TECHNICAL REPORT

IEC TR 62066

First edition
2002-06

Surge overvoltages and surge protection in low-voltage a.c. power systems – General basic information

Surtensions de choc et protection contre la foudre dans les réseaux à basse tension – Informations générales fondamentales

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PRICE CODE XF

For price, see current catalogue

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

SURGE OVERVOLTAGES AND SURGE PROTECTION IN LOW-VOLTAGE AC POWER SYSTEMS – GENERAL BASIC INFORMATION

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IEC 62066, which is a technical report, has been prepared by Technical Committee 64: Electrical installations and protection against electric shock.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
64/1125/CDV	64/1163/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 3.

The committee has decided that the contents of this publication will remain unchanged until 2006. At this date, the publication will be

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- withdrawn;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

This document, which is purely informative, is not to be regarded as an International Standard.

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

SURGE OVERVOLTAGES AND SURGE PROTECTION IN LOW-VOLTAGE AC POWER SYSTEMS – GENERAL BASIC INFORMATION

1 Scope

IEC 62066 is a technical report that presents a general overview on the different kinds of surge overvoltages that can occur on low-voltage installations. Typical surge magnitude and duration as well as frequency of occurrence are described. Information on overvoltages resulting from interactions between power system and communications system is also provided.

Additionally, general guidelines are given concerning surge protection means and systems on the basis of availability and risk considerations, including interactions and the need for coordination and consideration of temporary overvoltages in the selection of surge-protective devices.

2 Reference documents

IEC 60364-4-44:2001, *Electrical installations of buildings – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-5-53:2001, *Electrical installations of buildings – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control*

IEC 60664-1:1992, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*
Amendment 1 (2000)

IEC/TR 61000-2-5:1995, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 5: Classification of electromagnetic environments.* Basic EMC publication

IEC 61000-4-1:2000, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Overview of IEC 61000-4 series*

IEC 61000-4-4:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test.* Basic EMC publication

IEC 61000-4-5:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 5: Surge immunity test*
Amendment 1 (2000)

IEC/TR 61000-5-2:1997, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*

IEC 61024-1:1990, *Protection of structures against lightning – Part 1: General principles*

IEC 61024-1-1:1993, *Protection of structures against lightning – Part 1: General principles – Section 1: Guide A – Selection of protection levels for lightning protection systems*

IEC 61312-1:1995, *Protection against lightning electromagnetic impulse – Part 1: General principles*

IEC/TS 61312-3:2000, *Protection against lightning electromagnetic impulse – Part 3: Requirements of surge protective devices (SPDs)*

IEC 61643-1:1998, *Surge protective devices connected to low-voltage power distribution systems – Part 1: Performance requirements and testing methods*

IEC 61643-12:2002, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*

IEC 61662:1995, *Assessment of the risk of damage due to lightning*
Amendment 1 (1996)

IEC 61663-2:2001, *Lightning protection – Telecommunications lines – Part 2: Lines using metallic conductors*

ITU-T K.20, *Resistibility of telecommunication equipment installed in a telecommunications centre to overvoltages and overcurrents*

ITU-T K.21, *Resistibility of telecommunication equipment installed in customers' premises to overvoltages and overcurrents*

IEEE 1036:1992, *Guide for application of shunt power capacitors*

NOTE Other documents are listed in the bibliography, which includes documents that were used in developing the present report, documents cited in support of a recommendation, and documents suggested as further reading for information.