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IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations

IEEE Power Engineering Society

Sponsored by the
Substations Committee

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IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations

Sponsor

Substations Committee
of the
IEEE Power Engineering Society

Approved 20 March 2003

IEEE-SA Standards Board

Abstract: Service conditions, electrical ratings, thermal ratings, and environmental testing requirements are defined for communications networking devices to be installed in electric power substations. This standard establishes a common reproducible basis for designing and evaluating communications networking devices for use in this harsh environment.
Keywords: autodialers, bridges, communications networking device, derating, dielectric test, environmental requirements, ESD test, Ethernet hubs, fast transient test, firewalls, humidity, impulse test, insulation test, modems, power apparatus, RF test, routers, SWC test, switches, temperature range, temperature rise, voltage rating

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Introduction

(This introduction is not part of IEEE Std 1613-2003, IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations.)

This standard has been compiled from the relevant clauses of IEEE Std C37.90™-1989 [B6][a], IEEE Std C37.90.1™-2002 [B7], IEEE Std C37.90.2™-1995 [B8], and IEEE Std C37.90.3™-2001 [B9]. In addition, it establishes more stringent requirements than exist in these IEEE or relevant IEC standards in the following areas:

- Clause 4 requires the operation of the device with no fans or forced ventilation. It also requires startup after soaking at the temperature extremes (not required in IEEE Std C37.90-1989 [B6] or in IEC 60255-6:1988 [B1]).
- Clause 7, Clause 8, and Clause 9 define the communications required during tests and two performance classes. Class 1 allows communications errors or interruption during the defined transient, but requires automatic recovery. Class 2 requires communication without errors or interruption. (Neither are presently defined in IEEE or IEC).
- Clause 8 requires testing at a field strength level of 35 V/m, as defined in IEEE Std C37.90.2-1995 [B8] and reflecting North American experience. This is more severe than IEC 60255-22-3:2000 [B2] that requires only 10 V/m maximum. The test method is the one defined by IEC 60255-22-3:2000.
- Clause 9 requires testing at voltage levels corresponding to a relative humidity less than 35%, identical to IEEE Std C37.90.3-2001 [B9] (not required by IEC 61000-4-2:2001 [B3]).

The protection of metallic communications circuits into electric power substations is not covered in this standard, but is the specific topic of IEEE Std 487™-2000 [B10]. The following excerpt is Clause 1 from IEEE Std 487-2000:

"**1. Overview**

"Wire-line telecommunication facilities serving electric supply locations often require special high voltage protection against the effects of fault-produced ground potential rise or induced voltages, or both. Some of the telecommunication services are used for control and protective relaying purposes and may be called upon to perform critical operations at times of power system faults. This presents a major challenge in the design and protection of the telecommunication system because power system faults can result in the introduction of interfering voltages and currents into the telecommunication circuit at the very time when the circuit is most urgently required to perform its function. Even when critical services are not involved, special high-voltage protection may be required for both personnel safety and plant protection at times of power system faults. Effective protection of any wire-line telecommunication circuit requires coordinated protection on all circuits provided over the same telecommunication cable."

Participants

This standard was prepared by the C2 TF1 Task Force of the Substations Committee of the IEEE Power Engineering Society. At the time this standard was approved, the task force had the following membership:

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Contents

1. Overview 1

1.1 Scope 1
1.2 Purpose 1

2. References 2

3. Definitions and word usage 2

3.1 Definitions 2
3.2 Word usage 2

4. Service conditions 3

4.1 Usual service conditions 3
4.2 Other conditions 4

5. Electrical ratings of control power inputs 4

5.1 DC rated control power inputs 5
5.2 Allowable ac component in dc control voltage supply 5
5.3 AC rated control power inputs 5

6. Insulation tests 5

6.1 General requirements 6
6.2 Dielectric power frequency test 6
6.3 Impulse voltage test 7

7. SWC tests 9

7.1 Scope 9
7.2 Purpose 9
7.3 Test waveforms 9
7.4 Test generator characteristics 11
7.5 Verification of test generator characteristics 12
7.6 Equipment to be tested 13
7.7 Test points 13
7.8 Application of test wave 13
7.9 Conditions of tests 14
7.10 Coupling to test generator 15
7.11 Test procedures 18
7.12 Device performance classes 20
7.13 Conditions to be met (acceptance criteria) 20
7.14 Test records 21

8. Radio frequency (RF) susceptibility tests 21

8.1 Electromagnetic environment 22
8.2 Test conditions 22
8.3 Test levels 23

--`,,`-`-`,,`,,`,`,,`---

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8.4 In-Service conditions 23
8.5 Test environment 23
8.6 Test equipment 24
8.7 Test procedure 25
8.8 Device performance classes 26
8.9 Conditions to be met (acceptance criteria) 26
8.10 Test records 27

9. Electrostatic discharge (ESD) tests 27

9.1 ESD disturbance tests 28
9.2 Device performance classes 34
9.3 Conditions to be met (acceptance criteria) 34

10. Vibration and shock 35

Annex A (normative) Verification of test generator characteristics 36

Annex B (informative) Bibliography 40

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IEEE Standard for Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations

1. Overview

Communications networking devices are being installed in electric power substations. Examples include radios, encryption devices, port switches, autodialers, modems, Ethernet hubs and switches, routers, gateways, and firewalls. This standard establishes a common reproducible basis for designing and evaluating communications networking devices for this harsh environment. It does not include communications facilities and equipment integral to protective relaying applications.

1.1 Scope

This document specifies standard service conditions, standard ratings, environmental performance requirements, and testing requirements for communications networking devices installed in electric power substations. It does not cover such equipment designed for operation in other environments, such as office locations. It does not cover such equipment used in protective relaying applications, for which IEEE Std C37.90™-1989 [B6][1], IEEE Std C37.90.1™-2002 [B7], IEEE Std C37.90.2™-1995 [B8], and IEEE Std C37.90.3™-2001 [B9] apply.

1.2 Purpose

The purpose of this standard is to define the environmental conditions present in electric power substations and to establish a common reproducible basis for designing and evaluating communications networking devices to be installed in those substations. It is a freestanding document, with only one normative reference to another standard.

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2. References

This standard shall be used in conjunction with the following publication. When the following publication is superseded by an approved revision, the revision shall apply.

IEEE Std C37.100™-1992 (Reaff 2001), IEEE Definitions for Power Switchgear.[2, 3]

3. Definitions and word usage

For this standard, the following terms and definitions apply. IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B4], should be referenced for terms not defined in this clause.

3.1 Definitions

3.1.1 autodialer: A device that can open a telephone line and initiate a call by transmitting a stored telephone number. This functionality could be built into a modem or it may be a stand-alone device.

3.1.2 communications networking device: An intelligent electronic device (IED) that is an element of a communications network. Examples of such IEDs include modems, Ethernet hubs and switches, routers, bridges, autodialers, firewalls, and port switches.

3.1.3 firewall: A device or combination of hardware and software used to enforce communication security by blocking unauthorized access to a local area network (LAN).

3.1.4 port switch: A serial communication device that allows a user to connect to one of several communication ports through a single interface.

3.1.5 shielded enclosure: Screen or solid metal housing designed expressly for the purpose of isolating the internal equipment from the external electromagnetic environment.

3.2 Word usage

3.2.1 Shall

The word *shall,* equivalent to "is required to," is used to indicate mandatory requirements, strictly to be followed in order to conform to the standard and from which no deviation is permitted.

3.2.2 Recommended

The word *recommended* is used to indicate flexibility of choice with a strong preference alternative.

3.2.3 Must

The use of the word *must* is deprecated and shall not be used when stating mandatory requirements. The word *must* is used only to describe unavoidable situations.

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3.2.4 Should

The word *should*, equivalent to "is recommended that," is used to indicate the following:

— Among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others.
— That a certain course of action is preferred but not required.
— That (in the negative form) a certain course of action is deprecated but not prohibited.

3.2.5 May

The word *may*, equivalent to "is permitted," is used to indicate a course of action permissible within the limits of this standard.

3.2.6 Can

The word *can*, equivalent to "is able to," is used to indicate possibility and capability, whether material or physical.

4. Service conditions

(This clause is adapted from the IEEE Std C37.90-1989 [B6] revision that was in progress when IEEE Std 1613-2003 was approved.)

Service conditions include operational and nonoperational temperature and relative humidity. Conditions outside the scope of this standard are listed in 4.2.

4.1 Usual service conditions

Communications networking devices conforming to this standard shall be suitable for operation under the conditions outlined in 4.1.1 through 4.1.3.

4.1.1 Operational temperature range

Operational temperature is the temperature of still air (i.e., no fans or forced-air movement) measured 30 cm from the surface of the unit (i.e., communications networking device) enclosure while in operation. For a specified temperature range (e.g., –20 °C to +55 °C), a unit shall be able to start up and continue its operation at the specified minimum temperature (i.e., –20 °C) within 5 min after having been de-energized for a sufficient time so that its internal components have cooled to that temperature without condensation. A unit shall also be able to start up and continue its operation within 5 min at the specified maximum temperature (i.e., +55 °C) after having been de-energized for a sufficient time so that its internal components have heated to that temperature.

The manufacturer shall declare one of the following ranges of ambient temperature for which the unit is to be rated:

a) –40 °C to +70 °C
b) –30 °C to +65 °C
c) –20 °C to +55 °C (the default range if no other range is specified)
d) Range defined by the manufacturer

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4.1.2 Nonoperational temperature range

Nonoperational temperature is the air temperature for conditions of transport, storage, and installation, so that the unit will not experience damage due to indefinite exposure to such temperatures.

The manufacturer shall declare one of the following ranges of ambient temperature for which the unit is to be rated:

a) –50 °C to +85 °C
b) –40 °C to +75 °C
c) –30 °C to +65 °C
d) Range defined by the manufacturer

If a nonoperational temperature range is not specified, the default nonoperational temperature range shall be the same as the operational temperature range.

4.1.3 Relative humidity

Communications networking devices shall be capable of withstanding an average relative humidity up to 55% outside of the device or communication networking system's enclosure or cover for a temperature within the defined operational and nonoperational ranges, with excursions up to 95% without internal condensation for a maximum of 96 h.

4.2 Other conditions

Other conditions not covered by this standard may require special construction, treatment, or operational considerations. These conditions shall be brought to the attention of the people responsible for the application, manufacture, and operation of communications networking devices. Among such conditions are exposure to the following:

a) Damaging smoke, fumes, or vapors
b) Moisture or dripping water
c) Dust (abrasive, magnetic, conductive, obstructive, etc.)
d) Explosive mixtures of dust and gases
e) Steam
f) Salt air
g) Shock and vibration (see Clause 10)
h) Seismic disturbances
i) Transportation or storage conditions
j) Extreme temperature or sudden change in temperature
k) Extreme variations of supply voltage
l) Excessive electrical wave distortion
m) Excessive electrical noise
n) Electromagnetic radiation other than the radiation specified in Clause 8
o) Nuclear radiation

5. Electrical ratings of control power inputs

(This clause has been adapted from IEEE Std C37.90-1989 [B6].)

This clause defines the ratings of dc and ac control power inputs and allowable ripple on dc supplies.

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5.1 DC rated control power inputs

DC power supplies and auxiliary circuits with dc voltage rating shall be able to continuously withstand the maximum design voltage shown in Table 1. They shall be capable of operating successfully over a range from 80% of rated voltage to the maximum design voltage. Power supplies with a wide dc voltage range (i.e., 12 V to 250 V) are encouraged.

Table 1—Maximum design voltage for dc control power

Rated voltage (V)	Maximum design voltage (V)
12	14
24	28
48	56
110	123
125	140
220	246
250	280

5.2 Allowable ac component in dc control voltage supply

Communications networking devices shall operate properly with an alternating component (i.e., ripple) of 5% peak or less in the dc control voltage supply, provided the minimum instantaneous voltage is not less than 80% of rated voltage. The ripple content of dc supply expressed as percentage is defined as

$$\frac{(\text{peak value} - \text{dc component})}{(\text{dc component})} \times 100 \quad (1)$$

NOTE—Equation (1) refers to low-frequency ripple as might typically be introduced on the dc control power bus by a battery charger. Higher frequency effects, such as might be introduced by a dc-dc converter within the device or equipment itself, are not sufficiently defined at this time to be included in this standard.

5.3 AC rated control power inputs

AC power supplies and auxiliary circuits with ac voltage ratings shall be capable of operating successfully over a minimum range of 85% to 110% of rated voltage and frequency. The ac voltage rating shall be 120 V 60 Hz, 240 V 50 Hz, or 120–240 V 50–60 Hz.

6. Insulation tests

(This clause is adapted from IEEE Std C37.90-1989 [B6].)

Insulation tests include dielectric power frequency tests and impulse tests. These tests and their application to the device under test are identical to the tests and applications specified in IEEE Std C37.90-1989 [B6].

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6.1 General requirements

Atmospheric conditions for insulation tests shall be within the following ranges:

— Ambient air temperature: 15 °C to 35 °C
— Relative humidity: 45% to 75%
— Air pressure: 86 kPa to 106 kPa[4]

6.2 Dielectric power frequency test

The dielectric power frequency test consists of applying a specified voltage to the insulation systems of the device under test to prove that the insulation is in accordance with the rated insulation voltage stated by the manufacturer.

6.2.1 Test voltage and waveform

The test voltages and wave form shall be as shown in Table 2.

Table 2—Dielectric test voltage

Product rated voltage	Test voltage root mean square (rms)
50 and below[a]	500
51 to 250	2000

[a]Generally utilized for communications or low-level input/output.

The test source shall be substantially sinusoidal with a frequency between 45 Hz and 65 Hz.

The source voltage shall be verified with an accuracy better than 5%.

The test voltage source shall be such that, when applying the specified value to the device under test, the voltage drop observed is less than 10%.

These dielectric tests may be conducted using a dc source. For dc testing, the test voltages shall be 1.4 times the values given for ac tests.

6.2.2 Test requirements

Dielectric power frequency tests are considered to be both type tests and production tests to be performed by the manufacturer.

Dielectric tests, in accordance with this standard, may be performed once by the user on new devices to determine whether specifications are fulfilled. New devices, for this test, are defined as devices that

— Have not been in service,
— Are not more than one year old from the date of shipment, and
— Have been suitably stored to prevent deterioration.

[4]860 mbar to 1060 mbar.

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Additional dielectric tests may be made using 75% of the test voltage determined in accordance with Table 2 at the point of installation to determine the practicality of placing or continuing the equipment in service.

6.2.3 Points to be tested

Dielectric tests shall be performed

a) Between each independent circuit and the ground circuit. The terminals of each independent circuit may be connected together. For devices with an insulating enclosure, the ground circuit shall be represented by a metal foil covering the entire enclosure except the terminals around which a suitable gap shall be left to avoid flashover to the terminals. Insulation tests requiring this metal foil shall be performed as design tests only.
b) Between independent circuit groups, with the terminals of each independent circuit in the group being connected together. Independent circuit groups are to be defined by the manufacturer.
c) Between the terminals of open contacts—only as a design test. Dielectric tests are not required across contacts with surge-suppression components, nor across solid-state output circuits. If a dielectric test is not performed, the surge withstand capability (SWC) test (see Clause 7) is to be substituted for the dielectric test.

6.2.4 Test method

During the testing, no input or auxiliary energizing quantity shall be applied to the device.

Test voltage shall be applied directly to the device terminals.

The open-circuit voltage of the testing equipment is initially set to not more than 50% of the specified voltage. It is then applied to the device under test. From this initial value, the test voltage shall be raised to the specified value, in such a manner that no appreciable transients occur, and then maintained for 1 min. It shall then be reduced smoothly to zero as rapidly as possible.

As an alternate, to be used at the point of manufacture only, it is permissible to test any device for 1 s at a value 20% higher than the standard 1 min test voltage.

6.2.5 Criteria for acceptance

During the dielectric test, no breakdown or flashover shall occur and no components shall be damaged. After the test, the device shall still comply with all relevant performance requirements.

6.3 Impulse voltage test

The impulse voltage test consists of applying a specified impulse voltage to the insulation to prove the ability of the device to withstand, without damage, overvoltages of very high values and very short duration.

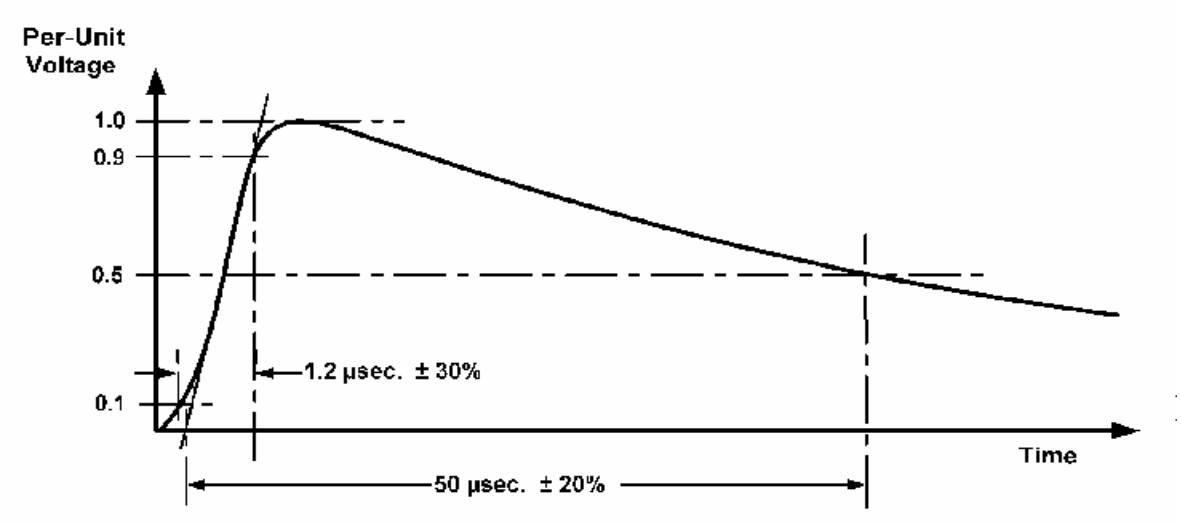
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6.3.1 Impulse test voltage and waveform

The impulse test wave form shall be in acordance with Figure 1 and its explanatory notes.



NOTES

a) *Waveform polarity:* Positive and negative
b) *Rise time:* 1.2 µs ± 30%
c) *Magnitude:* 5 kV +0/–10%
d) *Time to half value:* 50 µs ± 20%
e) *Source impedance:* 500 Ω ± 10%
f) *Output energy:* 0.5 J ± 10%

Figure 1—Impulse voltage waveform

6.3.2 Impulse test requirements

Impulse voltage tests are considered design tests.

Impulse tests, in accordance with this standard, may be repeated once by the user only on new devices, to determine whether specifications are fulfilled. New devices, for this test, are defined as devices that have not been in service, that are not more than one year old from the date of shipment, and that have been suitably stored to prevent deterioration.

Additional impulse tests may be made using 75% of the test voltage given (see 6.3.1) at the point of installation to determine the practicality of placing or continuing the equipment in service.

6.3.3 Points to be impulse tested

Impulse voltage tests shall be applied

a) Between each independent circuit and the ground circuit. The terminals of each independent circuit may be connected together. For devices with an insulating enclosure, the ground circuit shall be represented by a metal foil covering the entire enclosure except the terminals around which a suitable gap shall be left to avoid flashover to the terminals.
b) Between independent circuit groups, with the terminals of each independent circuit in the group being connected together. Independent circuit groups are to be defined by the manufacturer.

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c) Between the terminals of a given circuit unless otherwise specified by the manufacturer.

Circuits rated 50 V or less and not intended for connection to voltage transformers, current transformers, or the dc battery source, shall be excluded from impulse testing. These circuits shall be tested per Clause 7.

NOTE—When testing equipment incorporating components across the test circuit, e.g., voltage suppression, the test voltage may be noticeably distorted or chopped according to the characteristics of the voltage limiting components.

6.3.4 Impulse test method

During the impulse testing, no input or auxiliary energizing quantity shall be applied to the device.

Test voltage shall be directly applied to the device terminals.

Three positive and three negative impulses shall be applied. The interval between each impulse shall be 1 s or greater.

6.3.5 Criteria for acceptance of impulse test

During the impulse test, no breakdown or flashover shall occur, and no components shall be damaged. After the test, the device shall still comply with all relevant performance requirements.

7. SWC tests

Required surge test methods are identical to the methods specified in IEEE Std C37.90.1-2002 [B7]. Standardized test waveforms that are representative of surges observed and measured in actual substation installations are applied to the terminals of the device.

7.1 Scope

This clause specifies design tests for communications networking devices that relate to the immunity of these devices to repetitive electrical transients. Two types of tests are specified. The oscillatory and fast transient SWC tests are defined as distinct tests. However, it is not intended to prohibit a combined test, provided all requirements of the individual SWC tests are met.

7.2 Purpose

The purpose is to establish a common and reproducible basis for evaluating the performance of communications networking devices when subjected to repetitive transients on supply, signal, control, and communication lines or connections.

7.3 Test waveforms

The oscillatory and fast transient test waveforms are defined in 7.3.1 and 7.3.2.

7.3.1 Oscillatory waveform

Refer to Figure 2.

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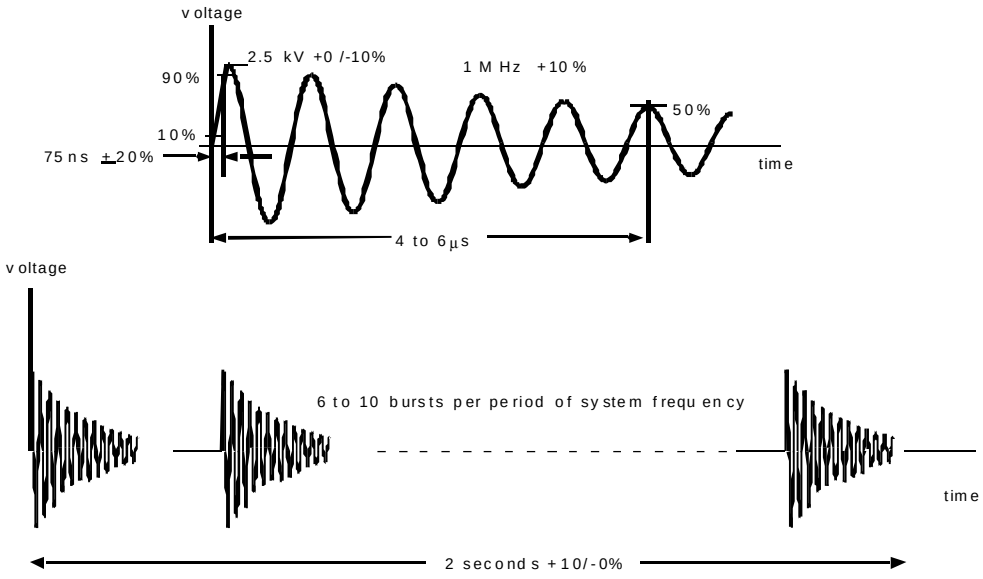


Figure 2—Oscillatory SWC test waveform

The test voltage parameters for an open-circuit generator condition at the generator terminals shall be as follows:

a) *Waveform envelope.* A damped oscillatory wave, with the envelope decaying to 50% of peak value between the third and sixth periods.
b) *Frequency.* 1 MHz (tolerance ± 10%).
c) *Rise time of first peak.* 75 ns (tolerance ± 20%), as measured between 10% and 90% of the peak value.
d) *Test voltage magnitude.* Initial crest of 2.5 kV for common-mode tests and for transverse-mode tests (tolerance +0/–10%).
e) *Repetition rate.* Six to 10 bursts per period of the power system frequency. Bursts shall be nonsynchronous with the power system frequency.
f) *Duration.* 2 s (tolerance +10%/–0%).
g) *Source impedance.* 200 Ω resistive at 1 MHz (tolerance ± 20%).

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7.3.2 Fast transient test waveform

Refer to Figure 3.

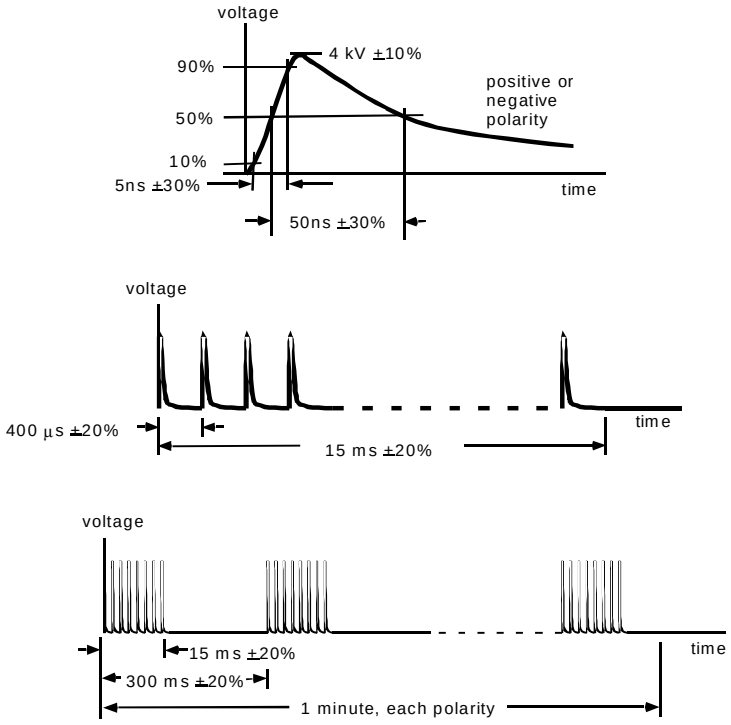


Figure 3—Fast transient SWC test waveform

The test voltage parameters for an open-circuit generator condition at the generator terminals shall be as follows:

a) *Waveform polarity.* Positive and negative.
b) *Rise time.* 5 ns (tolerance ± 30%).
c) *Magnitude.* 4 kV crest value (tolerance ± 10%).
d) *Pulse duration.* 50 ns (tolerance ± 30%) (50% value).
e) *Repetition rate.* The waveform consists of bursts of pulses that repeat periodically.
    1) *Burst duration.* 15 ms (tolerance ± 20%)
    2) *Repetition rate during bursts.* 2.5 kHz (tolerance ± 20%)
    3) *Burst period.* 300 ms (tolerance ± 20%)
f) *Duration.* Not less than 1 min, each polarity.
g) *Source impedance.* 50 Ω (tolerance ± 20%) between 1 MHz and 100 MHz.

7.4 Test generator characteristics

The required characteristics of the oscillatory SWC and fast transient SWC test generators are defined in 7.4.1 through 7.4.6.

7.4.1 Oscillatory SWC test generator output

The test generator shall be capable of producing the output test voltage waveform as described in 7.3.1. It shall also meet the requirements of 7.3.1 regarding frequency, rise time, magnitude, repetition rate, test burst duration, and source impedance and meet the requirements listed in 7.4.3.

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7.4.2 Fast transient SWC test generator output

The test generator shall be capable of producing the output test voltage waveform as described in 7.3.2. It shall also meet the requirements of 7.3.2 regarding polarities, rise time, magnitude, repetition rate, test burst duration, and source impedance and meet the requirements listed in 7.4.3.

7.4.3 Low frequency and dc blocking

The test generators shall have an internal blocking capacitor of 0.1 μF to allow application of the test to live input and output circuits without shorting or overloading the ac signal source or dc supply source during SWC testing.

7.4.4 Coupling/Decoupling network

A suitable network shall be included external to the test generators to couple the test voltage to the device under test and to prevent the SWC test voltage from being propagated back into the ac signal source.

7.4.5 Safety ground

The test generators shall have a dedicated safety ground connector terminal.

7.4.6 Test mode capability

The generators shall be capable of providing a common-mode output voltage with one output terminal grounded and a balanced transverse-mode output voltage where both output terminals are floating.

7.5 Verification of test generator characteristics

It is necessary to establish a simple test procedure intended to verify and document the SWC generator performance prior to its use for these tests. Two verification tests are defined:

a) SWC waveform validity tests
b) SWC test generator performance verification

The detailed test description is given in Annex A.

7.5.1 SWC waveform validity tests

The waveform validity tests shall be performed before and after each SWC test session, with the results recorded and included with the SWC test report. The tests described in A.2 are intended to verify that there is no major insulation breakdown, damage, or test system component failure that may have occurred during the physical test setup, test application, or prolonged instrument storage. The waveform validity tests shall include the following:

a) Measuring system feedthrough test
b) Oscillatory SWC test generator open-circuit voltage waveform test
c) Fast transient SWC test generator open-circuit voltage waveform test

Measurement methods different from the methods described in Annex A are acceptable, as long as the same level of precision and the same parameters are used to document the results.

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7.5.2 SWC test generator performance verification

A full set of SWC test generator characteristics shall be verified per the manufacturer's recommendations or at least once every year, with the test results dated, recorded, and included with each SWC test report. These tests are intended to precisely document the test generator characteristics and are used to track the SWC generator's compliance with this standard. The characteristics to be verified are given in Table 3.

Table 3—SWC test generator characteristics to be verified

Fast transient	Oscillatory waveform
Rise time	Rise time of the first peak
Peak voltage level (no load)	Peak voltage level (no load)
Output impedance	Output impedance
Impulse duration	Waveform envelope decay
n/a	Oscillation frequency
Repetition rate during the burst	Repetition rate
Burst duration	n/a
Burst period	n/a
Test duration	Test duration

All performance verification measurements shall be preceded by conducting an SWC waveform validity test as described in A.2.

7.6 Equipment to be tested

The tests described herein are design tests to be applied to communications networking devices that can be exposed to conducted or coupled transients under normal installed operating conditions. It is not the intent of these tests to test an isolated subassembly of a communications networking device unless that subassembly can be used independently and located more than 2 m from the rest of the device.

Prefabricated wiring harnesses, connectors, or shelf wiring shall not be disrupted.

Testing is not required for ports that are intended for use only during installation or maintenance and are not permanently connected during normal operation.

7.7 Test points

After the substation communication system is defined, all points of connection between the communications system and external circuits shall be tested.

7.8 Application of test wave

All external connections to the system shall be considered in one of the following four groups, as defined in IEEE 100 [B4]:

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a) Power supply
b) Outputs, such as alarms
c) Digital data
d) Signal circuits

Items that can be excluded from testing include the following:

— Temporary connections to maintenance computers or test equipment
— Connections that, as stated by the manufacturer, shall be less than 2 m in length
— Nonmetallic connections, such as fiber

The test voltage shall be applied to the respective external connection groups in common or transverse mode according to 7.11.

7.9 Conditions of tests

The tests shall be made under usual service conditions in accordance with 4.1. Typical test setups for small and large equipment are shown in Figure 4 and Figure 5, respectively.

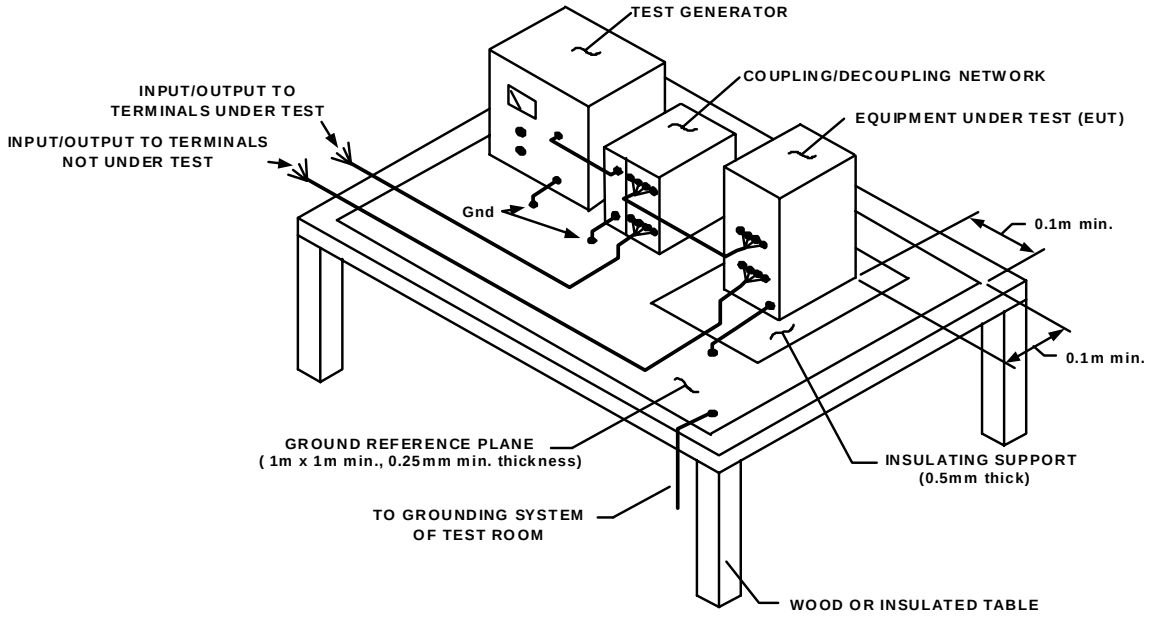


Figure 4—Example of SWC test setup for small equipment

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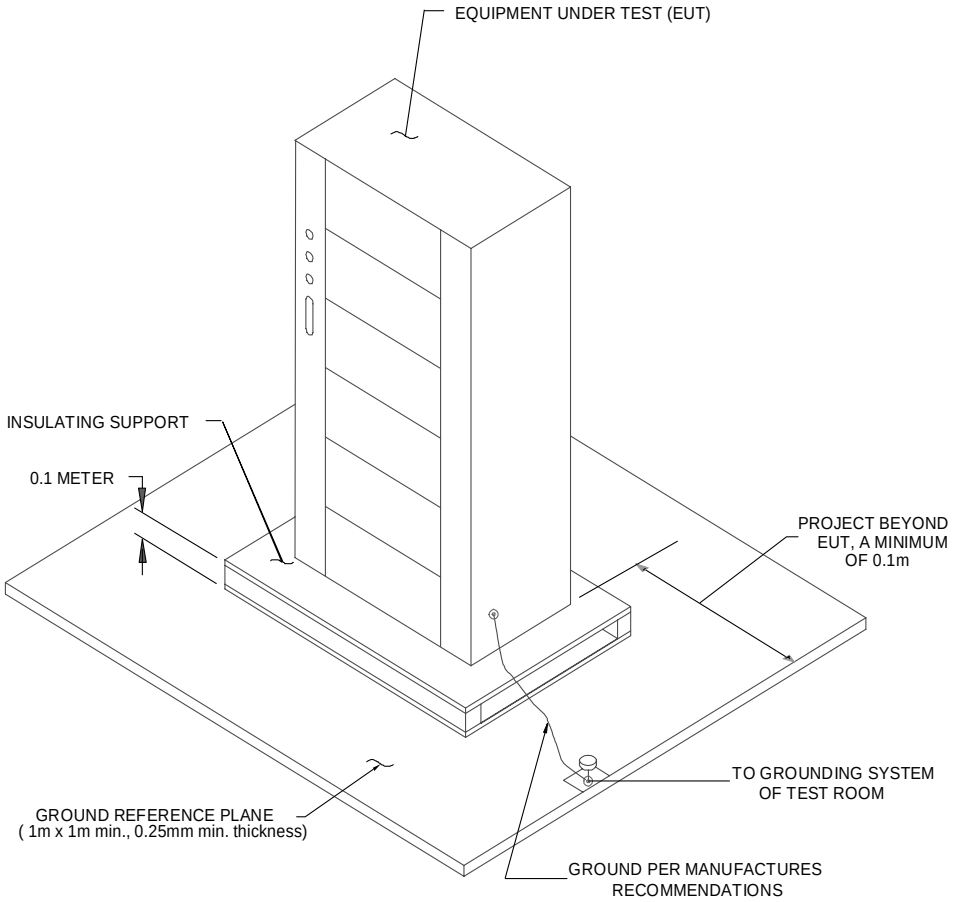


Figure 5—Example of SWC test setup for large equipment

7.10 Coupling to test generator

Application of the test wave to the device under test shall be done using coupling/isolating networks or capacitive coupling clamps as described in 7.10.1 and 7.10.2.

7.10.1 Coupling/Isolating networks

Figure 6 and Figure 7 show common- and transverse-mode connections where isolation from a normal current or voltage source is required. This method shall be used when testing power supply, input circuit, or output external connection groups.

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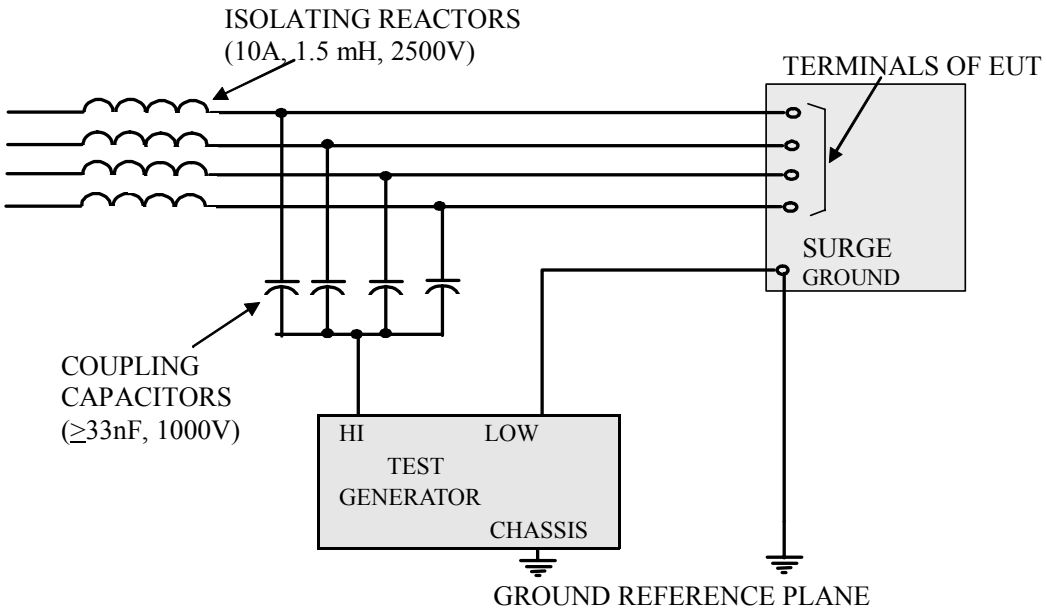


Figure 6—Application of common-mode tests using coupling/isolating network

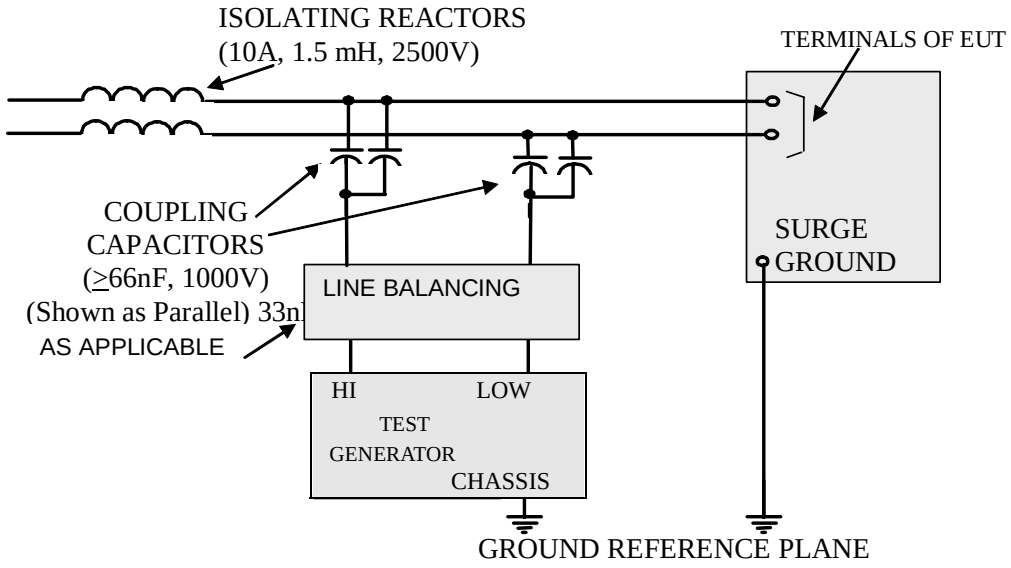


Figure 7—Application of transverse-mode tests using coupling/isolating network

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7.10.2 Capacitive coupling clamp

The capacitive coupling clamp is intended as a means for coupling test waveforms to shielded and other circuits where direct galvanic connection to the terminals of the equipment under test (EUT) or device under test may impair operation. Typical use of the clamp for common-mode tests is shown in Figure 8. The use of the capacitive clamp shall be limited to the uses indicated in Table 4 and Table 5 (in 7.11).

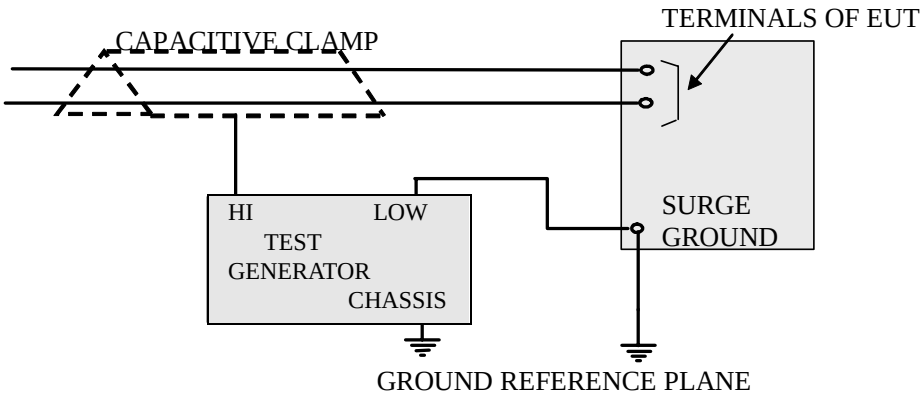


Figure 8—Application of common-mode tests using capacitive coupling clamp

The capacitive clamp consists of two conductive surfaces (made of galvanized steel, brass, copper, or aluminum) insulated from each other by means of high-quality insulating supports. Figure 9 shows construction details of the clamp. The coupling effect is established by placing an insulated cable (feeding the signals to the device under test) through the V-shaped duct on top of the clamp and subsequently closing the clamp as much as possible in order to maximize the coupling capacitance between the clamp and the cable. The lower conductive surface of the clamp shall be placed on (and solidly connected to) a ground plane with a minimum area of 1 m^2. The reference ground plane shall extend beyond the clamp by at least 0.1 m on all sides.

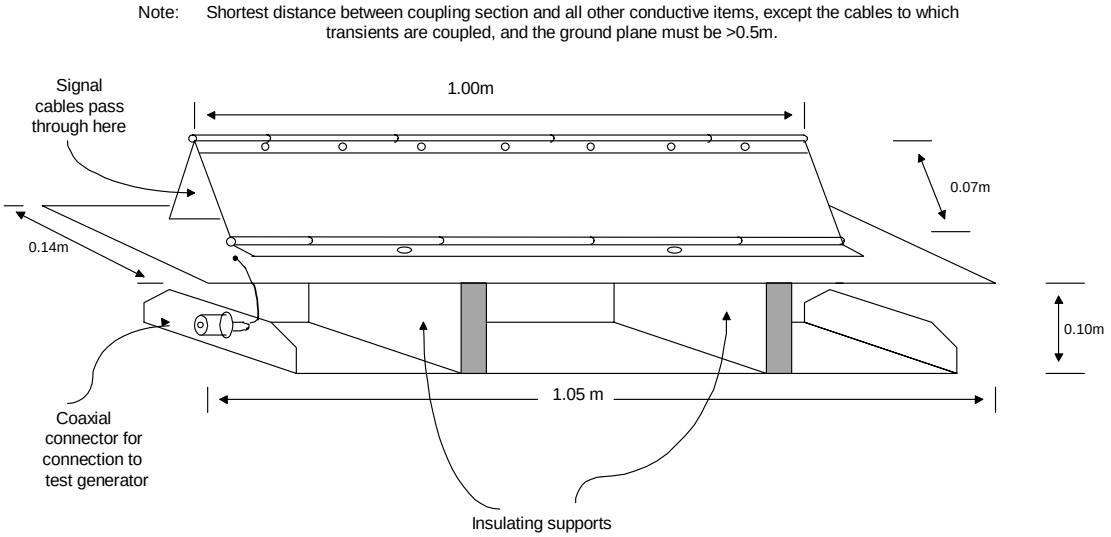


Figure 9—Capacitive coupling clamp

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The high-voltage coaxial connector intended for connection to the test generator may, for convenience, be provided on both ends of the clamp. Regardless of the design, however, during the test the generator shall be connected to the end of the clamp that is nearest to the device under test. Due to the high voltages involved, the external insulation on the cable to which the transients are being coupled shall be capable of withstanding a 5 kV 1.2/50 μs pulse.

7.10.3 Reference ground plane

A reference ground plane shall be used to get reproducible capacitive coupling conditions. The ground plane shall consist of a metallic sheet (copper or aluminum) of at least 0.25 mm thickness. It shall have a minimum size of 1 m by 1 m or project beyond the external dimensions of the device under test by at least 0.1 m on all sides, whichever is greater. The reference ground plane shall be connected to ground.

7.10.4 Device placement

The device shall be tested in its case above a ground reference plane placed on top of a nonconductive table approximately 0.8 m high. The device shall be isolated from the ground reference plane by an insulating support 0.5 mm thick. Floor standing equipment shall be placed on the reference ground plane with the interposition of an insulating support, 0.1 m thick, such as dry wood.

7.10.5 Wiring connections

Wiring to the device shall be consistent with the manufacturer's recommended procedures. When there are no recommendations given by the manufacturer, all parts to be grounded shall be connected with copper straps of at least 20 mm width through the shortest possible distance to the ground plane. Cables interconnecting the various external circuits of the device under test shall be kept at a distance of at least 0.1 m from the ground plane. Leads from the coupling/isolating network to the device or to the test generator shall be no longer than 1 m. When using the capacitive coupling clamp, the leads from the device shall be extended by 1 m to allow placement along the full length of the coupling plates. The minimum distance between the coupling plates and all conductive structures other than the ground plane shall be 0.5 m.

7.10.6 Power supply values

It is the intent of this test to duplicate as nearly as possible in-service conditions with the device in its normal operating state. Input voltage to power supply circuits shall be within specified limits.

7.11 Test procedures

The test waveforms described in 7.3 shall be applied to each external connection group using common and transverse modes as shown in Table 4 and Table 5. The voltage of the test waveforms shall be as defined by Table 4 and Table 5 unless specifically marked otherwise on the product or associated manufacturer's instruction manual. The device connections for the fast transient wave shapes shall be subjected to both polarities.

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Table 4—Test modes and voltage for each external connection group—oscillatory test

External connection group	Test modes		Oscillatory test voltage to be applied
	Common	Transverse	
Power supply	Yes	Yes	2.5 kV
Output	Yes	Yes	2.5 kV
Data communications	Yes	No	2.5 kV[a]
Signal circuit	Yes	No	2.5 kV[a]

[a]Applied through capacitive coupling clamp.

Table 5—Test modes and voltage for each external connection group—fast transient test

External connection group	Test modes		Fast transient test voltage to be applied
	Common	Transverse	
Power supply	Yes	Yes	4 kV
Output	Yes	Yes	4 kV
Data communications	Yes	No	4 kV[a]
Signal circuit	Yes	No	4 kV[a]

[a]Applied through capacitive coupling clamp.

7.11.1 Common-mode tests

The intent of a common-mode test is to expose an external connection group to a surge referenced to earth ground. One terminal of the test generator shall be connected to the external connection group to be tested using the coupling/isolating network as shown in Figure 6 (in 7.10.1) or capacitive coupling clamp as shown in Figure 8 (in 7.10.2). The other terminal of the test generator shall be connected to ground.

7.11.2 Transverse-mode tests

The intent of a transverse-mode test is to expose each pair of a given external connection group to a surge across its terminals. One terminal of the test generator shall be connected to one external connection, or logical group of connections, and the other terminal of the test generator shall be connected to another external connection of a pair or logical group as shown in Figure 7 (in 7.10.1). The test shall be repeated for other pairs until each pair has been tested.

7.11.3 Communications conditions during SWC tests

For Performance Class 1 equipment, the manufacturer shall declare the communications conditions during SWC testing. Although the bit rate and frame size of the communications conditions are not specified in this standard, there shall be communications underway in order to verify that, if disrupted, communications recover.

For Performance Class 2 equipment, SWC testing shall be conducted with devices under each of the communications profiles shown in Table 6 or Table 7, as applicable.

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Table 6—Device communications profiles (i.e., conditions) during SWC tests for equipment with specified ranges of frame size (e.g., an Ethernet switch)

Profile	Bit rate	Frame size	Frame rate (loading) (% of maximum)[a]	Comments
1	0	0	0	Idle conditions (no communications)
2	Maximum	Maximum	30	Simulate typical loading
3	Maximum	Maximum	90	Simulate heavy loading

[a]The "% of maximum" refers to the average throughput maintained during the test compared to the maximum sustainable throughput. The maximum sustainable throughput is the rate above which error-free communication cannot be sustained by the unit under test under normal service conditions.

Table 7—Device communications profiles (i.e., conditions) during SWC tests for equipment without specified ranges of frame size (e.g., serial media converters)

Profile	Bit rate	Comments
1	0	Idle conditions (no communications)
2	30% of maximum	Simulate lower bandwidth communications
3	Maximum	Simulate higher bandwidth communications

7.12 Device performance classes

There shall be two performance classes for devices during SWC tests:

— *Class 1.* This performance class is for communications devices used for general-purpose substation communications where temporary loss of communications and/or communications errors can be tolerated during the occurrence of the SWC transients. All devices shall meet Class 1 requirements unless Class 2 is specified by the user or manufacturer.
— *Class 2.* This performance class is for communications devices used in substation communications where it is desired to have error-free, uninterrupted communications during the occurrence of the SWC transients.

7.13 Conditions to be met (acceptance criteria)

The equipment shall be considered to have passed the oscillatory and fast transient SWC tests if—during, or as a result of, the tests—all of the applicable conditions in 7.13.1 through 7.13.5 are met for the performance class of the device.

7.13.1 Conditions to be met by Class 1 and Class 2 devices

The following conditions are to be met by both Class 1 and Class 2 devices:

a) No hardware damage occurs.
b) No loss or corruption of stored memory or data, including active or stored settings, occurs.
c) Device resets do not occur, and manual resetting is not required.
d) No changes in the states of the electrical, mechanical, or communication status outputs occur. These outputs include alarms, status outputs, or targets.

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e) No erroneous, permanent change of state of the visual, audio, or message outputs results. Momentary changes of these outputs during the tests are permitted.
f) No error outside normal tolerances of the data communication signals (e.g., SCADA analogs) occurs.

7.13.2 Additional condition to be met by Class 1 devices

Established communications in accordance with 7.11.3 may be disrupted or sustain errors during the period the SWC tests are applied. If disrupted, the communications recovers within the manufacturer's specified time period.

7.13.3 Additional condition to be met by Class 2 devices

Established communications in accordance with 7.11.3 shall NOT be disrupted or experience errors during the period the SWC tests are applied.

7.13.4 Equipment functioning

During and after the tests, the equipment shall be completely and accurately functional as designed, unless otherwise stated by the manufacturer, for the equipment to be considered as having passed the SWC tests.

7.13.5 Exceptions

Exceptions to the acceptance criteria pertinent to the equipment shall be stated in the specifications of the equipment.

7.14 Test records

The test program shall be recorded and made available upon request. The report shall be adequate to guide another person to duplicate the test program. The record shall include the following:

a) Product model and revision number for the product under test (serial number, if applicable) and firmware/software version of the product (if applicable).
b) Details of the product's settings, inputs, and operating conditions for each individual test.
c) Diagrams, schematics, or photographs showing the device under test, any externally connected equipment, and related cabling.
d) Description of the SWC test generator and its calibration date and of the coupling networks used.
e) Waveform validity test results per A.2.
f) A tabulation for each test performed. The tabulation of each test shall include the following:
    1) A list of each point that is electrically connected to the SWC test generator and/or coupling networks, with reference to schematics or diagrams as necessary. The list shall include the method of coupling for each point tested.
    2) The settings of the SWC test generator for the particular test, e.g., the voltage level, whether the test is oscillatory or fast transient, etc.
    3) A description of how the device under test was monitored to ensure that any failure was detected. In other words, describe the output lines, indicators, or other features of the device under test that were monitored.
    4) The test results.

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8. Radio frequency (RF) susceptibility tests

Required radio frequency (RF) susceptibility test methods and their application to the device or EUT are adapted from the methods and applications specified in the IEEE Std C37.90.2-1995 revision that was in progress when IEEE Std 1613-2003 was approved. The tests establish a method to evaluate the susceptibility of the device under test to single frequency electromagnetic fields in the RF domain such as the fields generated by portable or mobile radio transceivers.

Most electronic equipment is, in some manner, affected by electromagnetic radiation. This radiation is frequently generated by such sources as the small handheld radio transceivers that are used by operating, maintenance, and security personnel, fixed-station radio and television transmitters, vehicle radio transmitters, and various industrial electromagnetic sources.

In recent years, there has been a significant increase in the use of wireless communication devices and other radio transmitters operating at frequencies between 0.08 GHz and 1 GHz. Many of these services use modulation techniques with a nonconstant envelope, e.g., time division multiple access (TDMA).

The purpose of this clause is to establish a method of determining the susceptibility of equipment used for network communications in a substation to single frequency sources of RF interference. A method of developing electromagnetic fields in the vicinity of a device is described. To generate fields that are useful for simulation of field conditions may require significant antenna drive power to achieve high field-strength levels.

8.1 Electromagnetic environment

The electromagnetic environment is determined by the strength of the electromagnetic field (field strength in volts per meter). The field strength is not easily measured without sophisticated instrumentation nor is it easily calculated by classical equations and formulas because of the effect of surrounding structures or the proximity of other equipment that will distort and/or reflect the electomagnetic waves.

8.2 Test conditions

Subclauses 8.2.1 through 8.2.5 define the testing procedure for systems and individual communications networking devices, the selection of samples for this design test, and the external wiring and the grounding of the EUT.

8.2.1 Communication systems

Communications networking devices, when supplied as part of an integrated system with an enclosure, shall be tested in the enclosure. All components should be mounted and interconnected. Where system components are unavailable at the time of the test, dummy modules may be used, and these modules shall, insofar as possible, duplicate the shielding to be realized from the actual components.

8.2.2 Individual devices

Individual devices shall be tested separately without regard to their ultimate relationship to other circuit components after the devices are finally installed in a system. The responsibility for testing a complete system that is assembled by the user shall rest with the user.

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8.2.3 Selection of test sample

This test is a design test and shall, therefore, be applied to a randomly selected device of each type. The test shall be repeated for each modification to the physical arrangement or selection of components contained in the device, unless documentation is available to indicate tests are not needed.

8.2.4 External wiring

The equipment shall be tested in as close to the installed conditions as possible. Wiring shall be consistent with the manufacturer's recommended procedures. If the use of shielded cable is not specified by the manufacturer for normal installation, unshielded wiring shall be used for the test. At least 1 m of the external wiring shall be run vertically to simulate rack wiring. All external connection terminals of the device shall be connected to external wiring. To reduce the amount of wiring required, more than one terminal may be connected to a wire provided that such grouping does not interfere with the normal operation of the device.

8.2.5 Grounding

All equipment used in the tests, such as hubs, switches, enclosures, and cable shields, shall be properly grounded. Cable trays, conduit, or external cables shall also be grounded.

8.3 Test levels

The field strength prior to modulation shall be 20 V/m rms. The waveform shall be amplitude modulated with a 1 kHz sine wave. Modulation index shall be equal to 80%, with the resulting peak field strength not being less than 35 V/m.

8.4 In-Service conditions

It is the intent of this test to duplicate as nearly as possible in-service conditions with the device in its normal communicating state. Input voltage to the power supply circuit should be within the specified limits. Wiring shall be consistent with the manufacturer's recommended procedures, and the device shall be tested in its case with the covers and access doors, if any, in the closed position.

If the device under test is designed to be mounted in a panel, rack, or cabinet, it shall be tested in this configuration.

8.5 Test environment

A shielded enclosure is recommended for testing. An anechoic chamber is recommended to minimize the effects of reflection within the enclosure. Dimensions for such an enclosure, along with the location of the radiating element and the test specimen, are shown in Figure 10.

A metallic ground plane is not required. When a means is required to support the test unit, it shall be constructed of a nonmetallic, nonconducting material. Grounding of the housing or case of the device under test shall be consistent with the manufacturer's installation recommendations.

Temperature, atmospheric pressure, and relative humidity are not recognized as influential factors for this testing.

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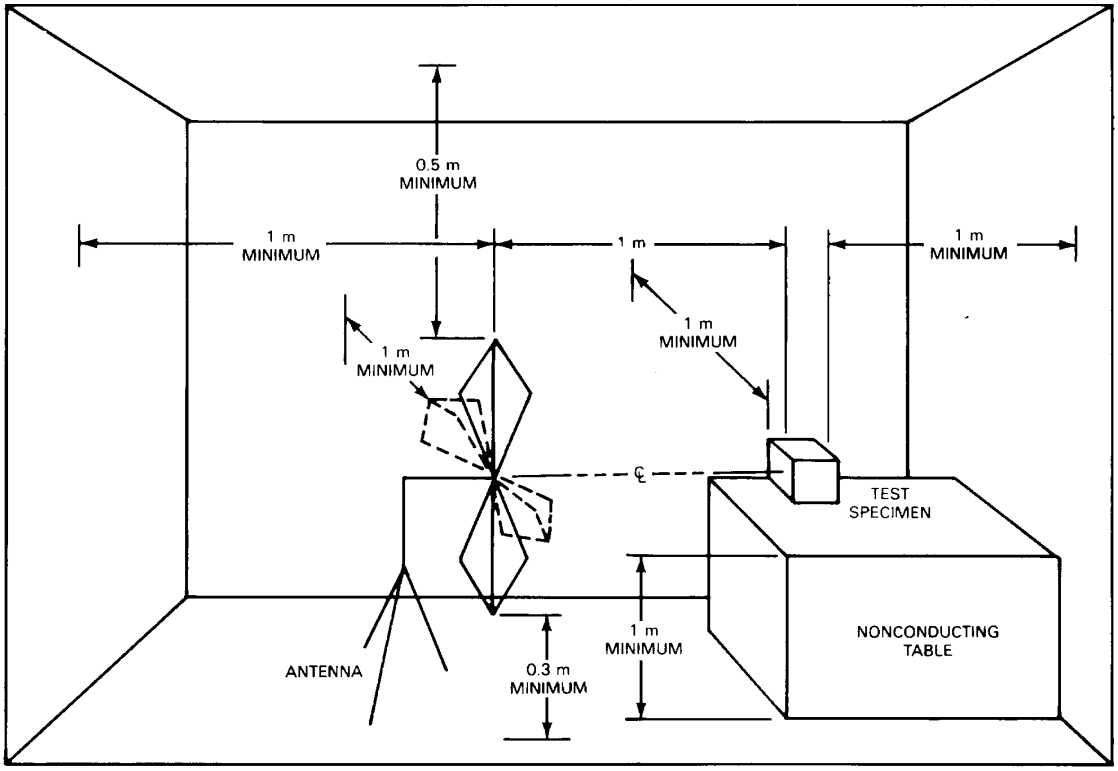


Figure 10—Test setup for RF radiation susceptibility

8.6 Test equipment

The following types of test equipment are recommended. The use of other means of establishing and controlling the field is acceptable providing the following required conditions can be verified:

a) *Anechoic chamber.* Of a size adequate to maintain a uniform field of sufficient dimensions with respect to the EUT. Additional absorbers may be used to damp reflections in chambers that are not fully lined.

NOTE—Alternative methods of generating electromagnetic fields include transverse-electromagnetic (TEM) cells and stripline circuits, unlined screened rooms, partially lined shielded rooms, and open area test sites. Care should be taken to ensure that the conditions of tests are equivalent to the conditions in the anechoic chamber.

b) *Electromagnetic interference (EMI) filters.* Consideration shall be taken to ensure that the filters introduce no additional resonance effects on the connected lines.

c) *RF signal generator(s).* Capable of covering the frequency range and of producing an 80% amplitude modulation by a 1 kHz sine wave. (If automatic sweep, sweep rate should be capable of achieving 1.5×10^{-3} decade/s.)

d) *Power amplifier*. To amplify signal and provide antenna drive to the necessary field level, if signal generator is inadequate.

e) *Field generating antennas.* Capable of covering the frequency range such as biconical, conical logarithmic spiral, or any other linearly polarized antenna system capable of satisfying frequency requirements.

f) *Associated recording and control equipment.* To record the power levels necessary for the required field strength and to control the generation of that level for testing.

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g) *Associated monitoring equipment.* To monitor output of the relay under test to establish operating performance and signals during test.

8.7 Test procedure

The test procedure assumes the use of biconical or conical logarithmic antennas and continuous automatic control of the test level. Other methods of establishing the fields are acceptable providing the proper fields can be generated.

8.7.1 Field-strength measurement

The applied field strength shall be directly measured at a point 5 cm in front of the device surface being radiated and near the center of that surface.

1) Set up the test sample and the transmitting antenna per the distance restrictions of Figure 10. For the biconical transmitting antenna, adjust it so that the electromagnetic field is polarized vertically.
2) Sweep or step the test frequency through the range of 0.08 GHz to 1 GHz, maintaining a field strength of not less than 35 V/m. Document the response of the test sample. If the frequency is stepped through the range, the step size shall be not more than 1 MHz. The minimum duration at each frequency step shall not be less than 0.5 s. If the frequency is swept, the sweep rate shall be not more than 1.5×10^{-3} decade/s.
3) Step 2 shall be repeated three times to expose each of the four sides of the test sample (excluding top and bottom) to the maximum radiation.
4) When using the biconical antenna, change the electromagnetic wave polarization to horizontal and repeat Step 2, exposing only the back and front of the sample.

8.7.2 Keying test

Some equipment is susceptible to repeated operation of a transmitter. This test shall be performed to evaluate the test specimen in this mode. Exposure needs be to the front of the test specimen only.

If the frequency is swept, the signal source shall be 100% pulse or square-wave modulated. The modulating signal shall have on and off durations of not less than 0.5 s each. The pulse or square wave shall have a rise and fall time of no greater than 50 μs. There shall be at least three keying cycles per frequency octave.

Alternatively, if frequency steps are used, the test signal may be turned off between steps to produce the keying simulation. The on and off periods should not be less than 0.5 s. The on/off procedure may be done during the basic test to eliminate the need for a separate keying test.

8.7.3 Communications conditions during RF tests

For Performance Class 1 equipment, the manufacturer shall declare the communications conditions during RF testing. Although the bit rate and frame size of the communications conditions are not specified in this standard, there shall be communications underway in order to verify that, if disrupted, the communications recover.

For Performance Class 2 equipment, RF testing shall be conducted with devices under each of the communications profiles shown in Table 8 or Table 9, as applicable.

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Table 8—Device communications profiles (i.e., conditions) during RF tests for equipment with specified ranges of frame size (e.g., an Ethernet switch)

Profile	Bit rate	Frame size	Frame rate (loading) (% of maximum)[a]	Comments
1	0	0	0	Idle conditions (no communications)
2	Maximum	Maximum	30	Simulate typical loading
3	Maximum	Maximum	90	Simulate heavy loading

[a]The "% of maximum" refers to the average throughput maintained during the test compared to the maximum sustainable throughput. The maximum sustainable throughput is the rate above which error-free communication cannot be sustained by the unit under test under normal service conditions.

Table 9—Device communications profiles (i.e., conditions) during RF tests for equipment without specified ranges of frame size (e.g., serial media converters)

Profile	Bit rate	Comments
1	0	Idle conditions (no communications)
2	30% of maximum	Simulate lower bandwidth communications
3	Maximum	Simulate higher bandwidth communications

8.8 Device performance classes

There shall be two performance classes for devices during RF susceptibility tests:

— *Class 1.* This performance class is for communications devices used for general-purpose substation communications where temporary loss of communications and/or communications errors can be tolerated during the occurrence of EMI. All devices shall meet Class 1 requirements unless Class 2 is specified by the user or manufacturer.
— *Class 2.* This performance class is for communications devices used in substation communications where it is desired to have error-free, uninterrupted communications during the occurrence of EMI.

8.9 Conditions to be met (acceptance criteria)

The equipment shall be considered to have passed the RF tests if—during, or as a result of, the tests—all of the applicable conditions in 8.9.1 through 8.9.5 are met for the performance class of the device.

8.9.1 Conditions to be met by Class 1 and Class 2 devices

The following conditions are to be met by both Class 1 and Class 2 devices:

a) No hardware damage occurs.
b) No loss or corruption of stored memory or data, including active or stored settings, occurs.
c) Device resets do not occur, and manual resetting is not required.
d) No changes in the states of the electrical, mechanical, or communication status outputs occur. These outputs include alarms, status outputs, or targets.
e) No erroneous, permanent change of state of the visual, audio, or message outputs results. Momentary changes of these outputs during the tests are permitted.

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f) No error outside normal tolerances of the data communication signals (e.g., SCADA analogs) occurs.

8.9.2 Additional condition to be met by Class 1 devices

Established communications in accordance with 8.7.3 may be disrupted or sustain errors during the period the RF tests are applied. If disrupted, the communications recover within the manufacturer's specified time period.

8.9.3 Additional condition to be met by Class 2 devices

Established communications in accordance with 8.7.3 shall NOT be disrupted or experience errors during the period the RF tests are applied.

8.9.4 Equipment functioning

During and after the tests, the equipment shall be completely and accurately functional as designed, unless otherwise stated by the manufacturer, for the equipment to be considered as having passed the RF tests.

8.9.5 Exceptions

Exceptions to the acceptance criteria pertinent to the equipment shall be stated in the specifications of the equipment.

8.10 Test records

The test program shall be recorded and made available upon request. The report shall be adequate to guide another person to duplicate the test program. The record shall include the following:

a) Product model and revision number for the product under test (serial number, if applicable) and firmware/software version of the product (if applicable).
b) Details of the product's settings, inputs, and operating conditions for each individual test.
c) Diagrams, schematics, or photographs showing the device under test, any externally connected equipment, and related cabling.
d) Description of the RF test equipment and its calibration date.
e) Identification of the field strength verification measurement method used.
f) A tabulation for each test performed. The tabulation of each test shall include the following:
    1) Side to which the electromagnetic waveform was directed and the waveform polarization.
    2) Identification of all settings of the unit under test and of the input levels and type applied.
    3) A description of how the device under test was monitored to ensure that any failure was detected. In other words, describe the output lines, indicators, or other features of the device under test that were monitored.
    4) The test results.

9. Electrostatic discharge (ESD) tests

Required ESD test methods and their application to the device under test are identical to the methods and applications specified in IEEE Std C37.90.3-2001 [B9]. Generators that produce a standard waveform are used to apply discharges to conductive and nonconductive points on the device under test.

Annex B in IEEE Std C37.90.3-2001 [B9] states the following:

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“Electronic equipment may be affected by electrostatic discharges that are applied directly to the equipment or to metal objects in the proximity of the equipment. The primary concern of this standard is the effect these electrostatic discharges, generated by the human body, have on protective relay equipment.

“Electrostatic charges are easily generated in an environment with dry atmosphere and synthetic fabrics. The operator’s body may be charged either directly or by electrostatic induction. There are many possible variations in the charging process. A common situation is one where an operator walks over a carpet and at each step loses or gains electrons relative to the fabric. The charges can be carried over a long distance by people wearing insulating shoes. In such cases, it does not help if the floor, where the electronic equipment is placed, consists of conducting material. An exchange of electrostatic charges can also occur due to the friction between a person's clothing and a seat or chair. The level to which the human body is charged depends on the material in the clothing and in the room (specifically the floor), and on the relative humidity of the room.

“The effect of discharge from the operator may be a malfunction of the equipment or damage to electronic components. The dominant effects can be attributed to the parameters of the discharge current (rise time, duration, etc.)”

ESD currents are characterized by extremely fast rise times. IEEE Std C37.90.3-2001 [B9] specifies that, for the contact discharge test at 8 kV ± 5%, the first peak of discharge current have a rise time of 0.7 ns to 1.0 ns, 30 A ± 10% decaying to 16 A ± 30% in 30 ns and further decaying to 8 A ± 30% in 60 ns and with a specified wave shape. Examples of electrostatic charges include the following:

a) *Below 2 kV.* Environments where floors are covered with antistatic material and the relative humidity is greater than 35%.
b) *2 kV to 4 kV.* Environment where floors are covered with antistatic material and the relative humidity is greater than 10% up to 35%.
c) *4 kV to 8 kV.* Environment where floors are covered with material that tends to generate static electricity (e.g., synthetic material) and the relative humidity is greater than 50%.
d) *8 kV to 15 kV.* Environment where floors are covered with material that tends to generate static electricity (e.g., synthetic material) and the relative humidity is between 10% and 35%.

9.1 ESD disturbance tests

Two test methods and two application methods are common:

a) Test methods
    1) Contact discharge
    2) Air discharge
b) Application methods
    1) Direct
    2) Indirect

Direct application to the unit under test using the contact discharge method shall be used when the points to be tested are conductive.

Direct application to the unit under test using the air discharge method shall be used when the points to be tested are nonconductive.

Indirect application (i.e., the use of a coupling plane) is applicable to protective equipment when the air discharge method fails to produce a spark.

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9.1.1 Test procedure

A simple overview diagram of the test procedure is given in Figure 11.

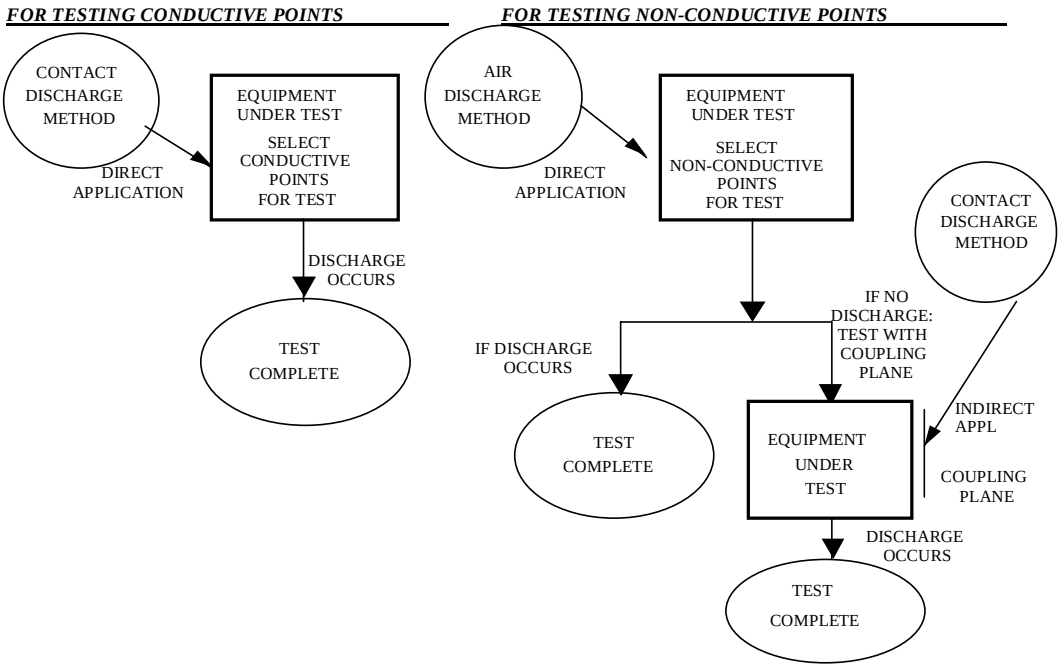


Figure 11—Overview of ESD testing procedure

The tests shall be performed with the equipment under the following climatic conditions:

a) Ambient temperature within the limits of +15 °C to +35 °C
b) Relative humidity 30% to 60%
c) Atmospheric pressure 86 kPa to 106 kPa

9.1.2 Device setup

It is the intent of this test to duplicate, as nearly as possible, in-service conditions with the device in its normal state and be energized with rated voltage. Input voltages to the power supply circuit shall be within the specified limits. The device shall be tested in its case and as described in 9.1.3 and 9.1.5. The external wiring to the device, including the ground connection, shall be consistent with the manufacturer's recommended installation practice.

9.1.3 Communications conditions during ESD tests

For Performance Class 1 equipment, the manufacturer shall declare the communications conditions during ESD testing. Although the bit rate and frame size of the communications conditions are not specified in this standard, there shall be communications underway in order to verify that, if disrupted, the communications recover.

For Performance Class 2 equipment, ESD testing shall be conducted with devices under each of the communications profiles shown in Table 10 or Table 11, as applicable.

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Table 10—Device communications profiles (i.e., conditions) during ESD tests for equipment with specified ranges of frame size (e.g., an Ethernet switch)

Profile	Bit rate	Frame size	Frame rate (loading) (% of maximum)[a]	Comments
1	0	0	0	Idle conditions (no communications)
2	Maximum	Maximum	30	Simulate typical loading
3	Maximum	Maximum	90	Simulate heavy loading

[a]The "% of maximum" refers to the average throughput maintained during the test compared to the maximum sustainable throughput. The maximum sustainable throughput is the rate above which error-free communication cannot be sustained by the unit under test under normal service conditions.

Table 11—Device communications profiles (i.e., conditions) during ESD tests for equipment without specified ranges of frame size (e.g., serial media converters)

Profile	Bit rate	Comments
1	0	Idle conditions (no communications)
2	30% of maximum	Simulate lower bandwidth communications
3	Maximum	Simulate higher bandwidth communications

9.1.4 Test wave shape

The wave shape of the contact discharge current is characterized by the values given in Table 12. The wave shape is shown in Figure 12. Generators that produce this test wave shape are commercially available. The same generator is used for air discharge, but the wave shape is a variable.

Table 12—Wave shape characteristics—contact discharge

Discharge voltage	First peak of current	Rise time (tr) 10%–90% Ip	Current at 30 ns	Current at 60 ns
8 kV ± 5%	30 A ± 10%	0.7 to 1 ns	16 A ± 30%	8 A ± 30%

9.1.5 Test setup

A test setup example for small equipment is shown in Figure 13 and for large equipment is shown in Figure 14.

A ground reference plane shall be used to assure reproducible conditions regarding capacitive coupling. The ground reference plane shall

a) Consist of a copper or aluminum sheet with at least 0.25 mm thickness. Other metallic materials may be used, but they shall have at least 0.65 mm thickness.
b) Project beyond the EUT at least 0.5 m on all sides, except that it shall project 50% of the height of the EUT if the EUT is taller than 1 m.
c) Be connected to the facility ground.
d) Be a minimum distance to walls and metallic structures of at least 1 m.

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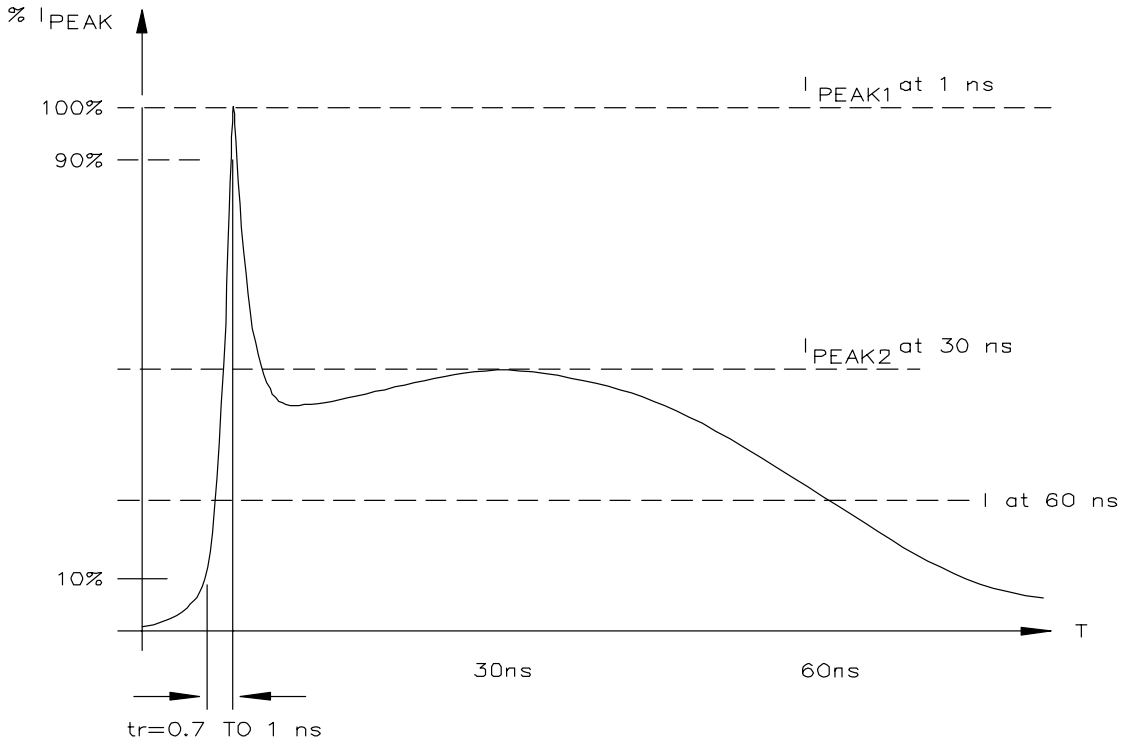


Figure 12—Typical waveform of the contact discharge current of the ESD generator

A floor-mounted EUT shall be separated from the ground reference plane by insulation of approximately 0.1 m thickness. A small EUT shall be separated from the ground reference plane by an insulated table approximately 0.8 m high.

The discharge generator shall be grounded directly to the ground reference plane, close to the EUT using a ground cable 2 m long with a width of at least 20 mm. A ground cable longer than 2 m may be used. Cables interconnecting the EUT, test supplies, and monitoring equipment shall be kept at least 0.1 m from the ground plane.

For small equipment, a horizontal coupling plane (HCP) shall be used between the table when required to reach test points on large equipment. Also, the test supplies and monitoring equipment shall be grounded to the ground reference plane. During the test, the grounding cable of the discharge generator shall be kept at least 0.1 m from the EUT, and at least 0.2 m from metal surfaces other than the ground reference plane and the EUT. Insulation with thickness of 0.5 mm or smaller shall be placed between the HCP and the EUT. A vertical coupling plane (VCP) may be needed for both floor-mounted equipment and table-mounted equipment (see Figure 11).

The HCP and VCP are to be constructed from the same material and thickness as the ground reference plane. The HCP shall be a minimum of 1.6 m by 0.8 m and project beyond the EUT by at least 0.1 m on each side. The VCP shall be 0.5 m by 0.5 m and located 0.1 m from the vertical face of the EUT. Each coupling plane shall be grounded through resistors as shown in Figure 13 and Figure 14. The 1 MΩ resistors (RH) located at each end of the charge bleed strap shall have a transient withstand voltage of 10 kV or greater to prevent breakdown that would cause false current loops. The 2 kΩ resistor (RL) located between the two RH resistors prevents the stray capacitance of the high-voltage resistor from forming a ringing circuit.

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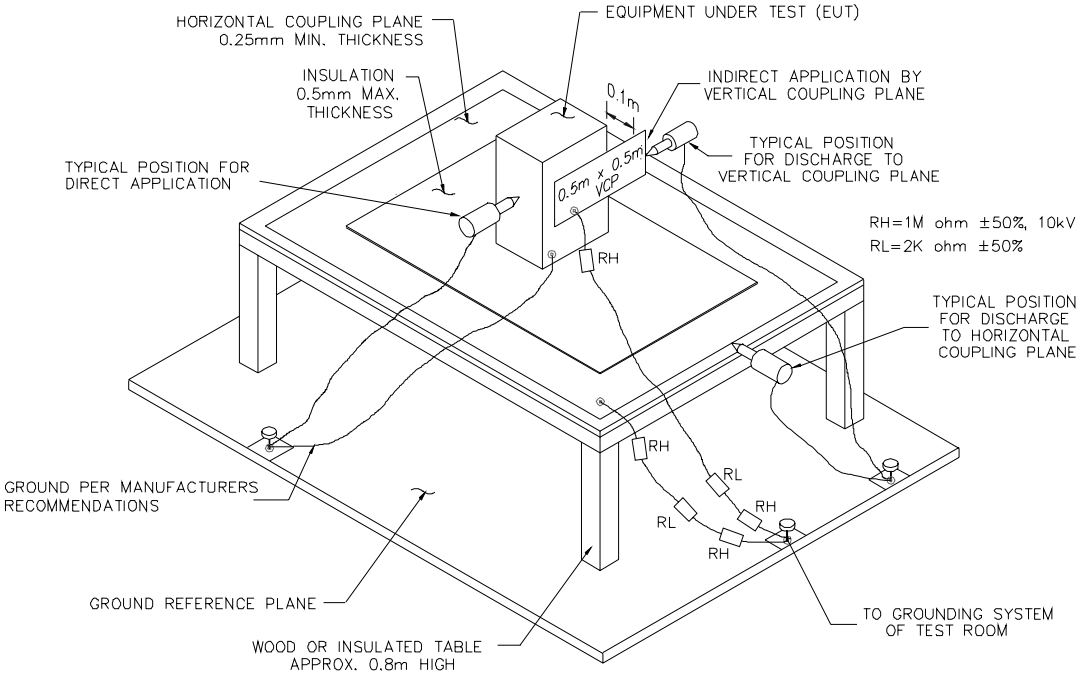


Figure 13—Example of ESD test setup for small equipment

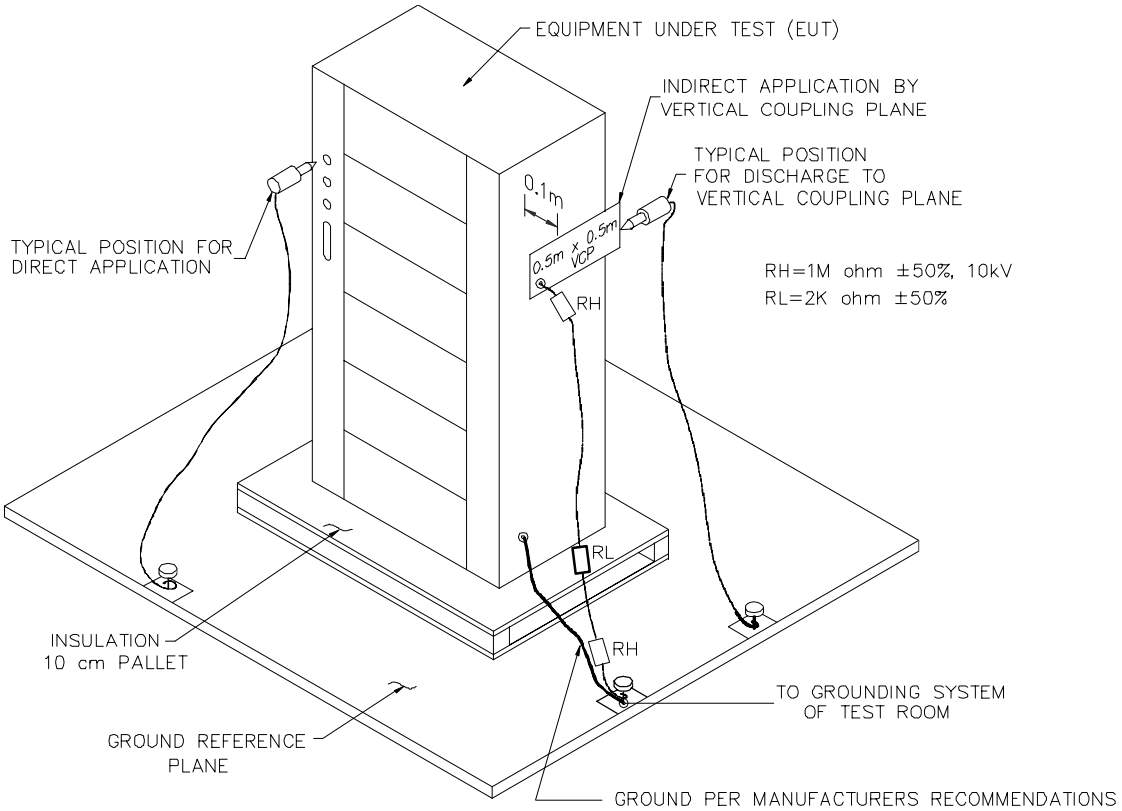


Figure 14—Example of ESD test setup for large equipment

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9.1.6 Test point selection

The points selected for the application of the test shall be points that are accessible under normal in-service conditions. Such points include case, knobs, pushbuttons, switches, terminals, data ports, keypads, and target resets.

The application of discharge to any point of the equipment that is accessed only for repair and maintenance purposes is outside the scope of this standard, e.g.,

— Terminals normally wired at installation
— Setting adjustments that are not accessed during normal service conditions

Categorize all test points as conductive or nonconductive and follow the testing procedure given in Figure 11. Test both the HCP and VCP when coupling plane testing is required by Figure 11. VCP testing shall be performed in all four positions relative to the EUT.

9.1.7 Test levels

The EUT shall be tested at each of the voltage levels shown in Table 13. Figure 11 and the text of 9.1 define when to use the contact method and when to use the air discharge method. These test levels apply to both the direct and indirect methods of application.

Table 13—Test levels

Test voltages (kV)	
Contact discharge	**Air discharge**
2	4
4	8
8	15

9.1.8 Discharge application

9.1.8.1 Direct application

The discharge generator shall approach the EUT perpendicularly to the plane being tested. Apply 10 positive and 10 negative discharges to each test point selected with a time interval between discharges of at least 1 s.

9.1.8.2 Indirect application

See Clause 9 and Figure 11 to determine whether an indirect application is required. When indirect is required, the discharge generator shall be applied to the center of one edge of both the HCP and VCP. Test with the VCP facing each surface where the air discharge method failed to produce a spark. Apply 10 positive and 10 negative discharges to each coupling plane with a time interval between discharges of at least 1 s.

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9.2 Device performance classes

There shall be two performance classes for devices during tests:

— *Class 1.* This performance class is for communications devices used for general-purpose substation communications where temporary loss of communications and/or communications errors can be tolerated during the occurrence of ESD interference. All devices shall meet Class 1 requirements unless Class 2 is specified by the user or manufacturer.
— *Class 2.* This performance class is for communications devices used in substation communications where it is desired to have error-free, uninterrupted communications during the occurrence of ESD interference.

9.3 Conditions to be met (acceptance criteria)

The equipment shall be considered to have passed the ESD tests if—during, or as a result of, the tests—all of the applicable conditions in 9.3.1 through 9.3.3 are met for the performance class of the device.

9.3.1 Conditions to be met by Class 1 and Class 2 devices

The following conditions are to be met by both Class 1 and Class 2 devices:

a) No hardware damage occurs.
b) No loss or corruption of stored memory or data, including active or stored settings, occurs.
c) Device resets do not occur, and manual resetting is not required.
d) No changes in the states of the electrical, mechanical, or communication status outputs occur. These outputs include alarms, status outputs, or targets.
e) No erroneous, permanent change of state of the visual, audio, or message outputs results. Momentary changes of these outputs during the tests are permitted.
f) No error outside normal tolerances of the data communication signals (e.g., SCADA analogs) occurs.

9.3.2 Additional condition to be met by Class 1 devices

Established communications in accordance with 9.1.3 may be disrupted or sustain errors during the period the ESD tests are applied. If disrupted, the communications recovers within the manufacturer’s specified time period.

9.3.3 Additional condition to be met by Class 2 devices

Established communications in accordance with 9.1.3 shall NOT be disrupted or sustain errors during the period the ESD tests are applied.

9.3.4 Test data records

The test program and test results shall be recorded and made available upon request. The report should be adequate to guide another person to duplicate the tests without having observed the original test program. This record would typically include the following:

a) Product model and revision level (serial number, if available) and firmware/software version of the product (if applicable)
b) Details of the product’s settings, inputs, and operating conditions
c) Diagram and/or photographs of the arrangement of the product and interface cables
d) Description of the types and characteristics of interface cables

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e) Diagram and/or photographs illustrating the discharge points, test method, and test application
f) Points tested and test results including a list of all indirect points
g) Record of the test site ambient temperature, relative humidity, atmospheric pressure, and date
h) Description of the ESD simulator used and its calibration credentials

10. Vibration and shock

(The text of this clause is identical to the text in IEEE Std C37.1™-1994 [B5].)

Where control and data acquisition equipment will be subjected to vibration or shock, the user shall express the local vibration environment as constant velocity lines to represent vibration severity levels over a specified frequency range.

Four severity classes are listed in Table 14 as examples in typical locations.

Table 14—Classes of vibration severity

Class	Velocity (v) (mm/s)	Frequency range (Hz)	Examples
V.S.1	< 3	1 to 150	Control room and general industrial environment
V.S.2	< 10	1 to 150	Field equipment
V.S.3	< 30	1 to 150	Field equipment
V.S.4	< 300	1 to 150	Field equipment including transportation
V.S.X	> 300	—	To be specified

Shock phenomena that may occur during handling for operation and maintenance of equipment shall be expressed in terms of an equivalent height of fall. This relationship is shown in Table 15.

Table 15—Shock phenomena

Height of fall (mm)	Treatment (hard surface)
25	Light handling
50	Light handling, heavy equipment (> 10 kg)
100	Normal handling
250	Normal handling, heavy material
1000	Rough handling
1500	Rough handling, heavy material

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Annex A

(normative)

Verification of test generator characteristics

A.1 Measuring system requirements

All tests are performed using a wide bandwidth digital oscilloscope with a suitable wide bandwidth voltage divider (e.g., shielded high-voltage probe, a high-voltage coaxial attenuator, or a current probe-based alternative scheme described in A.4) intended to reduce the measured generator output voltage to a level that can be safely applied to the oscilloscope input. The voltage calibration and transient response of the measuring system shall be verified prior to measuring the generator output. For the oscillatory SWC test generator, the measuring system shall have a frequency bandwidth of 50 MHz or better. For the fast transient SWC test generator, the measuring system shall have a frequency bandwidth of at least 500 MHz.

A.2 SWC waveform validity tests

The waveform validity tests shall be performed before and after each SWC test session, with the results recorded and included with the SWC test report. These tests are intended to verify that there is no major insulation breakdown, damage, or component failure that may have occurred during the physical test setup, test application, or prolonged instrument storage between the test sessions. The waveform validity tests shall include the following:

— Measuring system feedthrough test
— Oscillatory SWC test generator open-circuit voltage waveform test
— Fast transient SWC test generator open-circuit voltage waveform test

A.2.1 Measuring system feedthrough test

The measuring system feedthrough test is performed by shorting the high-voltage input of the voltage divider to ground and connecting this point to the SWC test generator output ground terminal. Then with the test generator operating at maximum voltage output, the oscilloscope waveform display should not deviate from a straight horizontal line more than 1% of the generator output voltage. This test verifies that there is a minimum of extraneous voltage pickup in the measuring system. For feedthrough check, the oscilloscope setting for vertical and horizontal calibration should be the same as stated in A.2.2 and A.2.3 for each specified SWC test. Whenever possible, a separate trigger channel should be established, enabling precise measurement of the undesired feedthrough signal magnitude.

If it is not possible to obtain a good feedthrough check with the voltage divider selected, the alternative voltage measuring scheme described in A.4 may be used.

A.2.2 Oscillatory SWC test generator open-circuit voltage waveform test

The high-voltage terminal of the measuring system voltage divider is connected to the high-voltage output terminal of the test generator. The oscilloscope horizontal calibration is set to 2 μs/div, and the vertical calibration is set to 1 kV/div, with the abbreviation *div* denoting oscilloscope screen division. This calibration shall include the voltage divider ratio. For example, if the divider ratio is 1000/1 then the scope vertical calibration would be set to 1 V/div. The horizontal sweep trigger of the oscilloscope is adjusted to display one

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oscillatory burst waveform on the screen starting from the initial voltage rise from zero. The specified generator output voltage waveform is then recorded.

A second recording is made with the horizontal calibration set to 50 ns/div. This recording will display the initial rise time of the waveform.

A final recording of the generator voltage is made with the divider input paralleled by a noninductive resistor equal to the test generator source impedance. The waveform amplitude should drop to one half its original value. This recording is to check the value of the generator source impedance. All other parameters of the test wave shall remain within the original generator specifications.

A.2.3 Fast transient SWC test generator open-circuit voltage waveform test

Fast transient SWC test generator open-circuit voltage waveform tests are performed in a similar manner as the oscillatory SWC tests except that the oscilloscope horizontal calibration setting should be set to 20 ns/div for the total waveform check and 5 ns/div for the initial rise time check.

A.3 SWC test generator performance verification

The full set of SWC test generator characteristics shall be verified per the manufacturer's recommendations or at least once every year, with the test results included with each SWC test report. The characteristics to be verified are specified in 7.5.2 and are repeated here for convenience in Table A.1.

Table A.1—SWC test generator characteristics to be verified

Fast transient	Oscillatory waveform
Rise time	Rise time of the first peak
Peak voltage level (no load)	Peak voltage level (no load)
Output impedance	Output impedance
Impulse duration	Waveform envelope decay
n/a	Oscillation frequency
Repetition rate during the burst	Repetition rate
Burst duration	n/a
Burst period	n/a
Test duration	Test duration

All measurements in this subclause shall be preceded by conducting an SWC waveform validity test as described in A.2. The addition of any components that are used during testing shall be incorporated into the verification of the generator (i.e., coupling and isolating networks).

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A.3.1 SWC waveform validity test

The performance verification measurements shall start by conducting the SWC waveform validity tests described in A.2. In addition to the required waveform plots, individual numbers for the following parameters shall be measured and documented:

a) Waveform rise time (fast transient test)
b) Rise time of the first peak (oscillatory test)
c) Peak voltage level with no load ($R_L \geq 1000\ \Omega$)
d) Impulse duration (fast transient)
e) Waveform envelope decay (oscillatory test)

A copy of all recorded waveforms shall be included in the report.

A.3.2 Test generator output impedance measurement

The generator output impedance shall be obtained by measuring the output voltage that the generator produces with two different load impedances. The voltage measurements shall be conducted in accordance with A.2.2 (for the oscillatory SWC test) and A.2.3 (for the fast transient SWC test).

Load impedance shall be resistive across the measurement bandwidth (see A.1) and shall include impedance contribution of the voltage divider used in the measurements. It shall be known to within ± 5% actual value.

The exact impedance value selection is arbitrary as long as the precision of the final generator impedance estimate remains within ± 10%, and one of the values selected is close to the expected generator output impedance Z_O. A good selection for Z_O = 200 Ω would be Z_{L1} = 1000 Ω, Z_{L2} = 200 Ω; and for Z_O = 50 Ω would be Z_{L1} = 200 Ω, Z_{L2} = 50 Ω.

The generator impedance shall be calculated according to Equation (A.1):

$$Z_O = \frac{Z_{L1} \times Z_{L2} \times (V_{L2} - V_{L1})}{V_{L1} \times Z_{L2} - V_{L2} \times Z_{L1}} \quad \text{(A.1)}$$

where

Z_O is generator output impedance,
Z_{L1} is load impedance applied in the first test,
Z_{L2} is load impedance applied in the second test,
V_{L1} is peak voltage measured with impedance Z_{L1},
V_{L2} is peak voltage measured with impedance Z_{L2}.

A.3.3 Oscillatory SWC test generator repetition rate measurement

The generator repetition rate measurement shall be conducted in accordance with A.2.2 with the oscilloscope horizontal calibration set to 1 ms/div. The period between the oscillatory bursts shall be documented and compared with the value specified in 7.3.1.

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A.3.4 Fast transient SWC test generator repetition parameter measurement

Three fast transient repetition parameters shall be measured: the fast transient repetition rate during bursts, individual burst duration, and burst period. The measurements shall be performed in accordance with A.2.3 with the horizontal calibration set to 0.1 ms/div for measuring the repetition rate during bursts and 50 ms/div for measuring the individual burst duration and the burst period. The parameters shall be documented and compared with the values specified in 7.3.2.

A.4 Alternative voltage measuring scheme

The alternative voltage measuring scheme replaces the voltage divider by a 1000 Ω resistor and a wide frequency bandwidth current transformer. The resistor shall be noninductive and be able to dissipate 4 W. It is connected across the output of the SWC test generator. The current transformer is used to measure the current through the resistor connections that are passed through its primary window. Several wideband current transformers are available commercially, with one typical device having a ratio of 1 V/1 A and a frequency response that is essentially flat from 900 Hz to 900 MHz when used with a special signal cable and a termination resistor, which are included. When used to measure the current in the 1000 Ω resistor, it is equivalent to using a 1000/1 voltage divider. The oscilloscope vertical calibration should be set to 1.0 V/div.

This method will load the test generator somewhat and the voltage measured will appear less than its true value. The true voltage can be estimated by multiplying the measured voltage by a correction factor, K_C in Equation (A.2):

$$K_C = 1 + \frac{Z_O}{1000} \tag{A.2}$$

where

Z_O is output impedance of the SWC test generator measured in A.3.2.

Because this measuring scheme inductively couples the current in the resistor, it eliminates the direct connection between the oscilloscope signal ground and the test generator. Therefore, stray transient ground currents, which can produce large errors, are significantly reduced.

If the transient signal feedthrough problem persists, it may be necessary to replace the oscilloscope with an alternate unit meeting minimum shielding/noise immunity requirements.

All measurements in this subclause shall be preceded by a measuring system feedthrough test specified in A.2.1.

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Annex B

(informative)

Bibliography

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[B2] IEC 60255-22-3:2000, Electrical Relays—Part 22: Electrical Disturbance Tests for Measuring Relays and Protection Equipment—Section 3: Radiated Electromagnetic Field Disturbance Tests.

[B3] IEC 61000-4-2:2001, Electromagnetic Compatibility (EMC)—Part 4: Testing and Measurement Techniques—Section 2: Electrostatic Discharge Immunity Test.

[B4] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.[6, 7]

[B5] IEEE Std C37.1-1994, IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control.

[B6] IEEE Std C37.90-1989 (Reaff 1994), IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus.

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[B9] IEEE Std C37.90.3-2001, IEEE Standard for Electrostatic Discharge Tests for Protective Relays.

[B10] IEEE Std 487™-2000, IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations.

[5]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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