,

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– thermal hazards.

Technical committees can use the IEC 60664 series [1] under the following considerations:

– the relevant limits a), the operation modes b) and the estimation of the associated safety risk or need for reliability;
– method and rules to design for normal, abnormal and single fault conditions applicable for the specific application. This includes the design of the applicable insulation type and applicable voltages (see IEC 60664-1:2020 [2] and IEC 60664-1:2020/AMD1:2025 [3], 4.2), as this can apply differently depending on the risk under consideration.

Without all the considerations above, the requirement for insulation coordination is not transparent and can be difficult to apply in practice.

4.2 Voltages

4.2.1 General aspects

With regard to voltage, there are the following considerations:

– the voltages which can occur within the low-voltage supply system, including working voltages (steady-state working voltage (RMS value of the AC or DC value) and steady-state peak voltage), temporary overvoltages (peak value) and transient overvoltages (peak value),
– the voltages generated by the equipment (which can adversely affect other equipment in the low-voltage supply system),
– the frequency of the steady-state voltage:

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- for frequencies up to and including 30 kHz, IEC 60664-1 [9] provides sufficient design and verification requirements;
- for frequencies above 30 kHz, IEC 60664-4 [12] is taken into account in addition to IEC 60664-1 [9] (see 5.1.2),

– the desired reliability and availability of the equipment,

– the safety of persons and property, so that the likelihood of hazardous events due to voltage stresses does not result in an unacceptable risk of harm.

4.2.2 Transient overvoltages

4.2.2.1 General

4.2.2.1.1 General information on transient overvoltages

Transient overvoltages in low-voltage systems are described in IEC 60664-1:2020 [2], 4.2.2.1. There are two types of transient overvoltages entering through the mains supply.

a) Lightning overvoltages

The lightning overvoltages are the result of a direct lightning strike to or near the low-voltage supply system or building structures, or to the soil at some distance from the low-voltage system. Those can be classified according to their point of impact: direct lightning strikes and indirect lightning strikes. Those indirect lightning strikes can be further distinguished in nearby lightning strikes and lightning strikes occurring at some distance.

1) For direct lightning strikes, the overvoltages result from the flow of lightning current in the building structure and the associated protective earthing system in the electrical installation.
2) For nearby lightning strike, the overvoltages result from capacitive or inductive coupling of voltages in the conductor loops and to some extent the rise in earth potential associated with the lightning current.
3) For lightning strikes at some distance, the overvoltages are limited to those induced into conductive circuit loops in the building structure and the protective earthing system.

IEC 60664-1 [9] does not address the aspect of direct lightning strikes or nearby lightning strikes. Increasing stresses occur when the point of impact of the lightning strike is closer to the structure of interest, but the likelihood of such high stress is less than that of a stress of lower magnitude associated with lightning strikes at some distance. In any case, statistical considerations, which are discussed in IEC TR 62066:2002 [19], 11.6 dealing with risk assessment, are an essential part of the decisions concerning protection against these lightning overvoltages.

NOTE 1 IEC TR 62066:2002 [19], Clause 11 provides considerations for the use of surge protection. The risk assessment due to lightning flashes is provided in IEC 62305-1:2024 [20].

b) Switching overvoltages

Most switching overvoltages are the result of intentional actions in the AC or DC power distribution system (see IEC 60664-1:2020 [2], 3.1.2). Typical sources are the switching of inductive or capacitive loads, heavy load dumps by the utility or by end user operations or switching between power supplies. But they can also be the result of unintentional switching events due to short circuits or earth faults in the power distribution systems, or low-voltage supply system faults (other than temporary overvoltages) and their elimination.

NOTE 2 Information on temporary overvoltages is provided in 4.2.3.

Other types of transient overvoltage not entering through the mains supply are those generated by external circuits (for example coaxial cable or twisted pair networks) or generated internally in the equipment.

4.2.2.1.2 Transient overvoltage control

Insulation coordination with regards to the transient overvoltages described in IEC 60664-1:2020 [2], 4.2.2.1.1 is based upon controlled overvoltage conditions. IEC 60664-1:2020 [2], Annex B provides information on nominal voltages of mains supply and related to rated impulse withstand voltages (U_{imp}) for equipment for two modes of overvoltage control:

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a) Inherent control is the condition within an electric system where the transient overvoltages are limited inherently by the design of the electrical distribution system (no additional means provided for attenuation of transients).

b) Protective control is the condition within an electric system where the transient overvoltages are limited by appropriate means such as SPD.

In general, the design of the installation will determine whether to provide protective control in an installation on the basis of local information, good practice, or regulation etc, or not. There are two significant elements in the decision-making process:

– the evaluation of the need for protective control, depending on the type of installation, the type and purpose of equipment and an assessment of the risk;

– the evaluation of the appropriate means for protective control against overvoltages, depending on the overvoltages which can be induced into the circuits of the installation or result from currents injected into the upstream network or low-voltage systems by an indirect lightning strike at some distance from the installation. A similar evaluation is applicable to switching overvoltages.

NOTE IEC 60664-1:2020 [2], Table B.1 and Table B.2 are very similar. They differ in the assignment of the nominal voltage levels 347 V, 380 V, 400 V, 415 V, 440 V, 480 V of column 3 to the values listed in column 1.

In IEC 60664-1:2020 [2], Table B.1 column 3 references “unearthed" systems only. And these values are assigned to the value 300 V of column 1. In IEC 60664-1:2020 [2], Table B.2 column 3 references "earthed or unearthed" systems. And these values are assigned to 600 V of column 1. This assignment can be specified and is possibly applied for three-phase three-wire systems when one of the phases is intentionally or unintentionally connected to earth.

If SPDs are present in an installation or equipment at more than one location (e.g. close to the point of supply and in sub-distribution boards or close to equipment), coordination of these SPDs are considered, as far as possible and reasonable. Further information on coordination of SPDs is provided in IEC 61643-12:2020 [21]. For SPDs in the installation IEC 60364-5-53:2019 [22] and IEC 60364-5-53:2019/AMD2:2024 [23], Clause 534 provide the requirements for selection and installation of appropriate SPDs. The voltage protection level (clamping voltage) of SPDs is always lower than the rated impulse withstand voltage of equipment (according to the assigned overvoltage category).

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4.2.2.1.3 Preventing permanent damage of equipment

Application of SPDs is generally focused on a consideration to prevent damage caused by the amplitude and energy-delivery capability of a surge (including the duration of the surge) while EMC interference generally reflects the parameters of the front of the surge. When the situation involves an overvoltage resulting from inductive effects associated with a surge current, the rate of current change, the front of the surge, is the relevant factor for the resulting overvoltage.

Of course, the probability of permanent damage can also be reduced by raising the inherent EMC immunity level of the equipment. This is the approach suggested in IEC 60664-1 [9] where the "equipment withstand voltage" is defined and several categories of withstand levels are identified, as discussed below.

It can be noted, however, that "insulation withstand strength" primarily refers to overvoltages occurring in the line-to-earth mode (a form of common mode), while electronic components are generally connected line-to-neutral or line-to-line (also described as “differential mode”).

Neutral earthing practices, in accordance with the local requirements, also influence the relative levels of surge stress in the common mode versus the differential mode. For instance, in TN systems, the bonding of the neutral and earth at the service entrance (origin of installation) prevents further propagation of common mode surges impinging upon the installation, by converting them to differential (line-to-neutral) surges. Many IEC publications define surge environments. For example, IEC 61000-4-5:2014 [24] suggests that immunity tests have a level for common mode surge higher than that for differential mode. However, the overvoltages to be expected in a TN system are generally lower compared to a TT system, due to the multiple earthing of the neutral conductor.

NOTE See IEC TR 62066:2002 [19], 10.3 for further information of neutral earthing practices.

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Notwithstanding these subtle differences, the following paragraphs summarize the approach taken in IEC 60664-1 [9], where a direct relation is established between equipment impulse withstand voltages and an overvoltage category assigned to the equipment. This relation is based on a probabilistic behaviour and is independent of the physical location of the equipment in a particular installation.

Overvoltage categories are used to determine the relevant insulation withstand strength of the components and equipment used within the low-voltage mains supply system. They are used for a classification of equipment and their selection according to the necessity of service continuity and acceptable low probability of failure. A higher overvoltage category defines a higher reliability and withstand capability.

Together with the preferred rated impulse voltage (see IEC 60664-1:2020 [2], 4.2.2.1) they make insulation coordination possible for the whole installation, reducing the probability of failure to an acceptable level and providing a basic overvoltage withstand capability.

A higher overvoltage category indicates a better withstand of the equipment and provides wider choice of a method for overvoltage protection. Overvoltages of atmospheric origin are not significantly attenuated downstream from the service entrance when relatively high impedance loads are connected to the branch circuits. Studies show that it is reasonable to use probabilistic analysis to evaluate the need for protection.

When protective measures are taken inside the equipment, information is provided by the manufacturer to allow appropriate assessment of the need for further surge mitigation. Misguided perceptions on the surge environment can lead to counter-productive inclusion of inadequate SPDs, decreasing the overall system reliability. Some electronic devices, in particular those with switch-mode power supply that include a large input capacitor, are an example where little is gained over inherent immunity and much can be lost when SPDs that are unsuited for the environment, are incorporated in equipment for which some enhancement of surge immunity is claimed.

Sample Document

4.2.2.2 Transient overvoltages entering through the mains supply

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4.2.2.3 Transient overvoltages generated by external circuits

The applicable value of the transient overvoltage is determined on the basis of the transients that can occur in the external circuit. Influencing factors for the determination of the transient overvoltages to be expected from the external circuits can be their physical expansion (for example, cable length) and their exposure to external influences.

Especially, for extended outdoor circuits, referring to the system of overvoltage categories defined for mains supply can offer a useful framework for determining the transient overvoltages.

4.2.2.4 Transient overvoltages generated internally in the equipment

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4.2.2.5 Attenuation of transient overvoltage levels

4.2.2.5.1 General

The following is a guideline on how to determine the applicable rated impulse withstand voltage of equipment, depending on either the intended installation location or the intended specific application.

The overvoltage category of a mains circuit cannot be reduced as it is a convention, a classification. However, the transient overvoltage value can be reduced. Therefore it can be acceptable to reduce clearances within equipment.

Most commonly transient overvoltages can be reduced using SPD, or isolation transformers, but other methods are also possible.

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