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(Revision of IEEE Std C37.20.1-1993)

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IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear

IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

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Approved 13 June 2002

IEEE-SA Standards Board

Abstract: Low-voltage metal-enclosed switchgear—which contains either stationary or drawout, manually or electrically operated low-voltage ac or dc power circuit breakers in individual grounded metal compartments, in three-pole, two-pole, or single-pole construction—is covered. Rated maximum voltage levels are 254 V, 508 V, or 635 V (ac) and 300/325 V, 800 V, 1000 V, 1200 V, 1600 V, or 3200 V (dc). The preferred continuous current ratings of the main bus in ac designs are 1600 A, 2000 A, 3000 A, 3200 A, 4000 A, or 5000 A. For dc designs, the preferred ratings are 1600 A, 2000 A, 2500 A, 3000 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, or 12 000 A. The switchgear may also contain associated control, instruments, metering, protective, and regulating devices as necessary. The standard deals with service conditions, ratings, temperature limitations, and classification of insulating materials, insulation (dielectric) withstand voltage requirements, test procedures, and application.
Keywords: circuit breaker, control, cumulative loading, current transformers, drawout, indoor, instrumentation, load current-carrying, metering, outdoor, protection, stationary

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Introduction

(This Introduction is not a part of IEEE Std C37.20.1-2002, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.)

This standard has been revised to reflect needed technical changes that have been suggested since the last revision to IEEE Std C37.20.1 that was published in 1993. Major editorial and technical changes have been incorporated. The more significant changes include the following:

a) Major expansion of text describing the design testing requirements in order to more fully delineate objective test criteria and performance evaluation guidelines. In most cases, it is felt that the text elaboration captures test requirements that were previously understood by test laboratories and designers, but not adequately delineated in the document.
b) Addition of new definitions for mechanism-operated contact (MOC) and truck-operated contact (TOC) switches, previously contained in IEEE Std C37.2-1996, but necessary to a full understanding of metal-enclosed low-voltage power circuit breaker switchgear.
c) Expansion of discussion of the requirements for LV dc switchgear, including devices commonly used in such switchgear, and coordination with on-going changes to related standards, including IEEE Std C37.14™-1999.[a]
d) Changes to coordinate with other documents in the IEEE Std C37.20.X series of documents, particularly with IEEE Std C37.20.2™-1999 for metal-clad switchgear. This coordination is maintained on an ongoing basis so as to treat common subjects in an equivalent manner.
e) Addition of explanatory text related to short-circuit current ratings in 5.4.4.
f) Updating and expansion of requirements for control wiring in 7.1.3.
g) Conversion to the International System of Units (SI), the modernized metric system.

It is also noted that the altitude correction factors listed in Table 11 of this standard are under review by an IEEE Switchgear Committee Working Group, PC37.100.1, on Common Requirements for Power Switchgear. The old values are included in this document for reference until the Working Group releases the new values, at which time the new values will supersede those in the current Table 11.

This standard includes only the requirements for metal-enclosed low-voltage power circuit breaker switchgear. These requirements were previously a part of IEEE Std C37.20™-1969 (Reaff 1981), IEEE Standard for Switchgear Assemblies Including Metal-Enclosed Bus (1974 consolidated edition). Other types of equipment previously included in IEEE Std C37.20-1969 are incorporated in separate publications.

The IEEE Switchgear Assemblies Committee was responsible for this revision.

This publication is one of a series covering switchgear assemblies as follows:

1) IEEE Std C37.20.1-2002, IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.
2) IEEE Std C37.20.2-1999, IEEE Standard for Metal-Clad Switchgear.
3) IEEE Std C37.20.3™-2001, IEEE Standard for Metal-Enclosed Interrupter Switchgear.
4) IEEE Std C37.20.7™-2001, IEEE Guide for Testing Medium-Voltage Metal-Enclosed Switchgear for Internal Arcing Faults.

[a]Information on references can be found in Clause 2.

5) IEEE Std C37.21™-1985, IEEE Standard for Control Switchboards.
6) IEEE Std C37.23™-1987, IEEE Standard for Metal-Enclosed Bus and Calculating Losses in Isolated Phase Bus.

Figure A depicts types of switchgear assemblies.

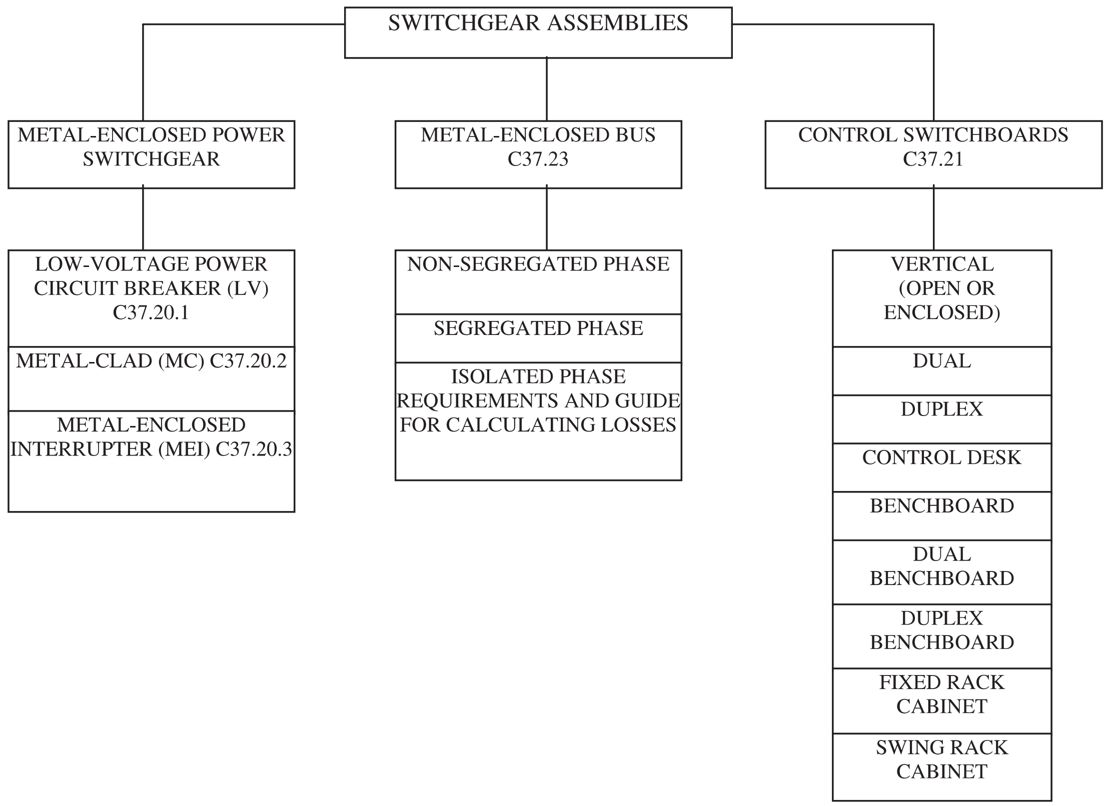

Figure A—Types of switchgear assemblies

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When the IEEE-SA Standards Board approved this standard on 13 June 2002, it had the following membership:

Contents

IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear

1. Scope

This standard covers metal-enclosed low-voltage power circuit breaker switchgear assemblies containing, but not limited to, such devices as low-voltage power circuit breakers (fused or unfused); other interrupting devices; switches, control, instrumentation, and metering; and protective and regulating equipment.

This standard is concerned with enclosed, rather than open, indoor and outdoor switchgear assemblies. It includes types of equipment that are part of secondary unit substations. It does not apply to equipment covered by industrial control standards, communication switchboards, communication switching equipment, switchboards for use on board ships, or dead-front distribution switchboards.

In this standard, metal-enclosed low-voltage power circuit breaker switchgear shall be called *LV switchgear*. For LV ac switchgear, the voltage shall be 1000 V or below; for LV dc switchgear, the voltage shall be 3200 V or below.

2. References

This standard shall be used in conjunction with the following publications. When the publications referenced in this standard are superseded by an approved revision, the revision shall apply.

ANSI C2-2002, National Electrical Safety Code® (NESC®), American National Standards Institute.[1,2]

ANSI C37.16-2000, Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors: Preferred Ratings, Related Requirements, and Application Recommendations.

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[1]ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org).

[2]The NESC is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA. (http://standards.ieee.org). National Electrical Safety Code and NESC are both registered trademarks and service marks of the Institute of Electrical and Electronic Engineers, Inc.

ANSI C37.50-1989, Low-Voltage AC Power Circuit Breakers Used in Enclosures—Test Procedures.

ANSI C37.51-1989 (Reaff 1995), Metal-Enclosed Low-Voltage AC Power-Circuit-Breaker Switchgear Assemblies—Conformance Test Procedures.

ANSI Z535.4-1998, Product Safety Signs and Labels.

ASTM B117-1997, Standard Practice for Operating Salt Spray (Fog) Apparatus.[3]

ASTM D229-2001, Standard Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation.

ASTM D412-1998A, Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension.

ASTM D714-1987 (Reaff 1994), Standard Test Method for Evaluating Degree of Blistering of Paints.

ASTM D1535-2001, Standard Practice for Specifying Color by the Munsell System.

ASTM D1654-1992, Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments.

ASTM G21-1996, Standard Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi.

IEEE Std 1™-2001, General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[4,5]

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.

IEEE Std 100™, *The Authoritative Dictionary of IEEE Standard Terms*, Seventh Edition.

IEEE Std 120™-1989 (Reaff 1997), IEEE Master Test Guide for Electrical Measurements in Power Circuits.

IEEE Std 141™-1993 (Reaff 1999), IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (*IEEE Red Book*).

IEEE Std 142™-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (*IEEE Green Book*).

IEEE Std 241™-1990 (Reaff 1997), IEEE Recommended Practice for Electric Power Systems in Commercial Buildings (*IEEE Gray Book*).

[3]ASTM publications are available from American Society for Testing and Materials, P.O. Box C700, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).
[4]The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Inc.
[5]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org).

IEEE Std 242™-2001, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (*IEEE Buff Book*).

IEEE Std 316™-1971, IEEE Standard Requirements for Direct Current Instrument Shunts.[6] (Note: this document has been withdrawn by IEEE, but the requirements for dc instrument shunts have not been adequately reflected in other standards. Therefore, IEEE Std 316-1971 continues as the relevant reference).

IEEE Std 446™-1995 (Reaff 2000), IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (*IEEE Orange Book*).

IEEE Std C37.09™-1999, IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.2™-1996 (Reaff 2001), IEEE Standard Electrical Power System Device Function Numbers and Contact Designations.

IEEE Std C37.13™-1990 (Reaff 1995), IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.14™-1999, IEEE Standard for Low-Voltage DC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.24™-1986 (Reaff 1998), IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear.

IEEE Std C37.26™-1972 (Reaff 1996), IEEE Standard Guide for Methods of Power-Factor Measurement for Low-Voltage Inductive Test Circuits.

IEEE Std C37.81™-1989 (Reaff 1999), IEEE Guide for Seismic Qualification of Class 1E Metal-Enclosed Power Switchgear Assemblies.

IEEE Std C37.100™-1992 (Reaff 2001), IEEE Standard Definitions for Power Switchgear.

IEEE Std C57.13™-1993, IEEE Standard Requirements for Instrument Transformers.

NEMA CC1-1993, Electric Power Connectors for Substations.[7]

NEMA WC70-1999/ICEA S-95-658, Non-Shielded Power Cables Rated 2000 V or Less.

NFPA 70-2002, *National Electrical Code*® (NEC®).[8]

UL 486A-1997, Wire Connectors and Soldering Lugs for Use With Copper Conductors.[9]

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[6]IEEE Std 310-1971 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. +1-303-792-2181 (http://global.ihs.com/).

[7]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA. (http://global.ihs.com)

[8]The National Electrical Code is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA. Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org). National Electrical Code and NEC are registered trademarks of the National Fire Protection Association, Inc.

[9]UL Standards are available from Comm-2000, 1414 Brook Drive, Downers Grove, IL 60515, USA (http://www.comm-2000.com).

3. Definitions

The definitions of terms contained in this standard, or in other standards referred to in this standard, are not intended to embrace all legitimate meanings of the terms. They are applicable only to the subject treated in this standard.

If a term is not defined in this standard, the definition in IEEE Std C37.100-1992[10] applies. An asterisk (*) following a definition indicates that the definition in this standard is not contained in IEEE Std C37.100-1992 while a dagger (†) indicates that the definition differs from that in IEEE Std C37.100-1992.

3.1 General

3.1.1 auxiliary compartment: That portion of the switchgear assembly that is assigned to the housing of auxiliary equipment, such as voltage transformers, control power transformers, or other miscellaneous devices.*

3.1.2 circuit breaker compartment: That portion of a switchgear assembly that contains one circuit breaker and the associated primary conductors and secondary control connection devices, including current transformers.*

3.1.3 design tests: Tests made by the manufacturer to determine the adequacy of the design of a particular type, style, or model of equipment or its component parts to meet its assigned ratings and to operate satisfactorily under normal service conditions or under special conditions if specified, and may be used to demonstrate compliance with applicable standards of the industry.†

NOTES
1—Design tests are made on representative apparatuses or prototypes to verify the validity of design analyses and calculation methods and to substantiate the ratings assigned to all other apparatuses of basically the same design. These tests are not intended to be made on every design variation or to be used as part of normal production. The applicable portion of these design tests may also be used to evaluate modifications of a previous design and to ensure that performance has not been adversely affected. Test data from previous similar designs may also be used for current designs, where appropriate. Once made, the tests need not be repeated unless the design is changed so as to modify performance.
2—Design tests are sometimes called *type tests*.

3.1.4 field tests: Tests made after the switchgear assembly has been installed at its place of utilization.

3.1.5 metal-enclosed low-voltage power circuit breaker switchgear (LV): LV switchgear of multiple or individual enclosures, including the following equipment as required:

a) Low-voltage power circuit breakers (fused or unfused) in accordance with IEEE Std C37.13-1990 or IEEE Std C37.14-1999.†
b) Bare bus and connections
c) Instrument and control power transformers
d) Instruments, meters, and relays
e) Control wiring and accessory devices

The low-voltage power circuit breakers are contained in individual grounded metal compartments and controlled either remotely or from the front of the enclosure. The circuit breakers may be stationary or

[10]Information on references can be found in Clause 2.

removable (drawout) type; when of removable type, mechanical interlocks are provided for proper operating sequence.†

NOTE—Bare bus and connections meet the requirements of this standard. However, the manufacturer may provide insulated bus and/or connections when required to meet dielectric requirements or as an option.

3.1.6 metal-enclosed power switchgear (ME): A switchgear assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows) containing primary power circuit switching or interrupting devices, or both, with buses and connections. The assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors or removable covers, or both.†

3.1.7 mechanism-operated cell switch. *See:* **mechanism-operated contact (MOC).**

3.1.8 mechanism-operated contact (MOC): A circuit breaker mechanism-operated auxiliary switch which is mounted in the stationary housing and is operated by linkage which cooperates with the circuit breaker mechanism. *Syn:* **mechanism-operated cell switch**.*

3.1.9 production tests: Tests made for quality control by the manufacturer on every device or representative samples, or on parts or materials as required to verify during production that the product meets the design specifications and applicable standards.†

NOTES
1—Certain quality assurance tests on identified critical parts of repetitive high-production devices may be tested on a planned statistical sampling basis.
2—Production tests are sometimes called *routine tests*.

3.1.10 switchgear: A general term covering switching and interrupting devices and their combination with associated control, instruments, metering, protective, and regulating devices; also assemblies of these devices with associated interconnections, accessories, and supporting structures used primarily in connection with the generation, transmission, distribution, and conversion of electric power.†

3.1.11 switchgear assembly: An assembled equipment (indoor or outdoor) including, but not limited to, one or more of the following categories: switching, interrupting, control, instrumentation, metering, protective, and regulating devices; together with their supporting structures, enclosures, conductors, electrical interconnections, and accessories. *See:* Figure A in the Introduction.†

3.1.12 tin-surfaced or equivalent: Metallic materials having satisfactory long-term performance that operate within the limits established for tin-surfaced electrical contact parts and conduction mechanical joints.*

3.1.13 truck-operated cell switch: *See:* **truck-operated contact (TOC).**

3.1.14 truck-operated contact (TOC): A circuit breaker truck-operated auxiliary switch which is mounted in the compartment of a removable circuit breaker and is operated by the circuit breaker frame. *Syn:* **truck-operated cell switch**.*

3.1.15 vertical section: That portion of the switchgear assembly between two successive vertical delineations, and may contain one or more circuit breakers, auxiliary compartments, and associated primary conductors.†

4. Service conditions

Standards for the design and performance of LV switchgear are based on usual service conditions as described below. The selection of equipment for a particular application can be based on the construction and ratings as defined in this standard provided that the following usual service conditions exist:

a) The temperature of the cooling air (ambient air temperature) surrounding the enclosure of the LV switchgear is within the limits of $-30\,^{\circ}C$ and $+40\,^{\circ}C$.
b) The altitude of the installation does not exceed 2000 m.
c) The effect of solar radiation is not significant. (The principles stated in IEEE Std C37.24-1986 may be used for guidance.)
d) Unusual service conditions, such as those outlined in 8.1, do not prevail.

The user should review 8.1 for unusual service conditions and other considerations when preparing specifications for LV switchgear because those unusual conditions impact the equipment design.

5. Ratings

5.1 General

The ratings of a switchgear assembly are designations of operating limits under specified conditions of ambient temperature, temperature rise, etc. Where the switchgear assembly comprises a combination of primary and secondary circuits, each may be given ratings.

Low-voltage switchgear shall have the following ratings:

a) Rated maximum voltage
b) Rated power frequency
c) Rated insulation level
d) Rated continuous current
e) Rated short-time withstand current
f) Rated short-circuit withstand current

The designated ratings in this standard are preferred, but are not to be considered restrictive. In addition to these ratings, a switchgear assembly may have interrupting or switching capabilities, which are determined by the ratings of the particular interrupting and switching devices that are integral parts of the switchgear assembly. Refer to specific standards for the ratings of these devices.

5.2 Voltage and insulation levels

5.2.1 Rated maximum voltage and insulation levels for LV ac switchgear

The rated maximum voltage of LV ac switchgear is the highest rms voltage for which the equipment is designed, and is the upper limit for operation. The rated insulation level of LV ac switchgear is equal to the power frequency withstand voltage. The rated maximum voltages and corresponding insulation levels for LV ac switchgear are listed in Table 1.

Table 1—Voltage and insulation levels for LV ac switchgear

Rated maximum voltage (rms)	Insulation levels (kV)[a]	
	Power frequency withstand (rms)	Reference dc withstand[b]
254	2.2	3.1
508	2.2	3.1
635	2.2	3.1

[a]For field test values, see 6.5.
[b]The column headed "dc withstand" is given as a reference only for those using dc tests to verify the integrity of connected cable installations without disconnecting the cables from the switchgear. It represents values believed to be appropriate and approximately equivalent to the corresponding power frequency withstand test values specified for each voltage class of switchgear. The presence of this column in no way implies any requirement for a dc withstand test on ac equipment, or that a dc withstand test represents an acceptable alternative to the power frequency withstand tests specified in this standard, either for design tests, production tests, conformance tests, or field tests. While power frequency withstand tests are preferred, it is recognized that users may choose to use dc withstand tests for field tests of assembled switchgear for reasons of convenience and availability of test apparatus. When making dc tests, the voltage should be raised to the test value in discrete steps and held for a period of 1 min.

5.2.2 Rated maximum voltage insulation levels for LV dc switchgear

The rated maximum voltage of LV dc switchgear is the highest dc voltage for which the equipment is designed, and is the upper limit for operation. The rated insulation level of LV dc switchgear is equal to the power frequency withstand voltage. The rated maximum voltages and corresponding insulation levels for LV dc switchgear are listed in Table 2.

Table 2—Voltage and insulation levels for LV dc switchgear

Rated maximum voltage (rms)	Insulation levels (kV)[a]	
	Power frequency withstand (rms)	Reference dc withstand[b]
300	2.2	3.1
325	2.2	3.1
800	3.7	5.2
1000	4.6	6.5
1200	4.8	6.8
1600	5.4	7.6
3200	8.8	12.4

[a]For field test values, see 6.5.
[b]For LV dc switchgear rated above 325 V (dc), it is preferred that a dc withstand voltage test be used. For tests conducted with dc voltage, the dc voltage is no less than 1.414 times the ac root-mean-square (rms) listed voltage.

5.3 Rated power frequency

The rated power frequency of a device, or an assembly, is the frequency of the circuit at which it is designed to perform. (Ratings for ac equipment are based on a frequency of 60 Hz.)

5.4 Rated current

5.4.1 Rated continuous current

The rated continuous current of LV switchgear is the maximum current in rms amperes at rated power frequency or direct current that can be carried continuously by the primary circuit components, including buses and connections, without causing temperatures or temperature rises in excess of specified limits for the following:

a) Any primary or secondary circuit component
b) Any insulating medium, or structural or enclosing member

The specified temperature and temperature rise limits applicable to switchgear assemblies are given in 5.5.1 through 5.5.6.

5.4.2 Continuous current ratings

The preferred continuous current ratings of the main bus in LV ac switchgear are 1600 A, 2000 A, 3000 A, 3200 A, 4000 A, or 5000 A. In LV dc switchgear, the preferred continuous current ratings are 1600 A, 2000 A, 2500 A, 3000 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, or 12 000 A.

The continuous current rating of a vertical section bus riser shall be equal to the frame size of the LV power circuit breaker connected to that riser (see ANSI C37.16-2000 or IEEE Std C37.14-1999).

EXCEPTION—The continuous current rating of riser bus may be as modified by the allowable cumulative loading of multiple circuit breakers in the same section (see Table 14), or by lower continuous current ratings for current transformers. In no case does the riser bus rating need to be greater than the rating of the main bus.

5.4.3 Rated short-time withstand current

The rated short-time withstand current of a LV ac switchgear assembly, or a LV dc switchgear assembly rated 300 V or 325 V (dc), is the designated limit of available (prospective) current at which it shall be required to withstand its short-time current duty cycle (two periods of 0.5 s current flow, separated by a 15 s interval of zero current) at rated maximum voltage under the prescribed test conditions. This current is expressed in rms symmetrical amperes and is measured from the envelope of the available current wave at a time one-half cycle after current is established.

The rated short-time withstand current of a LV dc switchgear assembly for use with solid-state rectifiers (regardless of rated voltage), or rated above 325 V (dc), is the designated limit of available (prospective) sustained rms current it shall be capable of carrying for not less than 250 ms.

Both LV ac and LV dc switchgear assemblies shall have a preferred short-time withstand current rating equal to the short-time current rating of the smallest frame size circuit breaker used in the assembly, as listed in ANSI C37.16-2000.

5.4.4 Rated short-circuit withstand current

The rated short-circuit withstand current of a LV ac assembly, or a LV dc switchgear assembly rated 300 or 325 V (dc), is the designated limit of available (prospective) current at rated maximum voltage that it shall be required to withstand for a period of no less than four cycles on a 60 Hz basis under the prescribed test conditions. This current is expressed in rms symmetrical amperes and is measured from the envelope of the available current wave at a time 1/2 cycle after current is established.

For a LV dc switchgear assembly, the rated short-circuit withstand current shall be the peak current that it shall be required to withstand when tested using a dc source.

Low-voltage ac switchgear assemblies shall have preferred short-circuit withstand current ratings equal to the short-circuit current rating of the smallest frame size circuit breaker used in the assembly as covered in ANSI C37.16-2000. The power factor (X/R ratio) shall be as required in 6.2.5.1.

Low-voltage dc switchgear assemblies shall meet the ratings and test parameters required for LV dc power circuit breakers as covered in IEEE Std C37.14-1999 and ANSI C37.16-2000.

NOTES
1—The rated short-circuit withstand current determines the *bus bracing* which is required of the design.
2—For LV ac and dc switchgear assemblies with no fused circuit breakers, the rated short-circuit withstand current is the short-circuit current rating of the circuit breaker with the lowest short-circuit current rating in the assembly.
3—For LV ac switchgear assemblies with all fused circuit breakers, the rated short-circuit withstand current is the short-circuit current rating of the fused circuit breakers used in the assembly.
4—For LV ac switchgear assemblies with both fused and unfused circuit breakers, the rated short-circuit withstand current is the short-circuit current rating of the unfused circuit breaker with the lowest short-circuit current rating in the assembly.
5—The rated short-circuit withstand current (from notes 2, 3, or 4 above), which is expressed in rms symmetrical amperes, times 2.3 (for unfused circuit breaker assemblies) or times 2.16 (for fused circuit breaker assemblies), equals the peak current for which the assembly must be qualified by the short-circuit current withstand tests of 6.2.5. The short-circuit withstand current can also be expressed in rms asymmetrical amperes by multiplying times 1.33 or 1.247 for unfused and fused circuit breaker assemblies, respectively. The rms asymmetrical current values for low-voltage switchgear assemblies are similar in concept to the rms asymmetrical momentary current ratings for medium-voltage switchgear assemblies, except that larger multipliers are required for medium-voltage switchgear assemblies for the higher X/R ratings. The short-circuit withstand current has also sometimes been called *bus bracing*, but continued use of this term is discouraged. If *bus bracing* is used, the specifier must state whether the current is in rms symmetrical or rms asymmetrical amperes. Refer to the column for curve MM in Table 2 of IEEE Std C37.26-1972 for multipliers to convert from rms symmetrical amperes to rms asymmetrical amperes at a specific power factor or X/R ratio.

5.5 Temperature limitations

5.5.1 Limiting temperature

The limiting temperature for LV switchgear is the maximum temperature permitted for the following:

a) Any component such as insulation, buses, instrument transformers, and switching and interrupting devices
b) Air in cable termination compartments
c) Any noncurrent-carrying structural parts
d) Air surrounding devices

5.5.2 Temperature limits for insulating materials

The total temperature to which insulating materials are subjected shall not exceed the values listed in Table 3 for the various classes of insulating materials.

Table 3—Temperature limits for insulating materials as used in switchgear assemblies

Class of insulating material	Limit of hottest-spot temperature rise (°C)	Limit of hottest-spot total temperature (°C)
Class 90	50	90
Class 105	65	105
Class 130	90	130
Class 155	115	155
Class 180	140	180
Class 220	180	220

NOTES
1—For additional information on temperature limits, see IEEE Std 1-2001.
2—These temperature limits for insulating materials may not apply to insulation in circuit breakers or other devices. For temperature limitations on devices, refer to the appropriate standards for the devices. See also 5.5.4.

5.5.3 Temperature limits for buses and connections

The total temperature and temperature rise of buses and connections shall not exceed the values listed in Table 4.

Table 4—Temperature limits for buses and connections as used in switchgear assemblies

Type of bus or connection (see NOTE 1)	Limit of hottest-spot temperature rise (°C)	Limit of hottest-spot total temperature (°C)
Buses and connections with unplated copper to copper connecting joints	30	70
Buses and connections silver-surfaced or equivalent connecting joints	65	105
Buses and connections tin-surfaced or equivalent connecting joints	65	105
Connection to insulated cables unplated copper to copper[a]	30	70
Connections to insulated cables silver-surfaced or equivalent[a]	45	85
Connections to insulated cables tin-surfaced or equivalent[a]	45	85
Shunt terminals (in LV dc switchgear)	see NOTE 2	see NOTE 2

[a]Based on 90 °C insulated cables. Refer to 5.5.5.

NOTES
1—All aluminum buses shall have silver-surfaced or equivalent, or tin-surfaced or equivalent connecting joints. Welded bus connections are not considered connecting joints.
2—No specified limit except to avoid damaging adjacent parts.

5.5.4 Temperature limitations for air surrounding devices within an enclosed assembly

The temperature of the air surrounding all devices within an enclosed assembly, considered in conjunction with their rating and loading as used, shall not cause these devices to operate outside their rated temperature range when the enclosure of the assembly is surrounded by air in an ambient temperature range of −30 °C to +40 °C.

5.5.5 Temperature limitations for air surrounding insulated power cables

The temperature of the air surrounding insulated power cables within any compartment of an enclosed assembly shall not exceed 65 °C when the assembly is

a) Equipped with devices having maximum current rating for which the assembly is designed
b) Carrying rated continuous current at rated voltage and at rated power frequency or direct current, whichever applies
c) In an ambient air temperature of 40 °C

NOTE—This temperature limitation is based on the use of 90 °C insulated power cables. Use of lower temperature rated cables requires special consideration.

5.5.6 Temperature limitations for external parts subject to contact by personnel

a) External parts handled by the operator in the normal course of his or her duties shall have no higher total temperature than 50 °C.
b) External surfaces accessible to an operator in the normal course of his or her duties shall have no higher total temperature than 70 °C.
c) External surfaces not accessible to an operator in the normal course of his or her duties shall have no higher total temperature than 110 °C.

5.6 Current transformer ratings (LV ac switchgear)

5.6.1 Current transformer mechanical ratings

The mechanical ratings of current transformers shall be such that they will successfully withstand the short-circuit current for which the associated circuit-interrupting devices are applied. When the primary circuit is protected by current-limiting fuses, the current transformers shall successfully withstand the maximum let-through current of the fuses. Unless specifically limited to a shorter time by the associated protective equipment, the duration of the short circuit shall be considered as being four cycles.

5.6.2 Current transformer thermal ratings

The thermal ratings of current transformers shall be such that they will successfully withstand the short-circuit current for which the associated circuit-interrupting devices are applied. When the primary circuit is protected by current-limiting fuses, the current transformers shall successfully withstand the maximum I^2t of the fuses. Unless specifically limited to a shorter time by the associated protective equipment, the duration of the short circuit shall be considered as being 1 s.

The continuous thermal current rating factor of a current transformer shall be chosen so that the established temperature limits for the current transformer will not be exceeded at the rated secondary current of the current transformer or the rated continuous current of the main circuit, whichever is lower. See 4.4.2 of IEEE Std C57.13-1993.

5.6.3 Current transformer ambient temperature

Current transformers for use in switchgear assemblies shall be rated on the basis of at least 55 °C ambient temperature in accordance with 4.1.1.2 in IEEE Std C57.13-1993.

5.7 Phase current transformer accuracies

Accuracies tabulated hereafter are the minimum that shall be supplied. The manufacturer should be consulted if higher accuracies are required by the user. It should be recognized that current transformers with higher accuracies may not meet the requirements of 5.6.1 and 5.6.2.

For installation in LV ac switchgear, the standard current transformer accuracies for metering are listed in Table 5.

Table 5—Standard accuracy class rating[a] for current transformers in LV ac switchgear

Ratio	B 0.1	B 0.2
100:5	1.2	2.4[b]
150:5	1.2	2.4[b]
200:5	1.2	1.2
300:5	0.6	0.6
400:5	0.6	0.6
600:5	0.6	0.6
800:5	0.3	0.3
1200:5	0.3	0.3
1500:5	0.3	0.3
2000:5	0.3	0.3
3000:5	0.3	0.3
4000:5	0.3	0.3
5000:5	0.3	0.3
6000:5	0.3	0.3

[a]See IEEE Std C57.13-1993.
[b]Not in IEEE Std C57.13-1993.

5.8 Shunts for use in LV dc switchgear

Shunts used in LV dc switchgear shall have continuous current ratings that are consistent with the circuit breakers with which they are used (see 5.4.2). The shunts shall have rated secondary output voltage of 50 mV or 100 mV to coordinate with the associated metering and protective devices. Shunts shall mechanically withstand the short-circuit current rating of their associated circuit breaker, and shall withstand the thermal effects of the short-time withstand current rating of their associated circuit breaker. Shunts used in LV dc switchgear shall meet the requirements of IEEE Std 316-1971. Shunts are basically a resistance element, and can influence bus temperature rise, particularly in certain locations within the switchgear assembly. Refer to IEEE Std 120-1989 for recommendations regarding application of shunts.

6. Tests

6.1 General

This clause establishes physical and electrical conditions for tests and methods of determining temperatures and test values. All apparatuses and devices in the power circuit shall be mounted in their normal locations during tests. No statement in this clause is to be construed as modifying the test requirements for devices included in switchgear assemblies.

Tests are classified as design tests, production tests, conformance tests, and field tests. These are generally defined in Clause 3 or in IEEE Std C37.100-1992.

6.2 Design tests

Design tests, as applicable, shall be made in accordance with 6.2.1 through 6.2.11.

6.2.1 Test arrangements

For the tests specified in 6.2.2 through 6.2.5, the test arrangement construction shall consist of an indoor vertical section of circuit breaker compartments plus an additional representative structure (to simulate actual installation of two adjacent sections), so that the main bus extends through both sections and includes a main bus splice.

For the tests specified in 6.2.3 through 6.2.5, the test circuit shall be configured with the test power source connected to the main bus in such a manner that the test current passes through a main bus splice.

For the tests specified in 6.2.2, the section (riser) bus shall be the configuration with the least clearances (typically, the largest size) intended for use with the circuit breaker used in the test arrangement.

For the tests specified in 6.2.3 through 6.2.5, the section (riser) bus shall be the minimum size furnished by the manufacturer for the frame size of the circuit breaker used in the test arrangement. The intent is to perform the continuous current and short-circuit current tests with the smallest bus configuration.

Voltage transformers, control power transformers, and associated disconnecting means and fuses are not required for the tests specified in 6.2.3 through 6.2.5. If they are present in the sample, they should not have any effect on the test and need not be removed.

For the tests specified in 6.2.4 through 6.2.5, the circuit resistance of each phase shall be measured with a dc current of at least 100 A flowing prior to the test as a baseline for performance evaluation.

Test arrangement 1: 1–600 A frame breaker with 1600 A main bus

Test arrangement 2: 1–800 A frame breaker with 1600 A main bus

Test arrangement 3: 1–1600 A frame breaker with 1600 A main bus

Test arrangement 4: 1–2000 A frame breaker with 2000 A main bus

Test arrangement 5: 1–3000 A frame breaker with 3000 A main bus

Test arrangement 6: 1–3200 A frame breaker with 3200 A main bus

Test arrangement 7: 1–4000 A frame breaker with 4000 A main bus

Test arrangement 8: 1–5000 A frame breaker with 5000 A main bus

For frame and bus ratings not covered above, the test arrangement will include a breaker of the frame size to be tested. The main bus shall be of equal ampacity.

If the switchgear is manufactured in both stationary and drawout designs and the bus design is identical for both, the stationary design may be qualified by testing only the drawout design.

6.2.2 Dielectric tests

Power frequency withstand tests on LV switchgear shall be performed to demonstrate the ability of the insulation system to withstand the voltages in accordance with Table 1 and Table 2. All voltages shall be measured in accordance with IEEE Std 4-1995. The voltage is to be increased gradually from zero to the required test value within 5 s to 10 s and shall be held at that value for 1 min.

The ac test voltages shall be essentially sinusoidal and applied with a minimum crest value equal to 1.414 times the specified values. The frequency of the test voltage shall be within ±20% of the rated power frequency of the LV ac switchgear, or 60 Hz ± 20% for the LV dc switchgear being tested with a power frequency voltage. For LV dc switchgear rated above 325 V (dc), it is preferred that a dc withstand voltage test be used. For tests conducted with dc voltage, the dc voltage shall be no less than 1.414 times the ac rms listed voltage. If a test transformer of less than 500 VA is used, a suitable voltmeter shall be provided to measure the applied output voltage directly. The applicable test voltage, in accordance with Table 1 and Table 2, shall be applied for a period of 1 min to the primary circuit of the LV switchgear in the following manner:

a) For equipment with stationary devices and for equipment with drawout-mounted devices with the removable elements in the connected position, apply the test voltage as follows:
   1) With the circuit breaker contacts closed, between each phase of the switchgear assembly individually with the frame and the other phases and the neutral bus (if present) grounded
   2) With the circuit breaker contacts open, between each terminal of the switchgear assembly with the frame and all other terminals grounded
b) With the drawout circuit breaker in the test position and closed, apply the test voltage as follows:
   1) Simultaneously to all the incoming terminals of the switchgear assembly with the frame and outgoing terminals grounded. Repeat tests by applying the test voltage to the outgoing terminals with the frame and incoming terminals grounded.
   2) Simultaneously between all incoming and outgoing terminals of the switchgear assembly. This test shall be made with a value of voltage 10% higher than that specified in Table 1 and Table 2.
c) Apply test voltage between neutral and ground, except at 1800 V instead of 2200 V (not applicable to LV dc switchgear without neutral bus, or to LV ac switchgear without neutral bus).

NOTES
1—For the test across the open gap at 10% higher voltage, an intermediate point of the voltage source may, if practicable, be connected to ground and to the frame of the assembly so that the voltage between any live part and the frame will not exceed that specified in Table 1 and Table 2. If this is not practicable, the frame may be insulated from ground.
2—Successful completion of these tests does not necessarily provide assurance that with the circuit breaker in the test position, it will always flashover to ground instead of across the gap between line and load terminals. Switchgear insulation does not provide surge protection for the open gap. Where surge protection of the gap is required, suitable protective devices shall be applied.
3—Except for the main switching or interrupting device, other devices such as voltage transformers that are mounted in the switchgear assemblies may be disconnected during the dielectric test. Such devices are individually tested in accordance with the standards applying to them.

6.2.3 Rated continuous current tests

To determine compliance with continuous current ratings, it is necessary to determine that temperatures and temperature rises of the various components of the switchgear assembly are within the limits set forth in 5.5. Temperature measurements shall be made in accordance with 6.2.3.1 through 6.2.3.8.

6.2.3.1 Test area conditions

Temperature tests shall be conducted indoors in a test room that is reasonably free from drafts. The air velocity around the tested equipment shall not exceed 0.5 m/s at the beginning of the test.

6.2.3.2 Ambient air temperature limits

Tests may be made at any ambient air temperature between 10 °C and 40 °C.

6.2.3.3 Measurement of ambient air temperature

Indoor ambient air temperatures shall be determined by taking the average of the readings of three temperature-measuring devices, such as thermometers or thermocouples, placed as follows:

a) One level with the top of the structure
b) One 30 cm above the bottom of the structure
c) One midway between the two positions a) and b)

All temperature-measuring devices shall be placed 30 cm from the structure, not in front of ventilators, and in locations unaffected by drafts caused by the structure or appreciable radiation from the equipment. When the ambient air temperature is subject to variations that might result in errors in measuring the temperature rise, the temperature-measuring devices should be immersed in a suitable liquid, such as oil in a suitable container, or reliably attached to a suitable mass of metal.

NOTE—A convenient form for such a container consists of a metal cylinder with a hole drilled partly through it. This is filled with liquid and the temperature-measuring device is placed therein. The size of the container should be at least 2.5 cm in diameter and 5.0 cm high.

6.2.3.4 Method of measuring temperature

Thermocouples, when used for measuring the temperature of insulation, shall be located on the current-carrying member or other metal part at a point as close as practical to the accessible junction of the insulation and the current-carrying member or other metal part. Thermocouples used for measuring the temperature of the circuit breaker separable primary contacts shall be located approximately 13 mm from the contacts on the current-carrying member. For cable terminations, the thermocouples shall be located at the junction of the conductor and its insulation.

Thermocouples shall be held in intimate contact with the conductor surface by such methods as welding, drilling and peening, or cementing.

The thermocouples on a design test shall be located in a manner so as to measure the hottest spot even though it may involve drilling holes that destroy some parts. It is recognized that thermocouples cannot be located in the actual contact point of line or point contacts without destroying the effectiveness of such line or point contacts.

Measurements shall be made at junction points of insulation and conducting parts to ensure against exceeding temperature limits of the insulation.

6.2.3.5 Duration of tests

The continuous current test shall be made for such a period of time that the temperature rise of any monitored point in the assembly has not increased by more than 1 °C over a one hour period, with readings taken at not greater than 30-minute intervals. The switchgear is considered to have passed the test if the temperature and temperature rise limits in Table 3 and Table 4, and those in Table 2 of

IEEE Std C37.13-1990 or Table 2 of IEEE Std C37.14-1999 (as applicable), have not been exceeded in any of the readings over the one-hour period. The terminal connection limit of 55 °C rise in Table 2 of IEEE Std C37.13-1990 or Table 2 of IEEE Std C37.14-1999 is not applicable.

6.2.3.6 Frequency of test current

The frequency of the test current shall not be less than the rated power frequency of the assembly tested. A sinusoidal wave shape is recommended. The test shall be made with alternating current having a peak value equal to 1.414 times the rms test current. Direct current assemblies should be tested using a dc power supply with an rms ampere output equal to the continuous current rating.

6.2.3.7 Value of test current

The continuous current test may be performed at any convenient voltage.

For tests of LV ac switchgear, the switchgear assembly shall be tested using a three-phase source of power. Each individual phase current is to be maintained at no less than the rated continuous current.

For tests of LV dc switchgear, the test current is to be maintained at no less than the rated current of the assembly.

6.2.3.8 Copper conductors for use in continuous current tests

Bus bars are to be used for the connections to the main bus per Table 6 and cables or bus per Table 7 for connection to the circuit breaker unit outgoing terminals. If test arrangement internal bus sizes are different from those in Table 6 and Table 7, external bus sizes or configurations equal to internal bus sizes may be substituted at the option of the manufacturer.

Table 6—Copper conductors for use in continuous current tests (main bus)

Main bus rating (A)[a]	Copper bus per terminal[c,d,e]	
	Quantity	Size, in (mm)
1600	2	0.25 × 3 (6.4 × 76.2)
2000	2	0.25 × 4 (6.4 × 102)
3000	3	0.25 × 5 (6.4 × 127)
3200	3	0.25 × 5 (6.4 × 127)
4000[f]	4	0.25 × 5 (6.4 × 127)
5000[f]	5	0.25 × 6 (6.4 × 152)
5000[f]	6	0.25 × 5 (6.4 × 127)

See notes following Table 7.

The conductors connected to the terminals shall be a minimum of 1.2 m long.

6.2.4 Short-time withstand current tests

Short-time withstand current tests shall be made to demonstrate the thermal and mechanical capability of the buses and connections in LV switchgear to withstand the rated short-time current of the

Table 7—Copper conductors for use in continuous current tests (outgoing terminals)

Circuit breaker frame size (A)[a]	Size of copper conductor		
	Cable size[b]	Bus per terminal[c,d,e]	
		Quantity	Size, in (mm)
600	2–350 kcmil	–	–
800	2–500 kcmil	–	–
1600	4–600 kcmil	–	–
2000	5–600 kcmil	–	–
3000	–	3	0.25 × 5 (6.4 × 127)
3200	–	3	0.25 × 5 (6.4 × 127)
4000[f]	–	4	0.25 × 5 (6.4 × 127)
5000[f]	–	5	0.25 × 6 (6.4 × 152)
5000[f]	–	6	0.25 × 5 (6.4 × 127)

Notes applicable to both Table 6 and Table 7:
[a]When dc main bus or circuit breaker frame sizes larger than those listed are utilized, refer to IEEE Std C37.14-1999 and ANSI C37.16-2000 for guidance in testing.
[b]Tests based on cross-sectional area, not cable insulation classification.
[c]Where multiple bus bars are used, they are to be spaced 0.25 in (6.4 mm) apart.
[d]Vertical or horizontal configuration shall be the option of the manufacturer.
[e]Bus sizes (and the spacing in note c) are expressed in trade sizes (in), with approximate metric conversion.
[f]For LV ac switchgear, the 4000 and 5000 A groups are to be two sets of two or three bars with not more than 102 mm between pair centers.

assembly. This test may be conducted as a single phase test. This test is not required for fused breaker compartments.

The test shall be made with a circuit breaker of a type that has previously met the design test requirements for short-time current performance as specified in ANSI C37.50-1989 or IEEE Std C37.14-1999, and shall be located in the uppermost compartment.

The circuit breaker shall be closed and the overcurrent trip device shall be made inoperative, or the circuit breaker may be replaced by an equivalently sized dummy breaker provided the primary disconnecting devices are identical, and the circuit breaker has been qualified by previous testing.

6.2.4.1 Primary bus and connections

6.2.4.1.1 Test current

For LV ac switchgear, and LV dc switchgear rated 300 or 325 V dc, the prospective current shall be the rms value calculated in accordance with IEEE Std C37.09-1999. Single-phase testing is permitted.

For LV dc switchgear used with solid-state rectifiers, a dc test source is preferred. If the initial peak current applied is 1.65 times the average rms or dc sustained current value, and the test current also meets the requirements of 6.2.5, this test may be combined with the short-circuit current withstand test. Either a dc prospective current may be used, or the test may be performed using the I^2t true rms current through the test assembly. The prospective current will be determined by calibrating the test circuit with a short circuit placed directly across the bus connection at the incoming switchgear terminals.

6.2.4.1.2 Test voltage and frequency

For prospective current testing of LV ac switchgear, the test circuit voltage prior to the inception of current flow shall be no less than the rated maximum voltage, and the frequency of the test current shall be the rated power frequency $\pm 20\%$.

For prospective current testing of LV dc switchgear, the test circuit voltage prior to the inception of current flow shall be no less than the rated maximum voltage. Through current tests may be at any convenient voltage not exceeding rated maximum voltage.

6.2.4.1.3 Test duration

For LV ac switchgear, the test current shall continue for two periods of 0.5 s separated by a 15 s interval of zero current. The alternating component of the current at the end of each 0.5 s period (or 1 s period if manufacturer elects to use 1 s duration) shall be no less than 80% of the alternating component measured at one-half cycle after the initiation of the current. At the option of the manufacturer, a single period of 1 s duration may be used if circuit breakers are not included in the test current path of the assembly.

For LV dc switchgear, the current duration shall be at least 250 ms.

6.2.4.1.4 Test connections

For LV ac switchgear, the main bus terminals shall be connected to the test circuit power source, and the circuit breaker compartment outgoing terminals shall be connected together by shorting bars.

For LV dc switchgear with a single bus, the test connections shall be made to the incoming main bus terminals and to the circuit breaker outgoing terminals.

For LV dc switchgear with positive and negative buses, the test connections shall be made to the incoming main bus terminals, with the outgoing circuit breaker terminals shorted.

6.2.4.1.5 Performance

After the test, the switchgear shall have

a) no breakage of insulation or structural components
b) no permanent deformation of bus or its support
c) no separation of bus or bus connections, and no reduction in the cross section of the bus or bus connections
d) the removable element shall be capable of moving from the connected to the disconnected position and back to the connected position via its intended means
e) no signs of pitting or welding of primary disconnect devices

If the switchgear has not met the requirements of item b) at the conclusion of the test, the dielectric tests described in 6.2.2 shall be repeated. The switchgear shall be considered to have passed this portion of the short-time current withstand test if it successfully passes the dielectric tests.

If the switchgear has not met the requirements of item e) at the conclusion of the test, a dc resistance test across the tested circuit shall be made with a minimum of 100 A flowing through the circuit. The switchgear shall be considered to have passed this portion of the short-time current withstand test if the dc resistance of the equipment after the short-time current withstand test does not exceed 200% of the circuit resistance of the circuit prior to the test.

6.2.4.2 Neutral bus and connections (If applicable)

A single-phase short-time current withstand test shall be made on the neutral bus. The test parameters shall be as described in 6.2.4.1.1 through 6.2.4.1.3, except that test voltage is to be applied between the neutral and nearest phase bus, and the voltage shall be at least rated maximum voltage divided by $\sqrt{3}$. The circuit resistance shall be measured with a dc current of at least 100 A flowing prior to the test as a baseline for performance evaluation. The short-circuit connection shall be made between the ends of the main and neutral bus bars at the end opposite the test source connection. The short-circuit connection shall be made with bolted bars of minimum length, and cross section equal to the bus being tested. Insofar as possible, the connections shall not add intentional bracing to the bus structure being tested.

6.2.4.2.1 Performance

After the test, the switchgear shall have

a) no breakage of insulation or structural components
b) no permanent deformation of bus or its supports
c) no separation of bus or bus connections, and no reduction in cross section of the bus or bus connections
d) the removable element shall be capable of moving from the connected to the disconnected position and back to the connected position via its intended means
e) no signs of pitting or welding of primary disconnect devices

If the switchgear has not met the requirements of item b) at the conclusion of the test, the dielectric tests described in 6.2.2 shall be repeated. The switchgear shall be considered to have passed this portion of the short-time current withstand test if it successfully passes the dielectric tests.

If the switchgear has not met the requirements of item e) at the conclusion of the test, a dc resistance test across the tested circuit shall be made with a minimum of 100 A flowing through the circuit. The switchgear shall be considered to have passed this portion of the short-time current withstand test if the dc resistance of the equipment after the short-time current withstand test does not exceed 200% of the circuit resistance of the circuit prior to the test.

NOTE—d) and e) are applicable only to assemblies that may include four-pole power circuit breakers.

6.2.4.3 Ground bus and connections

For LV ac switchgear (or LV dc switchgear that includes a ground bus), a single-phase short-time current withstand test shall be made on the ground bus. The test parameters shall be as described in 6.2.4.1.1 through 6.2.4.1.3, except that the test voltage is to be applied between the ground bus and nearest phase bus, shall be at least rated maximum voltage, and only a single 1/2 second test current period is required. The circuit resistance shall be measured with a dc current of at least 100 A flowing prior to the test as a baseline for performance evaluation. Tests for the ground bus shall be made by connecting the ground bus to one phase of the source and connecting the nearest phase bus to another phase of the source. The short-circuit connection shall be made between the ends of the main and ground bus bars at the end opposite the test source connection. The short-circuit connection shall be made with bolted bars of minimum length, and cross section equal to the bus being tested. Insofar as possible, the connections shall not add intentional bracing to the bus structure being tested.

This test is not applicable to LV dc switchgear which is intended for ungrounded installation (without ground bus).

6.2.4.3.1 Performance

After the test, the ground bus, joints and connections shall have

a) no breakage of insulation or structural components

b) no reduction in phase-to-ground or phase-to-phase clearance
c) no separation of bus or bus connections, and no reduction in cross section of bus or bus connections.

A dc resistance test across the tested circuit shall be made with a minimum of 100 A flowing through the circuit. The dc resistance of the circuit after the short-time current withstand test shall not exceed 200% of the circuit resistance prior to the short-time current withstand test.

If the switchgear has not met the requirements of item b) at the conclusion of the test, the dielectric tests described in 6.2.2 shall be repeated. The switchgear shall be considered to have passed this portion of the short-time current withstand test if it successfully passes the dielectric tests.

6.2.5 Short-circuit current withstand tests

Short-circuit current withstand tests shall be made to demonstrate the mechanical adequacy of the structure, buses, and connections when the bus is subjected to a high current for a specified time. The current for these tests is to be equal to the short-circuit rating of the circuit breakers intended for use in the tested switchgear.

The performance criteria for these tests are the same as for the short-time current withstand tests, as given in 6.2.4.1.5 (phase bus), 6.2.4.2.1 (neutral bus) and 6.2.4.3.1 (ground bus).

6.2.5.1 LV ac switchgear and LV dc switchgear (rated 300 or 325 V dc, and not for solid-state rectifier applications)

The duration of current flow during the short-circuit current withstand test shall be for no less than four cycles on a 60 Hz basis (0.067 s), unless the bus is protected by a current-limiting device, in which case the duration shall be for the time permitted by that device.

The three-phase rms symmetrical value of current that verifies the short-circuit withstand current rating shall be determined by calibrating the test circuit with the LV switchgear omitted and shall be measured one-half cycle after the inception of the current flow in the test circuit. This current in each phase shall be calculated in accordance with IEEE Std C37.09-1999. For three-phase circuits the symmetrical current value shall be the average of the phase currents.

The power factor of the test circuit shall be 15% lagging or less (X/R ratio of 6.6 or greater) with X and R in series connection. The power factor shall be determined in accordance with IEEE Std C37.26-1972. For fused circuit breaker equipment, the power factor shall be 20% lagging or less (X/R ratio of 5 or greater).

The rms value of the alternating component of the current at the end of three cycles shall be no less than 90% of the value measured at one-half cycle after initiation of the current.

The current shall be initiated in the test circuit in such a manner to ensure that the peak current available is no less than 2.3 times (2.16 for fused circuit breakers) the single-phase rms symmetrical value for the single-phase tests and 2.3 times (2.16 for fused circuit breakers) the three-phase rms symmetrical value in one phase for three-phase tests.

The test-circuit voltage prior to the inception of current flow shall be no less than the rated maximum voltage.

The frequency of the test circuit shall be the rated power frequency ±20%.

Individual single-phase tests are also to be made to prove the strength of the ground bus and the neutral conductor design with respect to the nearest phase bus during the test. Line-to-neutral voltage is to be applied between the neutral and the nearest phase bus during the test of the neutral bus. Line-to-line voltage is to be applied between the ground bus and the nearest phase bus during the test of the ground bus.

Low-voltage dc switchgear having no circuit breakers applied to solid-state rectifiers may be qualified using an ac test source as outlined in this subclause. The LV dc switchgear used in solid-state rectifier applications shall be tested in accordance with 6.2.5.2.

6.2.5.2 LV dc switchgear

For LV dc switchgear used with solid-state rectifiers, a dc test source is preferred. The circuit shall produce a current peak with a value no less than the associated short-time peak current rating of the circuit breaker within 10 ms.

For LV dc switchgear assemblies, the short-circuit withstand test may be performed with either a prospective test current or with a through peak current. The circuit breaker shall be closed and the overcurrent trip device shall be made inoperative, or the circuit breaker may be replaced by an equivalently sized dummy breaker provided the primary disconnecting devices are identical, and the circuit breaker has been qualified by previous testing.

For prospective current tests, the test circuit voltage prior to the inception of current flow shall be no less than the rated maximum voltage. Through current tests may be at any convenient voltage not exceeding rated maximum voltage.

6.2.5.3 Test connections

For LV ac switchgear, the main bus terminals shall be connected to the test circuit power source, and the tests shall be made with a short at the following locations:

a) At the opposite end of the main bus from the terminals to cause a short-circuit current to pass through the main bus and splice.
b) At a location on the section bus (riser) so that a short-circuit current will pass through the greatest possible length of the section bus (riser).

For LV dc switchgear with a single bus, the test connections shall be made to the incoming main bus terminals and to the circuit breaker outgoing terminals.

For LV dc switchgear with positive and negative buses, the test connections shall be made to the incoming main bus terminals, with the outgoing circuit breaker terminals shorted.

6.2.5.4 Auxiliary equipment primary disconnecting device short-circuit current withstand test

The primary disconnecting device and connecting bus or cable for voltage transformer (VT) and control power transformer (CPT) auxiliary sections shall be capable of carrying the short circuit current from a transformer failure until the primary fuse protection can operate. The test sample shall use fuses with the maximum rated peak let-through current allowed by the design.

6.2.5.4.1 Test current

The test current shall be a prospective value calibrated at the main bus connection point for the auxiliary section and no less than the peak, rms total, and rms symmetrical values specified in 5.4.4.

6.2.5.4.2 Test voltage

The test shall be performed at the rated voltage of the LV switchgear.

6.2.5.4.3 Test duration

The actual duration of current flow will be limited by operating time of the primary fuse protection for the transformer. The circuit shall be calibrated for a maximum duration of four cycles.

6.2.5.4.4 Test connections

The test circuit power source shall be connected to the incoming terminals of the auxiliary section.

The short circuit connection shall be a bolted connection made phase-to-phase on the load side of the fuses using cable of the same size as used for the connection from the main bus to the disconnecting device.

The switchgear shall be grounded with a minimum of 4/0 copper conductor.

6.2.5.4.5 Performance

After the test

a) The primary disconnecting devices shall show no signs of burning
b) All connections remain effective
c) No breakage of insulation or structural components
d) The primary disconnecting device shall be capable of operation from the connected (or closed) position to the disconnected (or open) position and back via its intended means.

6.2.6 Mechanical endurance tests

6.2.6.1 Test procedure

Low-voltage switchgear with drawout circuit breakers shall be subjected to at least the number of mechanical endurance test cycles as specified in Table 8, for each frame size and type of circuit breaker. A test cycle, as specified in 6.2.6.2, consists of operations between connected, test and disconnected positions to demonstrate proper sequential operation and to establish satisfactory function of the following elements:

a) Separable primary contacts
b) Separable control contacts
c) Circuit breaker removable element position interlocks (every fiftieth operation)
d) Stored energy mechanism interlocks, as applicable (every fiftieth operation)
e) Structure mounted breaker position switches (TOC)
f) Auxiliary switches mounted on stationary structure (MOC) (every fiftieth operation)
g) Shutters (as applicable)

All primary power should be disconnected during these mechanical tests.

Mechanical performance tests of fused circuit breakers are not required when the drawout mechanisms are of equivalent design on fused and unfused circuit breakers.

The tests shall be performed either with an electrically operated circuit breaker or with a manually operated circuit breaker having a stored-energy closing mechanism and equipped with separable control contacts, if the design of the drawout mechanism and the interlocks are the same for both. If they are not, both manually and electrically operated designs shall be tested.

The test shall consist of the number of complete cycles of operation (per Table 8), as described in 6.2.6.2, without repair or replacement of any functional parts. Proper operation of structure mounted breaker position switches (TOC) and auxiliary switches mounted on stationary structure (MOC) shall be verified during the following tests by monitoring the contact position of these switches as applicable.

Table 8—Mechanical endurance test cycles

LV ac circuit breakers		LV dc circuit breakers	
Below 3000 A	**3000 A and above**	**4000 A and below**	**Above 4000 A**
500 cycles	250 cycles	500 cycles	250 cycles

At the beginning of the test, the circuit breaker shall be open and in the disconnected position with the stored-energy mechanism discharged. Separable contacts shall be lubricated according to the manufacturer's recommendations.

6.2.6.2 Cycles of operation

Each complete cycle of operation shall consist of movement of the circuit breaker, by its intended means, from the disconnected position to the connected position, followed by movement of the circuit breaker from the connected position to the disconnected position.

Every fiftieth operation, the following seven steps shall be performed:

Step 1. Move the breaker from the disconnected position to the test position and, if required, install a secondary test coupler.

a) Close the circuit breaker.
b) Check to assure that the circuit breaker cannot be moved to the connected position while closed.
c) Open the circuit breaker.

NOTE—The disconnected position may correspond to the test position.

Step 2. Move the circuit breaker to a position approximately midway between the test and connected positions or as close to a mid-position as the removable secondary test coupler (if required) will permit. Check to assure that the circuit breaker cannot be closed, either electrically or mechanically.

Step 3. Remove the secondary test coupler if present, and move the circuit breaker to the connected position.

a) Close the circuit breaker.
b) Check to assure that the circuit breaker cannot be moved out of the connected position while closed.
c) Open the circuit breaker.

Step 4. Move the circuit breaker to a position approximately midway between the test and disconnected positions or as close as possible to a midpoint position as the removable secondary test coupler (if required) will permit. If required, install a secondary test coupler. Check to assure that the circuit breaker cannot be closed, either electrically or mechanically.

Step 5. Move the circuit breaker to the test position.

a) Close the circuit breaker.
b) Check to assure that the circuit breaker cannot be moved to the connected position while closed.
c) Open the circuit breaker.

Step 6. Remove the secondary test coupler, if present, and move the circuit breaker to the disconnected position.

Step 7. Check to assure that, when the mechanism is in the fully charged condition, the closing function is blocked or the interlocks ensure mechanism discharge before or during withdrawal of the circuit breaker from the housing. (Automatic discharge is a commonly accepted method.)

NOTE—This step is not required if the stored-energy mechanism and contact assembly are fully enclosed within the breaker element and access for service is not possible.

6.2.6.3 Performance

At the completion of these tests:

a) No maintenance shall have been necessary
b) All interlocks shall function in the intended manner
c) The removable element shall be capable of operating from connected to disconnected positions by its intended means without difficulty
d) The switchgear shall be structurally intact and in a condition to continue in service
e) The plating of the separable primary disconnect contacts (silver-surfaced or the equivalent) shall not have worn through to the underlying layer at the surfaces where the primary disconnecting devices make contact when in the connected position
f) Separable secondary disconnect devices, if plated, shall not have worn through to the underlying layer at the surfaces where the secondary disconnecting devices make contact when in the test and connected positions.

6.2.7 Flame-resistance tests

Sheet, molded, or cast insulating material used in a switchgear assembly shall not be classified as flame resistant unless they have a minimum average ignition time of 60 s and a maximum average burning time of 500 s when tested in accordance with method II of ASTM D229-2001.

6.2.8 Rod entry test

6.2.8.1 Method for ventilated enclosures

This test shall prevent the insertion of a straight rod having a diameter of 13 mm into the opening.

EXCEPTION—If the distance between the openings and the nearest live part is greater than 10 cm, a rod having a diameter greater than 13 mm shall be permitted to enter the opening, but a rod having a diameter greater than 19 mm shall not be permitted to enter the opening.

6.2.8.2 Evaluation

The enclosure is considered to have met the requirements of this test if the appropriate rod cannot enter the enclosure.

6.2.9 Coating (paint) qualification test

The coating qualification test applies to all enclosures incorporating external ferrous parts. Nonferrous enclosures with no external ferrous parts need not be tested.

The coating qualification test shall be performed to ensure the adequacy of finishes to inhibit the buildup of rust on ferrous metal materials used for enclosures. The methods used are described in 6.2.9.1 through 6.2.9.7.

6.2.9.1 Test specimens

Representative test panels of a 7.6 cm × 15 cm minimum size that can be accommodated by the test chamber shall be provided. Each specimen shall be uniformly processed in the standard production coating system. At least four panels shall be selected for the test. All the test specimens shall be of standard gauge ferrous metal equivalent to that used for the enclosure. The specimen shall be allowed to age for a minimum of seven days before being tested.

6.2.9.2 Test apparatus

The test apparatus shall consist of a fog chamber, salt-solution reservoir, compressed-air supply, provisions for heating, and means of control. The conditions in the salt-spray chamber, including the positioning of the specimens, content of the salt solution, and temperature and pressure to be maintained, shall be as defined in ASTM B117-1997.

6.2.9.3 Preparation of test specimens

Two of the test panels shall be suitably scribed for testing in accordance with ASTM D1654-1992.

6.2.9.4 Exposure of test specimens

All test specimens shall be tested in the salt-spray chamber for a period of 200 h continuously except for the short daily interruptions necessary to inspect the test specimen or replenish the solution in the reservoir.

6.2.9.5 Procedure

After completion of the exposure period, the scribed specimens shall be processed in accordance with ASTM D1654-1992, either method A (tape) or method B (scraper).

6.2.9.6 Evaluation

The scribed specimens shall then be evaluated for creepage from the scribe mark in accordance with ASTM D1654-1992, rating schedule No. 1. The non-scribed specimen shall be evaluated for degree of blistering in accordance with ASTM D714-1987.

6.2.9.7 Performance

The scribed specimens shall be judged to have met the requirements of the test if their rating number is 5 or higher as determined by ASTM D1654-1992. The non-scribed specimens shall be judged to have met the requirements of the test if their blistering size is No. 6 or higher, and their frequency designation is F or M as determined by ASTM D714-1987.

6.2.10 Rain test for outdoor LV switchgear

The enclosure to be tested shall be equipped and complete with typical appurtenances, and placed in the area to be supplied with artificial precipitation. For multiple unit construction a minimum of two units shall be used to test the joints between units. A roof joint shall be included.

The artificial precipitation shall be supplied by a sufficient number of nozzles to produce a uniform spray over the entire surface or surfaces under test. The various vertical surfaces of an enclosure may be tested separately or collectively, provided that a uniform spray is simultaneously applied to both a) and b) as follows:

a) The roof surface, from nozzles located at a suitable height

b) The floor outside the enclosure for a distance of approximately 0.9 m in front of the surface under test with the enclosure located at floor level.

The nozzles used for this test shall deliver a square-shaped spray pattern with uniform spray distribution and shall have a capacity of at least 0.45 L/s at a pressure of 410 kPa, and a spray angle of approximately 75 degrees. The centerline of the nozzles shall be inclined downward so that the top of the spray is horizontal as it is directed toward the vertical and roof surfaces being tested.

The pressure at the nozzles shall be a minimum of 410 kPa under flow conditions. (This is approximately equivalent to rain driven by a 105 km/h wind.) The quantity of water applied to each surface under test shall be at least 0.5 cm per unit surface per minute, and each surface so tested shall receive this rate of artificial precipitation for a duration of 5 min. The spray nozzle shall not be more than 3.0 m from the nearest vertical surface under test.

After the test is completed, an inspection shall be made promptly to determine if the enclosure meets the requirements of outdoor construction. More specifically, the equipment shall have satisfactorily met the requirements of this test if the visible inspection indicates the following:

1) No water on primary or secondary insulation
2) No water on any electrical components or mechanisms of the assembly
3) No significant accumulation of water retained by the structure or other noninsulating parts (to minimize corrosion).

6.2.11 Gaskets used in outdoor LV switchgear

The requirements of this section are applicable to rubber or rubber-like gaskets (elastomeric, thermoplastic, or other composition materials) relied upon to enable an enclosure to meet the rain test specified in 6.2.10.

6.2.11.1 Accelerated aging test

Samples of the gasket shall be subjected to a temperature of $70 \pm 1^{\circ}$C in circulating air for 168 hours. The tensile strength after exposure shall not be less than 60% and the elongation shall not be less than 75% of the values determined with unaged samples. Testing shall be conducted per the methods in ASTM D412-1998A.

6.2.11.2 Securement of gaskets

Gaskets shall be suitably secured to the door or enclosure so that they are not readily dislodged when the door is opened and closed. The means used to secure a gasket shall not require the operator to manually place or retain the gasket while opening or closing the door.

6.3 Production tests

Production tests for LV switchgear shall include power frequency dielectric tests, mechanical tests, grounding of instrument transformer case tests, and electrical operation and control wiring tests. Drawout circuit breakers need not be tested in the assembly if they are tested separately.

6.3.1 Dielectric tests

Power frequency withstand tests shall be made on each LV switchgear in accordance with the general requirements of 6.2.2 with the exception that tests in item b) of 6.2.2 are not required. Tests shall be made between each phase and ground with the other phases grounded. The duration of the test may be reduced to 1 second if a voltage 20% greater than that specified in 6.2.2 is used.

Apply a test voltage of 1800 V between neutral and ground. The test duration may be reduced to 1 second if a voltage of 2200 V is used.

6.3.2 Mechanical operation tests

Mechanical tests shall be performed to ensure the proper functioning of mechanical interlocks, etc. These tests shall ensure the interchangeability of removable elements designed to be interchangeable.

6.3.3 Grounding of instrument transformer case test

The effectiveness of grounding of each instrument transformer case or frame shall be checked by a low potential source such as 10 V or less using bells, buzzers, or lights. This test is required only when instrument transformers are of metal-case design.

6.3.4 Electrical operation and control wiring tests

6.3.4.1 Control wiring continuity

The correctness of the control wiring of a switchgear assembly shall be verified by either or both of the following:

1) Actual electrical operation of the component control devices
2) Individual circuit continuity checks by electrical circuit testers

6.3.4.2 Control wiring insulation test

A 60 Hz test voltage shall be applied after all circuit grounds have been disconnected. Either 1500 V for 1 min or 1800 V for 1 s may be utilized, except that wires connected directly to the main power circuit shall be subjected to the test voltage applicable to the main power circuit (see 6.2.2). All wires shall be tested either individually or in groups. At the option of the manufacturer, switchgear-mounted devices that have been individually tested may be disconnected during the test.

Circuits in LV dc switchgear that operate at voltages exceeding 325 V (dc) shall be tested using the corresponding power frequency withstand voltage or dc withstand voltage from Table 2 for the voltage involved.

6.3.4.3 Polarity verification

Tests or inspections shall be made to ensure that connections between instrument transformers and meters or relays, etc., are correctly connected with proper polarities in accordance with circuit diagrams. Instruments shall be tested to ensure that pointers move in the proper direction. This does not require tests using primary voltage and current.

6.3.4.4 Sequence tests

Low-voltage switchgear involving the sequential operation of devices shall be tested to ensure that the devices in the sequence function properly and in the order intended.

This sequence test need not include remote equipment controlled by the switchgear assembly. However, this equipment may be simulated, where necessary.

6.4 Conformance tests

Conformance test procedures for LV ac switchgear are given in ANSI C37.51-1989.

6.5 Field dielectric tests

When power frequency withstand voltage tests or dc voltage withstand tests are to be made on LV switchgear after installation in the field, the switchgear shall not be tested at greater than 75% of the test values given in Table 1 and Table 2.

NOTE—Field tests are recommended when new units are added to an existing installation or after major field modifications. The equipment should be put in good condition prior to the field test. It is not expected that equipment shall be subjected to these tests after it has been stored for long periods of time or has accumulated a large amount of dust, dirt, moisture, or other contaminants without first being restored to good condition.

7. Construction

7.1 General requirements

7.1.1 Buses and primary connections

Buses and primary connections shall be of copper or aluminum, or both. For bus ratings see 5.4.2.

7.1.1.1 Phase or polarity arrangements

Panel-mounted devices shall be mounted in the same arrangement as described in a) and b), as viewed from the front of the panel.

a) The phase arrangement on three-phase assembled switchgear buses and primary connections shall be 1, 2, 3 (or A, B, C), from front to back, top to bottom, or left to right, as viewed from the front of the switchgear. Certain types of equipment may require other phasing arrangements and a neutral conductor. In these cases the phasing shall be suitably indicated.
b) Polarities on dc assembled switchgear buses and connections shall be positive, neutral, negative, front to back, top to bottom, or left to right, as viewed from the front of the switchgear. Certain types of equipment may require other polarity arrangements. In these cases the polarity shall be suitably indicated.

7.1.1.2 Phase sequence (LV ac switchgear)

The phase sequence on connection diagrams shall be such that when considering voltages to neutral on a polyphase system with respect to the element of time, the voltage of phase 1 will reach a maximum ahead of the voltage of phase 2, phase 3, etc. This sequence shall be designated as phase sequence in the consecutive numerical order starting with 1.

7.1.1.3 Cable terminations

The LV switchgear shall provide space for the devices used for making electrical and mechanical connections to incoming and outgoing cables. Each cable terminal connection point shall meet the bolt hole requirements of NEMA CC1-1993.

7.1.1.4 Main bus splices

When bolts, nuts, and washers are provided for connecting through buses to other sections, the length of the bolts shall be such that the dielectric integrity is not impaired.

7.1.2 Grounding

Circuit connections to a ground bus shall be made so that it is not necessary to open-circuit the ground bus to remove any connection made to the ground bus.

Ground connections shall be provided for all removable elements to ensure that the frame and mechanism are grounded until the primary circuit is disconnected and the removable element is moved a safe distance. (See IEEE Std C37.100-1992 for definitions of test and disconnected positions.)

When mounted on metal switchgear structures, cases of instruments, instrument transformers, meters, relays, and similar devices shall be considered as being adequately grounded when secured to these structures by metal mounting hardware with adequate provision for penetrating the paint film (see 6.3.3).

When devices are door-mounted, the door shall be bonded to the main structure with a minimum No. 14 AWG conductor or equal.

7.1.2.1 LV ac switchgear

A ground bus shall be included. The ground bus shall run the entire length of the assembly.

The ground bus electrically connects together the structures in a switchgear assembly in or on which primary equipment or devices are mounted.

At all points of connection between a ground bus and the assembly, any nonconductive coatings, such as paint, shall be removed or penetrated to ensure good electrical contact.

The ground bus for each group of vertical sections shall have facilities for connection to a station ground bus by suitable conductors.

7.1.2.2 LV dc switchgear

A ground bus may be included, based on the application. If a ground bus is supplied, the requirements of 7.1.2.1 apply.

7.1.3 Control and secondary circuits and devices, and all wiring

7.1.3.1 Wiring

Flame-resistant, 600 V insulated stranded copper wire shall be used for internal wiring between components of switchgear assemblies, and to terminals for connection to external controls, metering or instrumentation. Wiring within components is assumed to be covered by standards applicable to those devices, and is not covered by this standard. Wiring for the purpose of conveying power to external switchgear loads is not covered by this section.

For LV dc switchgear, wiring used to connect instrument, meters, and relays directly on circuits up to 800 V, and any wiring connected directly to higher voltage circuits in LV dc switchgear rated up to 3200 V, shall use wire rated for the voltage involved.

The switchgear manufacturer is responsible for the performance of the wiring system provided by the manufacturer within the switchgear. This applies to the integrity of internally generated signals in the control wiring, and may require the use of special precautions such as shielded wire, twisted-pair wire, or segregation of certain wires, such as those connected directly to the main or riser bus.

7.1.3.1.1 Wiring across a hinge

Wiring that crosses a hinge shall be suitable for this use, as defined by the following criteria:

a) The wire shall be sufficiently flexible to withstand repeated door movement without sustaining damage to wire strands or insulation, and
b) the loop formed by the wiring as it crosses the hinge shall be secured to the equipment at both ends, in such a manner that negligible strain is transmitted to wire beyond the securements, and
c) the wire loop is to be protected between the securements to provide a degree of protection against damage to the wire insulation as the door is moved.
d) No sharp edges or objects are allowed in the path swept by the wire loop as the door is operated.
e) No. 14 AWG and larger wire is to be Class C or D stranding.

7.1.3.1.2 Wire size

Wire shall be suitable for the anticipated maximum steady-state load. The size chosen shall also accommodate voltage drop within the switchgear, including the effect of intermittent heavy loads (shunt trip coils, inrush from relays, and the like). The following criteria shall be used as minimums:

Maximum steady-state load (A)	Minimum wire size (AWG)
$30 < \text{Load} \leq 40$	No. 8
$20 < \text{Load} \leq 30$	No. 10
$15 < \text{Load} \leq 20$	No. 12
$10 < \text{Load} \leq 15$	No. 14
$7 < \text{Load} \leq 10$	No. 16
$\text{Load} \leq 7$	No. 18

EXCEPTION—Multiple-conductor cable (two or more insulated wires inside a common insulated jacket) used in logic-level and/or supervisory circuits may use wire sized as required by the circuit.

Wiring for control loads over 40 A shall be applied using ampacities from the 75 °C column of Table 310-16 in NFPA 70-2002 (NEC).

Wiring for current transformer and shunt trip circuits shall be no less than No. 14 AWG, regardless of load.

Thermocouple wiring is specifically excluded from the above ampacity requirements. It shall meet the voltage, current and temperature requirements of the circuit in which it is used and the location where it is installed.

7.1.3.1.3 Wire protection and support

Bushings, grommets, or other mechanical protection shall be provided for wiring where it passes through a metal sheet, barrier, or raceway. Wiring shall be adequately supported to prevent stress from causing damage of any kind to the conductors or the insulation.

7.1.3.1.4 Wire type

Wiring shall be rated for 600 V, 90 °C, be flame-retardant, and shall meet the requirements of NEMA WC70-1999 / ICEA S-95-658. Preferred wire is type SIS as listed in NFPA 70-2002 (NEC). Other wires which meet the requirements of this clause are also acceptable.

Wiring used for connection directly on dc circuits above 600 V shall be rated for the voltage involved (or higher), 90 °C, and shall be flame-retardant.

In addition, wiring used for dc circuits for rated voltages of 48 V (dc) or above shall not contain PVC insulation.

7.1.3.2 Secondary wiring terminals

Stranded control wire shall have solderless terminals of the type wherein the body of the terminal is crimped or indented onto the conductor. Solderless terminals are not required for connection to devices that have integral pressure terminal connectors. The wire may be soldered into terminals or, where desirable, directly to devices, such as secondary disconnecting contacts, or to soldered terminals on supervisory control and annunciator equipment. Connections external to a component shall not require soldering to replace the component.

NOTE—In the absence within this standard of definitive performance requirements, compliance with this subclause can be assessed by referencing UL 486A-1997.

7.1.3.3 Terminal blocks

Terminal blocks incorporating screw- or stud-and-nut-type terminals shall accommodate wire lugs or similar devices affixed to stranded wire. Screw- or stud-and-nut-type terminals intended for use with stranded wire shall be such that all strands of the conductor are confined. Terminal blocks incorporating pressure connectors shall not damage the wire and, when terminating stranded conductors, all strands shall be clamped within the connector.

Terminal blocks for external connections shall be suitable to accept No. 10 AWG stranded wire.

The use of solid wire for external connections is not recommended.

NOTES
1—Where long connections to the control battery are necessary, the cable should be large enough to prevent excessive voltage drop.
2—In the absence within this standard of definitive performance requirements, compliance with this subclause can be assessed by referencing UL 486A-1997.

7.1.3.4 Designation of auxiliary switches and contacts

The operation of auxiliary switches and contacts for circuit-interrupting and switching devices shall be designated as follows:

a is open when the device is in the de-energized or nonoperated position
b is closed when the device is in the de-energized or nonoperated position
aa is open when the operating mechanism of the main device is in the de-energized or nonoperated position
bb is closed when the operating mechanism of the main device is in the de-energized or nonoperated position
e, *f*, *h*, *k* are special contacts and auxiliary switches other than *a*, *b*, *aa*, or *bb*

Auxiliary switches mounted on the stationary housing used to indicate the connected position of the removable element shall have the suffix TOC (circuit breaker *truck*-operated contact, or truck-operated cell switch). The position of the removable element in which the contacts are closed or open shall be designated. The following are examples:

a) 52TOC / NO or 52TOC / a is open when the circuit breaker is not in the connected position
b) 52TOC / NC or 52TOC / b is closed when the circuit breaker is not in the connected position

Auxiliary switches mounted on the stationary housing operated by the circuit breaker to indicate circuit-breaker open–closed position shall have a suffix MOC (circuit-breaker *mechanism*-operated contact, or mechanism-operated cell switch). The open–closed position of the circuit breaker shall be designated for the contacts. The following are examples:

1) 52MOC / a is open when circuit breaker is open
2) 52MOC / b is closed when circuit breaker is open

If several auxiliary switches and contacts are present on the same device, they shall be designated numerically consecutive starting at 1.

On all diagrams of all types, contacts and switches shall be shown in the de-energized position of the device.

7.1.3.5 Device function numbers

Device function numbers shall be in accordance with IEEE Std C37.2-1996.

7.1.3.6 Polarity of dc connections to device coils

Where coils on devices used in LV switchgear are connected to a dc supply and, when de-energized, are not disconnected from both the positive and negative supply leads, such coils shall be so connected that, when de-energized, they will be left connected to the negative supply lead to minimize the possibility of corrosion.

7.1.3.7 Voltage limits of instrument and control circuits

For LV ac switchgear, instruments, meters, and relays may be used directly on circuits up to 254 V if their cases are grounded to the switchgear structures in accordance with 7.1.2. Voltage and current transformers, or other suitable means, shall be used for all instruments, meters, and relays connected to ac circuits over 254 V so as to reduce the voltage on instrument wiring to 254 V or less.

EXCEPTIONS
1—Voltage regulators may be connected directly to circuits up to 635 V ac, but the regulator and the associated wiring directly connected to the bus shall be grouped separately from the other components and wiring.
2—Ground detectors may be connected directly to circuits up to 635 V ac, if connected to ground through voltage dividing resistors. The resistors shall not be mounted on the instrument panel, and the wires shall be isolated from other control wiring.

For LV dc switchgear, instrument, meters, and relays may be used directly on circuits up to 800 V if their cases are bonded to the switchgear structures in accordance with 7.1.2. Instruments, meters, and relays together with their associated wiring and accessories, when used on circuits over 800 V shall be connected through isolating transducers.

EXCEPTION—Instruments, meters, and relays, along with their associated wiring and accessories may be connected directly to circuits over 800 V dc when the instrument, meter, or relay and its associated wiring and accessories are isolated from other instruments, meters, relays, and their associated wiring and accessories and where the cases of such devices are left ungrounded and are provided with suitable protective barriers, insulated covers, or guards.

7.1.3.8 Voltage circuit protection

Voltage circuits used for control, relaying, or metering shall be protected within the LV switchgear as follows:

a) Circuits supplied from external sources (ac or dc) shall have short-circuit protection within the control source incoming section. This may be provided by a single set of short-circuit protective devices.
b) Circuits supplied from internal sources (ac or dc) shall have short-circuit protection within the same vertical section as the supply source.
c) Overcurrent protection shall be provided in accordance with NFPA 70-2002 (NEC), except in circuits where interruption of the circuit may create a hazard.
d) Circuits connected directly to the bus shall be grouped separately from the other components and wiring, and be kept to minimum length.
e) Other circuits supplying loads such as heaters, receptacles, or lights shall have both overcurrent and short-circuit protection.

7.1.3.8.1 Control power transformers

Short-circuit protection of control power transformers shall be provided in accordance with Table 9.

Table 9—Control power transformer short-circuit protection[a,b]

Single phase (kVA)	Primary maximum current-limiting fuses for control power transformers (A)		
	240 V	480 V	600 V
1	10[c]	5[c]	4[c]
2	20	10[c]	8[c]
3	30	15	12
5	50	25	20
7.5	70	35	30
10	100	50	40
15	150	70	60

[a]Voltage and control power transformer primary fuses are intended for use as a protective function only and are not intended to be used as disconnect devices. When a primary disconnect means is required, a dead-front design switch or fuse pullout should be used with these transformers.
[b]Fuse sizes listed assume that secondary protection is provided. If secondary protection is not provided, primary protection shall be as required by NFPA 70-2002 (NEC).
[c]Due to inrush current, certain types of current-limiting fuses may require larger ratings than those shown, but shall not exceed 20 A.

7.1.3.8.2 Voltage transformers

Voltage transformers shall be protected in the primary circuit with current-limiting fuses not larger than 10 A.

7.1.3.8.3 Isolation

Switches, fuse pullouts, and molded-case circuit breakers used to connect devices to the primary circuits shall be of a dead-front design.

7.1.3.9 Current transformer secondary circuit protection

Overcurrent protection of current transformer secondary circuits shall not be provided. Open circuit protection should be considered where current transformer wiring connects to devices external to the switchgear assembly.

7.1.4 Miscellaneous

7.1.4.1 Nameplate marking

The following minimum information shall be given on switchgear assembly nameplates:

a) Manufacturer's name and address
b) Manufacturer's type designation
c) Manufacturer's identification reference
d) Rated maximum voltage (where applicable)
e) Rated power frequency (where applicable)
f) Rated continuous current (main bus)
g) Rated short-circuit withstand current
h) Date of manufacture
i) Instruction manual number

7.1.4.2 Wiring devices

Lighting fixtures provided in outdoor switchgear shall be of a type and shall be so located that lamps may be safely replaced without de-energizing the primary equipment. Convenience outlets shall be of the two-pole, three-wire grounding type and protected by a Class A ground-fault circuit interrupter.

7.1.4.3 Ventilation openings and vent outlets

Openings for pressure relief or ventilation shall be so arranged that the gas or vapor escaping during normal operation will not endanger personnel operating the switchgear.

7.1.4.4 Service disconnecting means

Switchgear assemblies designated as the service disconnecting means shall be designed so that they can be installed in accordance with the applicable provisions of Article 230 in NFPA 70-2002 (NEC).

7.2 Materials and finish

7.2.1 Materials

The materials for LV switchgear assemblies shall be sheet metal suitably supported. Barriers between compartments as listed in 7.3 shall not be less than MSG No. 11 (nominal thickness 3 mm). All other covers, barriers, panels, and doors shall not be less than MSG No. 14 (nominal thickness 1.9 mm).

The minimum thickness of sheet metal used for LV switchgear is based on the use of steel. Where other metals are used the thickness shall be modified to provide equivalent strength and deflection. For example, if aluminum alloy sheet, having a yield strength of 140 MPa, is used in the place of steel to provide equivalent strength and deflection, it is required that the thickness specified above be increased by 50%.

Doors or panels used to support devices shall be increased in thickness or otherwise strengthened, as necessary, to support the devices.

7.2.2 Finishes and color

All steel surfaces to be painted shall receive a phosphatizing treatment or equivalent prior to application of finish coating or paint.

External and internal surfaces shall be coated with at least one coat of corrosion-resistant coating or paint. The coating system shall comply with the requirement of 6.2.9.

The undersurfaces of outdoor assemblies shall additionally receive either a corrosion-resistant undercoating or an additional thickness of corrosion-resistant coating.

The preferred color for the finish on switchgear assemblies shall be light gray No. 61 in accordance with ASTM D1535-1997 (Munsell notation 8.3 G6.10/0.54).

NOTES
1—Internal detail parts may have metallic plating or equivalent in lieu of coating or paint finish.
2—For conformance testing, a recognized organic coating system that has been investigated and found suitable for use as protection against atmospheric corrosion of electrical equipment steel enclosures for outdoor use may be utilized.
3—Exposed surfaces on outdoor equipment shall be coated with material capable of withstanding UV radiation without chalking or other degradation.

7.2.3 Insulating materials for the support of primary conductors

These insulation materials shall withstand the dielectric tests in 6.2.2 (dielectric tests), and be flame-resistant per 6.2.7 (flame-resistance tests).

7.3 Barriers

Each circuit breaker shall be mounted in a separate metal-enclosed compartment ventilated as necessary. Ventilation openings between compartments within the LV switchgear shall be such that the gases produced by circuit breaker interruption shall not impair the operation of adjacent compartments. When a bus sectionalizing breaker (or breakers) is included, barriers shall be provided in the bus compartment to segregate the separate bus sections from each other. If no bus sectionalizing breaker is involved, no barriers are provided in the bus compartments. Where buses and connections penetrate internal barriers, suitable insulation or clearance shall be provided.

7.4 Buses and connections

The bus and connections shall be bare except where close clearances may make insulation necessary. The buses shall be mounted on Class 105 or higher insulation. See Table 3.

NOTE—Bare bus and connections meet the requirements of this standard. However, the manufacturer may provide insulated bus and/or connections when required to meet dielectric requirements or as an option.

7.5 Access doors and covers

A hinged door shall be furnished on the front of the structure to cover each circuit breaker compartment. Removable top and back plates shall also be provided in sufficient number to permit access to the bus and connection compartments. For LV switchgear with stationary circuit breakers, a bolted cover may be used in the front of the breaker compartment.

For ease in handling, cover plates that are intended to provide access for inspecting and maintenance shall not exceed 1.12 m^2 in area or 27 kg unless they are equipped with lifting means or hinges.

To prevent access to energized fuses associated with power circuit protectors, means shall be provided to interlock the door, cover, or barrier so that it cannot be opened unless the circuit breaker is in the open position.

7.6 Closing and tripping

Mechanical means for closing and tripping manually operated breakers and for manually tripping electrically operated breakers shall be provided and shall be accessible without exposing the operator to live parts. See IEEE Std C37.13-1990 for limitations on manually operated breakers.

7.7 Indoor LV switchgear

LV switchgear for indoor applications shall be ventilated enclosures intended primarily to provide a degree of protection against contact with the enclosed equipment.

7.7.1 Requirements

When completely and properly installed, these enclosures

a) Shall provide a degree of protection against limited amounts of falling dirt; however, they will not prevent the entry of dust or liquids.
b) Shall prevent the insertion of the end portion of a straight rod of the specified diameter into the equipment cavity of the enclosure when subjected to the rod entry test.
c) Shall not rust when subjected to the coating qualification test for 200 h.

7.7.2 Design tests

The enclosures shall be tested and evaluated by

a) The rod entry test in 6.2.8
b) The paint qualification test in 6.2.9

7.8 Outdoor LV switchgear

Low-voltage switchgear for outdoor applications shall be housed in ventilated enclosures intended primarily to provide a degree of protection against falling rain, sleet, and external ice formations.

When completely and properly installed, these enclosures

a) Shall not permit water to enter the equipment cavity at a level higher than the lowest live part except if constructed to divert water from live parts, insulation, wiring, and shall have provisions for drainage.

b) Shall require the use of a tool to gain access to the equipment cavity or have provision for locking.
c) Shall have doors that are equipped with latches and stops to hold the doors in the open position.
d) Shall prevent the insertion of the end portion of a straight rod of the specified diameter into the equipment cavity of the enclosure.
e) Shall not rust when subjected to the paint qualification test for 200 h.
f) Shall have heaters or other effective means to minimize internal condensation.

For the design tests, the enclosures shall be tested and evaluated by

1) The rod entry test in 6.2.8
2) The paint qualification test in 6.2.9
3) The rain test in 6.2.10

NOTE—External icing tests are not required.

7.9 Pull box

A pull box for cables is not included in the standard equipment, but it may be furnished as an option.

7.10 Arrangements with stationary circuit breakers

Circuit breakers may be stationary mounted with or without disconnecting switches.

7.11 Arrangements with drawout circuit breakers

Drawout circuit breakers shall be equipped with self-coupling disconnecting devices and shall conform to the requirements of 7.11.1 through 7.11.6.

7.11.1 Interlocks

Mechanical interlocks shall be provided in LV switchgear as follows:

a) To prevent moving the circuit breaker to or from the connected position when the circuit breaker is in the closed position.
b) To prevent closing the circuit breaker unless the primary disconnecting devices are in full contact or are separated by a safe distance.
c) Circuit breakers equipped with stored energy mechanisms shall be designed to prevent the release of the stored energy unless the mechanism has been fully charged. Operators and service personnel shall be protected from the effects of accidental discharge of the stored energy by any of the following means:
    1) Interlocks provided in the housing to prevent the complete withdrawal of the circuit breaker from the housing when stored energy mechanism is charged.
    2) A suitable device provided to prevent the complete withdrawal of the circuit breaker until the closing function is blocked.
    3) A mechanism is provided to automatically discharge the stored energy during the process of withdrawing the circuit breaker from the housing.
    4) Mechanisms as described above are not required provided the stored energy mechanism and contact assembly are isolated within the breaker element and service is not possible.

7.11.2 Circuit breaker retention and locking

Means shall be provided for positively holding the circuit breaker in place in the housing when the removable element is in the connected or test position. When breakers are left in the housing in the disconnected position, they shall be securely held in that position by suitable mechanical means.

Additionally, means shall be provided for locking the circuit breakers in the disconnected position to prevent them or replacement breakers from being moved to the connected position.

7.11.3 Fuse accessibility

Where the removable element consists of a fused circuit breaker, the fuses shall be accessible only when the removable element is withdrawn to the test, disconnected, or into the withdrawn position.

7.11.4 Removable element interchangeability

All removable elements of the same type and rating in a given assembly shall be physically interchangeable in the corresponding stationary housings. This need not include electrical interchangeability of secondary control circuits. Means shall be provided to prevent removable elements with greater continuous current rating from being inserted into circuit breaker compartments with lesser continuous current rating. Means shall be provided to prevent removable elements with lesser short-circuit current rating from being inserted into circuit breaker compartments with greater short-circuit current rating.

7.11.5 Fuses on separate removable elements

Current-limiting fuses may be mounted on separate removable elements. The requirements of 7.11.4 apply to these elements, and in addition, these elements shall be only used in series with circuit breakers.

The fuses on these removable elements shall be interlocked such that they must be disconnected from the primary circuit(s) before access can be obtained.

Interlocking of a breaker and its associated fuses shall be provided to prevent connection or disconnection under load.

7.11.6 Secondary disconnect devices

Control wiring connections between stationary structure and the removable element shall be provided with automatic (self-coupling) contacts or manual plug and receptacle for disconnection.

The manual control connector shall be either interlocked or inaccessible to prevent connection or disconnection of the control circuits when the removable element is in the connected position and the removable element shall be prevented from being installed in the connected position unless the manual control connector is connected.

With the manual arrangement, all connections shall be group connectable simultaneously with the male contacts on the removable element and the female receptacles on the stationary structure.

NOTE—The intent of this requirement is to ensure that the control connection is always made to the circuit breaker when the circuit breaker is in the connected position.

7.12 Primary cable space

The clear cabling space independent of all projections, obstructions, or interference from moving parts, shall not be less in total area than 250% of the total cross-sectional area of the maximum number of cables that may be used in such space.

Table 10 gives the minimum area for the more common multiple-cable connections.

Table 10—Minimum areas (cm^2) for multiple cable connections (based on factor of 250%)

Size of cable AWG	Two cables	Three cables	Four cables	Five cables	Six cables	Seven cables
1	1.35	2.03	2.70	3.38	4.05	4.73
0	1.55	2.33	3.10	3.88	4.65	5.43
00	1.80	2.70	3.60	4.50	5.40	6.30
000	2.10	3.15	4.20	5.25	6.30	7.35
000	2.40	3.60	4.80	6.00	7.20	8.40
250 kcmil	2.95	4.42	5.90	7.36	8.85	10.32
350 kcmil	3.80	5.70	7.60	9.50	11.40	13.30
500 kcmil	4.90	7.35	9.80	12.25	14.70	17.15

7.13 Precautionary labels

Each LV switchgear should be provided with appropriate precautionary labels to call the user's attention to potential hazards that are inherent to the equipment and that cannot be eliminated by design. See ANSI Z535.4-1998 for recommendations.

7.14 Lifting devices

Lifting devices may be provided to facilitate the insertion or removal of drawout circuit breakers from their individual compartments and consist generally of a wheeled hoist device or an overhead lift device attached to the switchgear itself.

8. Application guide for LV switchgear

8.1 Unusual service conditions

It is strongly recommended that the usual service conditions, as described in Clause 4, be provided for LV switchgear applications, if practical (artificially, if necessary). However, if unusual conditions exist and cannot be eliminated, the following considerations apply.

8.1.1 Ambient air temperature above 40 °C

When LV switchgear is applied where the ambient air temperature is higher than 40 °C, its performance may be affected, and special consideration should be given to these applications. The total temperature limits for parts and materials as given in 5.5 should not be exceeded. Therefore, for the higher ambients, the equipment should be derated to a continuous current value that maintains the total temperature limits.

8.1.2 Ambient air temperature below −30 °C

Special consideration is also required when LV switchgear is applied where the ambient air temperature is less than −30 °C. Space heating and thermal insulation to minimize the effects of exposure should be considered. If this is not possible, the effect of low temperatures on the functional performance of such materials as oils, plastic insulation on primary and secondary circuits, electronic devices and displays, control wire insulation, and lubricants should be considered.

8.1.3 Application at unusual altitudes

Switchgear assemblies that depend on air for an insulating and cooling medium will have a higher temperature rise and a lower dielectric withstand capability when operated at altitudes above values specified in Clause 4. For applications at higher altitudes, the rated power frequency withstand voltage and continuous current rating of the assemblies should be multiplied by the correction factors in Table 11 to obtain the modified ratings.

Table 11—Altitude correction factors

Altitude (m)	Voltage	Current
2000 m and below	1.00	1.00
2600 m	0.95	0.99
3900 m	0.80	0.96

NOTES
1—Intermediate values may be obtained by interpolation.
2—For devices used in switchgear assemblies, standards covering the specific devices should be used to determine the specific altitude correction factors.
3—1000 m is approximately 3300 ft.
4—All values are under review by an IEEE Switchgear Committee Working Group, PC37.100.1, on Common Requirements for Power Switchgear and are provided here for reference until revised values are available.

8.1.4 Modification of equipment for unusual environment

Successful performance of standard LV switchgear may be extended to unusual environments by special considerations when developing equipment specifications. Several construction modifications that will mitigate the effects of these environments may be made in accordance with 8.1.4.1 through 8.1.4.6, but the emphasis should be on eliminating such conditions if at all possible. However, if these undesirable conditions cannot be eliminated, more frequent maintenance may be required.

8.1.4.1 Exposure to damaging fumes, vapors, steam, salt air, and oil vapors

Indoor and outdoor equipment should be provided with the following modifications:

a) All structural parts should be covered with a corrosion- or rust-resistant finish.
b) All steel parts that are not coated, painted, or plated should be covered with protective grease.
c) All current-carrying joints should be covered with a coating of nonoxidizing grease. Greasing of arcing contacts should only be done on recommendations of the manufacturer.
d) All coils should be impregnated with insulating compound and covered with an appropriate protective coating.
e) Heaters, in quantity and sufficient rating to minimize condensation in all compartments, should be furnished.

8.1.4.2 Exposure to excessive dust, abrasive dust, and magnetic or metallic dust

Indoor or outdoor equipment should be provided with the following modifications. Totally enclosed nonventilated equipment should be furnished with a current rating of 70% of the ventilated rating or as specified by the manufacturer. Condensation could be a problem and should be evaluated.

For outdoor assemblies, ventilated enclosures may be furnished with the ventilating openings equipped with dust filters. The requirements for these filters vary over such a range that standard specifications for their application are not practicable. Filters are available in both the washable type and the disposable type. Where used, they must be cleaned or replaced at intervals, depending upon the amount of dust in the air. Filters that are not cleaned or changed when required can cause excessive equipment temperature or condensation.

The type of filter used should be selected based on the size of dust particles encountered and the extent to which dust is to be excluded. Where very fine dust particles are to be excluded, disposable filters soaked in oil should be used. These must be changed at frequent intervals.

Forced ventilation may be required depending upon the volume of air required for ventilation and the severity of the environment. When a blower and filter are furnished based on conditions of the environment, they should be installed on the intake to minimize the possibility of drawing dust or other foreign matter into and throughout the switchgear assembly.

8.1.4.3 Exposure to hot and humid climate

Indoor and outdoor equipment intended for exposure to hot and humid climates should be made fungus-resistant by the following modifications:

a) Heaters in quantity and sufficient rating to minimize condensation in all compartments should be furnished.
b) Secondary wiring that is not inherently fungus-resistant should have fungus-resistant coating applied. Secondary wiring that has fungus-resistant insulation should not require further treatment.
c) All impregnated coils should be given an external treatment with fungus-resistant coating. Encapsulated coils that are inherently fungus-resistant should not require further treatment.
d) Coatings or paints such as alkyd enamels having a fungus and rust-resistant property should be used.
e) Insulation that is not inherently fungus-resistant should have fungus-resistant coating applied. Insulation in switchgear assemblies that is inherently fungus-resistant should not require further treatment. Fungus-resistant coatings should not be applied where they will interfere with proper operation of apparatus. In such cases, the part should be inherently fungus-resistant. These coatings should not reduce the dielectric or flame-resistant properties.
f) The fungus-resistance of materials should be determined in accordance with ASTM G21-1996. Materials to be classified as fungus-resistant should have a rating not greater than 1.

g) Materials that are made fungus-resistant by means of a coating should have the coating reapplied at periodic intervals.

8.1.4.4 Exposure to explosive mixtures of dust or gases

Application of LV switchgear for explosion-proof requirements is not recommended.

8.1.4.5 Exposure to abnormal vibration, shocks, or tilting

Indoor and outdoor equipment is designed for mounting on level structures free from vibration, shocks, or tilting.

Since these conditions vary so widely, it is recommended that the manufacturer be consulted for each specific application where vibration, shocks, or tilting are to be encountered.

It is important that the full nature of the abnormal motion be specified. The magnitude and frequency range of the dynamic motion is required so that resonance may be investigated. This is usually specified by means of an acceleration response spectrum curve for the mounting surface on which the LV switchgear is to be installed. The response spectrum is a plot of the maximum response of single-degree-of-freedom bodies, at a damping value expressed as a percent of critical damping of different natural frequencies. These bodies are plotted when they are rigidly mounted on the surface of interest (i.e., on the ground for the ground response spectrum or on the floor for the floor response spectrum) when that surface is subjected to a given abnormal motion as modified by any intervening structures. The response spectrum is useful in designing a test or in making an analysis of the performance of the LV switchgear equipment mounted on the same surface and subjected to the same motion.

In the case of tilting, it is also important that the maximum angles of tilt, both transverse and longitudinal, be specified. The exact performance requirements should also be defined. It should be recognized that equipment specifically designed for a usual installation on a substantially level surface free from excessive vibration, shock, or tilting may be damaged and may not be able to function properly when subjected to excessive motion and displacement. Hence, the application should be carefully analyzed and the essential performance requirements should be precisely defined.

8.1.4.6 Exposure to seismic shock

Because of the importance of adequate performance of equipment when applied as Class 1E equipment in a nuclear power generating station, IEEE Std C37.81-1989 was developed for this application.

Other than as may be required for use as Class 1E equipment, seismic capability is not required for LV switchgear assemblies. Seismic capability is subject to agreement between supplier and user. For those applications where seismic events are of concern, the following guidance is given:

For critical equipment whose function both during and after the seismic event must be assured: see IEEE Std C37.81-1989.

For equipment applied where mis-operation during the seismic event can be accepted, but maintaining structural integrity and the ability to function after the seismic event is required, IEEE Std C37.81-1989 can be utilized by omitting the requirement for the equipment to function during the seismic event, and by reducing the generic response spectra levels by 50%.

8.2 System characteristics—voltage and frequency

Low-voltage ac switchgear is designed for use on three-phase, 60 Hz, grounded (solidly grounded, low-resistance grounded, or high-resistance grounded), or ungrounded ac systems. Application on other types of systems, such as the following, should be reviewed with the manufacturer:

a) Two phase
b) Frequency other than 60 Hz, and/or other than sinusoidal waveform

Low-voltage dc switchgear is designed for systems which have

1) A double bus system for use with two pole circuit breakers [usually 300 or 325 V (dc) systems], or
2) A double bus system with a neutral bus [usually 300 or 325 V (dc) systems], or
3) A single bus system for use with single pole circuit breakers [usually 800 V (dc) systems or higher].

Low-voltage switchgear is intended for application on systems where the maximum operating voltage of the system does not exceed the rated maximum voltage for which the equipment is designed. The voltages for various types of LV switchgear are listed in Table 1 and Table 2.

8.3 Overvoltage considerations—insulation levels

The insulation levels to which LV switchgear is designed are listed in Table 1 and Table 2.

Information on the application of surge arresters and surge capacitors for protection against overvoltages is given in 8.7.2.

8.4 Continuous current rating and overload capability

Low-voltage switchgear assemblies are designed for normal application where the sustained load current does not exceed the rated continuous current, the altitude above sea level does not exceed 2000 m, the ambient air temperature does not exceed 40 °C, and the effects of solar radiation can be neglected. For unusual altitudes, derating factors should be applied in accordance with 8.1.3. If solar radiation is significant, continuous current capability is limited. Refer to IEEE Std C37.24-1986.

The rated continuous current is based on not exceeding the limits of the hottest spot total temperature of the various parts of the switchgear assembly when this value of current is sustained in an ambient air temperature of 40 °C. When the ambient air temperature is greater than 40 °C, the current should be reduced to less than rated continuous current to keep the total temperature of these parts within allowable limits. The application of switchgear assemblies should be based on avoiding operation at current higher than the rated continuous current of the assembly. However, since the criterion is total temperature, the following considerations are in order:

a) It is permissible to exceed rated current
    1) For short periods, such as in the starting of motors or when energizing cold loads. Generally, the short duration of this type of current increase does not raise temperatures significantly.
    2) When operating at an ambient air temperature below 40 °C (see 8.4.1).
b) Since trip devices, current transformers, and cable current ratings are frequently less than the continuous current rating of the circuit breaker, their capabilities to carry more than rated continuous current must be verified.
c) When several switchgear compartments are included in the same vertical section, consideration must be given to the allowable cumulative loading of the section (see 8.4.2).

8.4.1 Load current-carrying capabilities under various conditions of ambient temperature and load

When ambient air temperature is other than 40 °C, on which continuous ratings in 5.4.2 are based, the allowable continuous current can be calculated by the following formula:

$$I_a = I_r \left\{ \frac{\theta_{\max} - \theta_a}{\theta_r} \right\}^{1/2}$$

where

I_a is the allowable continuous load current, A, at the actual ambient temperature θ_a (I_a is not to exceed two times I_r)

I_r is the rated continuous current, A, on the basis of 40 °C ambient

$\theta_{\max}$ is the allowable hottest-spot total temperature

θ_a is the actual ambient temperature expected (between –30 °C and 60 °C), °C

θ_r is the allowable hottest-spot temperature rise at rated current, °C

NOTE—The temperature rise of a current-carrying part is proportional to an exponential value of the current flowing through it. The exponent value of 1/2 in the formula observed has been found to be generally valid for overload capability of LV switchgear and is therefore used in this standard.

The construction features of LV switchgear dictate the appropriate values of θ_r and $\theta_{\max}$. The major components have several different temperature limits specified in the standards or clauses of this standard as listed in Table 12.

Table 12—Switchgear component—temperature limitations

Circuit breakers	IEEE Std C37.13-1990 or IEEE Std C37.14-1999
Current transformers	IEEE Std C57.13-1993
Shunts	IEEE Std 316-1971
Insulating material in switchgear assemblies	Table 3
Buses and connections	Table 4
Air surrounding insulated power cables	Subclause 5.5.5
Parts subject to contact by personnel	Subclause 5.5.6[a]

[a]When applying switchgear at higher than the standard 40 °C maximum ambient temperature, the limitations of this subclause may be exceeded.

To assure that none of the temperature limitations specified in the standards or the sections of this standard as listed in Table 12 are exceeded, the permissible load current based on the actual ambient air temperature is determined by using the values of θ_r and $\theta_{\max}$ selected as follows:

a) If the actual ambient air temperature is *less* than 40 °C, the component with the *highest* specified limit of total temperature should be selected.
b) If the actual ambient air temperature is *greater* than 40 °C, the component with the *lowest* specified limit of total temperature should be selected.

The use of this value in the calculation will result in an allowable continuous current that will not cause the temperature of any part of the assembly to exceed the specified limit.

Table 13 lists the calculated values of I_a/I_r for each specified temperature limit for the various components of LV switchgear over a range of typical ambient air temperatures. The allowable current in any given situation can be estimated from Table 13 or may be calculated directly from the stated formula.

Table 13—Ratios of (I_a/I_r) for various ambient temperatures

Maximum ambient °C	Limiting temperatures of different switchgear components								
	θ_{max}	50	65	70	85	90	105	110	125
	θ_r	10	25	30	45	50	65	70	85
60[a]	—	—	0.45	0.58	0.75	0.77	0.83	0.85	0.87
50[a]	—	—	0.77	0.82	0.88	0.89	0.92	0.93	0.94
40	—	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30[b]	—	1.41	1.18	1.15	1.11	1.10	1.07	1.07	1.06
25[b]	—	1.58	1.26	1.22	1.15	1.14	1.11	1.10	1.08
20[b]	—	1.73	1.34	1.29	1.20	1.18	1.14	1.13	1.11
10[b]	—	2.0[c]	1.48	1.41	1.29	1.26	1.21	1.20	1.16
0[b]	—	2.0[c]	1.61	1.53	1.37	1.34	1.27	1.25	1.21
–10[b]	—	2.0[c]	1.73	1.63	1.45	1.41	1.33	1.31	1.26
–20[b]	—	2.0[c]	1.84	1.73	1.53	1.48	1.39	1.36	1.31
–30[b]	—	2.0[c]	1.95	1.83	1.60	1.55	1.44	1.41	1.35

[a]For limiting current, use lowest θ_r and θ_{max}.
[b]For limiting current, use highest θ_r and θ_{max}.
[c]Designated limit—not calculated.

8.4.2 Load current-carrying capability of LV switchgear

For LV switchgear, which may include one to four compartments in a single vertical section, the following guidelines are recommended for estimating the allowable cumulative loading.

8.4.2.1 Determination of main bus load current-carrying capability

The ampacity for the main bus is usually a function of the main circuit breaker frame size or the current output of the supply transformer. The ampacity of the main bus is based on the temperature limitations as described in 5.5.

8.4.2.2 Determination of vertical section load current-carrying capability

The load current-carrying capability of a vertical section consisting of one, two, three, or four circuit breakers should be determined by the lesser of the following two considerations:

a) The main bus continuous current rating
b) The allowable cumulative circuit-breaker loading

Table 14—Allowable cumulative load

Number of compartments	Allowable load for each compartment
Four circuit breaker compartments	
Bottom compartment	90% of compartment rating
Next to bottom compartment	75% of compartment rating
Next to top compartment	60% of compartment rating
Top compartment	50% of compartment rating
Three circuit breaker compartments	
Bottom compartment	90% of compartment rating
Middle compartment	75% of compartment rating
Top compartment	60% of compartment rating
Two circuit breaker compartments	
Bottom compartment	90% of compartment rating
Top compartment	75% of compartment rating
One circuit breaker compartment	100% of compartment rating

Table 15—Circuit breaker loads

Circuit breaker frame size (A)	Number of circuit breakers carrying load	Allowable cumulative load (A)[a]
600	1	600
600	2	1000
600	3	1400
600	4	1700
800	1	800
800	2	1300
800	3	1800
800	4	2200
1600	1	1600
1600	2	2600
1600	3	3600
1600	4	4500
2000	1	2000
2000	2	3200
3000/3200	1	3000/3200
3000/3200	2	4800/5200
4000	1	4000
5000	1	5000
6000 (dc)	1	6000
8000 (dc)	1	8000
10 000 (dc)	1	10 000
12 000 (dc)	1	12 000

[a]Without forced ventilation.

8.4.2.3 The cumulative circuit-breaker load—LV switchgear

The cumulative circuit breaker loading is the total current that all circuit breakers within a vertical section can carry simultaneously without exceeding the temperature limits in 5.5. In the absence of data from the manufacturer for a specific LV switchgear configuration, it is recommended that the values for the allowable cumulative loading given in Table 15 not be exceeded for an indoor ambient temperature of +40 °C.

The values of allowable cumulative load can be based on equal loading (as a percentage of rating) of all compartments in the same vertical section. If equal loading is not practical, the load distribution should be such that the heavier loads are connected to the lowest circuit breaker compartment. Typically, a section with multiple circuit-breaker compartments carrying load should be loaded as shown in Table 14.

If other arrangements are required, such as forced ventilation, it is recommended that the manufacturer be consulted.

When different ratings of circuit breakers are utilized in the same vertical section, the allowable cumulative circuit breaker loading should be determined based on the number of circuit breakers in the vertical section and the corresponding value for each circuit breaker.

The following examples will illustrate the above:

a) One 1600 A and three 800 A

1)

Compartment	Equal loading factor[a]	Equal loading	Distributed loading factor[b]	Distributed loading
Top 800 A	2200/4	550	0.5	400
Next to top 800 A	2200/4	550	0.6	480
Next to bottom 800 A	2200/4	550	0.75	600
Bottom 1600 A	4500/4	1125	0.9	1440
Cumulative loading		2775	—	2920

[a]From Table 15.
[b]From Table 14.

2)

Compartment	Equal loading factor[a]	Equal loading	Distributed loading factor[b]	Distributed loading
Top 1600 A	4500/4	1125	0.5	800
Next to top 800 A	2200/4	550	0.6	480
Next to bottom 800 A	2200/4	550	0.75	600
Bottom 800 A	2200/4	550	0.9	720
Cumulative loading		2775	—	2600

[a]From Table 15.
[b]From Table 14.

b) One 1600 A and two 600 A

1)

Compartment	Equal loading factor[a]	Equal loading	Distributed loading factor[b]	Distributed loading
Top 600 A	1400/3	467	0.6	360
Middle 600 A	1400/3	467	0.75	450
Bottom 1600 A	3600/3	1200	0.9	1440
Cumulative loading		2134	—	2250

[a]From Table 15.
[b]From Table 14.

2)

Compartment	Equal loading factor[a]	Equal loading	Distributed loading factor[b]	Distributed loading
Top 600 A	1400/3	467	0.6	360
Middle 1600 A	3600/3	1200	0.75	1200
Bottom 600 A	1400/3	467	0.9	540
Cumulative loading		2134	—	2100

[a]From Table 15.
[b]From Table 14.

c) One 3200 A and one 1600 A

Compartment	Equal loading factor[a]	Equal loading	Distributed loading factor[b]	Distributed loading
Top 1600 A	2600/2	1300	0.75	1200
Bottom 3200 A	5200/2	2600	0.9	2880
Cumulative loading		3900	—	4080

[a]From Table 15.
[b]From Table 14.

8.4.2.4 Conductor temperature

Cables connected to LV switchgear should be capable of withstanding the 65 °C ambient temperature to which they may be subjected.

8.4.2.5 Conductor terminations

Consideration should be given to the use of suitable connectors that are designed for use with the outgoing conductors and terminals in the switchgear units.

8.5 Short-circuit considerations

Low-voltage switchgear should have short-circuit capability equal to or greater than the short-circuit capability of the system on which it is applied. The short-circuit capability of the LV switchgear is equal to that of the smallest frame size circuit breaker utilized.

8.5.1 Selective trip arrangement (LV ac switchgear only)

Low-voltage power circuit breakers are suitable for selective tripping arrangements when the following precautions are taken:

a) All the requirements of IEEE Std C37.13-1990 or IEEE Std C37.14-1999 shall be met.
b) Selective tripping is usually accomplished with circuit breakers utilizing direct-acting overcurrent trip devices integral with the circuit breaker. Relay tripping may be used provided the total time to clear the circuit (including relay, shunt trip, and circuit breaker time) does not exceed the short-time rating of any of the circuit breakers.
c) All other equipment shall be properly coordinated, including the protective equipment on the high-voltage side of power transformers, and also short-time ratings of current transformers, series reactors, cables, and buses. For further information on selective tripping, see IEEE Std 141-1993.

8.5.2 Application of circuit breakers in cascade

Application of circuit breakers in cascade (above their short-circuit current ratings) is not recommended.

8.6 Nuclear power plant application

Low-voltage switchgear applied in nuclear power generating stations, and particularly as Class 1E equipment, shall meet the requirements of pertinent standards that have been developed for such applications.

8.7 Associated devices often used in LV switchgear

8.7.1 Current transformers

Current transformers included in LV ac switchgear are in accordance with 5.6 and 5.7. The accuracies listed in 5.7 are the minimum supplied in the usual design of this equipment, and are adequate for most applications. If an application requires higher accuracy, the accuracy required should be specified by the user. It should be recognized that current transformers with higher accuracies than those listed in 5.7 may not meet the requirements of 5.6. The manufacturer should be consulted for possible solutions to the problem of obtaining required accuracy without compromising other requirements.

Proper selection of current transformers is imperative for proper operation and protection of ME switchgear. The following information should be considered in the selection process:

a) Circuit load current
b) Continuous current (thermal) rating factor
c) Mechanical and short-time (thermal) current rating
d) Accuracy class
e) Secondary burden
f) Type of protection (single circuit overcurrent or differential)
g) Available short-circuit current

8.7.2 Surge protective devices

8.7.2.1 Exposed circuits

Protection against lightning surges should be considered for all switchgear assemblies having exposed circuits. Exposed circuits are those outside of buildings or those that do not have adequate surge protection connected to limit voltages to less than the dielectric capabilities of the switchgear.

8.7.2.2 Surge arresters in switchgear assemblies

Surge arresters used in switchgear assemblies should have adequate discharge capability and be voltage limiting to keep voltage surges below the insulation level of the protected equipment. Special consideration should be given to the use of coordinated surge arresters for LV switchgear installed at high altitudes.

8.7.3 Ground detectors

The following methods are recommended for ground detectors furnished on power switchgear assemblies:

a) Application to nominal voltages up to and including 240 V alternating current.
   Lamps or voltmeters connected from the power conductors to ground without the use of transformers.
b) Application to nominal voltages above 240 V
   1) *Transformers connected wye-wye*. For three-phase systems, use three transformers rated for line-to-line voltage connected wye-wye with primary neutral grounded and lamps or voltmeters connected across the secondaries of the transformers.
      The primary neutral of the transformers should be stabilized by either connecting resistors in parallel with the lamps or voltmeters across the transformer secondaries, or connecting a resistor between the primary neutral of the transformers and ground.
   2) *Transformers connected wye-broken delta*. For three-phase systems, use three transformers rated for line-to-line voltage connected wye-delta with neutral of primary wye-grounded and with a voltage relay, to give indication of ground, connected in the broken-delta corner of the three transformer secondaries.
      The primary neutral of the transformers should be stabilized by either connecting a resistor in parallel with the voltage relay across the broken-delta corner of the three transformer secondaries or connecting a resistor between the primary neutral of the transformers and ground. The relay should have a minimum voltage rating of 1.73 times the nominal secondary line-to-line voltage of the transformers.
   3) Lamps or voltmeters may be used for nominal voltages up to 600 V if connected to ground through voltage dividing resistors that will limit the voltage applied to a lamp receptacle (with bulb removed) or to a voltmeter during ground conditions to 240 V.

NOTES
1—These ground detectors are useful only on normally ungrounded circuits.
2—Due to variations in brilliance between lamps, voltmeters are preferred for ground indication.

8.7.4 LV dc shunts and dc current transducers

Shunts provided in LV dc switchgear shall be in accordance with IEEE Std 316-1971 for accuracy and performance. Basic shunt accuracy will be 0.5%. Shunt metering connection wiring shall be run separately from other control wiring bundles up to the fuse (or to the connected device if no fuse is used). Note that shunts are basically resistive, and installation of a shunt will increase the temperature rise of surrounding bus structures. Location of the shunt in enclosed switchgear can create higher operating temperatures, and consideration should be given to allowing adequate air circulation. Also, a shunt becomes part of the bus bar assembly, and the shunt depends on the bus to conduct away a major portion of the heat generated within the shunt.

Also note that shunt connection terminals are typically not tin- or silver-surfaced. Shunts may be allowed to operate with a higher temperature rise if the terminals are tin- or silver-surfaced. See IEEE Std 120-1989 for further shunt application information.

Hall-effect current transducers may also be used in LV dc switchgear. The accuracy of Hall-effect current transducers are usually affected by bus geometry and the magnetic fields resulting from currents in adjacent bus conductors. It is necessary to calibrate the output voltage of those Hall-effect transducers that are mounted adjacent to a dc high-current bus for the specific geometry of bus size, shape, and spacing from the bus involved in each specific variation of switchgear design used. See IEEE Std 120-1989 for further Hall-device application information.

8.7.5 LV dc switchgear enclosure ground/live relays (e.g., for transit applications)

In dc transit applications, the LV dc switchgear enclosures may be isolated from the station ground and operated with a surrounding clearance distance sufficient for operator safety. This is done in order to minimize the possibility of a dc main bus fault. In these instances, the LV dc switchgear enclosure is maintained at a known reference voltage to ground by use of an enclosure ground/live relay. Typically, this relay initiates an alarm if the enclosure is accidentally connected directly to station ground, and the relay will remove main bus voltage and trip both local and remote feeder circuit breakers so as to remove the voltage source in the case the enclosure is accidentally raised to bus potential because of insulation or component failure.

Among the system configurations in use are the following:

a) In a low-resistance grounding scheme, a sensor is connected between the switchgear enclosure and ground. A relay is connected to the sensor to monitor the condition.
b) In the high-resistance grounding scheme, a relay is connected directly between the isolated switchgear enclosure and ground.

As these protection schemes are quite sophisticated, and vary greatly according to certain special requirements established by users, it is recommended that the manufacturer be consulted for additional information on this subject.

8.8 Protection and isolation of switchgear connected to other circuit protective equipment

When LV switchgear is electrically connected to other power switching and circuit-protective equipment, tie-circuit protective equipment should be provided in the connection between the two so that a fault in one assembly will not result in the loss of the other assembly.

NOTE—Where both assemblies supply power to an entire integral unit process, so that the shutdown of one part necessitates the shutdown of the entire process, tie circuit protective equipment is not required. For additional information and further study of switching arrangements, see industrial and commercial power systems standards IEEE Std 141-1993, IEEE Std 142-1991, IEEE Std 241-1990, IEEE Std 242-2001, and IEEE Std 446-1995.

8.9 Overcurrent protection

For ac applications, overcurrent protection shall be provided for each ungrounded phase conductor.

9. Guide for handling, storage, and installation

9.1 General

This clause is a guide for the handling, storage, and installation of LV switchgear, and emphasizes safety aspects and other considerations when working with this type of equipment. It supplements, but does not replace, the manufacturer's detailed instructions on these subjects. The objective is to furnish additional guidelines to promote and enhance a reliable installation.

The manufacturers of LV switchgear include instruction books and drawings with their equipment, containing detailed recommendations for storage, handling, installation, operation, and maintenance.

Personnel responsible for these functions should review these recommendations before handling the equipment. Particular attention should be given to recommendations for preparation of foundation and forms on which the switchgear is to be mounted. One set of manufacturer's instruction books should remain with the LV switchgear when in storage or at the installation site.

9.2 Handling

9.2.1 Receiving

Low-voltage switchgear should be carefully inspected and packed before leaving the factory. Immediately upon receipt, the equipment should be examined for damage that may have been sustained during transit. If damage is evident or indications of rough handling are visible, the carrier (transportation company) and the manufacturer should be notified promptly.

Only authorized personnel should be permitted to handle the equipment. Care should be exercised in handling each piece of equipment (even if crated) because parts may be damaged.

9.2.2 Rigging

Instructions for lifting and handling of the equipment are contained in the manufacturer's instruction books and drawings. The rigging should be adequate for the size and weight of the equipment.

9.2.3 Storage

Indoor switchgear that cannot be installed immediately should be stored in a dry, clean location and should remain protected during the storage period. The longer the period of storage, the greater the care required for protection of the equipment. During storage, the LV switchgear should be placed on a level surface to prevent unnecessary strain and possible distortion. During the construction period, protection should be provided against dust, dirt, falling objects, dripping water, excessive water, excessive moisture, and other possible causes of damage to the equipment. Any temporary covering should not restrict ventilation and should not be removed until the equipment is ready for installation. It is preferable to store indoor equipment within a heated building. If this is not possible, special precaution should be taken to keep the equipment sufficiently warm with adequate ventilation to prevent condensation during the storage period. If necessary, temporary heating should be installed in the equipment. When provisions for temporary power connection are provided as part of the switchgear assembly, provisions should be included to prevent energization of primary buses or connections by means of backfeed through fuses or control power transformers connected to the primary buses or connections.

If outdoor switchgear cannot be installed and energized, temporary power must be provided for the operation of the space heaters provided so as to prevent condensation of moisture within the housing.

Ventilation openings in LV switchgear should be left open to permit proper circulation of air.

9.2.4 Installation

When installing LV switchgear

a) Protect workers adequately from live parts with barriers, screens, etc.
b) ASC C2-2002 NESC, Part 1, Rule 124, guarding live parts shall be observed.

9.2.5 Removal of shipping members

Prior to completion of installation of LV switchgear, a careful check should be made to ensure that all members included for shipping purposes have been removed.

9.2.6 Connections

9.2.6.1 Bus connections

When the LV switchgear consists of several shipping sections, the main bus is necessarily disconnected before shipping. The main bus should be reconnected with particular attention to the cleanliness of and pressure between the contact surfaces. It is essential that the connections be securely bolted because the conductivity of the joints is dependent on the applied pressure. The manufacturer's torque instructions and any other special instructions should be followed.

9.2.6.2 Cable connections

Before making up the cable connections, the phasing of each cable shall be determined in accordance with the connection diagram, and the cables tagged accordingly. The cable manufacturer's instructions should be followed when installing cable terminations and during the installation of the cable. It is essential that the connections be clean and securely bolted, since the conductivity of the joints is proportional to the applied pressure. The terminating devices (where required) should be installed pursuant to the terminator manufacturer's instructions.

9.2.6.3 Control connections

Control wires and ground connections between shipping sections should be reconnected as marked by the manufacturer. Connections that are to be connected to terminals in apparatus remote from the switchgear should be carefully checked against the connection diagram. When making connections to terminals, care should be exercised to ensure that the connections are properly made.

9.2.6.4 LV ac switchgear grounding

Sections of ground bus previously disconnected at shipping sections shall be reconnected when the units are installed. The ground bus should be connected to the system ground with as direct a connection as possible and should not be run in metal conduit unless the conduit is adequately bonded to the circuit. The grounding conductor should be capable of carrying the maximum line-to-ground short-circuit current for the duration of a fault. A reliable ground connection is necessary for every switchgear installation, and should be independent of the grounds used for other apparatuses. A permanent low-resistance ground is essential for adequate protection and safety.

This clause also applies to LV dc switchgear which is intended for grounded application.

9.2.6.5 LV dc switchgear grounding

In the case of LV dc switchgear that is designed to be operated grounded, 9.2.6.4 is applicable.

In the case of LV dc switchgear (e.g., for transit applications) that is designed to be operated with isolated switchgear enclosures that are either low-resistance or high-resistance grounded, additional precautions are necessary. Ensure that the ground bus and secondary wiring across all shipping section splits is reconnected during installation.

In the case of a low-resistance grounded system design, prior to connection of the low-resistance ground bus and enclosure ground/live relay station ground reference wiring, the enclosure to station ground insulation system integrity must be verified. This insulation should be verified using a 1000 V insulation resistance test device, as in this case the maximum voltage rise of the enclosure above ground even under fault conditions should only be a few volts. Consult the manufacturer for specific test voltages.

In the case of a high-resistance grounded system design, prior to connection of the enclosure ground/live relay station ground reference wiring, the enclosure to station ground insulation system must also be verified. In this case, this insulation system must withstand the full bus potential and should be dielectric tested using a test voltage per Table 2.

In both cases, there may be multiple isolated sections of LV dc switchgear or components such as rectifiers, where each has separate enclosure ground/live relay connections. In these cases, the above dielectric tests must be performed with the corresponding adjacent isolated switchgear enclosure grounded. Note that particular care must be taken with interconnecting wiring in these cases, and it may be necessary to isolate wiring or devices to prevent dielectric failure during the dielectric testing.

9.3 Preoperation check

Care shall be exercised to prevent the LV switchgear from being energized from the power system while preliminary tests are being conducted. If disconnecting means is not available, line leads should be disconnected. All internal connections should be examined to ensure that they have not been loosened or damaged during shipment or installation and all bolted connections and joints should be tightened to ensure good contact. If spring washers are used under bolt heads and nuts, they should be tightened in accordance with manufacturer's instructions. All wiring connections should be checked for tightness, including those at instrument transformers and all terminal blocks. Current transformer shorting devices on all active circuits should be removed.

All ties and blocking from the relay armatures or discs should be removed before the control energy is applied.

Protective relays, overcurrent trip devices, and breaker attachments included with the LV switchgear should be tested for correct connections and operation at the factory. However, the protective device settings for current, voltage, or other quantities shall be made by the user in accordance with the manufacturer's instructions and a short-circuit and protective device coordination study. The manufacturer's instruction books should be studied carefully before setting the protective devices.

It is recommended that the integrity of control buses be checked with an ohmmeter to ensure against short circuits in the control wiring. Control wiring should be given a high-potential test or have insulation verified using a 500 V insulation resistance test device. Power circuits, such as buses and circuit breakers, should be given a power frequency withstand test as described in 6.3.1 and 6.5. After LV switchgear has been installed and all interconnections completed, any control schemes should be operationally tested and power connections given a final check for phase rotation/sequence before the switchgear is finally energized for service.

9.4 Removable elements

All circuit breakers should be inspected for damaged parts and any loose connections in accordance with the manufacturer's instructions. Check manual operation with the manual closing lever or with the maintenance closing handle on the larger size circuit breaker elements. Trip each circuit breaker by operating the manual trip device. Operation with maintenance handle and slow closing should be done outside the breaker cubicle. Power-operated circuit breakers should be checked for proper operation while in the switchgear cubicle test position for both closing and tripping at the normal control voltage, and at the lower limit of the voltage range as indicated in ANSI C37.16-2000.

9.5 Interlocks

Interlocks should be checked for proper operation before power is applied to the switchgear. The interlock between the removable element and housing should be checked to see that

a) The element cannot be moved to or from the connected position when the circuit breaker is in the closed position.
b) The circuit breakers cannot be closed unless it is in the fully connected position or in the test position.

So as to maintain the integrity of key interlock systems, duplicate keys should be destroyed or retained in a place accessible only to authorized personnel.

9.6 Energizing

After the removable circuit breaker elements and interlocks have been tested satisfactorily, the circuit breakers may be moved to the connected position. Each compartment door should be closed and latched before energizing the circuit.