



IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage (1000 V or Less) AC Power Circuits

IEEE Power Engineering Society

Sponsored by the
Surge Protective Devices Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA
3 August 2007

IEEE Std C62.72™-2007

IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage (1000 V or Less) AC Power Circuits

Sponsor

**Surge Protective Devices Committee
of the
IEEE Power Engineering Society**

Approved 8 March 2007

IEEE-SA Standards Board

Abstract: Information is provided to specifiers and users of surge-protective devices (SPDs) about the application considerations of SPDs associated with power distribution systems within North America. This guide applies to SPDs to be connected to the load side of the service entrance main over current protective device of 50 Hz or 60 Hz ac power circuits rated at 100 V to 1000 V rms. The effects and side effects on the presence and operation of SPDs in low-voltage power distribution systems are described. The coordination of multiple SPDs on the same circuit is described.

Keywords: lightning protection, surge protection coordination, surge-protective device

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2007 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 3 August 2007. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by the Institute of Electrical and Electronics Engineers, Incorporated.

National Electrical Code and NEC are registered trademarks in the U.S. Patent & Trademark Office, owned by The National Fire Protection Association.

Print: ISBN 0-7381-5537-3 SH95633
PDF: ISBN 0-7381-5538-1 SS95633

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “**AS IS.**”

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854
USA

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

This introduction is not part of IEEE Std C62.72-2007, IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage (1000 V or Less) AC Power Circuits.

One purpose of this guide is to provide specifiers and users of surge-protective devices (SPDs) with an understanding of numerous application considerations to be evaluated before SPDs are installed in low-voltage ac power circuits. Given this understanding, specifiers and users can exercise due diligence in applying SPDs, take steps to prevent their misapplications, and act to either prevent or mitigate adverse effects that SPDs may have on a power distribution system.

The growth of interest in low-voltage SPDs parallels the increasing number of installations with sensitive, sophisticated, and expensive electronic equipment and components that can be exposed and susceptible to surge voltages. Specifiers and users of SPDs might be under the impression, or might be led to believe the misconception, that by installing one or more SPDs in their respective facility or within specific equipment, there will be total immunity to any and all power system disturbances. Actually, unanticipated and unexpected events can occur, which makes absolute immunity to the events of surges an unreasonable and unrealistic goal. In addition, there are numerous misconceptions that SPDs are so generic in application and construction that the method employed in their installation and their respective locations within a power distribution system are not variables in their functionality. In reality, SPDs will respond to and have an effect on some power system disturbances but not on others. The functionality of any SPD is also directly related to the specific location where it is connected to a low-voltage power distribution system and the methods used to make the required electrical connections to ac power circuits. The effects that SPDs will have on power system disturbances are often less than desired. SPDs installed at various locations in the low-voltage power distribution system, as well as in specific equipment, can interact with each other, with protective relaying systems, and with other components of the power distribution system. In those scenarios, the effect of a given SPD is often imprecise and can be unpredictable. Due to the complex nature of surges and the numerous environments where surges are generated and SPDs exist, the application of SPDs has yet to become an exact science.

This guide is one member of the IEEE C62™ family that deals with power systems surges and surge protection. Other IEEE C62 documents describe performance characteristics of SPDs, recommend standard test protocols for verifying performance, and provide guidance on the interaction between power systems disturbances and SPDs.

Suggestions for improvements to this guide will be welcomed. They should be sent to Secretary, IEEE Standards Board, Institute of Electrical and Electronic Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA.

Notice to users

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/updates/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/interp/index.html>.

Patents

Attention is called to the possibility that implementation of this guide may require use of subject matter covered by patent rights. By publication of this guide, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Participants

At the time this guide was completed, the Low Voltage AC Power Circuit Protective Devices Working Group had the following membership:

Douglas S. Dorr, *Chair*

Ken Brown
William Bush
Richard Chadwick
Bryan R. Cole
Tom Conrad
James Funke

Randy Goodrich
Ronald W. Hotchkiss
Charles B. Jensen
Francois Martzloff
Pat McCurdy
Richard Odenberg
Tom Phipps

Joe Ramirez
Alan Rebeck
Mario Stolzenberg
Tony Surtees
S. Frank Waterer
Darrell Wilson

The Task Force that developed this guide had the following membership:

S. Frank Waterer, *Chair*

Bryan R. Cole
Douglas S. Dorr

Joseph O. Enk
James Funke

Gary Goedde
Patrick J. Howard

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

William J. Ackerman
Adam J. Bagby
Paul D. Barnhart
Steven Bezner
William J. Bloethe
Chris Brooks
William E. Brumsickle
Vern L. Buchholz
Ramesh R. Butani
William A. Byrd
Thomas P. Callsen
Thomas Carpenter
James S. Case
Yunxiang Chen
Danila Chernetsov
Bryan R. Cole
Tommy P. Cooper
Stephen Dare
Eugene P. Dick
Carlo Donati
Mark M. Drabkin
Donald G. Dunn
Gary R. Engmann
C. C. Erven
Keith Flowers
Rabiz N. Foda
James Funke
Fernando Genkuong

Frank J. Gerleve
William R. Godlbach
Ron K. Greenthaler
Randall C. Groves
Thomas M. Gruzs
Ajit K. Gwal
Kenneth S. Hanus
John E. Harder
Adrienne M. Hendrickson
Steven P. Hensley
Gary A. Heuston
Raymond Hill
Philip J. Hopkinson
Dennis Horwitz
Ronald W. Hotchkiss
David W. Jackson
Charles B. Jensen
Paul R. Johnson Jr.
J. L. Koepfinger
Jim Kulchisky
Chung-Yiu Lam
Benny H. Lee
Solomon Lee
Paul Lindemulder
Albert Livshitz
G. L. Luri
William A. Maguire

Ahmad Mahinfallah
Keith N. Malmadal
Michael J. Maytum
Mark F. McGranaghan
Richar D. Meininger
Gary L. Michel
Charles A. Morse
Jerry R. Murphy
Dennis K. Neitzel
Arthur S. Neubauer
Hans-Wolf Oertel
Lorraine K. Padden
Donald M. Parker
Percy E. Pool
Michael A. Roberts
Thomas J. Rozek
Steven Sano
Robert J. Schuerberger
Perry L. Schwartz
James E. Smith
Donald B. Turner
Joe D. Watson
Steven G. Whisenant
James W. Wilson Jr.
Larry E. Yonce
Larry S. Young
Donald W. Zipse
Ahmed F. Zobia

When the IEEE-SA Standards Board approved this guide on 8 March 2007, it had the following membership:

Steve M. Mills, *Chair*
Robert M. Grow, *Vice Chair*
Don Wright, *Past Chair*
Judith Gorman, *Secretary*

Richard DeBlasio
Alex Gelman
William R. Goldbach
Arnold M. Greenspan
Joanna N. Guenin
Julian Forster*
Kenneth S. Hanus
William B. Hopf

Richard H. Hulett
Hermann Koch
Joseph L. Koepfinger*
John Kulick
David J. Law
Glenn Parsons
Ronald C. Petersen
Tom A. Prevost

Narayanan Ramachandran
Greg Ratta
Robby Robson
Anne-Marie Sahazizian
Virginia C. Sulzberger
Malcolm V. Thaden
Richard L. Townsend
Howard L. Wolfman

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*
Alan H. Cookson, *NIST Representative*

Jennie M. Steinhagen
IEEE Standards Program Manager, Document Development

Matthew J. Ceglia
IEEE Standards Program Manager, Technical Program Development

Contents

1. Overview	1
1.1 Scope	1
1.2 Purpose	2
2. Normative references.....	2
3. Definitions	2
4. Beginning the surge-protective device selection	3
5. Surge origins.....	3
5.1 Lightning	3
5.2 Switching.....	4
6. Effects of surges	4
6.1 No observed change.....	4
6.2 Upset.....	5
6.3 Damage.....	5
6.4 Consequential damage	5
7. Number and magnitude of surge events	5
7.1 General	6
7.2 Environmental factors.....	6
7.3 Changes in the power distribution system	6
7.4 Rate of occurrence (vs.) current level.....	7
7.5 Exposure levels.....	8
8. Location categories.....	9
9. Power distribution systems.....	10
9.1 System configuration.....	12
9.2 System arrangement or distribution	15
9.3 Common North American voltages	15
9.4 Available short-circuit current and surge-protective device short-circuit current rating	15
9.5 Voltage ratings of surge-protective devices.....	18
10. Grounded and ungrounded systems.....	18
10.1 Grounded systems.....	18
10.2 Impedance grounded systems	19
10.3 Ungrounded systems.....	19
10.4 Ferroresonance.....	20
11. Grounding and bonding.....	22
11.1 Bonding	22
11.2 Grounding.....	23
12. Modes of operation.....	25
12.1 Considerations for neutral-to-ground surge-protective device application	25

13. Surge-protective device specifications	26
13.1 Measured limiting voltage	26
13.2 Product response time	27
13.3 Surge current ratings	27
13.4 Labeling	28
13.5 Joule ratings	29
14. Surge-protective device lifetime	29
14.1 Overvoltage failures of surge-protective devices	30
15. Interactions of surge-protective device operations in a power distribution system	30
15.1 Interactions with ground-fault protection systems	30
15.2 Interaction of surge-protective device operation on other protective relaying systems	31
15.3 Interaction of surge-protective device operation on other protective devices	31
16. Surge-protective device coordination	31
16.1 Waveshapes and durations	32
16.2 Lead length	33
16.3 Distance between the origin of a surge and the end-use equipment	33
16.4 Voltage-limiting surge-protective devices	33
16.5 Surge current capacity of the surge-protective devices	34
16.6 Grounding of surge-protective devices	34
16.7 Modes of protection	34
16.8 Power distribution system configuration	34
16.9 Surge-protective devices within end-use equipment	35
16.10 Coordination methodologies	35
17. Summary	36
Annex A (informative) Bibliography	37
Annex B (informative) Glossary	40
Annex C (informative) IEC earthing (grounding) practices	41
Annex D (informative) Methods of transient mitigation	48

IEEE Guide for the Application of Surge-Protective Devices for Low-Voltage (1000 V or Less) AC Power Circuits

1. Overview

1.1 Scope

The transient overvoltages or surge events that are described and discussed in this guide are those that originate outside of a building or facility and impinge on a power distribution system (PDS) through the service entrance conductors. Transient overvoltages or surge events that originate from equipment within a specific facility are not within the scope of this document.

This guide applies to surge-protective devices (SPDs) that are manufactured for connections to 50 Hz or 60 Hz ac power circuits that are rated between 100 V rms and 1000 V rms. This guide applies to SPDs that are specifically identified, labeled, or listed for connections on the load side of the service entrance main overcurrent protective device. This guide does not cover those SPDs identified, labeled, or tested as a secondary surge arrester intended for connections on the line side of the service entrance main overcurrent protective device.

The SPDs covered in this guide are those manufactured for use in an association with electrical power distribution equipment such as load centers, motor control centers, panelboards, switchboards, switchgear, and end-use equipment installed in commercial and industrial facilities. This guide excludes SPDs associated with retail and consumer appliances and components for residential use.

This guide does not specify or set limits on insulation levels of any components associated with power distribution systems or end-use equipment. In addition, it is not the intent of this guide to address individual SPD component specifications associated with any specific manufacturer of surge protection products.

The SPDs discussed in this guide contain at least one nonlinear component for either diverting surge currents and/or dissipating surge energy. Examples of such nonlinear components are metal-oxide varistors (MOVs), silicon avalanche diodes (SADs), spark gap tubes, or thyristors. Ferroresonators, motor-generators, uninterruptible power supplies, and filters containing only inductive or capacitive components are not considered SPDs in the guide.

1.2 Purpose

The primary purpose of an SPD is to provide a desirable level of surge protection by diverting surge currents and by reducing surge voltages to a level that can be tolerated by the PDS and the equipment connected to the system. When specifying and installing any SPD in low-voltage power distribution equipment associated with commercial and industrial installations, numerous application considerations should be reviewed and evaluated before installation. Failure to consider the applications or misapplications of any SPD can directly influence the expected performance of the SPD and can result in undesirable effects on a PDS and/or end-use equipment. It is the intent of this guide to inform specifiers and users of SPDs, such as specifying engineers, electrical inspectors, facilities engineers, or authorities having jurisdiction, of application and installation considerations for the purpose of desirable and satisfactory application of SPDs.

2. Normative references

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

IEEE Std C62.41.1™-2002, IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits.^{1, 2}

IEEE Std C62.41.2™-2002, IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V and Less) AC Power Circuits.

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B20]³ should be referenced for terms not defined in this clause.

3.1 cascade coordination: The planned interaction between two or more surge-protective devices (SPDs) on the same power distribution system.

3.2 main overcurrent protective device: The first overcurrent device between the secondary terminals of the distribution or power class transformer and the load terminals of the service entrance equipment. Also identified as the service entrance main.

¹ IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

² The IEEE standards or products referred to in this clause are trademarks of the Institute of Electrical and Electronics Engineers, Inc.

³ The numbers in brackets correspond to those in the bibliography in Annex A.

3.3 service entrance equipment: The necessary equipment, usually consisting of a circuit breaker(s) or switch(es) and fuse(s) and their accessories, connected to the load end of service entrance conductors to a building facility, or other structure, or an otherwise designated area, and intended to constitute the main control and cutoff of the electrical service supply.

3.4 short-circuit current rating (SCCR) of a surge-protective device: The level at which a surge-protective device (SPD) is suitable for use on an ac power circuit that is capable of delivering not more than the declared root-mean-square symmetrical current at a declared voltage during a short-circuit condition.

4. Beginning the surge-protective device selection

Protection of ac power circuits and connected equipment from surges is best achieved through the application of SPDs that are properly installed and rated for the particular application. An understanding of the origin of surges, exposure to the surge environment, location categories, configuration of a PDS, and characteristics of the end-use equipment are essential factors in the successful application of SPDs.

If the installation of SPDs is desirable for a specific PDS, then it is recommended that the application be considered during the initial design phase of the construction or when the PDS is to be renovated or updated.

In many cases, however, the installation of SPDs occurs well after the commissioning of a PDS or just after a damaging surge event has occurred.

Regardless of when SPDs are selected or installed, exercising due diligence in the selection and application of the SPDs relative to specific PDS will enable the optimum surge protection for both the system and the connected equipment.

5. Surge origins

Surges that occur in low-voltage ac power systems, and impinge on a PDS from outside a facility, originate primarily from two sources. These sources are lightning and switching.

- a) *Lightning surges.* Lightning surges are the result of a direct flash to the power system, to the structure of interest and nearby structures, or to the soil. Distant lightning flashes can also induce voltage surges in the circuits of an installation.
- b) *Switching surges.* Switching surges are the result of intentional actions on the power system, such as load or capacitor switching. They can also be the result of unintentional events, such as power system faults and the subsequent corrective actions.

5.1 Lightning

Lightning is a natural and unavoidable event that affects low-voltage systems (power systems as well as signal and communication systems) through several mechanisms. The obvious effect is a direct flash to the power system or to the building of interest, but other coupling mechanisms into overhead or buried power circuits can also produce overvoltages and associated surge currents. These lightning surges can be described under two distinct scenarios:

- a) *Scenario I.* In the event of a lightning flash not directly involving the structure, two different coupling mechanisms occur:
 - 1) Surges coupled into the power system, either directly or indirectly, and impinging at the service entrance of the building of interest.

- 2) Electric and magnetic fields penetrating the structure and coupling inductively in the building wiring.
- b) *Scenario II.* In the less common event of a direct flash to the structure (or a flash to earth very close to the structure), several coupling mechanisms exist:
 - 1) Surges coupled into the ac power circuits by direct coupling.
 - 2) Surges coupled into the ac power circuits by inductive coupling.
 - 3) Surges associated with local earth potential rise causing operation of a service-entrance SPD.

5.2 Switching

Switching transients result from electrical loads turning ON and OFF and the mechanical operation (opening and closing) of various power system electrical equipment (capacitors, breakers, reclosers, etc.) located throughout a PDS. These operations can occur as a result of normal and abnormal operations or conditions.

5.2.1 Normal operations

Normal operations are those such as switching electric loads ON and OFF, periodic transients caused by power converter switching devices, multiple reignitions or restrikes of power switches when they are opening or closing, and the energization of power factor correction capacitors.

The effects of normal operations typically result in transients that do not have sufficient amplitude or duration to damage power system wiring or load equipment, although occasional equipment upset may occur.

5.2.2 Abnormal operations

Abnormal operations include the opening and reclosing of circuit protective devices during fault conditions and major power system switching. Another abnormal operation would include capacitor bank switches inadvertently restriking. Abnormal operations can result in transient overvoltages of sufficient magnitude to cause equipment malfunctions and may cause SPD operation.

6. Effects of surges

The effects of a surge on power distribution systems or end-use equipment can range from no observable effect to obvious and severe damage.

6.1 No observed change

The absence of visible changes could seem to demonstrate that the equipment was immune to the surge level in question, and in some cases, it may be. However, the equipment can continue normal performance within specified limits and thus appear to meet the criterion of “No Loss of Function or Performance.” Yet significant consequences are possible such as degradation of performance still within specification but foreboding larger degradation, latent failure of a component, or an unforeseen consequence elsewhere in the equipment environment.

6.2 Upset

This consequence can be a self-recoverable upset by the planned design of the controls, components, or software and therefore not immediately apparent or permanent. Such upsets often require operator intervention or the programming of automatic actions that occur after some time delay. These upsets are identified in the following three categories:

- Minor
- Major
- Critical

6.2.1 Minor

Acceptable temporary loss of function but no faulty operation of equipment or processes.

6.2.2 Major

Temporary faulty operation or performance that might be self-recoverable through automatic self-test and restart programming.

6.3 Damage

This consequence includes the subtle as well as the obvious. Subtle damage (for example, insulation breakdown) can occur without being detected unless special assessment of the equipment condition is performed. Obvious damage would be burned circuit board traces or evidence of a flashover at a panel or at an equipment location.

6.4 Consequential damage

This consequence includes the possibility that equipment subjected to a surge could cause damage to its surroundings well beyond the importance of the damage or upset itself. Ignition of a fire or an explosion could occur. In these cases, facilities operations and equipment functions are dramatically disrupted.

Damage can result from unseen hardware upset, during which data become corrupted. The corruption can subtly degrade other elements in the database, automated controllers, or programmable logic controllers while the user is left unaware of the situation.

7. Number and magnitude of surge events

The magnitude of a surge and its effect on equipment varies, depending on the design and construction of the PDS and its specific geographical location. The prediction of the level or magnitude of a surge event at any point within a specific PDS is always difficult (and frequently impossible), based on current technology and the lack of understanding of all variables associated with surge events. Many variables can contribute to the rate and magnitude of surge events. Examples of some of these variables are the level and distribution of surges, changes in the environment, changes in the loads connected to the PDS, and changes in the medium voltage distribution system of a utility.

7.1 General

Low-level (low-magnitude) surges are more prevalent than high-magnitude surges. A surge voltage level observed in a PDS can be a function of one or more components of the original surge, the remnant energy available after a sparkover or flashover event, or the operation of an overcurrent protective device associated with the PDS.

Where an individual evaluation is not possible, such as in the case of a direct lightning strike, it might be assumed that 50% of the total lightning current enters the ground termination of the lightning protection system of the structure considered. The other 50% of the current is then assumed to be distributed among the services entering the facility. This distribution of lightning current is also noted in IEC 61643-12 [B19]. The effects of increased numbers of SPDs installed within the PDS will also directly effect the distribution of a surge. The repetitive operation of numerous SPDs within a PDS can significantly affect the voltage stability of the system.

7.2 Environmental factors

Variations in surge magnitudes and surge events can be related to changes in the environment. Environmental changes can alter the conductive path of a surge current or can facilitate a premature flashover or sparkover event. Changes in the environment are a function of one or more combinations of events.

Factors that can contribute to flashover or sparkover events are as follows:

- a) Indoor versus outdoor equipment ratings.
- b) Air temperatures exceeding the range of equipment.
- c) Air temperatures caused by a temporary external heat source near the SPD.
- d) Exposure of energized parts to damaging fumes or vapors.
- e) Excessive dirt or other contaminants within the electrical equipment and around the SPD.
- f) Exposure of energized equipment to salt spray or other current conductive deposits.
- g) Exposure of energized equipment to moisture, steam, or water.
- h) Exposure of energized equipment to explosive atmospheres.
- i) Exposure of energized equipment to abnormal vibrations or shocks.
- j) Insufficient clearances between energized parts and nearby conductive objects.
- k) Increase of voltage on conductive parts that are greater than the rating of the component, equipment, or part.

7.3 Changes in the power distribution system

The desired function of an SPD can be affected by changes in a PDS. Changes in the system can be a function of one or more combinations of events as a change in the nominal frequency of a PDS or operating conditions whereby the ratings of an SPD might be temporarily exceeded. The conditions listed below can cause conditions that exceed the listing voltage ratings of a specific SPD.

Abnormal changes that occur in PDS as follows:

- a) Loss of neutral ground on normally grounded circuit.
- b) Abnormal speed regulation on a station service generator.
- c) Resonance conditions during faults.

- d) System voltage instability.
- e) Persistent single line-to-ground fault on an ungrounded three-phase, three-wire PDS.

7.4 Rate of occurrence (versus) current level

Data collected from many sources show a decreasing number of occurrences for high crest surges with a slope that is independent from the site of data collection. The absolute number of occurrences varies from site to site. Data indicate that low-amplitude surges occur more frequently than high-amplitude surges. The events of higher amplitudes can be extrapolated or estimated from the general slope of occurrences.

IEEE Std C62.41.1-2002⁴ provides a large database with regard to the rate of occurrence of surges. A large number of studies are cited, and the reader is referred to that document for further information regarding the rate of occurrence.

The data collected indicate that the peak current levels of most lightning strikes are in the range of 10 kA to 40 kA. The median value of the peak current reported was in the range of 15 kA to 20 kA. Only 6% of the currents were above 60 kA, and less than 2% of the currents were above 100 kA (Key and Martzloff [B35], Lewis and Foust [B38], and Transient Voltage Suppression [B55]). The rate and peak current levels of surge events will also vary depending on the geographical location. In addition, the research data indicate the value of the initial stroke. Lightning is a usually a multiple stroke event, and the subsequent strokes often have less energy than the initial stroke.

7.4.1 Lightning characteristics and current level

Lightning is an environmental condition caused during the attempted equalization of charges between planetary locations of different polarity. During a thunderstorm, the separation of charges can occur within a cloud. As the separation of charges continues over a period of time, a dielectric breakdown will occur. When dielectric breakdown occurs between two points, the result is the neutralization of charges through a flow of current, which is defined as lightning. There are three types of lightning flashes: negative, positive, and bipolar. It is estimated that 90% of the lightning discharges are negative and that less than 10% are positive (Uman [B57]). Bipolar lightning discharges are rare, and they make up the remaining percentage of the lightning discharges from cloud to earth.

7.4.1.1 Negative lightning flashes

Research examining the peak current associated with lightning flashes occurred as far back as 1944 (McCann [B41]). Similar to the differences in the rate of rise of the stroke current between initial strokes and subsequent strokes, there are differences in the peak current between initial strokes and subsequent strokes. For negative flashes, 50% of the initial return strokes exceeds 30 kA, and only 5% of the initial peak return stroke currents measured exceeds 80 kA (Uman [B57], Thottappillili [B53], IEEE PES T&D Committee [B21], and Tominaga et al. [B54]).

In most cases, subsequent strokes have a peak current that is less than the measured value of the initial return stroke current (Uman [B57], Thottappillili [B53], and IEEE PES T&D Committee [B21]). Fifty percent of subsequent return strokes are between 12 kA and 15 kA (Uman [B57] and Thottappillili [B53]). Disagreement exists in the literature about the peak current of subsequent return strokes. Thottappillili indicates that the maximum current of a subsequent return strokes approach 75 kA (Thottappillili [B53]). In other studies, the maximum current of subsequent return strokes is determined to be 30 kA (Uman [B57] and IEEE PES T&D Committee [B21]).

⁴ Information on references can be found in Clause 2.