IEEE Std C37.41-1994
(Revision of
IEEE Std C37.41-1988)

IEEE Standard Design for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories

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IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories

Sponsor

Switchgear Committee
of the
IEEE Power Engineering Society

Approved September 22, 1994

IEEE Standards Board

Abstract: Required procedures for performing design tests for high-voltage distribution-class and power-class fuses, as well as for fuse disconnecting switches and enclosed single-pole air switches are specified. These design tests, as appropriate to a particular device, include the following test types—dielectric, interrupting, load-break, making-current, radio-influence, short-time current, temperature-rise, time-current, mechanical, and liquid-tightness.
Keywords: distribution enclosed single-pole air switches, fuse accessories, fuse design tests, fuse disconnecting switches, high-voltage fuses

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Introduction

(This introduction is not a part of IEEE Std C37.41-1994, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.)

This standard is a revision of IEEE Std C37.41-1988 in order to bring it up to date and in agreement with present day requirements for high-voltage fuses and switches. Previously approved supplements have been incorporated, and some of the values in tables 4, 6, and 7 have been revised.

This standard was prepared by the IEEE Subcommittee on High-Voltage Fuses with cooperation from the C37 Subcommittee on High-Voltage Fuses and the National Electrical Manufacturers Association (NEMA).

This standard is one of a series of complementary standards covering various types of high-voltage fuses and switches, so arranged that two of the standards apply to all devices while each of the other standards provide additional specifications for a particular device. For each device, IEEE Std C37.40-1993, IEEE Std C37.41-1994, plus the standard covering that device constitute a complete set of standards for each device. In addition, IEEE Std C37.48-1987 is an application, operation, and maintenance guide for all the devices.

The following standards comprise this series:

ANSI C37.42-1989, Specifications for Distribution Cutouts and Fuse Links.

ANSI C37.44-1981 (R1987), Specifications for Distribution Oil Cutouts and Fuse Links.

ANSI C37.45-1981 (R1992), Specifications for Distribution Enclosed Single-Pole Air Switches.

ANSI C37.46-1981 (R1992), Specifications for Power Fuses and Fuse Disconnecting Switches.

ANSI C37.47-1981 (R1992), Specifications for Distribution Fuse Disconnecting Switches, Fuse Supports, and Current-Limiting Fuses.

IEEE Std C37.40-1993, IEEE Standard Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

IEEE Std C37.41-1994, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.48-1987 (Reaff 1992), IEEE Guide for Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

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IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories

1. Scope and references

1.1 Scope

This standard specifies design test requirements for high-voltage fuses (above 1000 V but also including fuses rated 601 V to 1000 V that were designed prior to 1985), distribution enclosed single-pole air switches, fuse disconnecting switches, and associated accessories, all of which are intended for use on ac distribution systems. These test requirements apply to the following equipment:

a) Enclosed, open, and open-link types of distribution cutouts and fuses
b) Distribution current-limiting fuses
c) Distribution oil cutouts
d) Distribution enclosed single-pole air switches
e) Power fuses, including current-limiting types
f) Fuses in enclosures
g) Outdoor and indoor fuse disconnecting switches
h) Fuse supports, fuse mountings, fuse hooks, and fuse links—all of the type used exclusively with products listed in a) through g)
i) Removable switch blades for products listed in a) through c)

1.2 References

This standard shall be used in conjunction with the following publications. When these standards are superseded by a revision, the revision shall apply.

ANSI C37.42-1989, Specifications for Distribution Cutouts and Fuse Links.[1]

ANSI C37.44-1981 (R1987), Specifications for Distribution Oil Cutouts and Fuse Links.

ANSI C37.45-1981 (R1992), Specifications for Distribution Enclosed Single-Pole Air Switches.

ANSI C37.46-1981 (R1992), Specifications for Power Fuses and Fuse Disconnecting Switches.

[1]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

ANSI C37.47-1981 (R1992), Specifications for Distribution Fuse Disconnecting Switches, Fuse Supports, and Current-Limiting Fuses.

ANSI C63.2-1987, Specifications for Electromagnetic Noise and Field-Strength Instrumentation, 10 kHz to 1 GHz.

IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing (ANSI).[2]

IEEE Std C37.20.3-1987 (Reaff 1992), IEEE Standard for Metal-Enclosed Interrupter Switchgear (ANSI).[3]

IEEE Std C37.40-1993, IEEE Standard Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

IEEE Std C37.48-1987 (Reaff 1992), IEEE Guide for Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

2. Design tests

2.1 Test specifications

The design tests to be conducted upon completion of a design or following a change that affects the performance are specified in the following standards:

ANSI C37.42-1989[4]
ANSI C37.44-1981
ANSI C37.45-1981
ANSI C37.46-1981
ANSI C37.47-1981

These tests need not be performed on each design modification of a previously qualified design. To assure that overall performance has not been adversely affected as a result of design modification, the manufacturer shall ensure that the modified design will have performance at least equal to the design tested.

2.2 Required tests

See listing in table 1.

[2]IEEE Std 4-1978 has been withdrawn; however, copies can be obtained from the IEEE Standards Department, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[4]Information on references can be found in 1.2.

Table 1—Design tests

Design test given in following clauses of this standard	ANSI C37.42-1989			ANSI C37.44-1981			ANSI C37.45-1981	ANSI C37.46-1981	ANSI C37.47-1981
	Specifications for distribution cutouts and fuse links			Specifications for distribution oil cutouts and fuse links			Specifications for distribution enclosed single-pole air switches	Specifications for power fuses and fuse disconnecting switches	Specifications for distribution fuse disconnecting switches, fuse supports and current-limiting fuses
	Fuse cutouts	Disconnecting cutouts	Fuse links	Fuse cutouts	Disconnecting cutouts	Fuse links			
4 Dielectric	X	X	—	X	X	—	X	X	X
5 Expendable cap static relief pressure	X [a]	—	—	—	—	—	—	—	—
6 Interrupting	X	—	X [b]	X	—	—	—	X	X
7 Load-break	X [c]	X [c]	—	X	X	—	—	—	—
8 Making-current	—	—	—	X [d]	—	—	—	—	—
9 Radio-influence	X	X	—	X	X	—	X	X	X
10 Short-time current	—	X	—	—	X	—	X	—	—
11 Temperature-rise	X	X	X	X	X	X	X	X	X
12 Time-current	—	—	X	—	—	X	—	X	X
13 Mechanical	X	X	—	—	—	—	—	—	—
14 Liquid-tightness	—	—	—	—	—	—	—	X [e]	X [e]

NOTE—X indicates a required test.

[a] Only on expendable caps for expendable-cap cutouts.
[b] Only on open-link fuses.
[c] Only on load-break cutouts having means provided for breaking load current.
[d] Only on fuse cutouts that combine the functions of a current-interrupting device and a load-switching device.
[e] Only on liquid-submersible FEPs used in enclosures.

3. Common test practices

3.1 General test conditions

Test conditions prevailing at the test site shall conform to usual service conditions in accordance with 2.1 of IEEE Std C37.40-1993, except that temperature-rise tests shall be conducted in an ambient temperature of 10 °C to 40 °C, and time-current tests shall be conducted in an ambient temperature of 20 °C to 30 °C.

3.2 Condition of device to be tested

The device shall be new and in good condition, and tests shall be applied before the device is put into commercial service, unless otherwise specified.

3.3 Mounting of specimen and grounding

3.3.1 Mounting of power fuses

The fuse equipment shall be mounted on a structure in the normal service position or positions for which it is designed, and with the base grounded.

3.3.2 Mounting of distribution cutouts and enclosed air switches

Distribution enclosed, open and open-link cutouts, and enclosed air switches, shall be mounted on a wood crossarm that measures 3 1/2 in × 4 1/2 in (8.9 cm × 11.4 cm) in cross-section and shall be mounted in the position normally used in service.

Distribution oil cutouts shall be mounted on a rigid structure in the position normally used in service.

3.3.3 Grounding of distribution cutouts and enclosed air switches

The fuse mounting bracket or housing shall be grounded by a lead attached to the housing or to the mounting bracket on the side of the crossarm opposite the fuse support.

3.3.4 Lead connections of distribution cutouts

The source-side lead shall be connected to the upper terminal of the cutout, and the load-side lead shall be connected to the lower terminal when interrupting tests are being performed.

3.4 Frequency and wave shape of test voltage

3.4.1 Power-frequency tests

The frequency for all power-frequency tests shall be either 50 Hz or 60 Hz with limits of ± 2 Hz, except as otherwise specified. A sine wave of acceptable commercial standards shall be applied to the device. For the definition of the wave shape, see IEEE Std 4-1978.

3.4.2 Impulse tests

The wave shape and application of the 1.2/50 μs full wave test voltage are described in IEEE Std 4-1978 and shall have the following limits for design tests.

The impulse test wave shall have a virtual front time equal to or less than 1.2 μs, a crest voltage equal to or exceeding the rated full wave impulse withstand voltage, and a time to the 50% value of the crest voltage on the tail equal to or greater than 50 μs.

NOTES

1—For fuses designed and tested prior to the time of issuance of this new requirement, the impulse voltage limit wave shape is 1.5/40 μs. The manufacturer has the option of assigning a 1.2/50 μs rating on the basis of a prior design test with a –20% tail tolerance (time to 50% of crest voltage). For fuses designed and tested after the issuance of the 1978 requirement, the impulse voltage limit wave shape is 1.2/50 μs.

2—In the event that laboratory limitations are encountered due to the capacitance of the test fuse, then the maximum rise achievable may be used if it is mutually acceptable to the user and the manufacturer.

4. Dielectric tests

4.1 Test practices

Dielectric test practices shall be as specified in clause 3; 4.1.1 through 4.1.3; and 4.3 (if applicable).

4.1.1 Electrical connections

4.1.1.1 Distribution enclosed, open, and open-link cutouts

Electrical connections shall be made by means of AWG No. 6, or equivalent solid bare wire, inserted in each terminal.

4.1.1.1.1 Connector dimensions

These bare wires shall project horizontally, at least 12 in (30.5 cm) from the terminals, in a straight line approximately parallel to the face of the crossarm or steel structure and in such a manner as not to decrease the withstand value. Any necessary bends may be made at the terminals. For enclosed cutouts (and air switches), the bare wires shall be located approximately in the center of the entrance holes.

4.1.1.1.2 Terminal-to-ground tests

The test lead connections shall be made to one of the wires projecting from the terminals and to all groundable metal parts, with the fuse holder, including the conducting element (fuse link) or equivalent, or the blade in the closed position.

4.1.1.1.3 Terminal-to-terminal tests

The test lead connections shall be made to the wire projecting from the top terminal, with wire to the bottom terminal grounded and with the fuse holder or blade in the open position. The hanger shall not be grounded as specified in 3.3.3.

4.1.1.2 Distribution enclosed air switches

Electrical connections shall be made by means of an AWG No. 2/0, or equivalent stranded bare wire, inserted in each terminal.

The specifications in 4.1.1.1.1, 4.1.1.1.2, and 4.1.1.1.3 also apply to distribution enclosed air switches.

4.1.1.3 Distribution oil cutouts

Electrical connections shall be made by means of an AWG No. 6, or equivalent solid bare wire, connected to each terminal, to the end of the full length of insulated cables furnished with the cutout, or to the end of an insulated cable attached to the terminal in accordance with the manufacturer's instructions. Entrance terminals requiring taping or compound filling shall be assembled and taped or filled in accordance with the manufacturer's instructions. The connections projecting from the cutout shall not approach the metal parts of the cutout closer than a projection of the center line of the entrance terminal. Insulated conductors shall terminate 12 in (30.5 cm) or more from any grounded metal member of the terminal or of a cable sheathing attached to the grounded metal member in the normal assembly thereof.

Terminal-to-ground tests shall be made. The test lead connections shall be made to one of the wires projecting from the terminals and to all groundable metal parts, with the fuse carrier, including the conducting element (fuse link) or the blade in the closed position.

4.1.1.4 Power and distribution fuses (including current-limiting fuses) and fuse 8disconnecting switches

Fuse electrical connections shall be made by means of a bare wire inserted in each terminal.

4.1.1.4.1 Conductor position

These conductors shall project from the terminals of the fuse in substantially a straight line parallel to the fuse unit or fuse holder for an unsupported distance of at least the break distance of the fuse.

4.1.1.4.2 Terminal-to-ground tests

The test lead connections shall be made to one of the wires projecting from the terminals and to all groundable metal parts, with the fuse unit or fuse holder, including the conducting element (fuse link) or equivalent, or the switch blade in the closed position.

4.1.1.4.3 Terminal-to-terminal tests

The test lead connection shall be made to the wire projecting from the upper terminal, with the wire connected to the lower terminal grounded and with the fuse unit, fuse holder, or switch blade in one of the following positions:

a) For fuse disconnecting switches, in the fully open position
b) For dropout fuses, with the fuse holder or fuse unit in the dropout position
c) For non-dropout fuses, with the fuse holder or fuse unit removed from the support

A fuse or fuse disconnecting switch rated 72.5 kV and above shall be equipped with standard strength insulator units, and one or more insulator units identical to those supporting the current-carrying parts shall be added to each of the insulator supports or columns (only for the test).

A fuse or fuse disconnecting switch rated 48.3 kV or below shall be mounted with its base insulated from a grounded metal structure by means of insulator units identical to those assembled on the fuse. In the case of a rear-connected indoor power fuse, bus-support insulators of equivalent electrical characteristics shall be used to support the base (only for the test).

NOTE—Successful completion of these tests does not necessarily ensure that a fuse support or fuse disconnecting switch when open will always flash over to ground instead of across the open gap.

4.1.2 Temperature during testing

See 3.1.

4.1.3 Measurement of voltage

The voltage for dielectric tests shall be measured in accordance with IEEE Std 4-1978.

4.2 Test procedures

Dielectric tests shall be conducted as follows.

4.2.1 Power-frequency dry withstand voltage tests

4.2.1.1 Test voltage and time

The test voltage specified for the device, with appropriate atmospheric corrections, shall be applied to the specimen for 1 min without flashover or damage to the insulating material.

4.2.1.2 Voltage application

The application of 75% of the rated dry withstand voltage may be done in one step and gradually raised to the required value in not less than 5 s and not more than 30 s.

4.2.1.3 Correction of test voltage to standard conditions

The specified withstand voltage as given for standard atmospheric condition shall be corrected for the existing atmospheric conditions at the time of the test. This correction shall be made in accordance with IEEE Std 4-1978.

4.2.2 Power-frequency wet withstand voltage tests on outdoor devices

4.2.2.1 Test voltage and time

The test voltage specified for the device, with appropriate atmospheric corrections, shall be applied to the specimen for 10 s without flashover or damage to the insulating material.

4.2.2.2 Precipitation

See 1.3.3 of IEEE Std 4-1978. The water shall be projected downward toward the front of the device and at an angle of 45 degrees to the vertical and horizontal planes of the crossarm so that the spray strikes equally on the front and on one side wall of the device.

4.2.2.3 Voltage application

The application of 75% of the rated wet withstand voltage may be done in one step and gradually raised to the required value in not less than 5 s and not more than 30 s.

4.2.2.4 Correction of test voltage to standard conditions

The specified wet withstand voltage shall be corrected to standard air density in accordance with IEEE Std 4-1978. Corrections for relative humidity shall not be made on wet withstand tests.

4.2.3 Power-frequency dew withstand voltage tests on indoor devices

4.2.3.1 Test voltage and time

The test voltage specified for the device, with appropriate atmospheric corrections, shall be applied to the specimen for 10 s without flashover or damage to the insulating material.

4.2.3.2 Procedures

Thoroughly clean the insulation of the device. Place the cleaned device in a cold chamber (refrigerator) having temperature of –10 °C to –15 °C until it is thoroughly cooled (may take 10 h to 12 h). Then mount the device, as specified in 3.3, in a test chamber having a normal temperature of 22 °C to 25 °C and a humidity of approximately 100%. When the device is completely covered with dew, immediately apply the test voltage as specified in 4.2.3.1 and 4.2.3.3

4.2.3.3 Voltage application

Application of 75% of the rated dew withstand voltage may be done in one step and gradually raised to the required value in not less than 5 s and not more than 30 s.

4.2.3.4 Correction of the test voltage to standard conditions

The specified dew withstand voltage shall be corrected to standard air density in accordance with IEEE Std 4-1978. Correction for relative humidity shall not be made in dew withstand tests.

4.2.4 Impulse withstand voltage tests

4.2.4.1 General

Withstand voltage tests are made to determine that the test specimen is capable of withstanding a specified impulse voltage without disruptive discharge.

4.2.4.2 Procedure

Withstand voltage tests shall be made with an impulse of that polarity (usually the positive) that produces the lower withstand voltage on the test specimen. Three consecutive impulses shall be applied to the test specimen. The crest voltage of each shall be not less than the specified withstand voltage properly corrected.

4.2.4.3 Correction of test voltage to standard conditions

The specified impulse withstand voltage as given for standard atmospheric conditions shall be corrected for the existing atmospheric conditions at the time of test. Such corrections shall be made in accordance with IEEE Std 4-1978.

4.2.4.4 Interpretation of tests

If no disruptive discharge occurs during any of the three consecutive impulses, the test specimen has passed the test. If more than one disruptive discharge occurs, the test specimen has failed to pass the test. If one disruptive discharge occurs, then nine additional impulses are applied, and, if no disruptive discharge occurs, the test specimen has passed the test. If any failure in a non-self-restoring part of the insulation is observed, the test specimen has failed to pass the test.

4.3 Tests for in-air expulsion fuses in enclosures

When in-air expulsion fuses are used in an enclosure, a dielectric test of the complete fuse/enclosure combination is required. Using fuse links or fuse units of any convenient current rating, dielectric testing shall be conducted as specified for switches in enclosures in IEEE Std C37.20.3-1987, except test values shall be in accordance with table 4 of ANSI C37.46-1981, and the basic fuse device shall be capable of passing the dew withstand test specified in that standard.

5. Expendable cap static relief pressure tests

5.1 Test practices

The test specimen shall be tested without a fuse link. It shall be mounted and a means provided for exerting a prescribed test pressure through the medium of a liquid.

5.2 Test procedures

The test pressure shall be transmitted through the medium of a liquid and shall be exerted against the entire area of the pressure-responsive section.

6. Interrupting tests

6.1 Test practices

Interrupting test practices shall be as specified in clause 3 and in 6.2 through 6.5.

6.2 Test samples

In making tests on renewable fuses, use fuse links or refill units of the same manufacture as the fuses, fuse holders, or fuse units, or as recommended by the fuse manufacturer.

6.3 Characteristics of the test circuit

The interrupting tests shall be made in a single-phase ac circuit. The circuit elements used to control the current and X/R ratio shall be in series with each other and the fuse. The testing circuit frequency shall be rated frequency ± 2 Hz. If 60 Hz test facilities are not available, tests at 50 Hz ± 2 Hz are acceptable for verifying 60 Hz ratings. Note that 50 Hz tests may produce lower peak let-through currents, but may let through more I^2t than 60 Hz tests.

The parameters of the test circuits are specified in tables 2 through 14. Typical test circuits are shown in a) and b) of figure D.1 in annex D. Methods of determining transient recovery voltage (TRV) parameters are shown in annex D. Overvoltage protective equipment used on the test circuit shall be such that no sparkover occurs during the normal interrupting operation of the fuse.

6.4 Determination of prospective (available) short-circuit current of the test circuit

Short-circuit the device properly connected in the test circuit with a connection having negligible impedance and apply the power at the point of the voltage wave that produces maximum offset in the first loop. A fuse link may be used as the short-circuiting means, provided it is of sufficient capacity so that melting does not occur in the first major current loop.

Where desirable, and where the circuit will be cleared within the first loop of available current, the power applied may be with reduced voltage. Where this is done, the prospective current shall be equal to the measured current in the test circuit multiplied by the ratio of full power-frequency recovery voltage to measured reduced power-frequency test voltage.

Calculate the rms total current, including the direct-current component, in accordance with figures A.2, A.3, or A.4 in annex A for currents of 1-cycle duration or more, or with curve M of figure A.5 in annex A for currents of less than 1-cycle duration. The symmetrical current for the test shall be the asymmetrical value divided by the multiplying factor corresponding to the X/R used in the test circuit. See figure C.1 of annex C and the following note.

NOTE—If tests are made at an X/R ratio higher than specified in the appropriate table, the prospective asymmetrical current shall be equal to, or greater than, the rated symmetrical interrupting current multiplied by the appropriate multiplying factor for the X/R ratio specified in the appropriate table.

6.5 Tests on the device

The device shall be tested in the circuit described in 6.4 with the negligible-impedance connection removed. Power shall be applied at the point on the voltage wave to produce the conditions specified in table 2, 5, 8, 10, or 13 covering the particular device being tested.

6.6 Description of interrupting performance tests

6.6.1 Power fuses (except current-limiting)

Tests shall be made in accordance with table 2 and shall consist of six series of tests. The six series are as follows:

Series 1: Verification of the operation with prospective currents equal to the rated interrupting current at 87% of rated maximum voltage

Series 2: Verification of the operation with prospective currents ranging from 87% to 91% of rated interrupting current at rated maximum voltage

Series 3: Verification of the operation with prospective currents ranging from 60% to 70% of rated interrupting current at rated maximum voltage

Series 4: Verification of the operation with prospective currents ranging from 20% to 30% of rated interrupting current at rated maximum voltage

Series 5: Verification of the operation with prospective currents in the 400 A to 500 A range at rated maximum voltage

Series 6: Verification of the operation with small overload currents at rated maximum voltage

6.6.2 Distribution cutouts (except oil cutouts and open link cutouts)

6.6.2.1 Cutouts with single-voltage rating

Tests shall be made at rated maximum voltage in accordance with table 5 and shall consist of five series of tests. The five series that are conducted at rated maximum voltage are as follows:

Series 1: Verification of the operation with prospective currents equal to the rated interrupting current

Series 2: Verification of the operation with prospective currents ranging from 70% to 80% of the rated interrupting current

Series 3: Verification of the operation with prospective currents ranging from 20% to 30% of the rated interrupting current

Series 4: Verification of the operation with prospective current in the range of 400 A to 500 A

Series 5: Verification of the operation with small overload currents

6.6.2.2 Cutouts with slant-voltage (multiple-voltage) rating

Tests shall be made in accordance with table 8 and shall consist of six series of tests. The six series are as follows:

Series 1: Verification of the operation with prospective currents equal to the rated interrupting current at rated maximum voltage to left of slant (Example of a maximum voltage rating: 7.8/15 kV)

Series 2: Verification of the operation with prospective currents ranging from 70% to 80% of the rated interrupting current at rated maximum voltage to left of slant

Series 3: Verification of the operation with prospective currents ranging from 20% to 30% of the rated interrupting current at rated maximum voltage to right of slant

Series 4: Verification of the operation with prospective currents in the range of 400 A to 500 A, at rated maximum voltage to right of slant

Series 5: Verification of the operation with small overload currents and at rated maximum voltage to right of slant

Series 6: Verification of the operation of two cutouts in electrical series connection with prospective currents equal to the rated interrupting current and at rated maximum voltage to right of slant

6.6.3 Distribution oil cutouts

Five tests shall be made at maximum rated voltage with prospective current equal to the rated interrupting current. The X/R ratio of the test circuit shall be in accordance with table 7.

6.6.4 Distribution open link cutout

A sufficient number of tests shall be made at maximum rated voltage to satisfy the specified interrupting requirements. The X/R ratio of the test circuit shall be 1.3 for all values of test current and a lumped capacitance not exceeding 0.65 μF may be shunted across the fuse during the test.

6.6.5 Current-limiting power and distribution fuses

Tests shall be made in accordance with table 10 and shall consist of three series of tests. The three series are listed below. It is not necessary to make interrupting tests on fuse units of all current ratings of a homogeneous series. See 6.6.5.3 for requirements to be met and tests to be performed.

Series 1:

a) *Power fuses.* Verification of the operation with prospective currents equal to the rated interrupting current, I_1, at 87% of rated maximum voltage and with prospective currents equal to 87% of the rated interrupting current, I_1, at rated maximum voltage.
b) *Distribution fuses.* Verification of operation with prospective currents equal to the rated interrupting current, I_1, at rated maximum voltage.

Series 2: Verification of the operation with prospective current, I_2, at which current limitation occurs when a high level of energy is stored in the inductance of the circuit.

Series 3: Verification of the operation at low current, I_3.

a) For back-up type fuses, I_3 is the rated minimum interrupting current.
b) For general-purpose type fuses, I_3 is the current that causes melting of the fuse in not less than 1 h.
c) For full-range fuses, I_3 is the minimum test current, which is a current less than the minimum continuous current that causes melting of the fusible element(s) when the fuse is applied at the maximum ambient temperature specified by the fuse manufacturer. See 6.6.5.2.1 for the method of determining this test current.

NOTES

1—Values of I_1, I_2, and I_3 are the rms values of the ac component of the current.
2—As a guide, the value of the current I_2 to comply with this requirement may be determined by one or other of the following methods:

a) From the following equation, if one test at a current 150 times the current rating or higher has been made under symmetrical fault initiation in Series 1:

$$I_2 = i_1\sqrt{\frac{i_1}{I_1}}$$

where

I_2 is the prospective current for Series 2

i_1 is the instantaneous current at instant of melting in Series 1

I_1 is the prospective current in Series 1

b) By taking between three and four times the current that corresponds to a melting time of 0.01 s on the time-current characteristic.

3—If, when making tests in accordance with Series 2, the requirements of Series 1 are completely met on one or more tests (TRV parameters excepted), then these tests need not be repeated as part of Series 1.
4—Traditionally, the I_2 test condition has approximated a condition of maximum arc energy in the tested fuse. If a particular design exhibits maximum arc energy at a significantly different current than that meeting the I_2 criteria, additional tests should also be performed at a current that does approximate to maximum arc energy.
5—In very exceptional cases, the current I_2 may be higher than the rated interrupting current I_1. Series 1 and 2 shall then be replaced by six tests at rated interrupting current with making angles as nearly as possible equally distributed with approximately 30 degrees between each. (Parameters used will be those of Series 2 [see table 10] except making angle and value of instantaneous current at initiation of arcing.)

6.6.5.1 Alternate test method for Series-3 tests on current-limiting fuses

To avoid testing at the specified voltage for the full test period, an alternate test may be used for Series-3 tests of table 10, specified in 6.6.5. The characteristics of this circuit, as illustrated in figure 1, shall be as follows:

a) A low-voltage power source sufficient to cause the desired current to flow through the fuse to be tested and means for adjusting the circuit to hold the current constant.

b) A high-voltage test circuit having a voltage source equal to the rated maximum voltage of the fuse to be tested. The transient recovery voltage for this test circuit shall be critically damped. Shunting the load reactance X_{L1} with a resistance R having a value equal to approximately 40-times the value of the reactance is usually adequate to critically damp the circuit. However, if this value does not result in critical damping, the resistance may be reduced to achieve critical damping. For testing convenience, an oscillatory TRV may be acceptable with the agreement of the manufacturer. For general-purpose fuses, this circuit shall be pre-adjusted to provide the same test current as for the low-voltage part of the test, as well as the parameters as specified in table 10. For full-range fuses, this circuit shall be pre-adjusted to provide the test current specified in 6.6.5.2.1. The circuit parameters in table 10 shall apply.

c) A throw-over means for disconnecting the fuse undergoing test from the low-voltage circuit and connecting it into the high-voltage circuit.

d) The conductor size used to connect the fuse into the test circuit of figure 1 shall be the same as specified in table 12. With the fuse to be tested connected in the test circuits, apply the low voltage with random timing of initiation with respect to voltage zero. Hold the current constant during both the low- and high-voltage portions of the test. In the throw-over from the low-voltage to the high-voltage circuit, the current shall be interrupted for a time interval not longer than 0.2 s.

6.6.5.2 Description of test series 3 for a full-range fuse

6.6.5.2.1 Method of determining the minimum test current of the fuse

Three fuse samples of any given current size shall be tested as described in a) below.

a) Each sample is to be placed in a static thermal environment, which is held at the maximum ambient temperature that the manufacturer rates the fuse for use.

   Once the fuse body has stabilized at the prescribed temperature, current is applied until the fuse body temperature has again stabilized. Circulating air ovens may be used if the fuse is to be heated, but the air should be static, except for natural convection, while the current is being applied to the sample. Temperature stability is defined as having three successive temperature-rise readings, taken at one-half hour intervals, within 2% of the maximum. This will take about three thermal time constants. At the end of this period of time, the current is increased. This process is repeated until the fuse melts open.

b) For each sample tested per item a) above, the highest current that did not cause the fuse to melt is considered. The minimum test current, I_3, is 90% of the lowest of these three values.

NOTE—No specific range of increase is specified in item a) above. A typical range is 5% to 10%. It should be recognized that larger increases will reduce the number of steps but may make testing more onerous. Smaller steps may result in a slightly higher minimum test current but may increase the time required to find the minimum test current. The 90% level is picked to allow for manufacturing tolerance, similar to TCC curves.

6.6.5.2.2 Method of testing the high-voltage interrupting capability at the minimum test current of the fuse

The testing method shall be as follows:

1) The fuse should be physically mounted in the orientation that duplicates an actual orientation in use and results in the most onerous duty.
2) The fuse to be tested is to be immersed in a static thermal environment that is at the highest temperature at which the fuse manufacturer rates the fuse. Circulating air ovens may be used while the fuse is being heated, but the air should be static, except for natural convection, while current is being applied to the sample.
3) The fuse is to be tested at the minimum test current, at rated voltage. The test may be done
   a) In a circuit with full voltage and current applied for the duration of the test, or
   b) In a low-voltage melt circuit—one set to a current slightly greater than the minimum test current—that is switched over to a high-voltage circuit—one set to the minimum test current, as the fuse opens.

   The melting current shall be set at a level to cause melting in 1 h or more. The requirements detailed in 6.6.5.1 shall be followed if switchover test method b) is used.

   Temperatures higher than the maximum-use temperature may be used, if agreed to by the manufacturer, to expedite melting. Use of test method 1) above would require this procedure. In all cases, the melt time shall be at least 1 h. Note that physical changes that may affect interruption and may result from long-term application should be considered.

6.6.5.3 Interrupting tests for current-limiting fuse units of a homogeneous series

6.6.5.3.1 Characteristics of fuse units of a homogeneous series

Fuse units are considered as forming a homogeneous series when their characteristics comply with the following:

a) Rated voltage, interrupting current, and frequency shall be the same.
b) All material shall be the same.
c) All dimensions of the fuse-unit except the cross section of the fuse elements and the number of fuse element(s), as detailed below from items d) to g), shall be the same.
d) In any fuse unit, all the main fuse elements shall be identical.
e) The law governing the variation of the cross section of individual fuse elements along their length shall be the same.
f) All variations in fuse-element thickness, width, and number shall be monotonic (continually varying in the same direction for a given direction of the variable) with respect to rated current; thus, balancing an increase in cross section by reducing the number of fuse elements and vice versa, is not allowed.
g) The variation in distance, if any, between individual fuse elements and in distance, if any, between fuse element(s) and fuse barrel shall be monotonic with respect to the rated current.

A special fuse element used for an indicator or striker is exempt from items e) and f) above, but this element shall be the same for all the fuse units.

6.6.5.3.2 Test requirements

In a homogeneous series of fuse units, interrupting tests need only be made in accordance with the following table:

Homogeneous series achieved by	Test Series	Fuse units to be tested		
		A	B	C
Progressive monotonic change in n or s, or both, with respect to rated current	1	X	—	X
	2[a]	X	—	X
$n(A) \le n(B) \le n(C)$ $s(A) \le s(B) \le s(C)$	3[b]	X	X[c]	X
Constant *n*, increasing *s*	1	X	—	X
$s(A) < s(B) < s(C)$	2[a]	X	—	X
	3	—	—	X
Constant s, increasing n	1	X	—	X
$n(A) < n(B) < n(C)$	2	—	—	X
	3[b]	X	—	X

X shows tests that are to be performed.

Variables in the table are defined as
- *n* is the number of parallel fuse elements.
- *s* is the cross-sectional area of each fuse element.
- *A* is fuse unit of lowest current rating.
- *B* is any fuse unit of a current rating between A and C.
- *C* is fuse unit of highest current rating.

The parameters to be considered are
- $s(A),s(B),s(C)$ is the cross section of the individual main fuse element in *A, B, C.*
- $n(A),n(B),n(C)$ is the number of main fuse elements in *A, B, C.*

[a] The test current I_2 for the fuse units *A* and *C* will have been chosen according to the current ratings of fuse units *A* and *C*, respectively.
[b] The fuse unit of lowest current rating shall contain at least two main fuse elements in addition to the element, if present, used for operating the striker.
[c] Every rating need not be tested, but with diminishing current ratings, a test is only to be made for the current rating at which the number of elements is reduced.

6.6.5.3.3 Interpretation of interrupting tests

If the results of tests made according to 6.6.5.2.2 meet the requirements of 6.7, any current rating of fuse units within the homogeneous series shall be deemed to comply with the interrupting requirements of this specification. If a fuse unit does not perform satisfactorily according to 6.7 on one or more test series, that fuse unit shall be rejected from the homogeneous series, but such failure does not necessarily cause rejection of the other current ratings. It should be noted that a particular range of current ratings in one barrel size may constitute one homogeneous series for one test duty, but two or more homogeneous series for the purpose of another test duty. The values of minimum interrupting current of fuse units not tested are determined from Series 3 tests as follows:

a) Constant *n*, increase of *s*: It is assumed that the melting time at I_3 for fuse unit *A* and *B* is not less than that for fuse unit *C*. The test in accordance with the table is therefore considered as proving that fuse units *A* and *B* have a minimum interrupting current ascertained by reading from their time-current characteristics the currents corresponding to the melting time given by the minimum interrupting current of fuse unit C and its time-current characteristics.

b) Constant *s*, increase of *n*: The minimum interrupting current I_3 of fuse units *A* and *C* may or may not be the same. If they are the same, I_3 is deemed to apply to fuse unit *B*. If they are different, a straight line is drawn through the points corresponding to the respective minimum interrupting currents on the time-current characteristics of fuse units *A* and *C*. The intersection of this line and the time-current characteristics of fuse unit *B* is deemed to define the minimum interrupting current of fuse unit *B*.

If the manufacturer claims a value of minimum interrupting current less than that derived from either items a) or b) above, this shall be proved by a separate test.

6.6.5.4 Overvoltages for current-limiting power and distribution fuses

Overvoltages produced during the Series 1 and 2 interrupting tests specified in 6.6.5 shall be recorded by a cathode-ray oscilloscope or other instrument having a frequency response greater than that of the waveforms being measured.

6.6.5.5 Cutoff (peak let-through) current for current-limiting power and distribution fuses

The values of the cutoff (peak let-through) current, obtained from the oscillograms taken during Series 1 interrupting tests specified in 6.6.5 shall not exceed those given by the fuse manufacturer.

The characteristic curve showing the relationship of cutoff current to prospective current in the current-limiting range shall be plotted on log-log coordinate paper with cutoff current (peak let- through) on the Y-axis and prospective current (rms symmetrical prospective) on the X-axis so that the cutoff (peak let-through) current for each rating of current-limiting fuse can be obtained.

6.6.6 Current-limiting fuses in enclosures

Many applications require the use of current-limiting fuses in enclosures where the fuse and the associated contacts may be subjected to air temperatures above 40 °C. Other applications may require the fuse to be immersed in a liquid such as transformer oil. Current-limiting fuses intended for such service shall comply with the applicable design tests specified in 6.6.5 and in 6.6.6.4. When current-limiting fuses are applied in enclosures of any type, the performance characteristics of the total system must be evaluated. This evaluation of the total system shall be the responsibility of the supplier of the fuse-enclosure package (FEP). Subclauses 6.6.6.1 through 6.6.6.5 reflect this basic requirement for system capability and require tests of the total system.

The following five types of FEPs are covered by this standard:

Type 1: The fuse is mounted in a compartment such that relatively free air circulation exists. Reference ambient temperature is the enclosure air temperatures. (Example: Fuses in live-front pad-mounted transformers and vaults.)

Type 2: The fuse is inside a container that has restricted air flow surrounding the fuse, but relatively free air circulation outside of the container. Reference ambient temperature is that of the air outside the container. (Example: Fuse inside a canister in a vault.)

Type 3: The fuse is inside a container that has restricted air flow surrounding the fuse, but relatively free liquid flow outside of the container. Reference ambient temperature is that of the liquid outside the container. (Example: Fuse inside a canister immersed in transformer oil.)

Type 4: A combination of Types 2 and 3, where the container is partially in air and partially in liquid. The reference ambient temperature is that of the liquid outside the container. (Example: Fuse inside a transformer bushing.)

Type 5: The fuse is directly immersed in liquid, without the need for a separate fuse enclosure, and with relatively free liquid circulating around the fuse. The reference ambient temperature is that of the liquid surrounding the fuse. (Example: Liquid-immersible fuse in transformer or switchgear oil.)

NOTE—For Types 1 and 5, the FEP is the fuse itself; for Types 2, 3, and 4, the FEP is the container and fuse combination.

6.6.6.1 Reference ambient temperature

If the FEP uses a general-purpose fuse, the tests conducted on FEP Types 2, 3, or 4 in accordance with 6.6.6.4 shall be performed with the FEP placed both in the reference ambient temperature prevailing at the time of testing and also in the maximum reference ambient temperature specified by the FEP supplier. If the FEP uses a full-range fuse, the tests conducted on FEP Type 2, 3, or 4 in accordance with 6.6.6.4 shall be performed with the FEP placed in the maximum reference ambient temperature specified by the FEP supplier. FEP Types 1 and 5, whether using general-purpose or full-range fuses, shall be tested in the maximum reference ambient temperature specified by the FEP supplier. Liquid-immersible fuses may be tested in either liquid or air.

In all cases the test specimen shall be stabilized at the reference ambient temperature before the test current is applied to the fuse.

6.6.6.2 Test temperature for liquid-immersible fuses

Liquid-immersible fuses are designed for partial or total immersion in liquid, without the need for a separate fuse enclosure. These fuses are designed for use in various types of equipment, and the liquid temperature to which the fuse will be subjected will depend on the application. The tests in 6.6.6.4, therefore, do not specify a maximum test temperature but utilize the maximum reference ambient temperature specified by the FEP supplier.

6.6.6.3 Test specimen mounting

The tests specified shall be performed with the current-limiting fuse or FEP mounted in a manner that will simulate the service conditions specified by the supplier of the FEP.

6.6.6.4 Interrupting performance tests for FEP

Interrupting tests shall be performed in accordance with 6.6.5, Test Series 2 and 3, with the following as exceptions and additions:

Series 2: This series shall be the same as specified in 6.6.5.
Series 3: This series shall be the same as specified in 6.6.5, except as follows:

a) The test current for the FEP using a general-purpose type fuse shall cause fuse melting in not less than 1 h. For elevated reference ambient temperature tests, this current may require derating. Refer to IEEE Std C37.48-1987 for further information.
b) The test current for the FEP using a back-up type fuse shall be the rated minimum interrupting current of the fuse.
c) The test current for the FEP using a full-range type fuse shall be the minimum test current determined in 6.6.5.2.1.

The FEP shall be allowed to cool naturally during the voltage-withstand period.

6.6.6.5 Overvoltages for current-limiting fuses in enclosures

Overvoltages produced during the Series 2 interrupting tests specified in 6.6.6.4 shall be recorded by a cathode-ray oscilloscope or other instrument having a frequency response greater than that of the waveforms being measured.

6.6.7 Liquid-submerged expulsion fuses in enclosures

6.6.7.1 General

This subclause applies to expulsion fuses that are immersed in liquid and used in switchgear (not directly associated with transformers), for alternating current distribution systems. It is intended to provide testing requirements for such fuses in an enclosure. It is not intended to apply to distribution oil cutouts, which are devices covered by ANSI C37.44-1981.

6.6.7.2 Test practices

Additional interrupting test practices are as follows in 6.6.7.2.1 through 6.6.7.2.3.

6.6.7.2.1 Condition of the device to be tested

Where parts of a tested assembly are reusable, the manufacturer's guidelines should be followed regarding the number and type of tests. All specified cleaning, inspection, and maintenance steps recommended by the manufacturer shall be followed.

6.6.7.2.2 Grounding

The enclosure shall be grounded as specified by the manufacturer.

6.6.7.2.3 Liquid

The enclosure shall be filled with insulating liquid(s) as specified by the manufacturer. When testing liquid-submerged fuses to verify their ratings, the liquid shall not be changed or reconditioned during the tests.

6.6.7.3 Description of interrupting performance tests

Tests shall be made in accordance with table 13, and shall consist of two series of tests as follows:

Series 1: Verification of operation with prospective currents equal to the rated interrupting current level.

Series 2: Verification of operation in the long-time melt region, with currents from 2.7 to 3.3 times fuse-link rating.

6.6.8 In-air expulsion fuses in enclosures

6.6.8.1 General

The installation of a fuse or fuse-and-container combination (hereafter termed F/C) in an enclosure results in a total system that should have performance capabilities suitable for the application intended. The fuse or F/C manufacturer's guidelines for installation in an enclosure should be followed. These guidelines should present information on minimum electrical clearances required and minimum construction requirements for the enclosure. To evaluate the total system, certain additional interrupting tests beyond those specified in 6.6.1, shall be conducted to

a) Verify that the enclosure containing the fuse or F/C does not adversely affect proper performance and servicing of the fuse or F/C.

b) Verify that the operation of the fuse or F/C in an enclosure does not adversely affect the mechanical and dielectric integrity of the enclosure. The fuse or F/C shall be mounted in the enclosure in its normal service position. Normal ambient temperature conditions may prevail when testing a fuse or F/C having a maximum allowable reference ambient temperature (the temperature of the air surrounding the fuse or F/C) that is no higher than 55 °C. However, if the maximum allowable reference ambient temperature is higher than 55 °C, testing shall be performed with the fuse or F/C in its maximum allowable reference ambient.

6.6.8.2 Description of interrupting performance tests

For fuses or F/Cs that are applied to protect only single-phase circuits, single-phase interrupting tests shall be performed although a three-phase test is an acceptable alternative. For fuses or F/Cs that are applied to protect three-phase circuits, a three-phase interrupting test shall be performed.

With all conducting parts of the enclosure grounded, interrupting tests shall be performed in accordance with table 2 except as follows in 6.6.8.2.1 and 6.6.8.2.2.

6.6.8.2.1 Single-phase interrupting tests

Using a fuse link or fuse unit having a current rating between 20 A and 50 A, the three tests of table 2, Power Fuses, Test Series 1, shall be performed on a single fuse or F/C. However, the single-phase circuit voltage shall be equal to the single-phase voltage rating of the switchgear, and the TRV frequency and peak factor shall be those for rated maximum line-to-line voltage.

Use of a fuse current rating between 20 A and 50 A will result in duty-severity representative of, or exceeding, that which will result when using current ratings of larger size.

6.6.8.2.2 Three-phase interrupting test

In a three-phase circuit with voltage equal to the maximum rated voltage of the fuse or F/C and with either the neutral of the source grounded or the three-phase fault point grounded, but not both, a current equal to the maximum symmetrical interrupting rating of the fuse or F/C shall be applied. Fuse links or fuse units having a current rating between 20 A and 50 A shall be used. The current-making angle shall be such as to produce a current of maximum asymmetry in at least one of the phases. The circuit X/R and inherent TRV conditions specified in table 2, Power Fuses, Test Series 1, except with peak factor based upon 87% of the three-phase test voltage, shall prevail across the first phase to clear. TRV control elements may be selected by either

a) Using an ideal interrupting device to interrupt the three-phase circuit or

b) Current-injecting a phase while the other two phases are closed

6.6.8.2.3 Enclosure condition after test

The enclosure shall be capable of withstanding the forces resulting from the operation of the fuse or F/C. There shall be no operation-impairing deformation to, or effect upon, the enclosure and its doors, latches, and interlocks (if present), nor shall any internal components be affected, except the fuse and the exhaust-control device.

6.7 Condition after interrupting performance tests

After successful completion of performance tests specified in 6.6, and after renewing parts normally field renewable, excluding the fuse holder, the condition of the fuse, including the fuse support, fuse carrier, or fuse holder shall be as follows:

a) *Mechanically.* In substantially the same condition as at the beginning of the test, except for the erosion of the bore of the fuse holder employing a fuse link or a fuse carrier in an oil cutout.

b) *Electrically.* Capable of carrying rated current continuously at the rated maximum voltage. If there is evidence of contact deterioration, a temperature-rise test shall be made on the fuse at rated current with the maximum size of fuse link or refill unit for the time it takes the temperature to stabilize. If there is visible evidence of insulator contamination from the fuse operation, a power-frequency dry withstand test shall be made at 75% of the rated value.

7. Load-break tests

7.1 Test practices

Test practices shall be as specified in clause 3 and as follows in 7.1.1 through 7.1.5.

7.1.1 Mounting

The device shall be mounted in all positions for which it is designed or for which it is recommended for load-break operation.

7.1.2 Power-frequency recovery voltage

The power-frequency recovery voltage across the terminals of the device shall be the rated maximum voltage of the device.

7.1.3 Characteristics of test circuit

The power factor of the test circuit shall be between 70% and 80% for lagging power-factor tests and between 0% and 10% for leading power-factor tests. If test laboratory limitations or special applications require a more severe test circuit, the lagging power factor may be reduced to percentages of less than 70. For these cases, the allowable limits for test shall be agreed upon by the manufacturer and user.

The test circuit impedance Z shall consist of two components connected in series. The first component shall not be less than 10% or more than 20% of the total impedance of the test circuit and shall have an X/R ratio of two or more. This circuit component shall have its inductive and resistive elements in series relationship. The second component for lagging power factor tests shall consist of inductance and resistance in parallel relationship. The second component for leading power factor tests shall consist of capacitance alone. Refer to figure 2. When tests are made line-to-ground, at least the second component of impedance shall be on the load side of the device.

7.1.4 Shunt capacitance

The total shunt capacitance of the test circuit (measured across the open switch) when breaking inductive loads shall not exceed the following:

Test voltage kV	Maximum capacitance µF
2.6	0.003
5.2	0.066
7.8	0.10
15.0	0.20
18.0	0.20
27.0	0.35
38.0	0.40

NOTE—These values apply only to devices designed for use on distribution circuits.

7.1.5 Measurement and calculation of current and recovery voltage

The current interrupted is the rms symmetrical current measured from the envelope of the wave at the start of arcing. The rms alternating current and the recovery voltage shall be calculated from oscillograms, in accordance with annex A.

7.2 Test procedures

Tests shall be conducted as follows. One or more devices with means for interrupting load currents or one or more load-break mechanisms properly assembled on devices of the rating and type recommended by the manufacturer shall be opened manually, or automatically at an equivalent speed, when carrying the specified load current. The tests shall be the following:

a) *Distribution enclosed, open, and open-link cutouts.* The test shall be repeated five times with an interval between tests of not less than 3 min. There shall be no failure to interrupt the circuit for any one condition of test, fuse link rating, and mounting position. Tests shall be made under a sufficient number of conditions to ensure meeting the requirements specified for the device or mechanism undergoing test.

b) *Distribution oil cutouts.* Tests shall be as specified in 4.3 of ANSI C37.44-1981.

c) *Fuses.* Unless incorporating load-breaking means, fuses have no load-break rating.

NOTE—Disconnecting fuses may have some inherent load-break ability, which can best be evaluated by the user, based on experience under operating conditions.

7.3 Condition of device after test

At the conclusion of any series of five load-break operations for distribution enclosed, open, or open-link cutouts, or the duty cycle for distribution oil cutouts, the device and the load-break mechanism, after renewing the fuse link if destroyed in the normal load-break operation, shall be

a) In substantially the same condition as at the beginning of the test, except for the erosion of the bore of the fuse holder employing a fuse link or a fuse carrier in an oil cutout
b) Capable of carrying rated current continuously at the rated maximum voltage
   1) If there is evidence of contact deterioration, a temperature-rise test shall be made on the fuse at rated current, with the maximum size of fuse link or refill unit, for the time it takes the temperature to stabilize
   2) If there is visible evidence of insulator contamination from the fuse operation, a power-frequency dry withstand test shall be made at 75% of the rated value

8. Making-current tests (oil cutouts)

8.1 Test practices

Making-current test practices shall be as specified in clause 3 and in 8.1.1 through 8.1.3.

8.1.1 Test samples

In performing the test, use a fuse link of the maximum rating for the cutout and of the type recommended by the manufacturer. The test shall be made on one sample.

8.1.2 X/R ratio of test circuit

The X/R ratio of the test circuit in which the test is made shall not be less than the values specified in table 7.

8.1.3 Power-frequency voltage

The power-frequency voltage across the terminals of the device prior to closing the circuit shall be the rated maximum voltage of the device.

8.2 Test procedures

Making-current tests shall be conducted, at a current equal to the rated interrupting current, as follows in 8.2.1 through 8.2.3.

8.2.1 Determination of prospective (available) short-circuit current of the test circuit

The prospective short-circuit current of the test circuit shall be determined by short-circuiting the device with a connection having negligible impedance and applying the power at the point of the voltage wave that produces maximum offset in the first loop. A fuse link may be used as the short-circuiting means, provided it is of sufficient capacity so that melting does not occur in the first major current loop.

The rms total current, including the direct-current component, shall be calculated in accordance with figures A.2, A.3, or A.4 in annex A for currents of 1-cycle duration or more, or with curve M of figure A.5 in annex A for currents of less than 1-cycle duration. The symmetrical current for the circuit shall be the asymmetrical value divided by the multiplying factor corresponding to the X/R used in the test circuit. See figure C.1 of annex C and the following note.

NOTE—If tests are made at an X/R ratio higher than specified in table 7, the prospective asymmetrical current shall be equal to, or greater than, the rated making current multiplied by the appropriate multiplying factor for the X/R ratio specified in table 7.

8.2.2 Tests on the device

The making current shall be determined by the available short-circuit current of the test circuit in which the cutout is tested. The cutout shall be tested in the circuit described in 8.2.1 with the negligible impedance connection removed. It shall perform successfully under otherwise identical conditions to those described in 8.2.1, except that the magnitude of the dc component may be different when the circuit is closed by quickly moving the cutout contacts from the open to the closed position.

8.2.3 Number of tests

The test shall consist of one quick closing operation.

8.2.4 Condition of device after test

After completion of the test, the contacts may require inspection and, possibly, repair.

9. Radio-influence tests

9.1 Test practices

Radio-influence test practices shall be as specified in clause 3 and in 9.1.1 through 9.1.6.

9.1.1 Proximity of other objects

No other grounded or ungrounded object or structure (except mounting structure when required) shall be nearer to any part of the device or its terminals undergoing test than three times the longest overall dimension of the test piece, with a minimum allowable spacing of 3 ft (0.92 m). Where space limitations under test conditions do not permit the above clearance to be maintained, the test will be considered satisfactory if the limits of radio-influence voltage obtained are equal to or less than those specified for the device. In such cases, it is desirable that a record be made of the object, structures, etc., and their distances from the device under test. These data may be useful for future use in determining the proximity effect.

9.1.2 Liquid-immersed apparatus

The tanks having liquid-immersed apparatus shall be filled with the prescribed amount of liquid.

9.1.3 Electrical connections

Conductors of the largest size intended for use with the test piece may be connected to each terminal. The length of the conductors, when used, shall be equal to or greater than the longest overall dimension of the test piece and arranged as specified in 4.1.1, except that the length need not exceed 6 ft (1.83 m). The free end of any such conductor shall terminate in a sphere having a diameter twice the diameter of the conductor ± 10%, or shall be shielded in some other suitable manner to eliminate the effect of the end of the conductor as a source of radio-influence voltage.

9.1.4 Frequency

Variations from the 60-Hz frequency shall not exceed ± 5%.

9.1.5 Ambient radio noise

Tests may be made under the conditions prevailing at the time and place of test. However, it is recommended that tests be avoided when the radio-influence voltage of the test equipment (including the influence voltage of irrelevant electrical devices with the device under test disconnected from the test equipment) exceeds 25% of the radio-influence voltage of the device to be tested.

9.1.6 Atmospheric conditions

Tests shall be conducted under atmospheric conditions prevailing at the time and place of test, but it is recommended that tests be avoided when the vapor pressure of moisture in the atmosphere is below 0.2 in (5.1 mm) or exceeds 0.6 in (15.2 mm) of mercury. Since the effects of humidity and air density upon radio-influence voltage are not definitely known, correction factors are not recommended for either at the present time. However, it is recommended the barometric pressure and dry and wet bulb thermometer readings be recorded so that, if suitable correction factors should be determined, they can be applied to previous measurements.

9.2 Test equipment and procedures

The meter used in making radio-influence measurements shall be in accordance with ANSI C63.2-1987.

9.2.1 Instrument and measurements

Radio-noise meters shall meet the requirements of ANSI C63.2-1987. When making measurements on radio-influence voltage impulses with repetition rates so low that meter fluctuation makes reading of either the minimum or maximum pointer deflection doubtful, the slow-speed indicating output meter listed in 16.2 of ANSI C63.2-1987 shall be used. The highest pointer deflection of the meter during a 15 s interval of observation shall be recorded as the radio-influence voltage so that differences between various operators in recorded results for noise sources with low repetition rates may be minimized.

9.2.2 Radio-noise meter calibration

Calibrations and adjustments shall be made as specified in the instruction manual for the radio-noise meter.

9.2.3 Detector function selection

The detector function selector switch shall be set to the quasi-peak position on the radio-noise meter.

9.2.4 Monitoring

When it is desired to identify the character of the radio-influence voltage, measurements should be monitored using either a headset, loud-speaker, or oscilloscope. Precautions should be taken to determine whether or not these devices affect the radio-noise meter indications during measurements.

9.2.5 Procedures

Tests at 1 MHz shall be made on the device with the fuse unit or fuse holder including the conducting element (fuse link) or switchblade in the closed and open positions. When a test is made with the device in the open position, the pole or group of poles not connected to the influence-measuring equipment shall be grounded and ungrounded, and the radio-influence voltage determined for each condition.

9.2.6 Test on multiple devices

In the case of multiple devices, one pole or terminal, or groups of the same may be tested at a time.

9.2.7 Test on assembled apparatus

In the case of assembled apparatus, the test shall be made without removing any component part, and the test voltage shall be based on the lowest rated voltage of any component part. The limiting radio-influence voltage shall be identical with the highest value specified for any of the component parts that determine the test voltage.

9.2.8 Precautions

The following precautions shall be observed when making radio-influence tests:

a) The device shall be at approximately the same temperature as the room in which the test is made. It shall be dry and clean and shall not have been subjected to dielectric tests within 2 h prior to the radio-influence voltage test.
b) In some cases, it may be found that the radio-influence voltage falls off rapidly after the rated-frequency voltage has been applied for a short time. In such cases it is permissible to re-excite the test piece at normal operating voltage for a period not to exceed 5 min before proceeding with the tests.

9.3 Interpretation of test

The radio-influence voltage measured in the test is the total ionization voltage at the terminals of the device. Since this is conducted radio-influence voltage, the permissible maximum values specified for the device in the appropriate standard will add a negligible amount to the radio-influence radiated from an otherwise normal line to which the device is connected even at short distances from the device.

10. Short-time current tests

10.1 Test practices

Short-time current test practices shall be as specified in clause 3 except that

a) Only one position for mounting distribution cutouts and enclosed air switches is necessary.
b) Grounding of the hanger of distribution enclosed or open cutouts and enclosed air switches is not necessary.
c) The device shall have a bare conductor connected to each terminal of the size and length specified in table 12.

10.2 Test procedures

Devices shall be subjected to the specified currents for the stated times. The momentary rating may be proven in conjunction with either the 15-cycle rating, or the 3-s rating, or separate tests may be made to prove the individual ratings.

10.2.1 Determination of momentary current

The value of momentary current shall be the rms value, including the dc component if present, during the maximum cycle of current. The current shall be maintained for an adequate period of time to obtain an accurate measurement. For the method of determining the magnitude of current, see annex A.

10.2.2 Determination of 15-cycle current

The value of current shall be the rms symmetrical current as shown by oscillographic records of the test, as measured at the end of the test period. For the method of determining the magnitude of current, see annex A.

10.2.3 Determination of 3-second current

The value of current may be determined by measurement of the steady-state current with an ammeter where the circuit characteristics are such that there is no decay in current value after the initial transient.

Where the current in the circuit continues to decay after the initial transient, measurement shall be made by means of an oscillograph. The device shall be considered to have been properly tested if the integrated heating equivalent of the 3-s rating has been obtained.

Tests may be conducted at reduced current if the integrated heating equivalent of the 3-s rating is obtained in a period not exceeding 8 s.

10.2.4 Condition after test

There shall be no visible damage to the device after the tests have been completed. However, the tests may result in some visual evidence of the device having passed current such as slight contact markings. When this occurs, ratings shall be considered met when the device will withstand repeated mechanical operations without cumulative damage and is capable of carrying its rated continuous current without exceeding the temperature limits specified for the device being tested.

11. Temperature-rise tests

11.1 Test practices

Temperature-rise test practices shall be as specified in clause 3, and 11.1.1 through 11.3 (if applicable), except that grounding of the hanger of distribution cutouts or distribution enclosed air switches, as specified in 3.3.3, is not required, and electrical connections in 11.3 (if applicable) shall be as specified therein.

11.1.1 Test conditions

The device shall be mounted in a closed room substantially free from air currents other than those generated by heat from the device being tested.

11.1.2 Electrical connections

The device shall have a bare conductor connected to each terminal, of the size and minimum length specified for the device being tested as given in table 12. The connection shall be made to the ends of these conductors.

11.1.3 Test samples

The fuse links, fuse units, or blades shall be of the same manufacture as the device being tested or of a type recommended by the manufacturer for use in the device.

11.2 Test procedures

Temperature-rise tests shall be conducted as specified in 11.2.1 through 11.2.5.

11.2.1 Duration of temperature-rise test

The test current shall be applied continuously until three consecutive temperature readings taken at 0.5-h intervals show a maximum variation of 1 °C in the temperature-rise.

11.2.2 Value of ambient temperature during test

The ambient temperature shall be taken as that of the surrounding air, which should be not less than 10 °C and not more than 40 °C. Corrections shall not be applied to any ambient temperature within this range. For distribution oil cutouts when used in enclosures, see 4.7 in ANSI C37.44-1981.

11.2.3 Method of temperature determination

The temperature of a device shall be determined by either thermocouples, mercury, alcohol, or resistance thermometers. Any of these instruments shall be applied to the hottest parts of the device, excepting the conducting element of a fuse, while maintaining all parts in normal operating condition.

11.2.4 Determination of ambient temperature

11.2.4.1 Placement of thermocouples (or thermometers)

The ambient temperature shall be determined by taking the average of the readings of three thermocouples (or thermometers) placed as follows:

a) One 12 in (30.5 cm) above the device
b) One 12 in (30.5 cm) below the device (12 in [30.5 cm] above the floor and 12 in [30.5 cm] to the side of the floor-mounted apparatus)
c) One midway between the above two positions and 12 in (30.5 cm) from the side of the device

NOTE—For small devices such as distribution cutouts or air switches, one thermocouple (or thermometer) at location c) is sufficient.

11.2.4.2 Use of oil cups

In order to avoid errors due to the time lag between the temperature of large devices or apparatus and the variation in the ambient temperature, all reasonable precautions must be taken to reduce these variations and the errors arising therefrom. Thus, when the ambient temperature is subject to such variations that error in the calculated temperature-rises might result, the thermocouples (or thermometers) for determining the ambient temperature should be immersed in a suitable liquid such as oil, in suitably heavy metal cups, or should be attached to suitable masses of metal. A convenient form for an oil cup consists of a metal cylinder with a hole drilled partly through it. This hole is filled with oil and the thermocouple (or thermometer with its bulb) is placed therein so it is well immersed. The response of the thermocouple (or thermometer) to various rates of temperature change will depend largely upon the size, kind of material, and mass of the containing cup, and may be further regulated by adjusting the amount of oil in the cup. The larger the apparatus under test, the larger should be the metal cylinder employed as an oil cup in the determination of the ambient temperature. The smallest size of the oil cup employed in any case shall consist of a metal cylinder with 1 in (25 mm) diameter and 2 in (50 mm) height.

11.2.5 Covering of thermometer bulbs

If thermometers are used for taking temperatures, the bulbs of thermometers shall be covered by either felt pads, oil putty, or cotton waste cemented to the apparatus. Dimensions of felt pads for use with large apparatus shall be 1-1/2 × 2 × 1/8 in thick (40 × 50 × 3 mm thick). The use of smaller pads is permissible on small devices.

11.3 Tests for in-air expulsion fuses in enclosures

When in-air expulsion fuses are used in an enclosure, a temperature-rise test of the complete fuse/enclosure combination is required. Using fuse links or fuse units of the maximum current rating permitted by the rating of the mounting, additional rated continuous current testing shall be conducted as specified in 5.2.2 of IEEE Std C37.20.3-1987. Connecting conductors and temperature limits for buses and connections shall be the same as specified for switches in that section. The reference ambient temperature of the fuse or fuse-and-container combination (F/C) shall also be measured and related to both the ambient temperature surrounding the enclosure and the maximum reference ambient temperature specified by the manufacturer.

12. Time-current tests

12.1 Test practices

Time-current test practices shall be as specified in clause 3 and in 12.1.1 through 12.1.4, except

a) Only one position for mounting distribution cutouts is necessary.
b) Grounding of the hanger of distribution enclosed, open-, and open-link cutouts is not necessary.

12.1.1 Test samples

The fuse links or fuse units shall be tested in the fuse cutout or fuse support with which they are designed to be used. The fuse cutout or support shall be of the same manufacture as the fuse links or fuse units.

12.1.2 Electrical connections

The size and length of leads connected to the terminals of the fuse cutout or fuse support shall be the same as that specified for temperature-rise tests in table 12.

12.1.3 Time range of time-current tests

Tests shall be made so that time-current curves are plotted in the time range of

a) 0.01 s to 300 s for power fuses (except current-limiting fuses) and Types K and T distribution links rated 100 A and below
b) 0.01 s to 600 s for power fuses (except current-limiting fuses) and Types K and T distribution links rated above 100 A
c) 0.01 s to 1000 s for general-purpose type power and distribution current-limiting fuses

d) 0.01 s to 1000 s for minimum-melt time-current characteristics for back-up type power and distribution current-limiting fuses and from 0.01 s to the time corresponding to the rated minimum interrupting current for total-clearing time-current characteristics

12.1.4 Temperature of fuse at start of test

Tests shall be initiated with the fuse at an ambient temperature of 20 °C to 30 °C and without an initial load passing through the current-responsive element.

12.2 Test procedures

Time-current tests shall be conducted as specified in 12.2.1 through 12.2.4.

12.2.1 Melting time-current tests

Melting time-current tests shall be made at any voltage up to the rated maximum voltage of the unit being tested, with the test circuit so arranged that current through the fuse is held to essentially a constant value.

For low-voltage tests, when testing fuses having parallel elements that melt progressively such as a fusible element and a strain wire, the test circuit shall have sufficient impedance to prevent a material change in the current that cannot be quickly corrected when the fusible element melts.

12.2.2 Total-clearing time-current tests

Total-clearing time-current tests shall be made at the rated maximum voltage under the circuit test conditions specified for interrupting tests in 6.6.

12.2.3 Measurement of current during time-current tests

The measurement of current through the fuse during a time-current test shall be made as follows:

a) A current existing for 5 s or more may be measured with a standard indicating ammeter.

   NOTE—A standard ammeter equipped with an adjustable stop to reduce the movement of the needle during test will improve the accuracy of the measurement.

b) A current of less than 5-s duration shall be measured with an oscillograph, or other suitable instrument, and the current wave, including the dc component of current and the ac decrement, shall be corrected to steady-state conditions for plotting both melting- and total-clearing time-current curves. (See annex B for method of correction.)

12.2.4 Measurement of time during time-current tests

The measurement of the time shall be made as follows:

a) A time longer than 10 s may be measured with a stopwatch, electric clock, or timer.
b) A time longer than 1 s may be measured with a synchronous timer.
c) A time shorter than 1 s shall be measured with an oscillograph or other suitable instrument.

12.3 Presentation of data

The results of time-current tests shall be presented as standard time-current curves on log-log paper (such as Keuffel and Esser No. 48-5258 or equivalent). The curves shall show the following:

a) The relation between the time in seconds and the rms symmetrical amperes required either to melt and sever the conducting element or to interrupt the circuit
b) The basis of time on which the curves are plotted, that is, only the melting time required to melt and sever the conducting element or the total clearing time, which combines both melting and arcing time
c) The voltage at which the tests are made when plotted on the basis of total clearing time
d) The type and rating of distribution or power fuses for which data apply
e) The time range for the fuses as indicated in items a) through d) in 12.1.3

12.3.1 Melting time-current curves

Melting time-current curves for all fuse links, fuse units, or refill units shall be plotted to minimum values on the current axis, which shall be determined by subtracting the manufacturer's allowable minus variation from the average test values as determined by the test specified in 12.2.1.

12.3.2 Total-clearing time-current curves

The total-clearing time-current curves for all fuse links, fuse units, or refill units shall:

a) Be plotted to maximum values (using the current during the melting part of the total period), which shall include the minimum melting time plus tolerance
b) Add the maximum arcing time as determined by the test specified in 12.2.2. When arcing time factors are used in place of tests at rated voltage, show the method used in arriving at total clearing time

12.3.3 Color of time-current curves

The minimum-melting time-current curve should be black and the total-clearing time-current curve should be dark red.

13. Mechanical tests for distribution open fuse cutouts

13.1 Manual-operation tests

Three cutouts shall be closed and opened 200 times. The cutouts shall be mounted and operated per the manufacturer's specifications. At the conclusion of this test, the cutouts shall be in operable condition with no cracks in the insulator(s) or loose hardware.

13.2 Thermal-cycle tests

13.2.1 General

The thermal-cycle test shall consist of consecutive water immersion, cold chamber, and hot chamber cycling of the test specimens. Separate cold and hot chambers may be used, requiring movement of the test specimen.

13.2.2 Number of specimens

Five cutouts in new condition shall be tested. Open cutout fuse holders and disconnecting blades may be omitted from the test specimen during this test for the convenience of testing.

13.2.3 Testing arrangement

The specimens shall be mounted during the entire test in the manufacturer's specified service position(s) that would most likely permit water to enter any openings in the specimen. The position of the specimen shall not change during transfer from the water or between chambers.

13.2.4 Method of testing

Each specimen shall receive 10 thermal cycles. Each cycle shall consist of the following:

1) The specimen shall be immersed in water for a minimum of 1 h. Water temperature shall be from 5 °C to 35 °C. The depth of immersion shall provide a minimum water level of 1/2 in (12.7 mm) above any porcelain cavity, filled or open, or any hardware.
2) The specimen shall be removed from the water. The temperature of the air surrounding the specimen shall be lowered from ambient room temperature to –40 °C in not more than 2 h, at a rate not exceeding 2 °C per min. A temperature of –40 °C to –50 °C shall be maintained for a minimum of 2 h.
3) The temperature of the air surrounding the specimen shall be raised from –40 °C to +60 °C at a rate not to exceed 2 °C per min. A temperature of 60 °C to 70 °C shall be maintained for a minimum of 2 h. The specimen shall be permitted to return to room ambient temperature before reimmersing in water for subsequent test cycles.

13.2.5 Condition after testing

There shall be no cracks in the porcelain or loose hardware. A visual check for cracks may be used.

13.3 Torque test

Torque tests shall be conducted. Five cutouts in new condition shall be tested on those designs that utilize threaded fasteners to attach the hardware to the insulator. A torque of 125% of the nominal values specified by the manufacturer shall be applied to these bolts or nuts. No insulator breakage or thread failures shall occur.

14. Liquid-tightness tests (for certain current-limiting fuses used in enclosures)

14.1 General

Liquid-tightness tests are required on certain types of fuse enclosure packages (FEPs) that contain current-limiting fuses used in enclosures. These tests apply to any FEP that is used in a liquid environment, such as described in 6.6.6 for Types 3, 4, and 5.

14.2 Test samples

A total of five FEPs with the largest current-rated fuse in each of the physical fuse sizes shall be tested. The FEP shall be mounted or supported in the liquid as specified by the FEP supplier.

14.3 Test procedures

The FEP test samples shall be subjected to the sequential tests listed in 14.3.1 and 14.3.2, or to the alternate tests listed in 14.3.3.

14.3.1 Cycling test in air

The FEP shall be thermally cycled in air from –30 °C to the maximum reference ambient temperature as specified by the FEP supplier. The rate of temperature change shall be controlled to prevent thermal shock. Each thermal cycle from one temperature extreme to the other shall be accomplished in not more than 8 h with holding periods at the temperature extremes of sufficient duration for the temperature of the FEP to stabilize at the extreme temperature limit. The test series shall consist of ten thermal cycles over any convenient time period.

14.3.2 Cycling test in liquid

The FEP shall be thermally cycled in liquid with current passed through the fuse for part of the cycle. The FEP shall be immersed in liquid, and the liquid temperature shall be raised from room temperature to the maximum referenced ambient temperature specified by the FEP supplier in not more than 6 h. The rate-of-rise of liquid temperature should not exceed 0.5 °C per min. When the liquid temperature reaches the maximum specified, the fuse rated current, or the maximum permissible continuous current as specified by the FEP supplier shall be maintained through the fuse for a period of 2 h with the liquid temperature held at or above the specified maximum.

NOTE—Current may be used as a supplemental heat source during the heating cycle.

At the conclusion of the 2-h current period, the liquid shall be allowed to cool to ambient temperature (25 °C ± 5 °C [cold portion of cycle]). The test series shall consist of ten thermal cycles over any convenient time period.

14.3.3 Alternate tests

The requirements of 14.3.1 and 14.3.2 may be met by a single test series made according to 14.3.2 with the following exceptions. The test FEP shall be cycled from -30 °C to the maximum reference ambient temperature specified by the FEP supplier, in not more than 8 h, with a holding period at -30 °C of sufficient duration for the temperature of the fuse or FEP to stabilize. In addition, at the conclusion of the 2-h maximum-temperature period, the liquid shall be cooled to -30 °C in not more than 8 h.

14.3.4 Test criteria

All five FEP samples shall pass one of the alternate test-criteria methods selected for determining whether or not a particular FEP design passes the test for liquid-tightness. Alternate, but not necessarily equivalent, test-criteria methods are as follows:

a) Maintain a minimum of 14 psi positive pressure differential while the FEP is submerged in an appropriate liquid over a 5-min period. There shall be an absence of bubbles.

b) Measure the leak rate using a helium-detecting mass spectrometer. The maximum permissible leak rate, both before and after exposure to the above specified test cycles, shall be 1 × 10-6 standard cc per s (one atmosphere pressure differential).

c) The FEP shall be carefully inspected for liquid ingress using ultraviolet light, spectrographic analysis, or another equivalent, positive liquid-detecting technique. No liquid-ingress shall be detected.

   Note that the use of ultraviolet light or another technique for detecting presence of liquid inside the fuse will require further work to permit a quantizing of the test to provide a correlation with expected long-time service when submersed in liquid. The use of a fluorescent dye in the liquid, plus comparison with an unexposed fuse, are possible techniques that should be considered.

Table 2—Interrupting performance tests—power fuses (except current-limiting) (Parameters of test circuits and tests)

Parameters	Test Series									
	1		2[d]		3		4		5	6
Power-frequency recovery voltage	87% of rated maximum voltage +5%, –0%		Rated maximum voltage +5%, –0%							
Transient recovery voltage (TRV)	See table 3									See footnote[e]
Prospective (available) current—rms symmetrical	Rated interrupting current +5%, –0%		From 87% to 91% rated interrupting current		From 60% to 70% rated interrupting current		From 20% to 30% rated interrupting current		From 400 A to 500 A[a, b]	From 2.7 to 3.3 times link or fuse unit rating[b]
X/R ratio (power factor)	Not less than 15 (not greater than 0.067)[g]								See table 4	From 1.3 to 0.75 (from 0.6 to 0.8)
Making angle related to voltage zero—degrees	1st test: From –5 to +5 2nd test: From 85 to 105 3rd test: From 130 to 150						From 85 to 105		Random timing	
Current rating of fuse link or fuse unit	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Minimum	Minimum
Number of tests	3	3	3	3	3	3	1	1	2	2
Number of tests on each fuse employing refill units or fuse links[c]	3	3	3	3	3	3	2		4	
Number of tests on each nonrenewable fuse	1	1	1	1	1	1	1	1	1	1
Duration of power-frequency recovery voltage after interruption — Dropout fuses	Not less than dropout time or 0.5 s, whichever is greater									
Duration of power-frequency recovery voltage after interruption — Non-dropout fuses	Not less than 10 min[f]								Not less than 1 min	

[a] If the values are lower than those of Series 6, Series 5 tests need not be made.
[b] If the test involves a melting time appreciably higher than 2 s, the current may be increased to obtain a melting time of approximately 2 s.
[c] After each test, the refill unit or fuse link and expendable cap (if used) shall be replaced. Any exhaust-control device normally field-replacable should be replaced as follows:

Test Series 1, 2, and 3: Replace after each test.
Test Series 4, 5, and 6: Replace after each series of tests.

[d] If Series 1 tests are made at 100% of rated maximum voltage, Series 2 tests need not be made.
[e] The TRV for this test circuit shall be critically damped. Shunting the load reactance with a resistance having a value equal to approximately 40 times the value of the reactance is usually adequate to critically damp the circuit. However, if this value does not result in critical damping, the resistance may be reduced to achieve critical damping. For testing convenience, an oscillatory TRV may be acceptable with the agreement of the manufacturer. Critical damping is obtained when

$$R = \frac{fo}{2f_n} X$$

where

f_o is the natural frequency of test circuit without damping
f_n is the power frequency
X is the reactance of circuit at power frequency

[f] If leakage current through the fuse is monitored following interruption, recovery voltage may be removed after leakage current has been less than 1 mA for a 2-min duration.
[g] Only a minimum X/R ratio is specified. Testing with an X/R ratio greater than minimum may be acceptable but only with agreement of the fuse manufacturer.

Table 3—Test circuit TRV parameters for interrupting performance tests—power fuses (except current-limiting)

Rated maximum voltage kV[a]	Inherent TRV parameters of the test circuit			
	Test series 1, 2, 3, 4		Test series 5	
	Frequency -kHz +10%, –0% (f)	Peak factor +10%, –0% [b]	Frequency -kHz +10%, –0% (f)	Peak factor +10%, –0%[b]
2.8	8.5	1.4	38	1.45
5.1–5.5	6.0	1.4	29	1.55
8.3	4.7	1.4	19	1.65
15.0–15.5	3.2	1.4	18	1.65
23.0–27.0	2.1	1.4	12	1.65
38.0	1.6	1.4	8	1.65

[a] For rated maximum voltages above 38 kV, TRV parameters of the test circuit are not specified. Appropriate values may be selected by agreement between user and manufacturer.

[b] $\text{peak factor} = \dfrac{\text{first TRV peak in kV}}{\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)]}$

X/R is the value from table 2 for Test Series 1, 2, 3 and 4, and from table 4 for Test Series 5

peak factor should be determined based on a symmetrical current

TRV envelope is a (1-cos) shape, with time-to-peak $= \dfrac{1000}{2f \text{ in kHz}}$ µs

RRRV= average rate-of-rise of the (transient) recovery voltage

$$= \frac{\text{first TRV peak}}{\text{time-to-peak}}$$

$$= 2\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)] \times (\text{peak factor}) \times (f \text{ in kHz})\ V/\mu s$$

Table 4—X/R ratios for Test Series 5 for power fuses (except current-limiting)

Rated maximum voltage kV	Minimum X/R ratio [a]
2.8	1.5
5.1–5.5	1.5
8.3	1.8
15.0–15.5	8.0
23.0–27.0	8.0
38.0	12.0
48.3	12.0
72.5	15.0
121.0	15.0
145.0	15.0
169.0	15.0

[a] Only a minimum X/R ratio is specified. Testing with an X/R ratio greater than minimum may be acceptable but only with agreement of the fuse manufacturer.

Table 5—Interrupting performance tests—single-voltage-rated distribution cutouts (except oil cutouts and open-link cutouts) (parameters of test circuits and tests)

<table>
<tr><th rowspan="2">Parameters</th><th colspan="8">Test Series</th></tr>
<tr><th colspan="2">1</th><th colspan="2">2</th><th colspan="2">3</th><th>4</th><th>5</th></tr>
<tr><td>Power-frequency recovery voltage</td><td colspan="8">Rated maximum voltage +5%, –0%</td></tr>
<tr><td>Transient recovery voltage (TRV)</td><td colspan="7">See table 6</td><td>See footnote [g]</td></tr>
<tr><td>Prospective (available) current—rms symmetrical</td><td colspan="2">Rated interrupting current +5%, –0%</td><td colspan="2">From 70% to 80% rated interrupting current</td><td colspan="2">From 20% to 30% rated interrupting current [f]</td><td>From 400 A to 500 A [c]</td><td>From 2.7 to 3.3 times fuse link rating [d]</td></tr>
<tr><td>X/R ratio (power factor)</td><td colspan="7">See table 7</td><td>From 1.3 to 0.75 (from 0.6 to 0.8)</td></tr>
<tr><td>Making angle related to voltage zero—degrees</td><td colspan="4">1st test: from –5 to +15
2nd test: from 85 to 105
3rd test: from 130 to 150</td><td colspan="2">From 85 to 105</td><td colspan="2">Random timing</td></tr>
<tr><td>Fuse link rating</td><td>Min. [a]</td><td>Max. [b]</td><td>Min. [a]</td><td>Max. [b]</td><td>Min. [a]</td><td>Max. [b]</td><td>Min. [a]</td><td>Min. [a]</td></tr>
<tr><td>Number of tests</td><td>3</td><td>3</td><td>3</td><td>3</td><td>1</td><td>1</td><td>2</td><td>2</td></tr>
<tr><td>Number of tests on each cutout [e]</td><td>3</td><td>3</td><td>3</td><td>3</td><td colspan="2">2</td><td colspan="2">4</td></tr>
<tr><td rowspan="2">Duration of power-frequency recovery voltage after interruption</td><td>Dropout fuses</td><td colspan="7">Not less than 0.5 s</td></tr>
<tr><td>Non-drop-out fuses</td><td colspan="7">Not less than 0.5 s</td></tr>
</table>

[a] The minimum fuse link rating is 6K for cutouts rated 50 A and 100 A and 140 K for cutouts rated 200 A.
[b] The maximum fuse link rating is 50T for cutouts rated 50 A, 100T for cutouts rated 100 A, and 200T for cutouts rated 200 A.
[c] For cutouts rated 200 A, Test Series 4 need not be made.
[d] If the test involves a melting time appreciably higher than 2 s, the current may be increased to obtain a melting time of approximately 2 s.
[e] After each test, only the parts normally field-replaceable shall be replaced. These include the fuse link and expendable cap (if used).
[f] For cutouts with an interrupting rating of 2.8 kA or less, Test Series 3 need not be made.
[g] The TRV for this test circuit shall be critically damped. Shunting the load reactance with a resistance having a value equal to approximately 40 times the value of the reactance is usually adequate to critically damp the circuit. However, if this value does not result in critical damping, the resistance may be reduced to achieve critical damping. For testing convenience, an oscillatory TRV may be acceptable with the agreement of the manufacturer. Critical damping is obtained when

$$R = \frac{fo}{2f_n}X$$

where

f_o is the natural frequency of test circuit without damping
f_n is the power frequency
X is the reactance of the circuit at power frequency

Table 6—Test circuit TRV parameters for interrupting performance tests—single-voltage-rated distribution cutouts (except oil cutouts and open-link cutouts)

Rated maximum voltage kV	Inherent TRV parameters of the test circuit			
	Test Series 1, 2, 3		Test Series 4	
	Frequency-kHz +10%, –0% (*f*)	Peak factor +10%, –0% [a]	Frequency-kHz +10%, –0% (*f*)	Peak factor +10%, –0% [a]
2.6–2.8	6.1	1.3	37	1.45
5.2–5.5	4.3	1.3	37	1.45
7.8–8.3	3.3	1.3	31	1.55
15.0–15.5	2.3	1.3	24	1.6
23.0–27.0	1.7	1.3	15	1.6
38.0	1.5	1.3	10	1.6

[a] $\text{peak factor} = \dfrac{\text{first TRV peak in kV}}{\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)]}$

X/R is the value from table 7

peak factor should be determined based on a symmetrical current

TRV envelope is a (1-cos) shape, with time-to-peak = $\dfrac{1000}{2f \text{ in kHz}}$ µs

RRRV= average rate-of-rise of the (transient) recovery voltage

$= \dfrac{\text{first TRV peak}}{\text{time-to-peak}}$

$= 2\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)] \times (\text{peak factor}) \times (f \text{ in kHz})\ V/\mu s$

Table 7—X/R ratios for distribution cutout interrupting tests

Rated maximum voltage kV		Test Series 1, 2, 3, and 6 tables 5 & 8		Test Series 4 tables 5 & 8
Single-voltage-rated cutouts	Slant-voltage-rated cutouts [a]	Rated interrupting current—sym. rms amperes	Minimum X/R [b]	Minimum X/R [b]
2.6–2.8	—	≤ 16 000	5	1.5
5.2–5.5	—	≤ 12 500	5	1.5
7.8–8.3	—	≤ 10 000	8	1.8
		> 10 000	12	
15.0–15.5	7.8/15.0	≤ 7100	8	2.4
		> 7100	12	
23.0–27.0	15.0/27.0	≤ 2500	8	3.7
		> 2500	12	
38.0	27.0/38.0	≤ 10 000	15	5.1

[a] X/R ratios shown in the table apply to cutouts with rated maximum voltages within ±20% of values shown.
[b] Only a minimum X/R ratio is specified. Testing with an X/R ratio greater than minimum may be acceptable but only with agreement of the fuse manufacturer.

X/R ratios for distribution oil cutouts

Rated maximum voltage kV	Rated interrupting current-symmetrical rms amperes	Minimum X/R	
		Symmetrical rms current above 200 A	Symmetrical rms current 200 A and below
2.6–5.2	1000–8000	9.0	2.3
7.8	1000–4000	9.0	2.3
15.0	1000–2500	10.0	2.3
	2500–4000	12.0	2.3

Table 8—Interrupting performance tests—slant-voltage rated (multiple-voltage-rated) distribution cutouts (parameters of test circuits and tests)

Parameters		Test Series									
		1		2		3		4	5	6[g]	
Power-frequency recovery voltage		Rated maximum voltage to the left of the slant +5%, –0%				Rated maximum voltage to the right of the slant +5%, –0%					
Transient recovery voltage (TRV)		See table 9							see footnote[i]	See table 9	
Prospective (available) current—rms symmetrical		Rated interrupting current +5%, –0%		From 70% to 80% rated interrupting current		From 20% to 30% rated interrupting current[f]		From 400 A to 500 A[c]	From 2.7 to 3.3 times fuse link rating[d]	Rated interrupting current +5%, –0%	
X/R ratio (power factor)		See table 7							From 1.3 to 0.75 (from 0.6 to 0.8)	See table 7	
Making angle related to voltage zero—degrees		1st test: from –5 to +15 2nd test: from 85 to 105 3rd test: from 130 to 150				From 85 to 105		Random timing		1st test: from –5 to +15 2nd test: from 85 to 105 3rd test: from 130 to 150	
Fuse link rating		Min.[a]	Max.[b]	Min.[a]	Max.[b]	Min.[a]	Max.[b]	Min.[a]	Min.[a]	Min.[a, h]	Max.[b, h]
Number of tests		3	3	3	3	1	1	2	2	3	3
Number of tests on each cutout[e]		3	3	3	3	2		4		3	3
Duration of power frequency recovery voltage after interruption	Dropout fuses	Not less than 0.5 s									
	Non-dropout fuses	Not less than 0.5 s									

[a] The minimum fuse link rating is 6K for cutouts rated 50 A and 100 A and 140K for cutouts rated 200 A.
[b] The maximum fuse link rating is 50T for cutouts rated 50 A, 100T for cutouts rated 100 A, and 200T for cutouts rated 200 A.
[c] For cutouts rated 200 A, Test Series 4 need not be made.
[d] If the test involves a melting time appreciably higher than 2 s, the current may be increased to obtain a melting time of approximately 2 s.
[e] After each test, only the parts normally field-replaceable shall be replaced. These include the fuse link and expendable cap (if used).
[f] For cutouts with an interrupting rating of 2.8 kA or less, test series 3 need not be made.
[g] Test Series 6 uses two identically rated cutouts in electrical series connection. Test-circuit ground must not be between the cutouts.
[h] Use same fuse link rating in both cutouts.
[i] The TRV for this test circuit shall be critically damped. Shunting the load reactance with a resistance having a value equal to approximately 40-times the value of the reactance is usually adequate to critically damp the circuit. However, if this value does not result in critical damping, the resistance may be reduced to achieve critical damping. For testing convenience, an oscillatory TRV may be acceptable with the agreement of the manufacturer. Critical damping is obtained when

$$R = \frac{f_o}{2f_n}X$$

where

f_o is the natural frequency of test circuit without damping
f_n is the power frequency
X is the reactance of the circuit at power frequency

Table 9—Test circuit TRV parameters for interrupting performance tests—slant-voltage-rated (multiple-voltage-rated) distribution cutouts

Rated maximum voltage kV [a]	Inherent TRV parameters of the test circuit				
	Test Series 1, 2, 3 and 6			Test Series 4	
	Frequency-kHz +10%, –0% (f)		Peak factor +10%, –0% [b]	Frequency-kHz +10%, –0% (f)	Peak factor +10%, –0% [b]
	Series 1, 2	Series 3, 6			
7.8/15.0	3.3	2.3	1.3	24	1.6
15.0/27.0	2.3	1.7	1.3	15	1.6
27.0/38.0	1.7	1.5	1.3	10	1.6

[a] TRV parameters shown in the table apply to cutouts with rated maximum voltage within ± 20% of the values shown.

[b] peak factor = $\frac{\text{first TRV peak in kV}}{\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)]}$

X/R is the value from table 7

peak factor should be determined based on a symmetrical current

TRV envelope is a (1-cos) shape, with time-to-peak = $\frac{1000}{2f \text{ in kHz}}$ μs

RRRV= average rate-of-rise of the (transient) recovery voltage

$= \frac{\text{first TRV peak}}{\text{time-to-peak}}$

$= 2\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)] \times (\text{peak factor}) \times (f \text{ in kHz})\ V/\mu s$

Table 10—Interrupting performance tests—current-limiting power and distribution fuses (parameters of test circuits and tests)

Parameters		Type of fuse	Test Series			
			1		2	3 [d, f]
Power-frequency recovery voltage		Power	87% rated maximum voltage +5%, –0%	Rated maximum voltage +5%, –0%	Rated maximum voltage +5%, –0%	
		Distribution	Rated maximum voltage +5%, –0%	Not required		
Transient recovery voltage		Power	See table 11			See footnote [g]
		Distribution				
Prospective (available) current rms symmetrical		Power	I_1 +5%, –0%	87% of I_1 +5%, –0% [a]	I_2	I_3
		Distribution	I_1 +5%, –0%	Not required		
X/R ratio (power factor)		Power	Not less than 15 (not greater than 0.067) [h]			From 2.3 to 1.3 (from 0.4 to 0.6)
		Distribution	Not less than 10 (not greater than 0.100) [h]			
Making angle after voltage zero—degrees		Both	Not applicable		0 to 20	Random timing
Instantaneous current at initiation of arcing		Both	Not applicable		0.85 I_2 to 1.06 I_2	Not applicable
Initiation of arcing after voltage zero—degrees		Both	For one test: from 40 to 56 For two tests: from 65 to 90 [b]		Not applicable	Not applicable
Duration of power-frequency recovery voltage after interruption	Dropout fuse	Both	Not less than dropout time or 1 s, whichever is greater			
	Non-dropout fuse		Not less than 1 min [c, e]		Not less than 1 min [c]	
Number of tests		Power	3	3	3	2
		Distribution	3	0	3	2

NOTE—See tablenotes on page 42.

(Tablenotes continued from page 41.)

[a] Tests need not be made if tests at the I_1 level are made at 100% of rated maximum voltage.
[b] Since the operating conditions can produce a wide variety of stresses on the fuse and as the interrupting tests are intended in principle to produce the most severe conditions mainly as regards the arc energy and the thermal and mechanical stresses for this value of current, it is recognized that these conditions will be practically obtained at least once when making the three tests indicated.
[c] Should limitations of the test station so dictate, then subsequent to circuit interruption and within a period of no more than 15 s after interruption, the voltage may be interrupted for an interval no longer than 1 s. This interval may be used to effect switching to an auxiliary power supply of adequate KVA capacity, from which the specified test voltage can be maintained for the remainder of the specified duration.
[d] See 6.6.5.1 for an alternate test method.
[e] If Series 2 tests are not made, duration shall be not less than 10 min.
[f] Series 3 tests are made with a current value corresponding to the stated point of the time-current characteristic, with a tolerance of +0% and –10%, and leading to melting in not less than 1 h for general-purpose type fuses. When testing station limitation prevents the maintenance of constant current, the tolerance on the current can be exceeded in either direction during not more than 20% of the total melting time.
[g] The transient recovery voltage (TRV) for this test circuit shall be critically damped. Shunting the load reactance with a resistance having a value equal to approximately 40-times the value of the reactance is usually adequate to critically damp the circuit. However, if this value does not result in critical damping, the resistance may be reduced to achieve critical damping. For testing convenience, an oscillatory TRV may be acceptable with the agreement of the manufacturer. Critical damping is obtained when

$$R = \frac{f_o}{2f_n}X$$

where

f_o is the natural frequency of test circuit without damping
f_n is the power frequency
X is the reactance of the circuit at power frequency

[h] Only a minimum X/R ratio is specified. Testing with an X/R ratio greater than minimum may be acceptable but only with agreement of the fuse manufacturer.

Table 11—Test circuit TRV parameters for interrupting performance tests—current-limiting power and distribution fuses

Rated maximum voltage kV	Inherent TRV parameters of the test circuit			
	Test Series 1		Test Series 2	
	Frequency-kHz +10%, –0% (f)	Peak factor +10%, –0% [a]	Frequency-kHz +10%, –0% (f)	Peak factor +10%, –0% [a]
2.8	8.5	1.4	3.3	1.5
5.1–5.5	6.0	1.4	2.7	1.5
8.3	4.7	1.4	2.3	1.5
15.0–15.5	3.2	1.4	1.8	1.5
23.0–27.0	2.1	1.4	1.3	1.5
38.0	1.6	1.4	1.1	1.5

[a] $\text{peak factor} = \dfrac{\text{first TRV peak in kV}}{\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)]}$

X/R is the value from table 10

peak factor should be determined based on a symmetrical current

TRV envelope is a (1-cos) shape, with time-to-peak = $\dfrac{1000}{2f \text{ in kHz}}$ µs

RRRV= average rate-of-rise of the (transient) recovery voltage

$= \dfrac{\text{first TRV peak}}{\text{time-to-peak}}$

$= 2\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)] \times (\text{peak factor}) \times (f \text{ in kHz})\ V/\mu s$

Table 12—Size and length of bare conductors for specified tests

Rated continuous current of cutout, switch, or fuse support Amperes					Size and length of bare copper leads		
Distribution enclosed, open, and open-link cutouts when tested as a		Distribution oil fuse and disconnecting cutout	Distribution enclosed air switch	Power fuse and distribution current-limiting fuse	Size of leads	Minimum length	
Fuse cutout	Disconnecting cutout					in	(m)
50	—	—	—	up to 50	No. 6 AWG solid	48	(1.22)
—	100	—	—	—	No. 2 AWG stranded	48	(1.22)
100	—	—	—	100	No. 1 AWG stranded	48	(1.22)
—	200	—	—	—	No. 2/0 AWG stranded	48	(1.22)
—	—	100	—	—	No. 1/0 AWG stranded	48	(1.22)
200	—	200	200	200	No. 4/0 AWG stranded	48	(1.22)
—	300	300	300	300	250 kC mil [a]	48	(1.22)
—	—	—	400	400	400 kC mil [a]	48	(1.22)
—	—	—	600	–	600 kC mil [a]	48	(1.22)

[a] Thousand circular mils.

Table 13—Interrupting performance tests—Liquid-submerged expulsion fuses in enclosures (without current-limiting fuses) (parameters of test circuits and tests)

Parameters	Test Series			
	1		2	
Power-frequency recovery voltage	Rated maximum voltage +5%, –0%			
Transient recovery voltage (TRV)	See table 14		See footnote [c]	
Prospective (available) current—rms symmetrical	Rated interrupting current +5%, –0%		2.7 to 3.3 times link or fuse-unit rating [a]	
X/R ratio (power factor)	Not less than 8 (not greater than 0.124) [d]		From 1.3 to 0.75 (from 0.6 to 0.8)	
Making angle after voltage zero—degrees	1st term: from +5 to +15 2nd test: from 85 to 105 3rd test: from 130 to 150		Random timing	
Current rating of fuse link or fuse unit	Minimum	Maximum	Minimum	Maximum
Number of tests [b]	3	3	2	2
Duration of power-frequency recovery voltage after interruption	Not less than 1 min			

[a] If the test involves a melting time appreciably higher than 2 s, the current may be increased to obtain a melting time of approximately 2 s.

[b] The number of tests on any one holder for devices with replaceable links should be limited to the number recommended by the switchgear manufacturer.

[c] The TRV for this test circuit shall be critically damped. Shunting the load reactance with a resistance having a value equal to approximately 40 times the value of the reactance is usually adequate to critically damp the circuit. However, if this value does not result in critical damping, the resistance may be reduced to achieve critical damping. For testing convenience, an oscillatory TRV may be acceptable with the agreement of the switchgear manufacturer. Critical damping is obtained when

$$R = \frac{f_o}{2f_n}$$

where

f_o is the natural frequency of test circuit without damping
f_n is the power frequency
X is the reactance of the circuit at power frequency

[d] Only a minimum of X/R ratio is specified. Testing with an X/R ratio greater than minimum may be acceptable but only with agreement of the switchgear manufacturer.

Table 14—Test circuit TRV parameters for interrupting performance tests—Liquid-submerged expulsion fuses in enclosures (without current-limiting fuses)

Rated maximum voltage kV [a]	Inherent TRV parameters of the test circuit	
	Test Series 1	
	Frequency-kHz +10%, –0% (f)	Peak factor +10%, –0% [b]
5.1–5.5	4.3	1.3
7.8–8.3	3.3	1.3
15.0–15.5	2.3	1.3
23.0–27.0	1.7	1.3
38.0	1.5	1.3

[a] TRV parameters shown in the table apply to fuses with maximum rated voltages within ± 20% of the values shown.

[b] $$\text{peak factor} = \frac{\text{first TRV peak in kV}}{\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)]}$$

X/R is the value from table 13

peak factor should be determined based on a symmetrical current

TRV envelope is a (1-cos) shape, with time-to-peak = $\frac{1000}{2f \text{ in kHz}}$ µs

RRRV= average rate-rate-of-rise of the (transient) recovery voltage

$$= \frac{\text{first TRV peak}}{\text{time-to-peak}}$$

$$= 2\sqrt{2} \times (\text{power-frequency recovery voltage in kV}) \times [\sin(\arctan X/R)] \times (\text{peak factor}) \times (f \text{ in kHz})\ V/\mu s$$

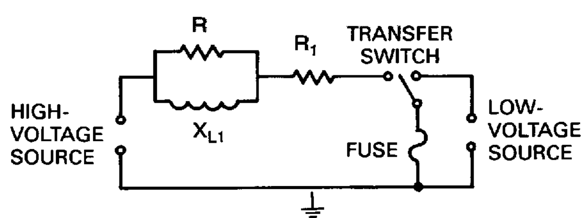
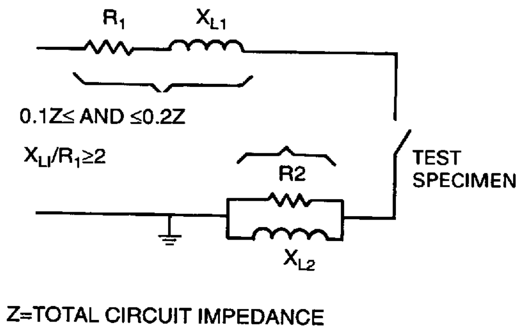
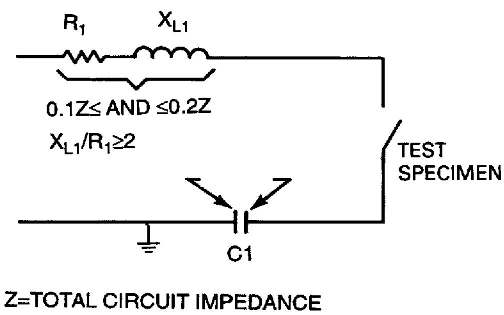


Figure 1—Alternate test circuit for Series 3 test of current-limiting fuses



Typical lagging power factor test circuit



Typical leading power factor test circuit

Figure 2—Test circuit for load-break tests

Annexes

Annexes A and C were compiled with modifications from ANSI C37.05-1964 (R1976), American National Standard Methods for Determining the Values of a Sinusoidal Current Wave and a Normal-Frequency Recovery Voltage for AC High-Voltage Circuit Breakers, and IEEE Std C37.5-1979, American National Standard Guide for Calculation of Fault Currents for Application of AC High-Voltage Circuit Breakers Rated on a Total Current Basis. Both standards have since been withdrawn.

Annex A
Recommended methods for determining the value of a sinusoidal current wave and a power-frequency recovery voltage

(informative)

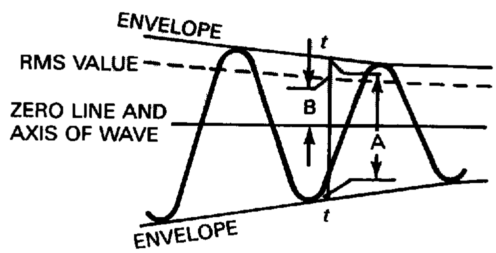
A.1 Current waves

A.1.1 Classification of current waves

The determination of the current interrupted by a circuit-interrupting device involves the measurement of the rms or effective values of sinusoidal waves. These waves may be divided into two groups, those that are symmetrical about the zero axis, and those that are asymmetrical with respect to the zero axis.

A.1.2 Symmetrical sinusoidal wave

The symmetrical sinusoidal wave has an rms value equal to the peak-to-peak value divided by 2.828. To determine the rms value at a given instant, draw the envelope of the current wave, determine from it the peak-to-peak value at the given instant, and divide by 2.828. See figure A.1 for example.



t = time for which measurement was made
A = peak-to-peak value
B = rms value = $\frac{A}{2.828}$

Figure A.1—Symmetrical sinusoidal current wave

A.1.3 Asymmetrical sinusoidal wave

The asymmetrical sinusoidal wave can be considered to be composed of two components—an alternating component and a direct component.

A.1.3.1 Measurement of the rms value

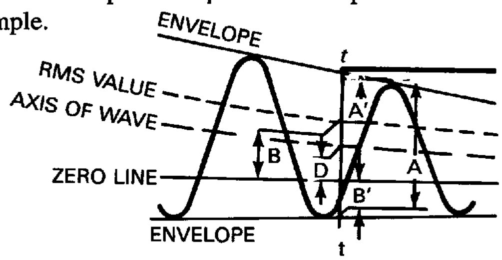
The measurement of the rms value is simplified by this conception of an asymmetrical wave since the rms value of the wave is a function of these two components.

A.1.3.2 Alternating component

The alternating component has a peak-to-peak value equal to the distance between the envelopes and has an axis midway between the envelopes.

A.1.3.3 Direct component

The direct component has an amplitude equal to the displacement of the axis of the alternating component. See figure A.2 for example.



T = time for which measurement was made
A = peak-to-peak value of alternating component = A + B
D = direct component = A + (A/2)
A′ = major ordinate
B′= minor ordinate

$$B = \text{rms value} = \sqrt{\left(\begin{matrix}\text{rms value of}\\ \text{alternating current}\end{matrix}\right)^2 + \left(\begin{matrix}\text{direct}\\ \text{component}\end{matrix}\right)^2}$$

$$= \sqrt{\left(\frac{A}{2.828}\right)^2 + D^2}$$

Figure A.2—Asymmetrical sinusoidal current wave

The direct use of the formula in figure A.2 involves a considerable amount of calculation to determine the components and to combine them, but it may be used to develop tables, charts, and scales by which the effective values are easily and quickly obtained.

A.1.3.4 Chart for determining rms value

A chart that gives the rms value of the asymmetrical wave in terms of the peak-to-peak and maximum values is shown in figure A.3. These two values are read on an oscillogram. The point, whose abscissa is the maximum value of the wave and whose ordinate is the peak-to-peak value, indicates the rms value of the asymmetrical wave. This value is multiplied by the scale of the oscillogram.

A.1.3.5 Scale for determining rms value

A transparent scale that can be laid over an asymmetrical sine wave and used for reading the rms value directly is shown in figure A.4. The scale is placed over the wave with the line X-X' parallel to the zero line and with the upper and lower edges of the scale passing through the points on the envelopes of the sinusoidal wave corresponding to the instant at which the rms value is to be obtained. The point on the zero line of the wave corresponding to the instant at which the rms value is to be obtained, then indicates the rms value on the scale. The scale in figure A.4 is full size and is read in inches. The rms value is multiplied by the scale of the oscillogram.

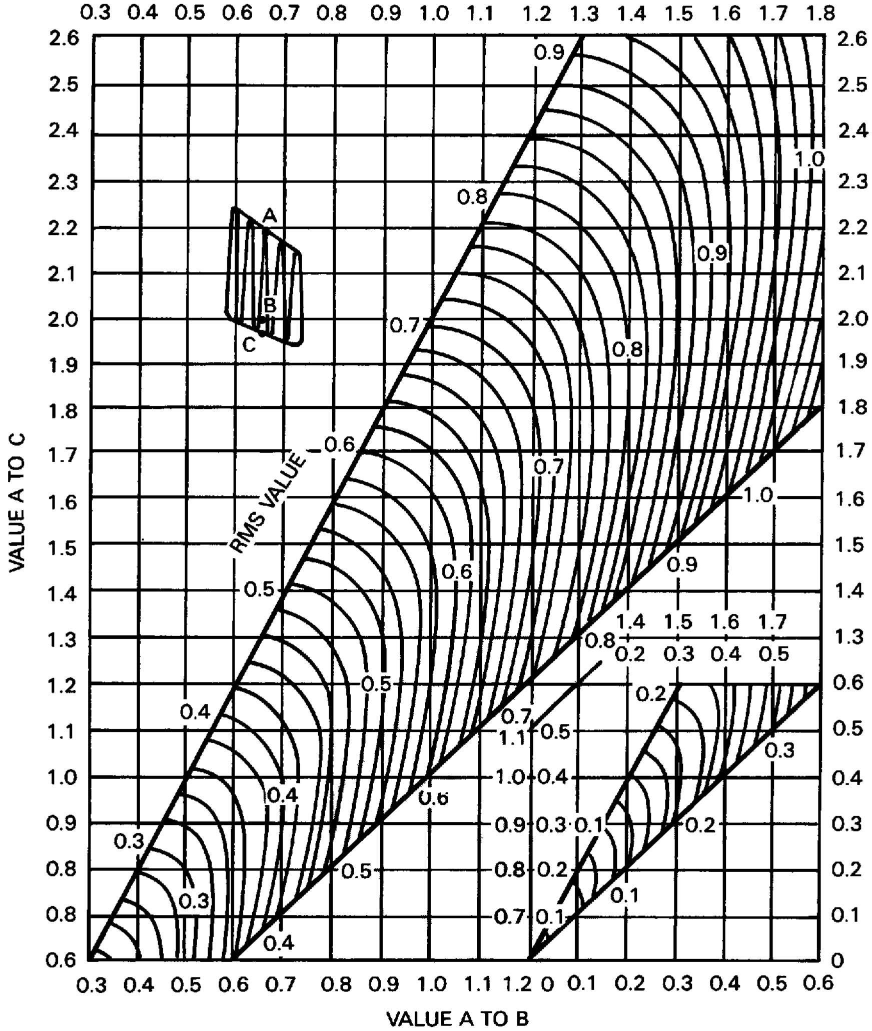


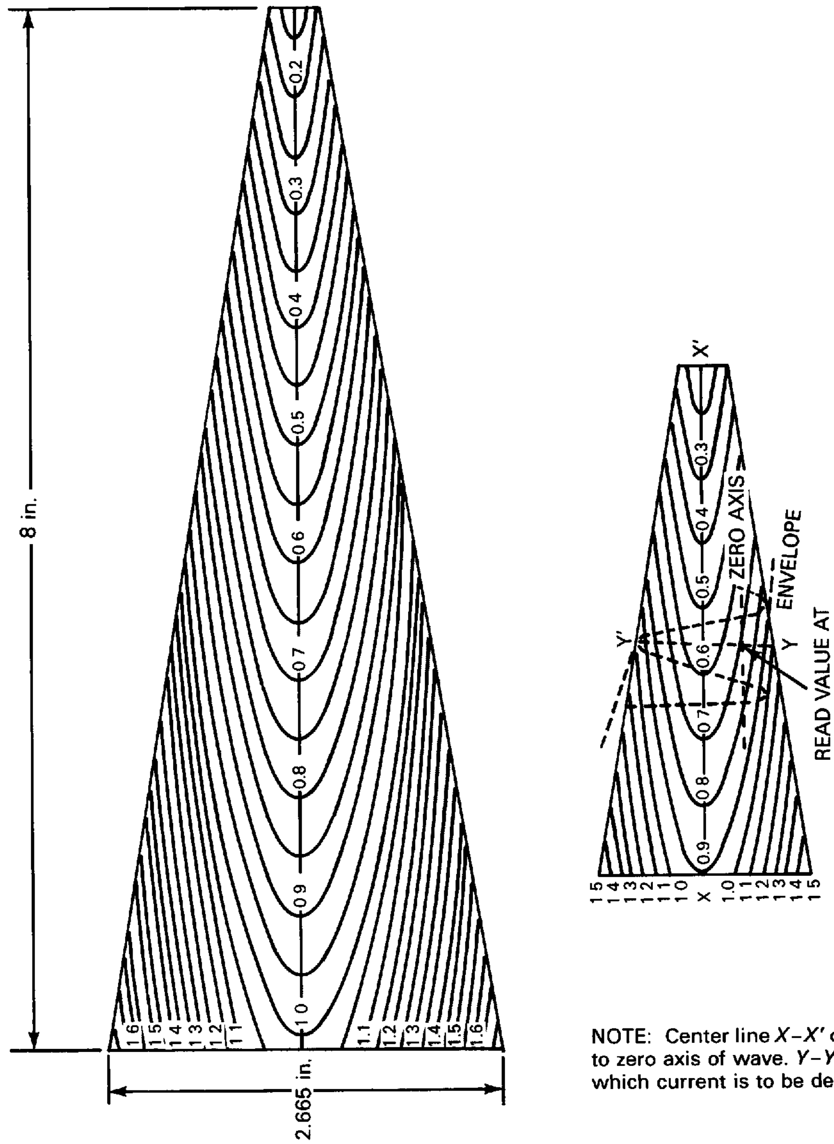
Figure A.3—Chart for determining the rms value of an asymmetrical sinusoidal wave

A.1.3.6 RMS values for currents of less than one cycle duration

The current to be measured may flow for less than one cycle and make it impossible to determine the envelope of the current wave by inspection of the oscillogram. Such currents can occur with fuses, breakers operating on low-frequency circuits, breakers that have started to open before the fault develops, or breakers pretripped on test. The rms value of the displaced sine wave integrated over a complete cycle may be determined from the amplitude of the single loop, its duration, and curve M of figure A.5. In some cases, the rms value of the current for the fraction of a cycle for which the current actually flowed may be desired. It may be determined from the amplitude of the single loop, its duration, and curve N of figure A.5.

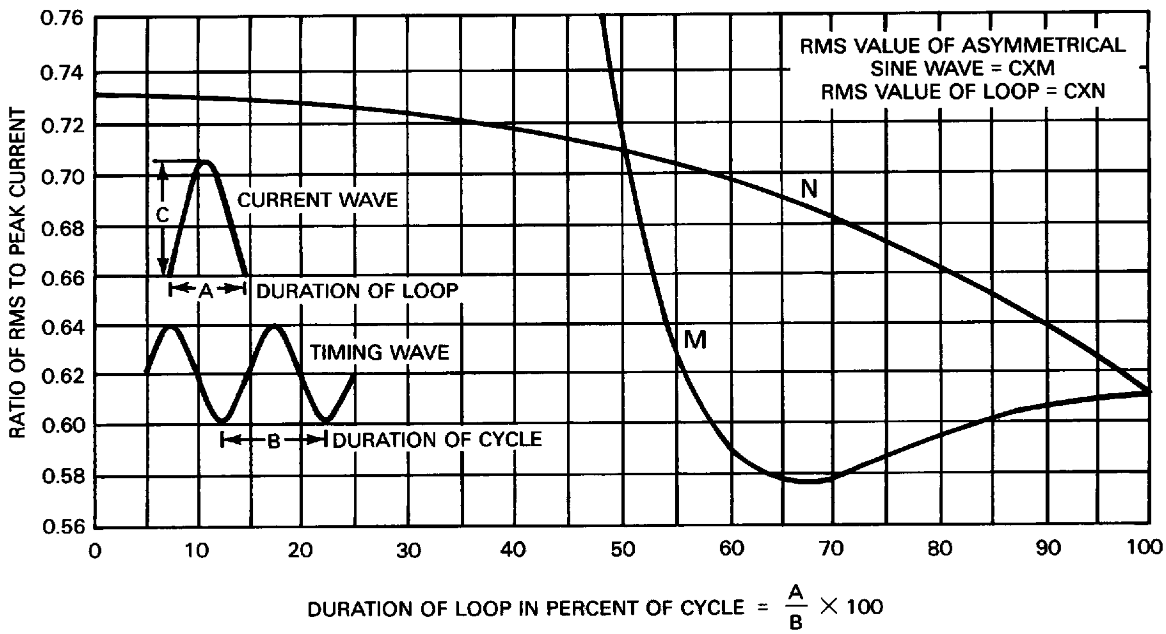
A.2 Power-frequency recovery voltage

Power frequency recovery voltage shall be determined from the envelope of each voltage wave at a point in time coincident with that peak that occurs more than 0.5 cycle, and not more than one cycle, after final arc extinction in the last phase to clear. The power-frequency recovery voltage for a three-phase short circuit shall be taken as the average of the three values obtained in this manner for the three voltage waves. See figure A.6.



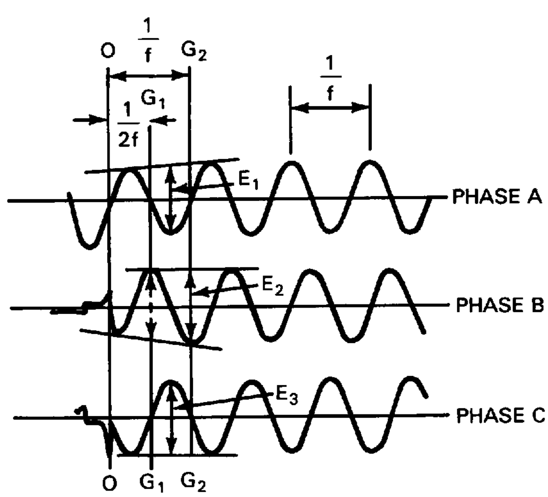
NOTE: Center line $X-X'$ of scale parallel to zero axis of wave. $Y-Y'$ instant for which current is to be determined.

Figure A.4—A scale for measuring the rms value of an asymmetrical sinusoidal wave



NOTE: The curves are based on the assumption of no decrement in the wave.

Figure A.5—Curves for determining from a single loop of a displaced sinusoidal wave the rms value of the wave integrated over a complete cycle or over the single loop



Phase A = first to open circuit
OO = instant of final arc extinction

G_1G_1 = interval $\frac{1}{2f}$ from OO

G_2G_2 = interval $\frac{1}{f}$ from OO

$\frac{1}{f}$ = 1 period at system frequency

$\frac{E_1}{2.828}$ = normal-frequency recovery voltage, phase A

$\frac{E_2}{2.828}$ = normal-frequency recovery voltage, phase B

$\frac{E_3}{2.828}$ = normal-frequency recovery voltage, phase C

Average normal-frequency recovery voltage

$$= \left(\frac{E_1}{2.828} + \frac{E_2}{2.828} + \frac{E_3}{2.828}\right) \div 3$$

NOTE: In phase B, a voltage peak occurs exactly at interval G_1G_1. In such event, measurement is made at the later interval, G_2G_2.

Figure A.6—Determination of power-frequency recovery voltage

Annex B
Recommended method of determining the equivalent steady-state rms current for plotting time-current curves

(informative)

The current that melts a fuse in less than 1 s may contain a number of transients in the wave. The magnitude of these transients varies with each fuse operation, and the equivalent steady-state rms value of the current wave can be obtained only by evaluating each case individually. The following methods are recommended for fuse tests that fall in this class:

a) When the fuse melts during transient conditions, the area under the melting part of the current wave is integrated to determine the root-mean-square value of the wave. This value is then multiplied by the scale of the oscillogram to give the rms current.
b) When the fuse melts after transient conditions subside, the transient part of the wave is integrated as described in a), and the crest-to-crest height of the steady-state wave is measured. The two values obtained are combined as follows:

$$\text{rms value of current wave to melting point} = \sqrt{\frac{\left[\text{rms value of transient part}\right]^2\left[\text{time of transient part}\right] + \left(\left[\dfrac{\text{crest-to-crest value of steady-state portion}}{2\sqrt{2}}\right]^2\left[\text{time of steady-state part}\right]\right)}{\text{total time to melt}}}$$

Annex C
Simplified fault-current calculation

(informative)

C.1 Interrupting duty

To select the proper interrupting rating, it is necessary to calculate the maximum symmetrical fault current on the load side of the fuse and compare this value with the interrupting capability of the fuse. Most power fuses, distribution current-limiting fuses, and distribution cutouts are now rated by the manufacturer in terms of symmetrical current. A direct comparison can be made between the calculated values of fault current and the fuse rating. Many power fuses and distribution cutouts of earlier manufacture (pre-1970) were rated on the basis of asymmetrical current. For those fuses, multiplying factors shall be applied to the calculated fault current before a comparison can be made with the fuse ratings.

The multiplying factors to be applied depend upon the system X/R ratios on the source side of the fuse. Some representative X/R ratios for application of fuses on systems are given in tables 2, 5, 8, 10, and 13. For specific applications, where the X/R values are known, multiplying factors can be obtained from figure C.1. Normally, the curve labeled rms multiplication factor will be used. Occasionally, the curve labeled peak multiplication factor is of interest during design testing.

C.2 Mechanical and momentary duty

For many purposes, it is necessary to know the maximum possible rms current (including both ac and dc components) that can flow in a circuit. Allowing for over-excitation of generators, the rms value of asymmetrical current as calculated for faults initiated at voltage zero is about 1.8 times the symmetrical fault current. As there will always be some decay even in the first half cycle, however, a multiplier of 1.55 is acceptable.

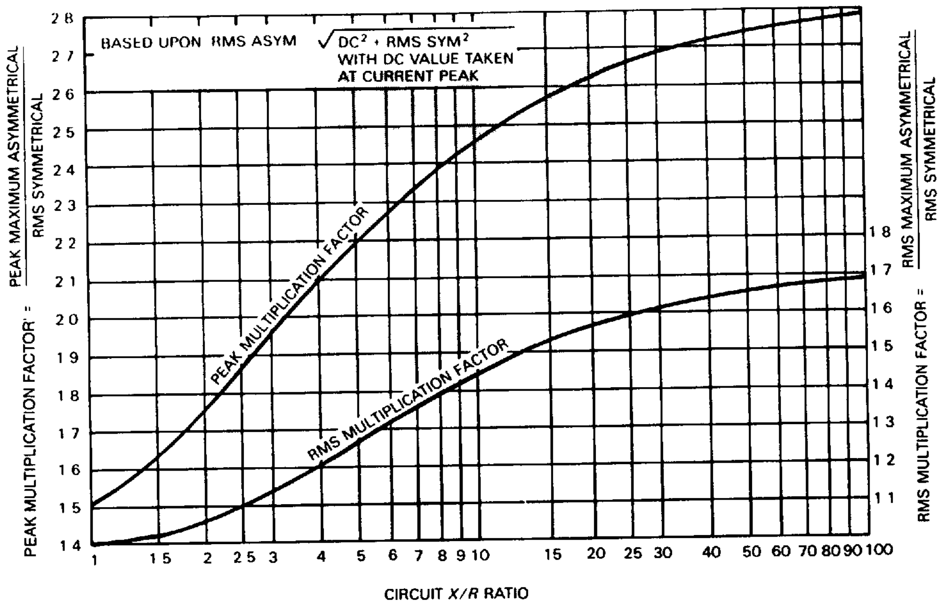


Figure C.1—Relation of *X/R* ratio to multiplication factor

Annex D
Transient recovery voltage parameters

(informative)

D.1 Measurement of peak factor

Peak factor is the ratio of the first peak of the transient recovery voltage (TRV) to the instantaneous value of source voltage at the time of current zero, and is defined by

$$\text{peak factor} = \frac{\text{first TRV peak}}{\sqrt{2} \times (\text{power-frequency recovery voltage}) \times [\sin(\arctan X/R)]}$$

This parameter is used in lieu of amplitude factor (the ratio of the first peak of the transient recovery voltage to the peak value of the power-frequency recovery voltage) and is considered superior especially when testing in circuits with low X/R ratios.

Peak factor may be measured by current-injecting the test circuit or, alternately, by conducting an actual fault-interrupting test using a low-arc-voltage interrupting device that does not distort the TRV. Either method, incidentally, can also be used to determine the frequency of the test circuit TRV.

The characteristics and use of current-injecting equipment shall be such as to not alter the inherent TRV characteristics of the circuit during measurement. For further information on such equipment, see the bibliography in D.2.

D.1.1 Measurement of peak factor by current injection

Peak factor is graphically determined from the TRV appearing across the open interrupting device when the circuit is current-injected at that point. See figure D.2.

D.1.2 Measurement of peak factor by fault interruption

Peak factor is determined from the TRV record of an actual fault-interrupting test on a circuit employing a low-arc-voltage device that does not distort the TRV. (Peak factor cannot be determined from the TRV record of a test employing a fuse cutout as the interrupting device, since cutouts typically distort the TRV.) See figure D.3.

For this case, the first peak of the TRV is measured from the extinction peak as its starting point, as is the measurement of the instantaneous power-frequency recovery voltage at the time of current zero. The following equation shows the calculation:

$$\text{peak factor} = \frac{(\text{first TRV peak}) + (\text{extinction peak})}{\left\{ \sqrt{2} \times \text{power-frequency recovery voltage} \times [\sin(\arctan X/R)] \right\} + (\text{extinction peak})}$$

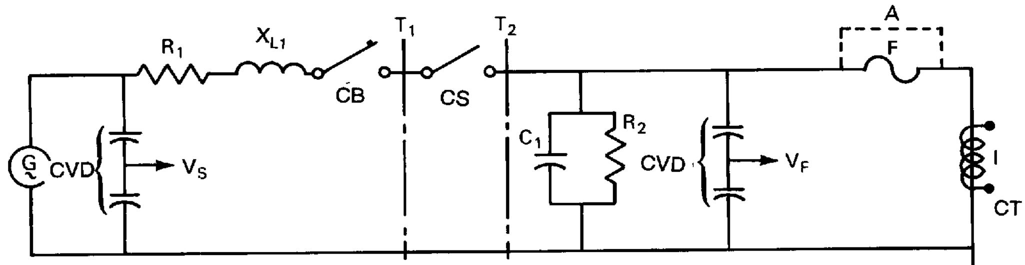
D.2 Bibliography to annex D

[D1] Hammarlund, P., "Transient Recovery Voltage Subsequent to Short-Circuit Interruption with Special Reference to Swedish Power Systems," *Proceedings*, No. 189, Royal Swedish Academy of Engineering Sciences, 1946.

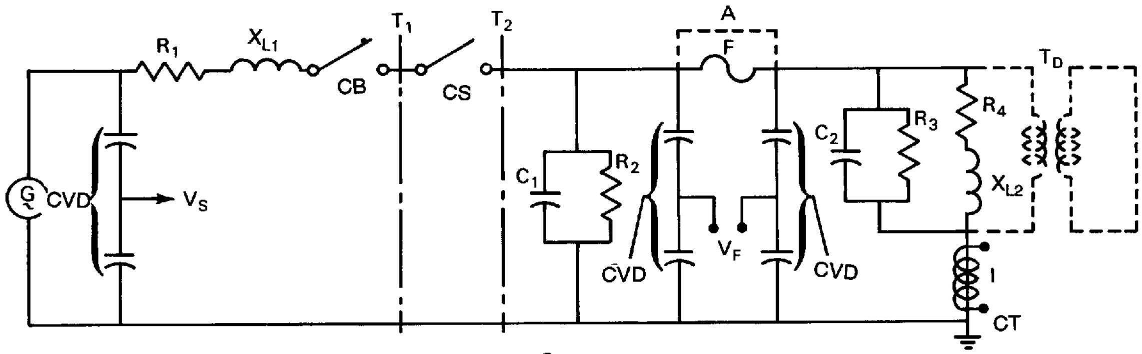
[D2] Jackson, R. L., "Low Voltage Injection Equipment for Determining the Transient Response of Power System Plant," *Internal Laboratory Report*, No. RD/L/R 1782, Central Electricity Research Laboratory, Leatherhead, England, Feb. 3, 1972.

[D3] Kotheimer, W. C., "A Method for Studying Circuit Transient Recovery Voltage Characteristics of Electric Power Systems," *AIEE Transactions*, vol. 74, pp. 1083–1086, 1955.

[D4] Sing-Yui-King "Determination of Restriking Transients on Power Networks by a Half-Wave Injection Method," *JIEE*, Part II, p. 700, 1949.



TYPICAL CIRCUIT DIAGRAM FOR TEST SERIES 1, 2, 3, 4 — TABLE 2
TEST SERIES 1, 2, 3, — TABLE 5
TEST SERIES 1, 2, 3, 6 — TABLE 8
TEST SERIES 1, 2, — TABLE 10
TEST SERIES 1—TABLE 13



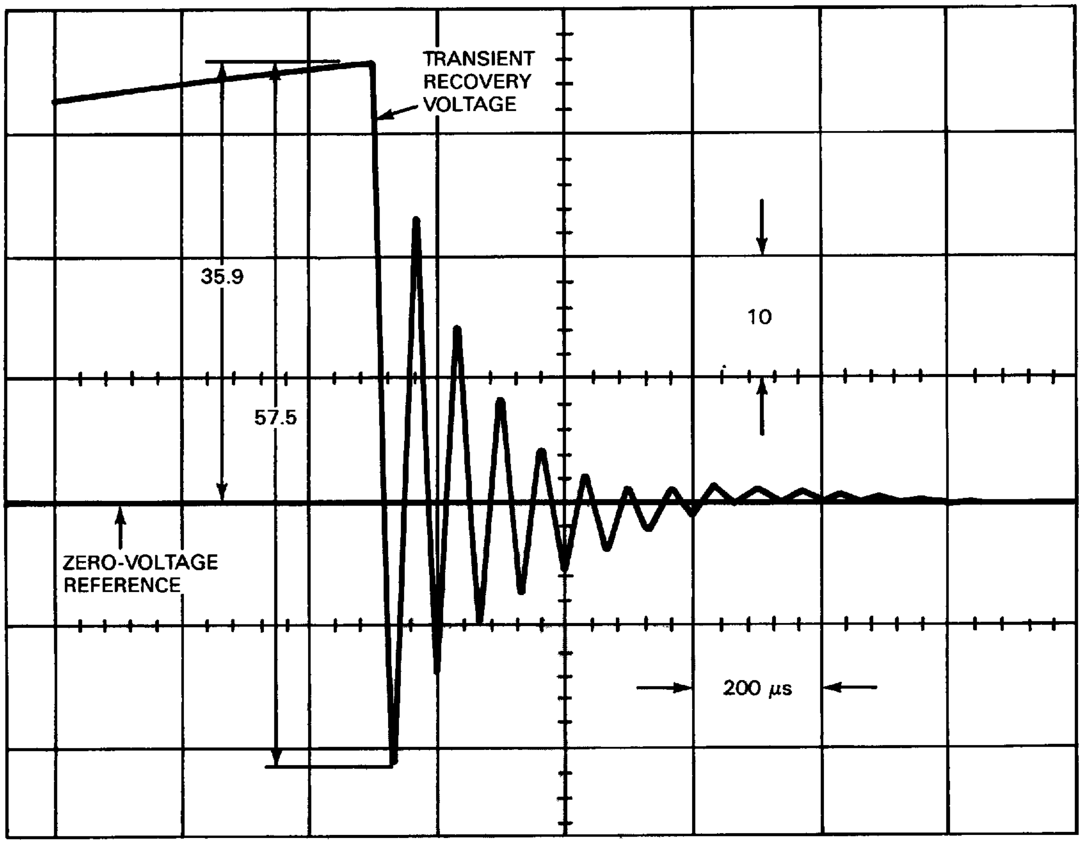
TYPICAL CIRCUIT DIAGRAM FOR TEST SERIES 5, 6[a]—TABLE 2
TEST SERIES 4, 5[a]—TABLE 5 AND 8
TEST SERIES 3[a]—TABLE 10
TEST SERIES 2[a]—TABLE 13

[a]For these Test Series (6, 5, 3, and 2), C_2 is not required and R_3 is connected across X_{L2}. Also, TD may be used as an alternate to X_{L2} and R_4 and may have impedance connected between secondary terminals.

A	=	removable link used for the calibration test
CB	=	circuit breaker protecting the source
CS	=	closing switch
CT	=	current transformer or noninductive current shunt
CVD	=	capacitance voltage divider
C_1	=	transient recovery voltage frequency control for source
C_2	=	transient recovery voltage frequency control for load
F	=	fuse under test
G	=	generator
I	=	current measurement
X_{L1}	=	reactance for source
X_{L2}	=	reactance for load (see T_D)
R_1	=	resistance to control X/R ratio of source
R_2	=	damping resistance to control peak factor of source
R_3	=	damping resistance to control peak factor of load
R_4	=	resistance to control X/R ratio of load
T_D	=	distribution transformer with short-circuited secondary terminals (alternative to X_{L2} and R_4)
T_1, T_2	=	possible locations of transformers for tests at voltages higher than generator voltage
V_F	=	recovery voltage measurement
V_S	=	reference voltage measurement

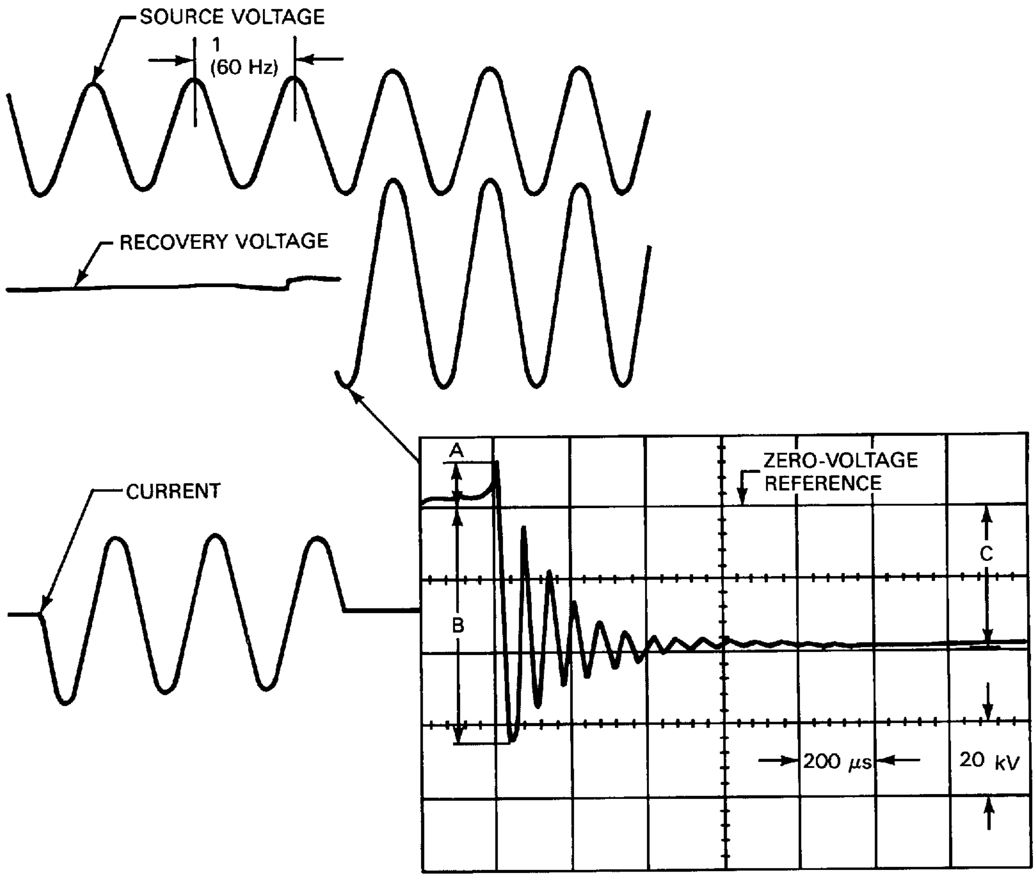
NOTE: Damping circuits other than shown, for controlling the inherent TRV parameters of the test circuit, may be used by mutual agreement between manufacturer and test laboratory. Such use shall be noted and explained in the test report.

Figure D.1—Typical test circuits



Peak Factor = $\frac{57.5}{35.9}$ = 1.6

Figure D.2—Peak factor determination from current-injection test record



$$\text{Peak Factor} = \frac{B + A}{C \sin(\tan^{-1} X/R) + A}$$

$$= \frac{64.2 + 11.5}{38.2 \sin(\tan^{-1} 2.8) + 11.5} = 1.6$$

Figure D.3—Peak factor determination from fault-interruption test record