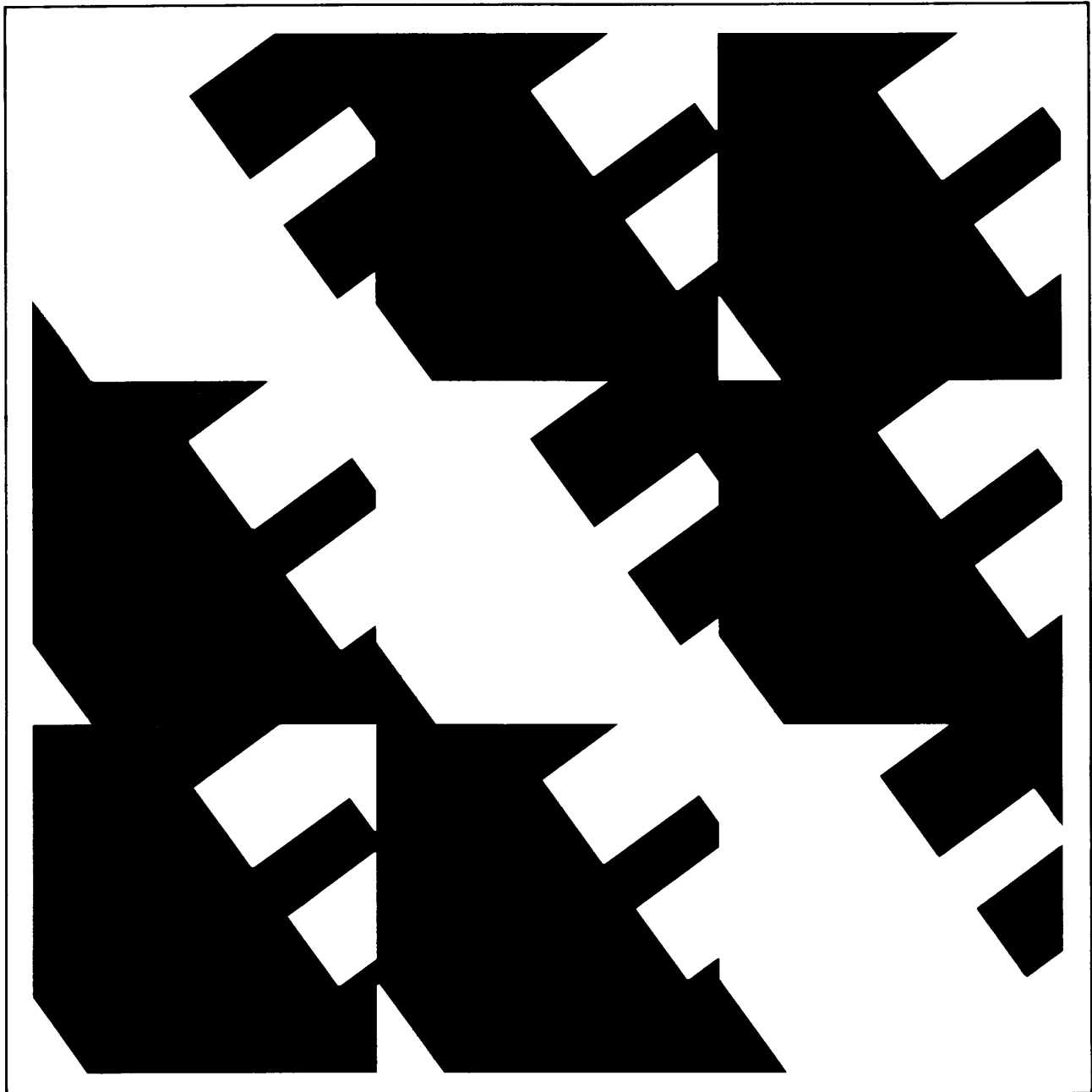


IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits

ANSI/IEEE C62.45-1987



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Co-secretariat

**Institute of Electrical and Electronics Engineers, Inc
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Foreword

(This Foreword is not a part of ANSI/IEEE C62.45-1987, IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits.)

This document, intended to serve as a guide to appropriate surge test methods, covers a range of diverse tests, each aimed at a particular aspect of design, quality control, acceptance, troubleshooting, and so forth. The suggestions provided herein should not be construed as mandatory nor should they be blindly applied to all types of equipment. The specification of performance or acceptance tests for any particular type of equipment properly remains the prerogative of manufacturers, users, and standard-writing groups involved in the particular equipment.

To provide further assistance with applications, the present document offers guidance on surge testing methods and includes specific surge test plan recommendations. The intent is to provide background that can help determine whether specific equipment or a circuit has adequate withstand capability (that is, maintains undisturbed operation, or merely is not damaged, depending on the criteria selected by the user) in the surge environment defined in ANSI/IEEE C62.41-1980, IEC Pub 664-1980, or any other applicable document specifying the power-line surge environment. While lightning is a major source of transient disturbances, it should be understood that there are many additional kinds of power disturbances, such as surges with extremely rapid rates of rise that are generated by other loads that may be operating inside a building. Fast rising surges may require special considerations in addition to those discussed in this guide. Manufacturers of sensitive equipment should consider additional tests to ensure reliable performance of their instruments in actual operating conditions.

Because of the complexity of the subject, the variations in equipment tested, and the difficulty in interpreting test results, the necessity for the reader to review and understand the entirety of this document prior to commencing equipment tests cannot be over-emphasized.

The Summary given after this Foreword is intended only for a rapid overview and therefore is not included as part of the guide.

Suggestions for improvement of this guide will be welcome. They should be sent to the Secretary, IEEE Standards Board, Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York, New York 10017.

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Summary

(This Summary is not a part of ANSI/IEEE C62.45-1987, IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits.)

This document provides guidance on surge testing ac power interfaces of equipment connected to low-voltage circuits that are subject to transient overvoltages. Signal and data lines are not addressed in this document, nor are any specifications stated on the withstand levels that might be assigned to specific equipments. An important objective of the document is to call attention to the safety aspects of surge testing.

The power-line surge environment is described in standards and other documents as either a statistical statement of measured occurrences or as a goal to be achieved through a coordinated control of the overvoltages, involving interface devices. ANSI/IEEE C62.41-1980, Guide for Surge Voltages in Low-Voltage AC Power Circuits, describes the power-line surge environment in which all equipment, with or without protection, connected to an uncontrolled ac power line must operate; IEC Pub 664-1980, Insulation Co-ordination within Low-Voltage Systems, Including Clearances and Creepage Distances for Equipment, sets forth a group of installation categories where the surge voltages are assumed to be controlled in a descending staircase from the service entrance to the most remote equipment in a building. The environment description of ANSI/IEEE C62.41-1980 provides guidance on the waveshapes of voltage as well as current surges that can be selected as representative of the environment. The recommendations of IEC Pub 664-1980 are directed toward the coordination of insulation.

The phrase *equipment connected to ac power lines* covers a wide range of devices and circuits, for which the need for surge testing can also vary over a wide range. Electromechanical devices tested only for insulation can often be dealt with by a simple dielectric withstand test. Electronic circuits and systems, however, may often require additional test complexity. It is important to recognize that specific test levels must be defined by a consensus process involving both designer and user and not by the present guide, which can only define procedures.

Planning a surge test program is a complex task involving many considerations, from the nature of the equipment and purpose of the test to procedures and instrumentation.

Major issues to be recognized include:

- (1) Outcome of the test and failure criteria: upset or damage?
- (2) Type of tests: Design tests involve pushing stresses to the limits while production tests are more likely to be pass/fail types. Diagnostic tests involve reproduction of field failures in the laboratory.
 - (a) Unpowered testing (simple dielectric withstand) versus powered testing, which is unavoidable when testing for upset or for failure effects.
 - (b) Test schedule, including a range of stresses rather than just maximum ratings in order to avoid blind spots, and the phase angle of the surge with respect to the power line sine wave. Limiting stresses is required when repetitive tests are performed in order to obtain meaningful results.
- (3) Appropriate selection of a voltage wave or of a current wave, or both, depending on the nature of the test piece and on the expected pass/fail criteria.
- (4) Implementation of the test:
 - (a) Selection of the appropriate test generator
 - (b) Coupling of the surge to the test circuit
 - (c) Decoupling of the surge from the ac power supply
 - (d) Points of application (coupling modes) of the surges
 - (e) Monitoring and measurements
 - (f) Safety precautions in the facilities

Since many of these considerations involve detailed discussions, the document has been organized in sections dealing with the major points of these considerations. References are made to detailed notes, contained in the appendix, to provide a more comprehensive treatment of the issues.

Contents

SECTION	PAGE
1. Scope	9
2. Definitions	9
2.1 Technical Definitions.....	11
2.2 Special Word Usage	11
3. References and Document in Preparation	11
3.1 References	11
3.2 Document in Preparation	13
4. Planning of Surge Testing: Basic Objectives.....	13
4.1 Surge Environment	13
4.2 Types of Tests	13
4.3 Results and Consequences of the Test	14
4.4 Unpowered Testing versus Powered Testing	14
4.5 Withstand Levels	15
4.6 Waveshape, Voltage, Current.....	15
4.7 Safety.....	15
5. Implementation of Surge Testing: Test Equipment	15
5.1 General.....	15
5.2 Surge Generators.....	15
5.3 Point of Test Surge Application	16
5.4 Coupling the Surge to the Equipment Under Test	16
5.5 Monitoring the Equipment Under Test.....	17
6. Performance of Surge Testing: Test Procedures.....	17
6.1 General.....	17
6.2 Limiting Stresses	19
6.3 Nature of the Equipment Under Test	19
6.4 Safety.....	19
7. Applying the Test Surge: Coupling and Decoupling Circuits	20
7.1 General.....	20
7.2 Requirements for Surge Coupling.....	20
7.3 Impedance Considerations	21
7.4 Requirements for Surge Decoupling	21
7.5 Surge Coupling Modes	21
8. Grounding	22
8.1 Grounding for Safety.....	22
8.2 Grounding Practices in Equipment Under Test	23
 FIGURES	
Fig 1 Guiding Considerations for Surge Testing.....	10
Fig 2 Surge Testing Equipment Considerations	16
Fig 3 Monitoring within Surged Equipment with Voltage Probes in Differential Connection	18
Fig 4 Monitoring within Surged Equipment with Current Transformers	18
Fig 5 Elementary Diagram of Series Coupling.....	20
Fig 6 Elementary Diagram of Shunt Coupling	20
Fig 7 EUT Being Surge Tested, Showing Required Interfaces, Filters, or Reterminations	22

TABLES	PAGE
Table 1 Selected Coupling Modes for Single-Phase (One Line and Neutral with Grounding Conductor)	23
Table 2 Selected Coupling Modes for Single-Phase (Two Lines and Neutral with Grounding Conductor)	24
Table 3 Selected Coupling Modes for Three-Phase (Three Phase Wires and Neutral with Grounding Conductor)	25
APPENDIX	
Notes on Definitions and Special Considerations	27
APPENDIX FIGURES	
Fig A1 Connection of the EUT with the Environment (a) Single Connection to the AC Power System (b) Connections to Both AC Power System and Signal Lines	27
Fig A2 Example of Blind Spot Condition (a) With Single Protective Device (b) With Multiple Protective Devices	29
Fig A3 Common Mode and Normal Mode in Communications Circuits and in Power Circuits	30
Fig A4 Difference of Potential Between Neutral and Grounding Conductor Resulting at Line End from Surge Applied at Line Beginning	30
Fig A5 Current Surge Test Example: Surging Ground or Common	31
Fig A6 Example of Protector with Multiple Devices	32
Fig A7 Simplified Test-Surge Generator Output Wave-Shaping Network	34
Fig A8 Rate of Surge Occurrences versus Voltage Level at Unprotected Locations for Different Exposures	35
Fig A9 Back Filter Added to Series Coupler	36
Fig A10 Back Filter Added to Shunt Coupler	36
Fig A11 Back Filter and Coupler with Input Isolation Transformer for GFCI Applications	36
Fig A12 Effect of Poor or Missing Connection to Grounding Conductor	37
Fig A13 Floating Reference (Floating Ground)	37
Fig A14 Single-Point Grounding (a) Parallel Single-Point Ground (b) Series Single-Point Ground	37
Fig A15 Multiple-Point Grounding	38
Fig A16 Location Categories Defined in ANSI/IEEE C62.41-1980	38
Fig A17 Similarities and Differences Between the Location Categories Concept of ANSI/IEEE C62.41-1980 and the Installation Categories Concept of IEC Pub 664-1980, Applied to a Typical Example	40
Fig A18 Phase Angle Effects	44
Fig A19 Series Coupling of Surge Generator	46
Fig A20 Shunt Coupling of Surge Generator	46
Fig A21 Excitation of Nonlinear Protectors	48
APPENDIX TABLES	
Table A1 Description of Surge Environment in ANSI/IEEE C62.41-1980	28
Table A2 OCV/SCI (Peak Open-Circuit Voltage)(Peak Short-Circuit Current)	33
Table A3 Suggested Wait Times as a Function of Total Number of Surges for Surges Applied as per Categories and Waves of ANSI/IEEE C62.41-1980	45
INDEX	50

An American National Standard

IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits

1. Scope

The purpose of this document is to provide guidance on applying surge testing to **ac power interfaces**¹ of equipment connected to **low-voltage** (up to 1000 V rms) ac power circuits that are subject to transient overvoltages. These transients may be defined by any applicable document, such as ANSI/IEEE C62.41-1980 [10],² IEC Pub 664-1980 [17]. Other documents (see [19], [20], [26], and [33]) may also be used as appropriate. While frequent reference is made to documents [10] and [17], the application of this guide is not limited to these two documents; the information they provide is primarily for line-to-neutral surges, while the guidance provided here applies to all configurations and all magnitudes and wave-shapes of surges. Signal and data lines are not included in the scope of this guide, but should not be overlooked in the complete evaluation of specific equipment.

In ANSI/IEEE C62.41-1980 [10], a description is given of the surge environment that can be expected to prevail in low-voltage ac power circuits where no special precautions have been taken to limit transient overvoltages; in IEC Pub 664-1980 [17], a recommendation made to establish a **controlled overvoltage situation** is justified if there is compliance with appropriate interface requirements, so that maximum overvoltage levels in a descending staircase can be assigned according to a specified **installation category** where such a category generally reflects the con-

figuration of the power system within a building. The environment description of ANSI/IEEE C62.41-1980 [10] provides guidance on the wave-shapes of current as well as voltage surges that can be selected as representative of the environment for different **location categories**. The recommendations of IEC Pub 664-1980 [17], provide the basis for **insulation coordination**. Other standards or specifications for surge withstand capability might also require surge testing to be performed, for which the guidance of the present document may also be applicable. In any case, equipment connected to the power system has to be capable of satisfactory operation or survival, or both, under these surge voltages, with or without additional protection. Surge testing is therefore required to demonstrate this capability.

The flow chart of Fig 1 shows the basic considerations involved in planning and performing surge tests in accordance with the scope of this guide. Note that the assignment of surge **withstand levels** to various equipment is not included in the scope of this guide.

2. Definitions

Systematic attempts have been made in this guide to use the definitions provided by ANSI/IEEE Std 100-1977 [3] and various IEC documents (see [12], [13], [14], and [15]) for the terms used in the text. However, complementary or more specific definitions are also necessary. These definitions are given in this section and are supported by appropriate discussion, as needed, in the Appendix of this guide. When a term covered by such a discussion appears for the first time in each section, it is printed in bold italics and can be found in the alphabetical listing of the Appendix.

¹ See the Appendix for a discussion of terms indicated in bold italic.

² The numbers in brackets correspond to those of the references listed in Section 3.

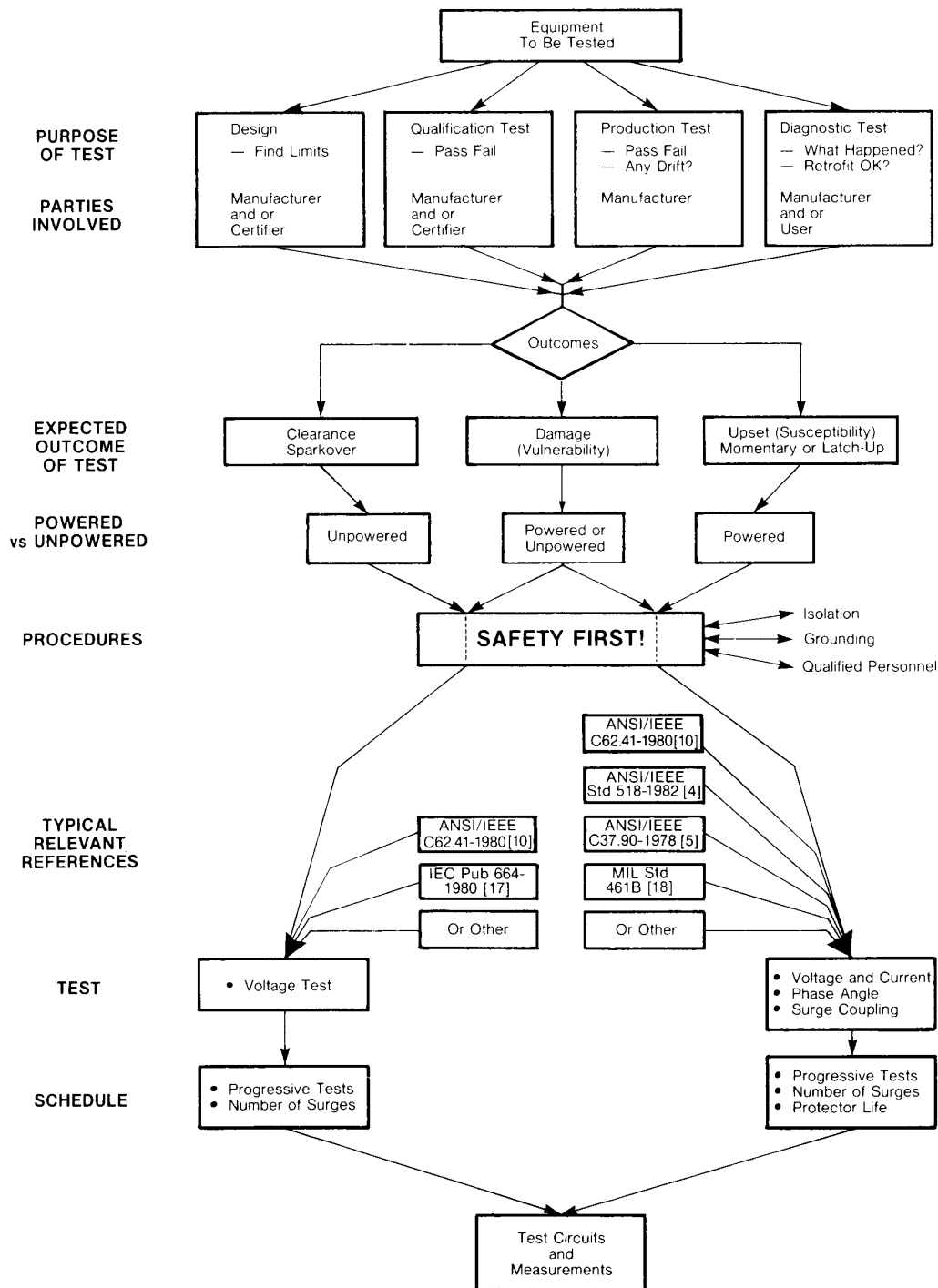


Fig 1
Guiding Considerations for Surge Testing

2.1 Technical Definitions

back filter. A filter inserted in the power line feeding an equipment to be surge tested; this filter has a dual purpose:

- (1) To prevent the applied surge from being fed back to the power source where it may cause damage;
- (2) To eliminate loading effects of the power source on the surge generator.

blind spot. A limited range within the total domain of application of a device, generally at values inferior to the maximum rating. Operation of the equipment or the protective device itself might fail in that limited range despite the device's demonstration of satisfactory performance at maximum ratings.

coupler. A device, or combination of devices, used to feed a surge from a generator to powered equipment while limiting the flow of current from the power source into the generator.

surge let-through. That part of the surge that passes by a surge protective device with little or no alteration.

surge remnant. That part of an applied surge that remains downstream of one or several protective devices.

susceptibility. The inability of a device, equipment, or system to resist an electromagnetic disturbance.

NOTE: Susceptibility is the lack of immunity.

vulnerability. The characteristic of a device for being damaged by an external influence, such as a surge.

2.2 Special Word Usage. The words will, can, may, and might are used in this guide with the following meanings:

will. Denotes the certainty of an event to occur.

can. Denotes that it is possible for an event to occur under the natural laws governing the situation.

may. Denotes that an event is possible, or that it is possible to exercise a choice at the discretion of the person conducting the test.

might. Denotes that an event is likely to occur, or that a choice has been made previously by a third party beyond the control of the person conducting the test, with actual occurrence uncertain.

3. References and Document in Preparation

The following publications shall be used in conjunction with this standard.

3.1 References

- [1] ANSI C2-1987, American National Standard National Electrical Safety Code.
- [2] ANSI C62.2-1981, American National Standard Guide for the Application of Valve Type Surge Arresters for Alternating-Current Systems.¹
- [3] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.²
- [4] ANSI/IEEE Std 518-1982, IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources.
- [5] ANSI/IEEE C37.90-1978, IEEE Standard Relays and Relay Systems Associated with Electric Power Apparatus.
- [6] ANSI/IEEE C62.1-1984, IEEE Standard for Surge Arresters for AC Power Circuits.
- [7] ANSI/IEEE C62.31-1984, IEEE Standard Test Specifications for Gas-Tube Surge-Protective Devices.
- [8] ANSI/IEEE C62.32-1981, IEEE Standard Test Specifications for Low-Voltage Air Gap Surge-Protective Devices (Excluding Valve and Expulsion Type Devices).
- [9] ANSI/IEEE C62.33-1982, IEEE Standard Test Specifications for Varistor Surge-Protective Devices.
- [10] ANSI/IEEE C62.41-1980, IEEE Guide for Surge Voltages in Low-Voltage AC Power Circuits.
- [11] ANSI/NFPA 70-1987, National Electrical Code.³

¹ ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

² ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Institute of Electrical and Electronics Engineers, Service Center, Piscataway, NJ 08854.

³ ANSI/NFPA publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from Publication Sales, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

- [12] IEC Multilingual Dictionary of Electricity. Institute of Electrical and Electronic Engineers, 1983.⁴
- [13] IEC Pub 50-111-1982, Physics and Chemistry.
- [14] IEC Pub 50-131-1978, Electric and Magnetic Circuits.
- [15] IEC Pub 99, Lightning Arresters.
- [16] IEC Pub 158-2, Semiconductor Contactors.
- [17] IEC Pub 664-1980, Insulation Co-ordination within Low-Voltage Systems, Including Clearances and Creepage Distances for Equipment (including IEC Pub 664A-1981, supplement).
- [18] MIL Std 461B, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference.⁵
- [19] NEMA ICS 2-1983, Devices, Controllers, and Assemblies for Industrial Control.⁶
- [20] UL 943-1985, Safety Standard for Ground Fault Circuit Interrupters.⁷
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- [35] RHOADES, W. T. Development of Power Main Transient Protection for Commercial Equipment. *Proceedings of the 22nd IEEE EMC Symposium*, Oct 7-9, 1980, pp 235-244.

⁴ IEC publications are available in the US from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

⁵ MIL publications are available from US Navy Publications and Forms, 5801 Tabor Avenue, Philadelphia, PA 19120.

⁶ NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street, NW, Washington, DC 20037.

⁷ UL publications are available from Publication Stock, Underwriters Laboratories, Inc, 333 Pfingsten Rd, Northbrook, IL 60062.

- [36] RHOADES, W. T. The Ratiocination of a Commercial Power Main Conducted Susceptibility Standard. *Proceedings of the 23rd IEEE EMC Symposium*, 1981, pp 269-276.
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- [42] VANCE, E. F. Electromagnetic Interference Control. *IEEE Transactions on Electromagnetic Compatibility*, vol EMC-22, Nov 1980, pp 319-328.
- [43] VANCE, E. F., NANEVICZ, J. E., and GRAF, W. *Unification of Electromagnetic Specifications and Standards*. Defense Nuclear Agency Report DNA 5433F-1, Washington, DC, 1980, pp 49-50.

3.2 Document in Preparation⁸

4. Planning of Surge Testing: Basic Objectives

This section outlines the basic objectives to be considered for planning surge testing, as indicated graphically in Fig 1. More detailed discussions of these considerations are provided in the Appendix.

⁸ When the following document is completed, approved, and published, it will become a part of the references of this standard: PC62.35, IEEE Standard Test Specifications for Avalanche Junction Semiconductor Surge-Protective Devices.

4.1 Surge Environment. Surge testing is generally performed to determine the surge withstand capability of specific equipment (*EUT*, or *equipment under test*) that will be exposed to known or unknown surge environments. Therefore, the first decision or assumption to be made in planning a surge test concerns the nature of the surge environment. ANSI/IEEE C62.41-1980 [10], IEC Pub 664-1980 [17], or some other applicable document will be used to define the environment.

While the test procedures discussed in this guide should be relevant to most surge tests, the major concern here is with switching- and lightning-induced surges. Surges associated with nuclear electromagnetic pulse (NEMP) and electrostatic discharges (ESD) involve rise times in the order of a few nanoseconds, requiring instrumentation of different characteristics from those discussed here. Furthermore, high-frequency *noise*, generally at amplitudes less than twice the normal voltage, is the subject of other documents (see [4], [16], [18], and [19]).

4.2 Types of Tests. Figure 1 shows a branching point involving the purpose of the surge test. Four types of tests are identified, with their purpose and interested parties, as follows.

Design tests are performed by an equipment manufacturer for establishing or demonstrating to others design margins and for optimizing the design. These tests may involve pushing the stresses to the limits until a failure is observed.

Qualification tests are performed by the manufacturer, purchaser, or independent test laboratory for demonstrating compliance with specifications. These tests generally are limited to a pass-fail criterion, but are more comprehensive than tests carried out on a routine basis on production products.

Production tests are performed by an equipment manufacturer for verifying conformity and consistency of the production process. These tests generally involve some statistical evaluation.

Diagnostic tests are performed by the manufacturer or user for investigating difficulties encountered in service. These tests generally involve attempts at laboratory reproduction of the failure modes observed in the field, followed by applying the same test on equipment that has been re-designed or provided with retrofit protection.

Prior to conducting tests on an EUT, acceptance criteria should be defined in accordance with the considerations of Fig 1, such as purpose of the test and expected outcome.

4.3 Results and Consequences of the Test.

While surge protective devices are generally provided for damage avoidance, they can also serve to prevent upset in the operation of an EUT. Therefore, a treatise on surge testing must include subject matter dealing with the evaluation of the test results. Any given surge test will produce one of four results:

- (1) upset (**susceptibility**)
- (2) damage (**vulnerability**)
- (3) no observed change, or
- (4) an **unforeseen consequence** elsewhere in the equipment environment.

The last result actually involves consideration of circumstances external to the EUT proper that might be overlooked or considered irrelevant to the scope of surge testing in the laboratory. Setting aside any consideration of unforeseen consequences on that basis would be a severe error. The note **unforeseen consequences** in the Appendix gives some scenarios that illustrate this concern.

Depending upon the nature and function of the EUT, six different outcomes of a surge test should be evaluated wherever direct, local results are noted:

- (1) No apparent response in the EUT — neither upset nor damage
- (2) Temporary upset of the EUT operation
- (3) Upset with trip-out or latch-up of the EUT circuits
- (4) Flashover of clearances without apparent permanent damage
 - (a) with no **power-follow** or with a self-clearing power-follow, which might seem a benign occurrence
 - (b) with power-follow resulting in operation of an overcurrent protective device (fuse or breaker), an occurrence similar to outcome (3)
- (5) **Insulation degradation** or breakdown due to **partial discharges** across the surfaces or in solid insulation, or both
- (6) Insulation breakdown or permanent component damage requiring replacement or repair.

The first outcome (no upset or damage) may represent a success from the point of view of acceptance, but yields incomplete information since the actual design margin is not determined until further tests, at higher stress, are performed.

The next two outcomes (upsets) are mainly concerned with control or data circuits, and are related to the susceptibility of the equipment. The electrical noise required to produce them can be quite low; in fact, low-level **noise** can be sufficient to upset sensitive circuits (see [4], [16], [18], and [19]). The emphasis in this guide,

however, is on surges, generally implying voltage levels of twice or more the normal voltage of the system.

The fourth outcome (flashover) might involve both control and power circuits, and is expected to occur at surge levels significantly above the normal circuit voltages. As long as no permanent damage or **insulation tracking** occurs as a result of the sparkover and eventual power-follow, this outcome is still in the category of susceptibility. Some EUTs might be insensitive to or unaffected by the flashover, while others would definitely be considered as having been upset by the flashover.

The fifth outcome (insulation degradation or breakdown) might occur across the surfaces of insulation or within solid insulation as a result of partial discharges, especially if multiple tests are applied.

The sixth outcome (permanent damage) might occur in either control or power circuits, as a result of sparkover with or without power-follow producing a permanent degradation, or as a result of semiconductor failure or excessive energy deposition leading to component or etch burnout. The fifth and sixth outcomes describe the vulnerability of the equipment.

Some of the outcomes can occur in combination so that the distinction made here might not be so clearcut in reality, but which is nevertheless useful as a starting point. It should be remembered that any surge test is potentially destructive to the EUT, so that appropriate precautions should be taken.

4.4 Unpowered Testing versus Powered Testing. Test surges may be applied to the EUT in two ways:

- (1) With normal operating power disconnected from the EUT (**unpowered testing**), and
- (2) With normal operating power applied to the EUT (**powered testing**).

The intended purpose of the test will determine whether one approach is sufficient or whether both are advisable.

Unpowered testing is sufficient in situations for which a test outcome does not depend on the evaluation of EUT performance during the surge, and for which power-follow is not considered to be a significant factor in regard to vulnerability. For instance, clearance flashover of an electro-mechanical device may be the selected failure criterion; in that case, there should usually be no need to power the EUT. Unpowered testing is usually necessary as a preliminary to powered testing, for design and diagnostic testing.

Powered testing is necessary under two circumstances:

(1) When a test outcome depends on the evaluation of EUT functional performance during the surge. Thus, a test for susceptibility implies normal equipment functioning prior to the surge; therefore, the EUT can only be checked in the powered mode.

(2) When determination of EUT vulnerability involves the likelihood or consequence of a power-failure (which might also depend in part on the **phase angle** at which the surge is applied with respect to the line voltage wave).

4.5 Withstand Levels. Surge testing is ordinarily carried out at different stages in a product life cycle, such as design, quality control, and protection retrofit. The extent and severity of the test will depend on the particular stage involved. A design test is likely to involve testing to failure while a production test must carefully avoid creating incipient failures. The voltage surge environment (see ANSI/IEEE C62.41-1980 [10]) is described only in statistical terms without imposing a fixed withstand level. On the other hand, IEC Pub 664-1980 [17] sets forth maximum levels for the various **installation categories** and system voltages in a **controlled overvoltage situation**. Thus, if equipment is to be classified as suitable for various installation or location categories, it will be desirable to establish durability or **withstand levels** for comparison purposes.

The withstand levels should be expressed in terms of voltage for equipment exhibiting high impedance to a surge; for those EUT that contain a surge protective device, the withstand level should be expressed in terms of current in order to give consideration to energy deposition, as discussed in 6.2.

4.6 Waveshape, Voltage, Current. The nature of the EUT will affect its response to an applied test surge. A high-impedance EUT, such as a winding, a clearance, or a semiconductor in the blocking mode, will be stressed by a voltage surge. The energy associated with the surge is not significant here. A low-impedance EUT, such as a circuit containing filter capacitors or surge-diverting protective devices, will be stressed by a current surge. The energy deposited in the components becomes a significant factor in this type of surge occurrence.

Current test surges applied between different points of the grounding connections can also provide essential information on the EUT capability.

While this aspect of surge testing is not directly within the scope of low-voltage ac power circuits, it should be recognized. Some discussion is provided in the Appendix under **current surging**.

Therefore the **waveshape** for both voltage and current tests should be included in specifying a test procedure. ANSI/IEEE C62.41-1980 [10] attempts to make such a distinction between current and voltage tests.

The specific selection of withstand levels, for voltage as well as current, depends on the **exposure** to transients as well as on the consequences of a failure to withstand the transient. This guide provides some perspective in selecting appropriate levels but the final choice must be made by the user of this document. This guide therefore includes a wide range of test alternatives to provide guidance in making such decisions with maximum flexibility. The guidance given here is applicable to all waveforms, including longer or shorter waves if the particulars of the application indicate that these waves are appropriate (see [26], [33], and data base in Section A1 of Appendixes to [10]).

4.7 Safety. Surge testing of electrical or electronic equipment presents potentially hazardous situations for both personnel and equipment. The surge tester generates potentially lethal voltage surges. Furthermore, failure of the EUT might result in a fire or explosion. Only qualified personnel should perform the tests, with safety precautions enforced according to national codes as well as the normal safety directives of the organization conducting the test. More specific aspects of safety are discussed in 6.4.

5. Implementation of Surge Testing: Test Equipment

5.1 General. Implementation of surge testing can proceed after the considerations discussed in Section 4 have been addressed. This section provides guidance on the major aspects of the equipment requirements, for generating and applying the surge as well as for **monitoring** the performance of the **EUT** (Fig 2). Occasional users might encounter difficulty and should obtain guidance from qualified sources. Test equipment that does not meet the requirements of applicable standards might give misleading results (see [30]).

5.2 Surge Generators. The test surge to be applied to the EUT will be produced by a surge generator capable of delivering the specified