

IEEE Std 3001.5™-2013

IEEE Recommended Practice for the
Application of Power Distribution
Apparatus in Industrial and
Commercial Power Systems



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IEEE Recommended Practice for the Application of Power Distribution Apparatus in Industrial and Commercial Power Systems

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Approved 11 December 2013

IEEE-SA Standards Board

Abstract: The selection and application of power distribution apparatus used in industrial and commercial power systems are covered in this recommended practice. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

Keywords: apparatus, busway, cable systems, circuit breakers, conductors, fuses, IEEE 3001.5™, panelboards, separable insulated connectors, switchboards, switches, switchgear, transformers

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

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PDF: ISBN 978-0-7381-8874-4 STD98509
Print: ISBN 978-0-7381-8875-1 STDPD98509

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This recommended practice was developed by the Technical Books Coordinating Committee of the Industrial and Commercial Power Systems Department of the Industry Applications Society as part of a project to repackage the popular IEEE Color Books®. The goal of this project is to speed up the revision process, eliminate duplicate material, and facilitate use of modern publishing and distribution technologies.

When this project is completed, the technical material in the thirteen IEEE Color Books will be included in a series of new standards—the most significant of which will be a new standard, IEEE Std 3000™, IEEE Recommended Practice for the Engineering of Industrial and Commercial Power Systems. The new standard will cover the fundamentals of planning, design, analysis, construction, installation, startup, operation, and maintenance of electrical systems in industrial and commercial facilities. Approximately 60 additional dot standards, organized into the following categories, will provide in-depth treatment of many of the topics introduced by IEEE Std 3000™:

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- Power Systems Analysis (3002 series)
- Power Systems Grounding (3003 series)
- Protection and Coordination (3004 series)
- Emergency, Standby Power, and Energy Management Systems (3005 series)
- Power Systems Reliability (3006 series)
- Power Systems Maintenance, Operations, and Safety (3007 series)

In many cases, the material in a dot standard comes from a particular chapter of a particular IEEE Color Book. In other cases, material from several IEEE Color Books has been combined into a new dot standard.

The material in this recommended practice largely comes from Chapter 10, Chapter 12, and Chapter 13 of IEEE Std 141™ (*IEEE Red Book™*), Chapter 5 of IEEE Std 241™ (*IEEE Gray Book™*), and Chapter 4 of IEEE Std 1100™ (*IEEE Emerald Book™*).

IEEE Std 3001.5™

This publication provides a recommended practice for the electrical design of commercial and industrial facilities. It is likely to be of greatest value to the power-oriented engineer with limited commercial or industrial plant experience. It can also be an aid to all engineers responsible for the electrical design of commercial and industrial facilities. However, it is not intended as a replacement for the many excellent engineering texts and handbooks commonly in use, nor is it detailed enough to be a design manual. It should be considered a guide and general reference on electrical design for commercial and industrial facilities.

Tables, charts, and other information that have been extracted from codes, standards, and other technical literature are included in this publication. Their inclusion is for illustrative purposes; where technical accuracy is important, the latest version of the referenced document should be consulted to assure use of complete, up-to-date, and accurate information.

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1. Overview

1.1 Scope

This recommended practice covers the selection and application of power distribution apparatus used in industrial and commercial power systems. It is likely to be of greatest value to the power-oriented engineer with limited experience with this equipment. It can also be an aid to all engineers responsible for the electrical design of industrial and commercial power systems.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Accredited Standards Committee C2-2007, National Electrical Safety Code® (NESC®).¹

AEIC CS8-07 (Edition 3), Specifications for Extruded Dielectric Shielded Power Cables Rated 5 kV Through 69 kV.²

ANSI C57.12.21-1992, American National Standard Requirements for Pad-Mounted, Compartmental-Type Self-Cooled, Single-Phase Distribution Transformers With High Voltage Bushings; High-Voltage, 34500 GRYD/19920 Volts and Below; Low-Voltage, 240/120 Volts; 167 kVA and Smaller.

ANSI C57.12.22-1993 (Reaff 1998), American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled Three-Phase Distribution Transformers With High-Voltage Bushings, 2500 kVA and Smaller: High Voltage, 34 500 Grd Y/19 920 Volts and Below; Low Voltage, 480 Volts and Below.

ANSI C57.12.25-1990, American National Standard for Transformers—Pad-Mounted, Compartmental-Type, Self-Cooled, Single-Phase Distribution Transformers With Separable Insulated High-Voltage Connectors; High Voltage, 34 500 Grdy/19 920 Volts and Below; Low Voltage, 240/120 Volts; 167 kVA and Smaller Requirements.

ANSI C57.12.55-1987 (Reaff 1998), American National Standard for Transformers—Used in Unit Installations, Including Unit Substations-Conformance Standard.

ICEA P-32-382 (2007), Short-Circuit Characteristics of Insulated Cable.³

ICEA P-45-482 (2007), Short-Circuit Performance of Metallic Shields and Sheaths of Insulated Cables.

IEEE Std 48™-2009, IEEE Standard for Test Procedures and Requirements for Alternating-Current Cable Terminations Used on Shielded Cables Having Laminated Insulation Rated 2.5 kV through 765 kV or Extruded Insulation Rated 2.5 kV through 500 kV.⁴

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

IEEE Std 142™-2007, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (*IEEE Green Book™*).

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

IEEE Std 386™-2006, IEEE Standard for Separable Insulated Connectors for Power Distribution Systems Above 600 V.

IEEE Std 400™-2012, IEEE Guide For Field Testing And Evaluation Of The Insulation Of Shielded Power Cables Systems Rated 5 kV And Above.

IEEE Std 446™-1995, IEEE Recommended Practice for Emergency and Standby Systems for Industrial and Commercial Applications.

¹ The NESC® is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org>).

² AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P. O. Box 2641, Birmingham, AL 35291-0992, USA (<http://www.aeic.org>). AEIC publications are also available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112-5704, USA (<http://global.ihs.com/>).

³ ICEA publications are available from the Insulated Cable Engineers Association, ICEA P.O. Box 1568 Carrollton, GA 30112, USA (<http://www.icea.net/>).

⁴ IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org>).

IEEE Std 519TM-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

IEEE Std 739TM-1995, IEEE Recommended Practice for Energy Conservation and Cost-Effective Planning in Industrial Facilities (*IEEE Bronze Book*TM).

IEEE Std 1215TM-2001, IEEE Guide for the Application of Separable Insulated Connectors.

IEEE Std C37.010TM-1999 (Reaff 2005), IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.011TM-2011, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers.

IEEE Std C37.04TM-1999 (Reaff 2006), IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.

IEEE Std C37.06TM-2009, IEEE Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities for Voltages Above 1000 V.

IEEE Std C37.13TM-2008, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.16TM-2009, IEEE Standard for Preferred Ratings, Related Requirements, and Application Recommendations for Low-Voltage AC (635 V and below) and DC (3200 V and below) Power Circuit Breakers.

IEEE Std C37.23TM-2003, IEEE Standard for Metal-Enclosed Bus.

IEEE Std C37.20.1TM-2002 (Reaff 2007), IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

IEEE Std C37.20.2TM-1999, IEEE Standard for Metal-Clad Switchgear.

IEEE Std C37.20.3TM-2001 (Reaff 2006), IEEE Standard for Metal-Enclosed Interrupter Switch-gear.

IEEE Std C37.20.7TM-2007, IEEE Guide for Testing Metal-Enclosed Switchgear Rated up to 38 kV for Internal Arcing Faults.

IEEE Std C37.24TM-2003, IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear.

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

IEEE Std C57.12.00TM-2010, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.01TM-2005, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers, Including Those with Solid Cast and/or Resin-Encapsulated Windings.

IEEE Std C57.12.10TM-2010, IEEE Standard Requirements for Liquid-Immersed Power Transformers.

IEEE Std C57.12.40TM-2011, IEEE Standard Requirements for Secondary Network Transformers, Subway and Vault Types (Liquid Immersed).

IEEE Std C57.12.51™-2008, IEEE Standard for Ventilated Dry-Type Power Transformers, 501 kVA and Larger, Three-Phase, with High-Voltage 601 V to 34 500 V; Low-Voltage 208Y/120 V to 4160 V—General Requirements.

IEEE Std C57.12.80™-2010, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90™-2010, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.91™-2011, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

IEEE Std C57.96™-1999 (Reaff 2004), IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

IEEE Std C57.110™-2008, IEEE Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load Currents.

NEMA BU 1.1-2010, General Instructions for Proper Handling, Installation, Operation, and Maintenance of Busway Rated 600 Volts or Less.⁵

NEMA FB 11-2000, Plugs, Receptacles, and Connectors of the Pin and Sleeve Type for Hazardous Locations.

NEMA PB 2-2011, Deadfront Distribution Switchboards.

NEMA PB 2.1-2007, General Instructions for Proper Handling, Installation, Operation and Maintenance of Deadfront Distribution Switchboards Rated 600 V or Less.

NEMA TP 1-2002, Guide for Determining Energy Efficiency for Distribution Transformers.

NEMA TR 1-1993 (Reaff 2000), Transformers, Regulators, and Reactors.

NEMA WC 70-2009, Power Cables Rated 2000 Volts or Less for the Distribution of Electrical Energy.

NEMA WC 71-1999, Standard for Nonshielded Cables Rated 2001-5000 Volts for use in the Distribution of Electric Energy.

NEMA WC 74-2006, 5-46KV Shielded Power Cable for Use in the Transmission and Distribution of Electric Energy.

NFPA 70®, National Electrical Code®.⁶

NFPA 70E®-2012, Standard for Electrical Safety in the Workplace.

UL 67, 12th Edition, Rev. 2010, Standard for Panelboards.⁷

UL 98, 13th Edition, Rev. 2012, Enclosed and Dead-Front Switches.

UL 486a-486b, 1st Edition, Rev. 2011, Wire Connectors.

⁵ NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

⁶ NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (<http://www.nfpa.org/>).

⁷ UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://www.global.ihs.com/>).

UL 489, 11th Edition, Rev. 2011, Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures.

UL 857, 13th Edition, Rev. 2011, Busways.

UL 891, 11th Edition, Rev. 2005, Switchboards.

UL 977, 5th Edition, Rev. 2012, Standard for Fused Power-Circuit Devices.

UL 1008, 6th Edition, Rev. 2012, Standard for Transfer Switch Equipment.

UL 1066, 4th Edition, Rev. 2012, Standard for Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures.

UL 1558, 4th Edition, Rev. 2010, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

UL 1561, 4th Edition, Rev. 2011, Standard for Dry-Type General Purpose and Power Transformers.

UL 1562, 3rd Edition, Rev. 2001, Standard for Transformers, Distribution, Dry-Type Over 600 Volts.

3. Introduction

This recommended practice provides information on the requirements for, and application of, major apparatus utilized in industrial and commercial electric distribution systems. More detailed information on this type of apparatus is available from the American National Standards Institute (ANSI), the National Electrical Manufacturers Association (NEMA), and nationally recognized testing laboratories (NRTLs), such as Underwriters Laboratories, Inc., (UL) or Factory Mutual (FM), as well as from manufacturers' publications.

The engineer should make basic decisions in the choice of equipment for a particular electric system. The decision-making process should entail all those factors involved in designing and maintaining an electric power system, such as safety, protection, continuity of service, reliability, security, protective coordination, initial installed cost, procurement time to meet the schedule, flexibility, staffing, and cost for operating and maintenance. Energy cost, conservation, and environmental protection should be considered in initial plant design and equipment. For information related to energy cost and conservation, refer to IEEE Std 141TM-1993 (*IEEE Red Book*TM) Chapter 14.

The engineer should anticipate how operating personnel will need to interface with energized equipment and the work that may be required to be performed in proximity to the equipment while energized. Such work must be conducted in accordance with NFPA 70E®, whose purpose is to “provide a practical safe working area for employees relative to the hazards arising from the use of electricity.” Procedures for risk assessment and the determination of required personal protective equipment (PPE) for specific tasks are provided in this standard. The PPE requirements can be affected significantly by the prospective arc flash available within the electrical equipment. Equipment choices may be available to the designer to reduce the risk of arc flash and/or reduce its severity to create a safer work environment. NFPA 70E® Annex O addresses safety-related design requirements. For information regarding the determination of arcing currents and arc flash energy for the purpose of selecting PPE, refer to IEEE Std 1584TM-2002.

3.1 Equipment installation

Electric equipment should be installed in a manner that is safe yet readily accessible to qualified personnel. Sufficient working space should be provided and maintained about all electric apparatus to permit ready

and safe operation and maintenance of such equipment. Minimum working clearances around electrical equipment as required by the National Electrical Code® (NEC®) (NFPA 70®) shall be considered for design and installation.

Installations in industrial plants require that adequate aisles, hatchways, wall openings, etc., be provided for easy removal and replacement of all electric equipment. For medium-voltage switching equipment, extreme care should be exercised in setting, grouting, aligning, and leveling the floor channels in order to prevent stressing insulators and bus structures and to provide for easy insertion and removal of the apparatus. Floor area in front of switchgear should be level or have only a moderate slope away from the equipment for adequate drainage.

Special attention should be given to the floor under and in front of any equipment that is required to roll in and out of the enclosure. More detailed installation procedures are given in NEMA PB 2.1-2007. If equipment is to be stored or installed in locations where internal condensation may occur, suitable internal heating should be provided (NEMA PB 2.1-2007, Section 3).

Article 450 of the NEC outlines the installation requirements for transformers of various types. In some industrial plants, the unit substation transformer is located outside a pressure-ventilated switchgear room with a secondary throat connection for buswork through the wall. This pressure-ventilated switchgear room may also house motor-control centers, panelboards, and other electrical and electronic equipment in addition to the switchgear. This particular type of design would be used for the following reasons:

- a) Protection of electric equipment from the accumulation of dirt, dust, and other foreign material.
- b) Use of less expensive and more readily maintainable general-purpose electric equipment enclosures, where appropriate.
- c) Prevention of access by unauthorized people.

3.2 Maintenance, testing, and safety

Maintenance, testing, and safety of an operating plant must be considered primary factors in the design of any electrical system.

An effective preventive maintenance program should sustain production at required levels, protect valuable investment, and reduce down time and maintenance costs. Planned maintenance should include a series of tasks to be performed on each unit of equipment in order to detect areas of potential failure and to provide a warning to plan for necessary repairs or replacement. The tasks should be performed either on a regularly scheduled basis or on the basis of time in service, cycles of operation, or having interrupted fault current. Record keeping is an essential part of the planned maintenance program. Inherent with any maintenance program is the testing of electric equipment and appropriate safety precautions for personnel and equipment. IEEE Std 3007.2™-2010 [B43] discusses general methods of testing protective equipment, such as circuit breakers, relays, etc. Specific procedures and testing procedures for other equipment are found in appropriate standards of the IEEE, the American National Standards Institute (ANSI), National Fire Protection Association (NFPA®), National Electrical Manufacturers Association (NEMA), and the National Electrical Testing Association (NETA), as well as in manufacturers' literature.

3.3 Heat losses

The heat generated by power losses in electric equipment, particularly transformers, motors, rectifiers, and motor control centers, should be considered in the initial design of a project. An estimate of the power losses that show up as heat should be developed and added to the cooling requirements of the building. Table 1 lists the range of losses in electric equipment. Heat losses for specific equipment should be obtained from the manufacturer.

Exhausting air from the equipment location and allowing cooler (even if filtered) air to enter may cause internal condensation and possibly create a hazardous atmosphere in the building. Alternate methods include air conditioning, ventilation with dehumidification, higher efficiency equipment, or locating the major heat-producing items outdoors. The amount of cooling air should be kept at the required minimum by use of the thermally controlled equipment.

Table 1—Range of losses in power system equipment

Component	Percent energy loss ^a (full load)
Outdoor circuit breakers (15 V to 230 kV)	0.002 to 0.015
Generators	0.09 to 3.50
Medium-voltage switchgear (5 V and 15 kV)	0.005 to 0.02
Current-limiting reactors (600 V-15 kV)	0.09 to 0.30
Transformers	0.40 to 1.90
Load break switches	0.003 to 0.025
Medium-voltage starters	0.02 to 0.15
Busway (480 V and below)	0.05 to 0.50
Low-voltage switchgear	0.13 to 0.34
Motor-control centers	0.01 to 0.40
Cable	1.00 to 4.00
Motors 1 hp to 10 hp 10 hp to 200 hp 200 hp to 1500 hp 1500 hp and up	 14.00 to 35.00 6.00 to 12.00 4.00 to 7.00 2.30 to 4.50
Rectifiers (large)	3.00 to 9.00
Static variable speed drivers	6.00 to 15.00
Capacitors (watts loss/var)	0.50 to 2.00
Lighting (lumens/watts)	8.00 to 9.00
NOTE—Data on capacitors and lighting systems (fixtures and controls) should be obtained from manufacturers and considered in calculating power losses. ^a Percent energy loss is simply a ratio of power consumed internally in equipment to the total energy passed through it.	

Source: Reprinted from H. N. Hickock, "Electrical Energy Losses in Power Systems," *IEEE Transactions on Industry Applications*, vol. JA-14, no. 5, Sept./Oct. 1978.

4. Switching apparatus for power circuits

4.1 Classifications

Switching apparatus can be defined as a device for opening and closing, or for changing the connections of a circuit. The general classification of switching apparatus as used in this chapter includes switches, fuses, circuit breakers, and service protectors.

4.2 Switches

The types of switches normally used for power circuits include the following:

- a) Isolating
- b) Load interrupter
- c) Safety switches for 600 V and lower power applications, including bolted-pressure switches and high-pressure contact switches and power protectors
- d) Transfer switches for load transfer, including emergency and standby switching

4.2.1 Isolating switches

An isolating switch is used to provide a visible disconnect and frequently has no interrupting current rating, in which case it may be referred to as a “no-load switch.” It should be operated only after the circuit has been opened by other means. Interlocking is generally provided to prevent operation when the switch is carrying current. Latches may be required to prevent the switch from being opened by magnetic forces under heavy fault currents.

4.2.2 Load interrupting switches

For services above 600 V, a load interrupter or load-break switch, generally associated with unit substations supplied from the primary distribution system, is a switch combining the functions of a disconnecting switch and a load interrupter for interrupting, at rated voltage, currents not exceeding the continuous-current rating of the switch. Load-break switches are of the air, fluid-immersed, or vacuum type. The interrupter switch is usually manually operated and has a quick-make, quick-break mechanism that functions independently of the speed-of-handle operation. Such switches usually have a fault-making current rating to provide additional capabilities in the event of closing-in on a faulted circuit.

With a fused load-break switch combination, fast fault clearing and circuit isolation can be provided. This application, if properly coordinated to protect the transformer and to interrupt transformer magnetizing currents and load currents within the switch rating, may be more economical than a circuit breaker.

Rollout fuse-switch assemblies, produced by several manufacturers, have advantages such as replacing of fuses without the necessity of de-energizing the primary circuit, the ability to fuse on the line side of the switch, and complete accessibility to mechanical parts for checkout and maintenance.

It may be desirable from a safety standpoint in the case of a transformer application to interlock the operation of an interrupter switch with the secondary circuit breaker to minimize the chance of operating the interrupter switch at a time when the current exceeds the interrupting rating of the switch. Load interrupter switches having isolating blades are also available with vacuum interrupters and electronic fuses and may be actuated by ground-fault protective relaying, or phase failure protective relaying and fuses.

4.2.3 Switches for 600 V and below

The application of fused safety switches is described in the NEC and requires a continuous-current rating of at least 115% of the full-load current rating of the motor.

For services of 600 V and below, safety circuit breakers and switches are commonly used. Safety switches are enclosed and may be fused or unfused. This type of switching device is operable by means of a handle from outside the enclosure and is interlocked so that the enclosure cannot be opened unless the switch is open or the interlock defeater is operated. Many safety switches have quick-make and quick-break features.

A safety switch for motors is rated in horsepower, and voltage and is capable of interrupting the maximum operating current of a motor of the same horsepower at rated voltage. The maximum operating current of the motor is the locked-rotor current and is recognized by the NEC as six times full-load motor current.

Safety switches with current-limiting fuses can be applied to circuits with up to 200 000 A rms symmetrical fault current if the switch-fuse combination has been tested by an NRTL. Switches are labeled either by an NRTL or the manufacturer to indicate the particular switch-fuse combination that must be used to obtain the specified rating. It should never be assumed that interchanging fuses of a different class, even if they have the same rating, will result in safe switch application.

The bolted-pressure switch consists of movable blades and stationary contacts with arcing contacts and a mechanism for applying bolted pressure to both the hinge and jaw contacts in a manner similar to a bolted bus joint. Thus, a high degree of short-circuit withstandability is accomplished. The bolted-pressure switch can be applied at 100% of its continuous current rating. Some mechanisms have a spring that is compressed by the operating handle and released at the end of the operating stroke to provide quick-make, quick-break switching action.

The electrical-trip bolted-pressure switch is basically the same as the manually operated bolted-pressure switch, except that a stored-energy latch mechanism and a solenoid trip release are added to provide automatic electrical opening. All the other features normally required on low-voltage main and feeder circuits rated 600 A and above are available. These switches also can be designed for use with ground-fault protection equipment that may be required by the NEC. Bolted-pressure switches have a contact interrupting rating of 12 times the continuous current rating. These switches are available in ratings of 600 A, 800 A, 1200 A, 1600 A, 2000 A, 2500 A, 3000 A, 4000 A, 5000 A, and 6000 A, 600 Vac, and are suitable for use on circuits having available fault currents of up to 200 000 A rms symmetrical, when applied in combination with Class L current-limiting fuses.

A switch with a shunt-trip device and with a stored energy release (opening) mechanism is triggered by a voltage signal derived from the main circuit or from an independent source. A shunt-trip is used on a switch to provide the tripping required for ground-fault protection or other requirements, such as an application where it is desirable to open all three phases when one or two fuses open.

A second specialized type of safety switch is the high-pressure contact switch, which has an over-center toggle mechanism that provides stored energy for quick-make, quick-break operation. Multiple spring-loaded high-pressure current-carrying contact arms and an arcing contact arm provide high current-carrying capability without sacrificing high interrupting fault performance.

These switches can be applied at 100% of their continuous current rating and can interrupt on a make-and-break basis a minimum of 12 times their nameplate continuous-current rating without fuse assistance at 600 Vac. Therefore, complete switch and current-limiting fuse (Class L) coordination is achieved for all levels of fault current to a maximum of 200 000 A rms symmetrical at 600 Vac. These switches are available in continuous current ratings of 800 A, 1200 A, 1600 A, 2000 A, 2500 A, 3000 A, and 4000 A at 600 Vac maximum and are suitable for use at all short-circuit currents up to 200 000 A rms symmetrical when used with Class L current-limiting fuses.

The high-pressure contact switch can be equipped for manual tripping when ground-fault or remote tripping is not required. When equipped with a shunt trip, the switch can be remotely tripped, and/or have remote ground fault function applied; external control power is required. When integral ground fault function is applied, it is self-powered; however, the test function does require an external power source. Single-phase protection is available, which will trip the switch when a fuse or fuses open or the switch is closed with an open fuse or fuses.

4.3 Transfer switches

Automatic transfer switches (ATS) of double-throw construction are primarily used for emergency and standby power generation systems rated 600 V and less. These transfer switches do not normally incorporate overcurrent protection and are designed and applied in accordance with UL 1008 and the NEC, particularly Articles 230, 517, 700, 701, 702, and 708. For reliability, most automatic transfer switches rated above 100 A are mechanically held and are electrically operated from the power source to which the load is to be transferred.

Automatic transfer switches are available in the following forms:

- 1) Automatic or manual transfer switches available in ratings to 4000 A in low-voltage class, and to 1200 A in medium-voltage class. These switches may be fusible or nonfusible.
- 2) Automatic power circuit breakers consisting of two or more power circuit breakers, which are mechanically or electrically interlocked, or both, rated 600 A to 3000 A, in both low- and medium-voltage classes. The breakers can be provided as a stand-alone automatic transfer switch, or the incoming main breakers on switchgear can be provided with electrical operators and used for transfer applications. Transfer control of circuit breakers can be handled by discrete control relays, a programmable logic controller, or a protective relay that has control logic capability. There are two major advantages to using circuit breakers. The circuit breakers provide an interrupting rating (as opposed to a withstand rating for a transfer switch, which is dependent on an upstream overcurrent device) and the circuit breakers also provide overcurrent protection.
- 3) Manually or electrically operated bolted pressure switches (600 V), which are fusible or nonfusible and are available from 800 A to 6000 A
- 4) Automatic Static Transfer Switches (ASTS) perform a similar function as an ATS, only much more quickly. They were developed to switch electronic loads so quickly from one source to another that the load was not impacted by the transfer; it continues to operate as if no transfer had occurred. For low-voltage applications, a pair of silicon controlled rectifiers (SCRs) in a back-to-back configuration is used for each source. In medium-voltage applications, a number of SCRs are used in series for each direction of the current. ASTS are most often used in critical applications to provide UPS power from two sources. For most types of ASTSs, a bypass is provided using molded case switches or circuit breakers, so maintenance and testing can be performed on the ASTS without impacting the load that the ASTS feeds.

These switches are applied to provide protection against failure of the normal service. The transfer switch's control logic usually includes full-phase close differential voltage sensing of the normal source, voltage and frequency sensing of the emergency source, time delays for programmed operation, and in-phase monitoring for motor load transfer. In addition to utility failures, continuity of power to critical loads can also be disrupted by the following:

- a) An open circuit within the building area on the load side of the incoming service
- b) Overload or fault conditions
- c) Electrical or mechanical failure of the electric power distribution system within the building

Therefore, many engineers advocate the use of lower-current-rated transfer switches located near the load rather than one large transfer switch at the point of incoming service. For critical applications where load interruptions must be minimized, transfer switches are available with built-in bypass/isolation switches to enable maintenance without any load interruption. Other types provide closed transition operation to momentarily parallel the sources for load transfer without interruption. For additional information, see IEEE Std 446™-1995 (*IEEE Orange Book™*).

4.4 Fuses

4.4.1 Types and rating basis

A fuse is an overcurrent-protective device with a circuit-opening fusible part that is heated and severed by the passage of overcurrent through it. Fuses are available in a wide range of voltage, current, and interrupting ratings, current-limiting types, and for indoor and outdoor applications.

Fuses rated greater than 600 V have an interrupting capability based on asymmetrical current, although their published ratings are expressed in symmetrical amperes. Current-limiting fuses interrupt a short circuit within the first half-cycle, and their equivalent asymmetrical rating includes a 1.6 multiplier to provide for the maximum expected current asymmetry.

Standard fuses without current-limiting capabilities are widely applied above 600 V. They are generally available in higher current ratings, but lower interrupting ratings, than current-limiting fuses.

Fuse ratings for 600 V and below are also published as symmetrical current values. These current-limiting fuses are extremely fast in operation at very high values of fault current, and act to limit the current in less than one-quarter cycle to a value well below the available peak short-circuit current. Several types of current-limiting fuses for 600 V and below are now available for ac service with interrupting ratings as high as 300 000 A rms symmetrical. For more information on fuses, see IEEE Std 141™-1993 (*IEEE Red Book™*), Chapter 5.

4.4.2 Application considerations

There is no general rule for deciding whether to use fuses or a circuit breaker. The designer's decision should be based on the demands of the particular application. The following considerations may be of assistance to the designer:

- a) Interrupting ratings. Current-limiting fuses with 300 000 A rms symmetrical ratings are available for 600 V and below applications.
- b) Component protection.
 - 1) Current-limiting fuses permit minimal short-circuit current let-through, thus helping to minimize damage to lower interrupting capacity-rated and withstand-rated components.
 - 2) Current-limiting fuses can cause transient voltages in clearing faults that may be detrimental to the system components, such as motors, surge arresters, etc. However, techniques are available to determine the suitability of equipment during the engineering phase.
 - 3) Fuses, in conjunction with shunt-trip switches and ground-fault sensing systems, can provide sensitive protection.
- c) Selective coordination. Fuse time—current clearing curves are accurate, and fuses' characteristics usually do not change over time. Selective coordination can be achieved by referring to

manufacturers' published fuse ratio charts. By adhering to these recommended ratios and exercising sound engineering judgment, coordination between different types of protective devices can be achieved. Also, protective coordination studies may be done on computers. Protective coordination software exists which contains libraries of fuse manufacturers' curves and other protective devices.

- d) Space requirements. Fusible switching devices require more space than circuit breakers.
- e) Economics. Initial capital cost and maintenance costs are lower for fusible equipment.
- f) Automatic switching. Fuses alone are not capable of automatic switching, but can be installed in suitable shunt-trip equipped switches to provide this service. Care must be exercised in applying a shunt-tripped switch. If the shunt-trip is actuated by a protective of phase failure relay, the switch must be capable of interrupting the fault duty to which it may be subjected, and the switch shall be prevented from opening when the fault current exceeds the interrupting capability of the switch.

4.5 Circuit breakers

A circuit breaker is a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a predetermined overload of current without damage to itself when properly applied within its rating. Circuit breakers are required to operate infrequently, although some classes of circuit breakers are suitable for more frequent operation. The interrupting and momentary ratings of a circuit breaker must be equal to or greater than the available system short-circuit currents.

To provide essential switching flexibility and circuit protection, power circuit breakers are used on medium- and low-voltage systems of utility and industrial distribution circuits.

Circuit breakers are available for the entire voltage range. They may be furnished single-, double-, triple-, or four-pole, and arranged for indoor or outdoor use. SF₆ gas-insulated circuit breakers are available for medium and high voltages, such as gas-insulated substations.

4.5.1 Circuit breakers over 600 V

The close-and-latch rating and current-interrupting capabilities are very important factors for use in the application of circuit breakers over 600 V. The close-and-latch capability is a measure of the equipment's ability to withstand the mechanical stresses produced by the asymmetrical short-circuit current during the first cycle without mechanical damage, and is normally expressed as total rms current. An asymmetrical current consists of a dc component superimposed on an ac component. The dc component decays with time, depending upon the resistance and reactance, or the X/R ratio of the circuit. The initial value of the dc component of the short-circuit current depends on the point of the normal voltage wave at which the fault occurs. The procedure to be used for short-circuit selection of power circuit breakers in the over 600 V class is covered in IEEE Std 141™-1993 (*IEEE Red Book*™), Chapter 5. Application data can be found in IEEE Std C37.010™-1999.

For the rating of power circuit breakers in the over 600 V class, refer to IEEE Std C37.06™-2009. Circuit breakers currently being manufactured are rated on the symmetrical basis. In specifying these circuit breakers, consideration should be given to the related values and required capabilities listed as headings in Table 2 and Table 3. These tables list preferred ratings for Class S1 (indoor oilless) circuit breakers. These ratings are applicable for service at altitudes up to 1000 m (3300 ft). For service beyond 1000 m, de-rating factors must be applied in accordance with IEEE Std C37.04™-1999.

In 2000, a significant change was made to the preferred ratings in IEEE Std C37.06™. Prior to this revision, the rating structure of all power circuit breakers rated over 600 V were those that were first established for air-magnetic type interrupters. The ratings were classified by a nominal MVA rating as the capability of the interrupters followed a constant MVA characteristic, that is, as the applied voltage was

decreased from the maximum voltage rating of the breaker, the interrupting current rating could be increased proportionately, up to the maximum short-circuit rating of the breaker. The relationship between the short-circuit rating at maximum voltage and the maximum short-circuit rating was indicated by a voltage range factor, K . In most cases K was equal to 1.30. On the other hand, vacuum and SF₆ breakers do not exhibit a constant MVA characteristic. Rather, their maximum short-circuit current rating is applicable to the entire range of voltages to which they can be applied. IEEE Std C37.06™-2000 was revised to reflect this. The MVA class designations and voltage range factor were removed. While many breakers rated under the previous rating structure are still in service and since it is still possible to specify breakers using the old rating structure, the preferred ratings of IEEE Std C37.06™-1987 are provided in Table 4 for reference purposes.

In switchgear manufactured through the 1980s, power circuit breakers used for applications through 15 kV have been predominantly of the air-magnetic type; however, vacuum and SF₆ types are now used almost exclusively for new installations. For voltages above 15 kV, the available types of circuit breakers include oil, compressed air or gas, and vacuum interrupters. In general, vacuum power circuit breakers are applied in accordance with the specific continuous and short-circuit current requirements in the same manner as air-magnetic power circuit breakers. However, under certain conditions vacuum interrupters have characteristics that are different from air-magnetic power circuit breakers. Vacuum interrupters will sometimes, in special applications, force a premature current zero by opening (“chopping”) the circuit in an unusually short time. When this occurs, a higher than normal transient recovery voltage occurs that can be of a magnitude that will impose excessive dielectric stress on the connected equipment. In some equipment, this magnitude may be greater than the basic impulse insulation level of any connected device, and failure may result.

When applying vacuum power circuit breakers, the following precautions should be taken:

- a) Switching unloaded transformers. When switching power transformers that are unloaded, that is, interrupting just the small magnetizing current on an infrequent basis (less than 50 operations per year), and where the basic impulse insulation level is 95 kV or higher, generally no special attention is required. However, should either a dry-type transformer be involved with less than a 95 kV basic impulse insulation level rating, or all switching be highly repetitive, then the applications should be checked with the transformer manufacturer.
- b) Switching loaded transformers. When a power transformer has a permanently connected load in kilovoltamperes of 5% or more of its nameplate rating, generally no special consideration is needed.
- c) Switching motors. When vacuum power circuit breakers are utilized to switch motors, the standard rotating-machine protection package of capacitors and surge arresters should be considered if required by the manufacturer’s design.

Transient recovery voltage (TRV) parameters remain an important consideration for proper application. Transformer-limited faults and air-core reactors are known to produce TRV stress exceeding TRV limits established for breakers. Vacuum circuit breakers are typically less sensitive to excessive TRV stress. SF₆-type units typically meet requirements for outdoor service. Circuits shall meet the TRV requirements as established by IEEE Std C37.04™-1999 and ANSI C37.06-2009. For guidance, consult IEEE Std C37.011™-2011 and the circuit breaker manufacturer.

Table 2—Preferred ratings for Class S1 (indoor) circuit breakers for cable systems^{a,b}

Rated maximum voltage U_r (1) (kV, rms)	Rated continuous current (4) (A, rms)	Rated short-circuit and short-time current* (kA, rms)	Rated interrupting time (2) (ms)	Maximum permissible tripping time delay Y (sec)	Rated closing and latching current (3) (kA, peak)
4.76	1200, 2000	31.5	50 or 83	2	82
4.76	1200, 2000	40	50 or 83	2	104
4.76	1200, 2000, 3000, 4000	50	50 or 83	2	130
4.76	1200, 2000, 3000, 4000	63	50 or 83	2	164
8.25	1200, 2000, 3000	40	50 or 83	2	104
15	1200, 2000	20	50 or 83	2	52
15	1200, 2000	25	50 or 83	2	65
15	1200, 2000	31.5	50 or 83	2	82
15	1200, 2000, 3000	40	50 or 83	2	104
15	1200, 2000, 3000	50	50 or 83	2	130
15	1200, 2000, 3000, 4000	63	50 or 83	2	164
27	1200	16	50 or 83	2	42
27	1200, 2000, 3000	25	50 or 83	2	65
38	1200	16	50 or 83	2	42
38	1200, 2000	25	50 or 83	2	65
38	1200, 2000, 3000, 4000	31.5	50 or 83	2	82
38	1200, 2000, 3000, 4000	40	50 or 83	2	104
^a Numbers in parenthesis refer to the items in 4.5.1.1.					
^b For preferred capacitance current switching ratings, see Table 3.					

Source: Based on IEEE Std C37.06™-2009

4.5.1.1 Information for Table 2

- 1) The voltage ratings are based on ANSI C84.1-2006 [B2] where applicable and are the maximum voltages for which the circuit breakers are designed and are the upper limit for operation.

- 2) The ratings in this column are the maximum time interval to be expected during a circuit-breaker opening operation between the instant of energizing the trip circuit and the interruption of the main circuit on the primary arcing contacts under certain specified conditions. The values may be exceeded under certain conditions as specified in IEEE Std C37.04b™-2008, subclause covering rated interrupting time.
- 3) For 60 Hz, rated closing and latching current (kA, peak) of the circuit breaker is 2.6 times the rated short-circuit current. (If expressed in terms of kA, rms total current, the equivalent value is 1.55 times rated short-circuit current.) For 50 Hz, the kA peak is 2.5 times the rated short-circuit current and the rms total current is 1.47 times the rated short-circuit current.
- 4) The traditional North American continuous current rating of 1200 A has been retained in this standard, while IEC prefers the continuous current rating of 1250 A. It is possible that the continuous current rating might be changed to 1250 A in a future edition.

Table 3—Preferred capacitance current switching ratings for Class S1 circuit breakers for cable systems below 100 kV^a

Rated maximum voltage Ur	Rated continuous current	Class C0 (1) (2)		Class C1 and C2 (2) (4)		Class C1 and C2 (2) (4) (7)						
		Rated cable charging current	Rated isolated capacitor bank current	Rated isolated capacitor bank current	Rated cable charging current	Back-to-back capacitor bank switching						
						Rated capacitor bank current (6)	Rated in-rush current (3) (5)					
							Preferred rating (8)		Alternate 1 rating (8)		Alternate 2 rating (8)	
							Peak value	Frequency	Peak value	Frequency	Peak value	Frequency
kV, rms	A, rms	A, rms	A, rms	A, rms	A, rms	A, rms	kA, peak	kHz	kA, peak	kHz	kA, peak	kHz
4.76	1200	10	400	630	10	630	15	2	6	0.8	14	1.8
4.76	2000	10	400	1000	10	1000	15	1.3	6	0.5	17	1.4
4.76	3000	10	400	1600	10	1600	25	1.3	6	0.3	22	1.1
8.25	1200	10	250	630	10	630	15	2	6	0.8	18	2.4
8.25	2000	10	250	1000	10	1000	15	1.3	6	0.5	22	1.9
8.25	3000	10	250	1600	10	1600	25	1.3	6	0.3	28	1.5
15	1200	25	250	630	25	630	15	2	6	0.8	24	3
15	2000	25	250	1000	25	1000	15	1.3	6	0.5	30	3
15	3000	25	250	1600	25	1600	25	1.3	6	0.3	38	2
15	4000	25	250	1600	25	1600	25	1.3	6	0.3	38	2
27	3000	31.5	160	250	31.5	250	15	4.3	6	2	19	7
27	3000	31.5	160	400	31.5	400	15	4.3	6	1.3	25	5
27	4000	31.5	160	630	31.5	630	25	4.3	6	0.8	31	4
38	4000	50	100	250	50	250	20	4.3	6	2	21	7
38	4000	50	100	630	50	630	20	4.3	6	0.8	33	5
38	4000	50	100	1000	50	1000	20	4.3	6	0.5	43	4

Source: Based on IEEE Std C37.06™-2009

^aNumbers in parenthesis refer to the items in 4.5.1.2.

4.5.1.2 Information for Table 3

- 1) For class C0 (general-purpose) circuit breakers, no ratings for back-to-back capacitor switching applications are established. The capacitor bank or cable shall be “isolated” as defined in 5.11 of IEEE Std C37.04aTM-2003.

For class C0 (general-purpose) circuit breakers exposed to transient in-rush currents from nearby capacitor banks during fault conditions, the capacitance transient in-rush peak current on closing shall not exceed the lesser of either (1.41 times rated short-circuit current), or 50 000 A peak. The product of transient in-rush current peak and transient in-rush current frequency shall not exceed 20 kA-kHz. The service capability and circuit-breaker condition for this duty shall be as defined in IEEE Std C37.012TM-2005, 4.2.1.1 (capacitor bank) or 4.2.2.1 (cable).

- 2) The circuit breaker shall be capable of switching any capacitive current of the ratings listed in the selected rating column by the user, in the preceding tables, at any voltage up to the rated maximum voltage.
- 3) The rated transient in-rush current peak is the highest magnitude of current that the circuit breaker shall be required to close at any voltage up to the rated maximum voltage and shall be as determined by the system and unmodified by the circuit breaker. The rated transient in-rush current frequency is the highest frequency that the circuit breaker shall be required to close at 100% rated back-to-back capacitor switching in-rush current rating.
- 4) For application at less than 100% of rating, the product of the in-rush current peak and frequency shall not exceed the product of the rated transient current peak and the rated transient in-rush current frequency. (This product quantifies the maximum rate of change of in-rush current and the minimum inductance between the banks or cables.)
- 5) For circuit breakers identified as a Class C1 or C2 (formerly referred to as definite purpose), the manufacturer shall state the in-rush current peak and frequency at which the circuit breaker meets Class C1 or C2 performance. The stated in-rush current peak and frequency may be the preferred values from Table 4 or other values as determined by the manufacturer.
- 6) The transient in-rush current in circuit breakers applied in GIS substations has a very high equivalent frequency (up to the MHz range, depending on the bus length) with an initial peak current of several thousand amperes (depending on the surge impedance of the bus). For reference, see IEEE Std C37.012TM-2005. Contact the manufacturer to determine the ability of the circuit breaker to withstand these in-rush current stresses.
- 7) Tests to prove Class C2 have to be performed according to the requirements of Table 2 of IEEE Std C37.09aTM-2005. Tests to prove Class C1 have to be performed according to the requirements of Table 2A of IEEE Std C37.09aTM-2005.
- 8) The preferred ratings and alternates 1 or 2 ratings have different values. These values are for qualification of circuit-breaker capacitance switching according to their capabilities. The preferred ratings list the previous values indicated in ANSI C37.06-2009 and represent the standard values for circuit breakers. Alternate 1 ratings were added in particular for some ratings of vacuum and some other circuit breakers, and alternate 2 ratings represent the exceptional maximum values as seen by users and manufacturers in some world-wide applications. As of the time of the printing, only synthetic tests for alternate 2 are available in some laboratories.
- 9) For Class C1 and C2 circuit breakers exposed to transient in-rush currents from nearby capacitor banks during fault conditions, the capacitance transient in-rush peak current shall not exceed the close and latch (peak withstand) capability of the circuit breaker. This is considered an infrequent event, and therefore the circuit breaker should be expected to handle this duty twice in the lifetime of the circuit breaker without requiring maintenance of the contacts.

Table 4—Preferred ratings for indoor oil-less breakers (MVA rated)^a

Rated maximum voltage (1) (kV, rms)	Rated voltage range factor <i>K</i> (2)	Rated continuous current at 60 Hz (3) (A, rms)	Rated short-circuit current ^b (at rated maximum kV) (4) (5) (6) (9) (kA, rms)	Rated interrupting time (7) (cycles)	Rated maximum voltage divided by <i>K</i> (kV, rms)	Maximum symmetrical interrupting capability and rated short-time current (4) (5) (8) (kA, rms)	Closing and latching capability 2.7 <i>K</i> times rated short-circuit current (4) (kA, crest)
4.76	1.36	1200	8.8	5	3.5	12	32 97 132
4.76	1.24	1200, 2000	29	5	3.85	36	
4.76	1.19	1200, 2000, 3000	41	5	4.0	49	
8.25	1.25	1200, 2000	33	5	6.6	41	111
15.0	1.30	1200	18	5	11.5	23	62 97 130
15.0	1.30	1200, 2000	28	5	11.5	36	
15.0	1.30	1200, 2000, 3000	37	5	11.5	48	
38.0	1.65	1200, 2000, 3000	21	5	23.0	35	95
38.0	1.0	1200, 3000	40	5	38.0	40	108

NOTE 1—For service conditions, definitions, and interpretation of ratings, tests, and qualifying terms, see IEEE Std C37.04™-1979, IEEE Std C37.09™-1979, and IEEE Std C37.100™-1992.

NOTE 2—The interrupting ratings are for 60 Hz systems. Applications on 25 Hz systems should receive special consideration.

NOTE 3—Current values have been rounded off to the nearest kiloampere (kA) except that two significant figures are used for values below 10 kA.

Source: Based on IEEE Std C37.06™-1987 [B24]

^aNumbers in parenthesis refer to the items in 4.5.1.3.

^bFor the related required capabilities associated with the rated short-circuit current of the circuit breaker, see d) in 4.5.1.3.

4.5.1.3 Information for Table 4

- The voltage rating is based on ANSI C84.1-1989, where applicable, and is the maximum voltage for which the breaker is designed and the upper limit for operation.
- The rated voltage range factor, *K*, is the ratio of rated maximum voltage to the lower limit of the range of operating voltage in which the required symmetrical and asymmetrical current-interrupting capabilities vary in inverse proportion to the operating voltage.
- The 25 Hz continuous current ratings in amperes are given herewith following the respective 60 Hz rating: 600 to 700; 1200 to 1400; 2000 to 2250; 3000 to 3500.
- Related required capabilities. The following related required capabilities are associated with the short-circuit current rating of the circuit breaker.
 - Maximum symmetrical interrupting capability (kA, rms) of the circuit breaker is equal to *K* times rated short-circuit current.
 - 3 s short-time current-carrying capability (kA, rms) of the circuit breaker is equal to *K* times rated short-circuit current.
 - Closing and latching capability (kA, rms) of the circuit breaker is equal to 1.6 *K* times rated short-circuit current. If expressed in peak amperes, the value is equal to 2.7 *K* times rated short-circuit current.
 - 3 s short-time current-carrying capability and closing and latching capability are independent of operating voltage up to and including rated maximum voltage.

- e) To obtain the required symmetrical current-interrupting capability of a circuit breaker at an operating voltage between $1/K$ times rated maximum voltage and rated maximum voltage, the following formula shall be used:

$$\left(\begin{array}{c} \text{Required symmetrical current} \\ \text{interrupting capability} \end{array} \right) = \left(\begin{array}{c} \text{rated short} \\ \text{circuit current} \end{array} \right) \times \frac{(\text{rated maximum voltage})}{(\text{operating voltage})} \quad (1)$$

For operating voltages below $1/K$ times rated maximum voltage, the required symmetrical current interrupting the circuit breaker shall be equal to K times rated short-circuit current.

- f) With the limitation stated in 5.10 of IEEE Std C37.04™-1979, all values apply for polyphase and line-to-line faults. For single phase-to-ground faults, the specific conditions stated in 5.10.2.3 of IEEE Std C37.04™-1979 apply.
- g) The ratings in this column are on a 60 Hz basis and are the maximum time interval to be expected during a breaker opening operation between the instant of energizing the trip circuit and interruption of the main circuit on the primary arcing contacts under certain specified conditions as specified in 5.7 of IEEE Std C37.04™-1979.
- h) Current values in this column are not to be exceeded even for operating voltages below $1/K$ times rated maximum voltage. For voltages between rated maximum voltage and $1/K$ times rated maximum voltage, follow e) above.
- i) Rated permissible tripping delay time (T) = 2 s.
- j) The rated values for T_2 are not standardized for indoor oilless circuit breakers; however, $E_2 = 1.88$ times rated maximum voltage; E_2 = transient recovery voltage; T_2 = rated time to point P μ s.

4.5.2 Circuit breakers of 600 V and below

Circuit breakers rated 600 V and below are divided into two basic classes and three types:

Classifications:

- a) Low-voltage power circuit breaker class
- b) Molded-case circuit breaker class

Types: The first two types are derived from the above classifications. The third type offers features from both the first and the second class.

- a) Low-voltage power circuit breakers (LVPCBs)
- b) Molded-case circuit breakers (MCCBs)
- c) Insulated-case circuit breakers (ICCBs)

4.5.2.1 Low-voltage power circuit breakers (LVPCBs)

Power circuit breakers of 600 V and below have historically been open-construction assemblies on metal frames with all parts designed for accessible maintenance, repair, and ease of replacement. The latest models utilize molded case designs that completely enclose the mechanism and primary components (see Figure 1). They are intended for service in switchgear compartments or other enclosures of dead-front construction. Tripping units are field-adjustable over a wide range and are interchangeable within their frame sizes. The tripping units used are the electromagnetic overcurrent direct-acting type, solid-state type, and microprocessor-based units with various selectivity and additional monitoring and network communication capabilities.

These types of breakers can be used with integral current-limiting fuses in drawout construction to meet interrupting current requirements up to 200 000 A rms symmetrical. When part of the circuit breaker, the fuses are combined with an integral-mounted open-fuse trip device to prevent single-phasing if one fuse should blow.

In current designs of power circuit breakers of 600 V and below, contacts often begin to part during the first cycle of short-circuit current but have a multicycle total clearing time. Consequently, these breakers should be designed to interrupt the maximum available quarter-cycle asymmetrical current. Power circuit breakers of 600 V and below are rated on a symmetrical current basis. The ability of the circuit breaker to interrupt the maximum available quarter-cycle asymmetrical current is indicated by the short circuit impedance X/R of the test circuit. Minimum test X/R ratios that the breaker designs must be subjected to are defined by the circuit breaker test standard. Provided that the circuit breakers are applied at a system location where the X/R ratio is equal to or lower than the X/R ratios at which they are tested, no further evaluation is necessary. (Note that caution should be applied when these power circuit breakers are supplied with short-time delay trips because increases in short-circuit stress on the breaker could result in both a lower breaker interrupting capacity rating and extensive equipment damage from exceeding withstand ratings. For more information consult manufacturers' literature.)



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Figure 1—Low-voltage power circuit breakers



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Figure 2—Molded-case circuit breakers

Power circuit breakers 600 V and below can be applied on a symmetrical basis to its nameplate rating up to X/R ratios of 6.6 for unfused breakers and up to X/R ratios of 4.9 for fused breakers. Power circuit breakers may be applied to systems with higher X/R ratios when applied in accordance with the application information provided in 9.1.4.4. of IEEE Std C37.13™-2008 and IEEE Std 1015™-2006 (*IEEE Blue Book™*).

Power circuit breakers are designed for periodic planned maintenance. This design permits higher endurance ratings and repetitive duty capabilities and some basis for a broader range of applications.

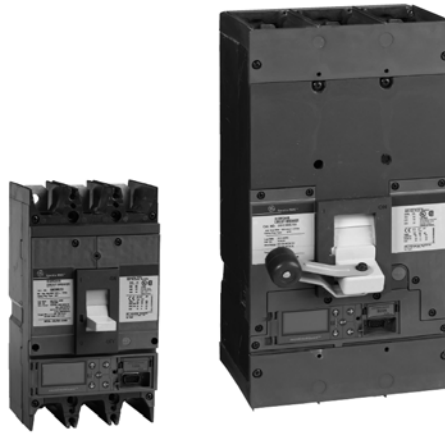
Manufacturers' publications give specific information on mechanical and electrical features of power circuit breakers 600 V and below. Refer to IEEE Std C37.13™-2008, ANSI C37.16-2009, and Table 5 for lists of standard ratings for 600 V and below circuit breakers. For service at altitudes above 6600 ft above sea level, de-rating factors must be applied in accordance with IEEE Std C37.13™-2008.

Unusual service conditions, as defined in IEEE Std C37.13™-2008, should be considered when applying power circuit breakers. Such conditions should be brought to the attention of the circuit breaker manufacturer at the earliest possible time.

4.5.2.2 Molded-case circuit breakers (MCCBs)

A molded-case circuit breaker (UL 489-2011) is a switching device and an automatic protective device assembled in an integral housing of insulating material. These breakers are generally capable of clearing a fault more rapidly than power circuit breakers and are available in the following general types:

- a) Thermal magnetic. This type employs thermal tripping for overloads and instantaneous magnetic tripping for short circuits. These are the most widely applicable molded-case circuit breakers (see Figure 2).
- b) Magnetic. This type employs only instantaneous magnetic tripping where only short-circuit interruption is required. The NEC recognizes adjustable magnetic types for motor circuit protection.
- c) Integrally fused. This type combines regular thermal magnetic protection against overloads and lower value short-circuit faults with current-limiting fuses responding to higher short-circuit currents. Interlocks are provided to help ensure safe and proper operation.
- d) High interruption rating. This fuseless type provides interrupting capabilities for higher short-circuit currents than do standard constructed thermal magnetic circuit breakers. This line incorporates sturdier construction of contacts and mechanism, plus a special high-impact molded casing.
- e) Current-limiting. This type provides high interruption rating protection, plus it limits let-through current and energy to a value significantly lower than the corresponding value for a conventional molded-case circuit breaker. Clearing time is also limited, and restoration of service is possible by resetting without replacement of any fusible elements or other parts.



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Figure 3—Fully adjustable molded-case circuit breakers with electronic trip devices

With the advent of electronic trip devices being incorporated into molded-case circuit breakers, the possibility for coordination with power circuit breakers is improved. The electronic trips of molded-case circuit breakers can be basic models with interchangeable rating plugs and adjustable instantaneous trips, or they may also be fully adjustable and provide short-time and ground-fault protection. This latter category is generally available in frame ratings of 400 A and larger, but may be available in frame ratings as low as 150 A, depending on the manufacturer. The fully adjustable electronic trips may also provide optional advanced protection, such as zone selective interlocking, and power metering and network communications. The fully adjustable molded-case circuit breaker still requires close scrutiny for proper application. Molded-case circuit breakers have an instantaneous override even when they are set on short-time delay. When a load-side (downstream) circuit breaker sees a large fault, not only will it trip, but if the fault exceeds the instantaneous setting of the line-side (upstream) circuit breaker, it might also trip. For system integrity, care must be exercised to ensure that coordination is maintained with line-side (upstream) devices and that load-side (downstream) equipment withstand ratings are not exceeded. Manufacturers' testing has identified combinations of circuit breakers whose instantaneous elements will be selectively coordinated up to a maximum short-circuit level. Consult manufacturers' literature for this information.

Molded-case circuit breakers generally are not designed to be maintained in the field as are power circuit breakers. Many molded-case breakers are sealed to prevent tampering, thereby precluding inspection of the contacts. In addition, replacement parts are not generally available. Manufacturers recommend total replacement of the molded-case circuit breaker if a defect appears, or if the unit begins to overheat. Molded-case circuit breakers, particularly the larger sizes, are not suitable for repetitive switching. Maintenance should be performed upon molded-case circuit breakers after they experience a fault that was near its interruption rating. It is important to recognize that differences in test criteria between power circuit breakers and molded-case circuit breakers can be significant in the application of circuit breakers at or near their interrupting rating. A combination of circumstances can reduce the performance of molded-case circuit breakers to less than adequate if they are applied at or near their interrupting rating on a par with power circuit breakers.

4.5.2.3 Insulated-case circuit breakers (ICCBs)

Insulated-case circuit breakers utilize characteristics of design from both power- and molded-case types. The basic requirements of these circuit breakers are governed by the same standard as molded-case circuit breakers, UL 489. The frame size of this type of breaker is larger than the frame size for molded-case breakers. The trip unit can be interchanged, and the breakers can be designed for fixed-mounting as well as with drawout configuration. In general, interruption of ICCBs is not fast enough to be a current-limiting type. Insulated-case circuit breakers are partially field-maintainable. The circuit breaker must be capable of

closing, carrying, and interrupting the highest fault current within its rating at that location. It is essential to select a circuit breaker whose interrupting rating at the circuit voltage is equal to or greater than the available short-circuit current at the point of installation. The procedure to be used for selection of power circuit breakers of 600 V and below with the proper interrupting rating is covered in IEEE Std 141™-1993 (*IEEE Red Book™*) Chapter 6.

Table 5—Preferred ratings for low-voltage ac power circuit breakers with direct-acting phase trip elements

Frame size	Rated maximum voltage	Three-phase short-circuit rating (kA) / Short-time current rating (kA) ^a (see Note 4)			Range of trip device current ratings (amperes) (see Note 1, Note 2, and Note 3)
		Minimum short circuit rating (kA)	Maximum short circuit current		
			Without instantaneous direct-acting trips (kA)	With instantaneous direct-acting trips (kA)	
600 ^b	254	22	22	42	300 to 600
800	254	22	85	200	60 to 800
1600	254	42	85	200	300 to 1600
2000	254	42	85	200	750 to 2000
3000 ^b	254	65	65	85	1200 to 3000
3200	254	65	100	200	1200 to 3200
4000	254	85	100	200	1600 to 4000
5000	254	85	100	200	3200 to 5000
6000	254	85	100	200	3200 to 6000
600 ^b	508	22	22	30	300 to 600
800	508	22	85	200	60 to 800
1600	508	42	85	200	300 to 1600
2000	508	42	85	200	750 to 2000
3000 ^b	508	65	65	65	1200 to 3000
3200	508	65	100	200	1200 to 3200
4000	508	85	100	200	1600 to 4000
5000	508	85	100	200	3200 to 5000
6000	508	85	100	200	3200 to 6000
600 ^b	600	22	22	22	300 to 600
800	600	22	85	200	60 to 800
1600	600	42	85	200	300 to 1600
2000	600	42	85	200	750 to 2000
3000 ^b	600	65	65	65	1200 to 3000
3200	600	65	100	200	1200 to 3200
4000	600	85	100	200	1600 to 4000
5000	600	85	100	200	3200 to 5000
6000	600	85	100	200	3200 to 6000

NOTE 1—Based on manufacturers' literature.

NOTE 2—The continuous current rating for an ac power circuit breaker with an electronic trip system shall be one of the following preferred values: 100 A, 150 A, 200 A, 400 A, 600 A, 800 A, 1200 A, 1600 A, 2000 A, 3000 A, 3200 A, 4000 A, 5000 A, or 6000 A. Consult manufacturers' literature.

NOTE 3—The minimum setting for long-time protection is typically 50% of the continuous current capability of the trip device.

NOTE 4—Ratings in this column are rms symmetrical values for single-phase (2-pole) circuit breakers and three-phase average rms symmetrical values of three-phase (3-pole) circuit breakers. When applied on systems where rated maximum voltage may appear across a single pole, the short-circuit current ratings are 87% of these values. See IEEE Std C37.13™-2008.

Source: Based on data taken from IEEE Std C37.16™-2009.

^a The preferred rated short-circuit current shall be one of the following values: 22 kA, 30 kA, 42 kA, 50 kA, 65 kA, 85 kA, 100 kA, 130 kA, 150 kA, or 200 kA.

^b Preferred ratings for 600 A and 3000 A frame sizes are provided for historical reference.

4.6 Service protectors

A service protector consists of a current-limiting fuse and non-automatic circuit-breaker-type switching device in a single enclosure. Stored energy operation provides for manual or electrical closing. The service protector, utilizing basic circuit-breaker principles, permits frequent repetitive operation under normal and abnormal current conditions up to 12 times the device's continuous-current rating. In combination with current-limiting fuses, it is capable of closing and latching against fault currents up to 200 000 A rms symmetrical. During fault interruption, the service protector will withstand the stresses created by the let-through current of the fuses.

Service protectors are available at continuous-current ratings of 800 A, 1200 A, 1600 A, 2000 A, 3000 A, 4000 A, 5000 A, and 6000 A for use on 240 Vac and 480 Vac systems, in two-pole and three-pole construction. An open-fuse trip device, which prevents the occurrence of single phasing after a fuse opening, is included in the design of the service protector.

5. Switchgear and switchboards

5.1 General discussion

Switchgear is a general term that describes switching and interrupting devices, either alone or in combination with other associated control, metering, protective, and regulating equipment, which are assembled in one or more sections.

A power switchgear assembly consists of a complete assembly of one or more of the above-noted devices and main bus conductors, interconnecting wiring, accessories, supporting structures, and enclosure. Power switchgear is applied throughout the electric power system of an industrial plant, but is principally used for incoming line service and to control and protect load centers, motors, transformers, motor control centers, panelboards, and other secondary distribution equipment. Switchboards are similar to switchgear in functionality but are not designed to the same standards as switchgear.

Outdoor switchgear assemblies can be of the non-walk-in (without enclosed maintenance aisle) or walk-in (with an enclosed maintenance aisle) variety. Switchgear for industrial plants is generally located indoors for easier maintenance, avoidance of weather problems, and shorter runs of feeder cable or bus duct. In outdoor applications, the effect of external influences, principally the sun, wind, moisture, and local ambient temperatures, should be considered in determining the suitability and current-carrying capacity of the switchgear. Further information on outdoor applications is contained in IEEE Std C37.24™-2003.

In many locations, the use of lighter colored (non-metallic) paints will minimize the effect of solar energy loading to avoid de-rating of the equipment in outdoor locations. See IEEE Std C37.24™-2003.

5.2 Classifications

An open switchgear assembly is one that does not have an enclosure as part of the supporting structure. Since open switchgear assemblies are rarely used in industrial installations, consideration will be given to metal-enclosed assemblies only.

An enclosed switchgear assembly consists of a metal-enclosed supporting structure with the switchgear enclosed on the top and all sides with sheet metal (except for ventilating openings and inspection windows). Access within the enclosure is provided by doors or removable panels.

Metal-enclosed switchgear is universally used throughout industry for utilization and primary distribution voltage service, for ac and dc applications, and for indoor and outdoor locations.

5.3 Types of metal-enclosed switchgear

Specific types of metal-enclosed switchgear used in industrial and commercial facilities are defined as (1) metal-clad switchgear, (2) low-voltage power circuit breaker switchgear, (3) low-voltage switchboards, and (4) interrupter switchgear.

5.3.1 Metal-clad switchgear

Metal-clad switchgear is metal-enclosed power switchgear characterized by the following necessary features:

- a) The main circuit switching and interrupting device is of the removable type arranged with a mechanism for moving it physically between connected and disconnected positions, and equipped with self-aligning and self-coupling primary and secondary disconnecting devices.
- b) Major parts of the primary circuit, such as the circuit switching or interrupting devices, buses, voltage transformers, and control power transformers, are enclosed by grounded metal barriers. Specifically included is an inner barrier in front of, or as a part of, the circuit interrupting device to ensure that no energized primary circuit components are exposed when the unit door is opened (see Figure 5).
- c) All live parts are enclosed within grounded metal compartments. Automatic shutters prevent exposure of primary circuit elements when the removable element is in the test, disconnected, or fully withdrawn position.
- d) Primary bus conductors and connections are covered with insulating material throughout. For special configurations, insulated barriers between phases and between phase and ground may be specified.
- e) Mechanical interlocks are provided to help ensure a proper and safe operating sequence.
- f) Instruments, meters, relays, secondary control devices, and their wiring are isolated by grounded metal barriers from all primary circuit elements, with the exception of short lengths of wire associated with instrument transformer terminals.
- g) The door, through which the circuit-interrupting device is inserted into the housing, may serve as an instrument or relay panel and may also provide access to a secondary or control compartment within the housing (see Figure 4).

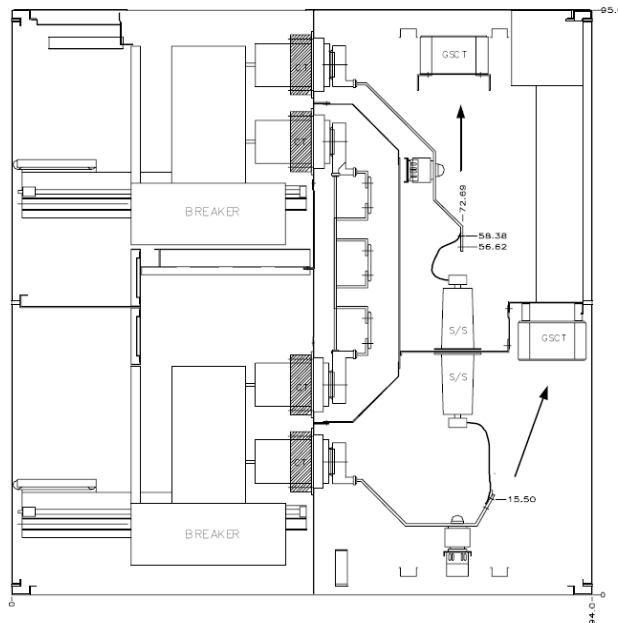
Auxiliary frames may be required for mounting associated auxiliary equipment, such as voltage transformers, control power transformers, etc.

The term metal-clad switchgear can be properly used only if metal-enclosed switchgear conforms to the foregoing specifications. All metal-clad switchgear is metal-enclosed, but not all metal-enclosed switchgear can be correctly designated as metal-clad. Metal-clad switchgear is designed and tested in accordance with IEEE Std C37.20.2™.



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Figure 4—Metal-clad switchgear



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Figure 5—Side view of typical metal-clad switchgear with “two-high” feeder breaker arrangement and cables exiting out top

5.3.2 Low-voltage power circuit breaker switchgear

Metal-enclosed power circuit breaker switchgear of 1000 Vac and below is metal-enclosed power switchgear, including the following equipment as required:

- a) Power circuit breakers of 635 Vac and below (unfused) or 600 Vac and below (fused)
- b) Non-insulated bus and connections (insulated and isolated bus is available)
- c) Instrument and control power transformers
- d) Instruments, meters, and relays
- e) Control wiring and accessory devices
- f) Cable and busway termination facilities
- g) Shutters to automatically cover line-side contacts when the circuit breaker is withdrawn

Low-voltage metal-enclosed power switchgear must follow the requirements of IEEE Std C37.20.1™-2002. The NRTL listing standard is UL 1558. The power circuit breakers of 1000 V and below are contained in individual grounded metal compartments and controlled either remotely or from the front of the panels. The circuit breakers are required by IEEE Std C37.20.1™ to be drawout type (see Figure 6). The standard also contains specific requirements for mechanical interlocks that must be provided to help ensure a proper and safe operating sequence.



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**Figure 6—Low-voltage metal-enclosed switchgear,
with drawout circuit breaker in withdrawn position**

5.3.3 Low-voltage switchboards

Low-voltage switchboards of 600 V and below share the same functionality as metal-enclosed power switchgear, and can include the following equipment as required:

- a) Molded-case circuit breakers of 600 V and below
- b) Fusible load-break switches of 600 V and below
- c) Power circuit breakers of 600 V and below (generally unfused)
- d) Non-insulated bus and connections
- e) Instrument and control power transformers
- f) Instruments, meters, and relays
- g) Control wiring and accessory devices
- h) Cable and busway termination facilities



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Figure 7—Low-voltage switchboard, designed for front-only access to connections

Most low-voltage switchboards provided in the United States are designed and tested in accordance with UL 891 and NEMA PB2. Switching devices are typically circuit breakers listed to UL 489 or fusible switches listed to UL 977 or UL 98. Devices rated 1200 A and less can be provided in a “group-mounted” design, similar in appearance to a panelboard, with the panel assembly mounted in the switchboard enclosure and a deadfront covering all but the operating handles. Devices rated greater than 1200 A are individually mounted, and the switchboard design may allow for only one or two individually mounted devices per section.

The devices are stationary mounted with bolted power connections to the switchboard bussing. Group mounted devices may be available in a “plug-in” design that allows their removal and replacement without the need to unbolt the line-side connections. Individually mounted circuit breakers may be available in drawout mounting.

Most low-voltage switchboard designs provide front access for power cable terminations, which allow the switchboard enclosures to be located in front of walls. Most front access switchboard designs are not available with the same options for bus insulation or section barriers as available in low-voltage metal-enclosed switchgear. However, some manufacturers may provide rear access switchboards that share many of the same optional features as low-voltage metal-enclosed switchgear, the difference being that drawout mounting is not a standard requirement of these switchboards, UL 489 listed circuit breakers may be furnished rather than UL 1066 listed power circuit breakers, and fusible switches as well as circuit breakers may be installed.

5.3.4 Interrupter switchgear

Metal-enclosed interrupter switchgear is metal-enclosed power switchgear, including the following equipment as required:

- a) Interrupter switches or circuit breakers
- b) Power fuses (if required)
- c) Non-insulated bus and connections
- d) Instrument and control power transformers
- e) Control wiring and accessory devices

An example of a fused load interrupter switch is shown in Figure 8. The interrupter switches and power fuses may be of the stationary or removable type. For the removable type, mechanical interlocks are provided to facilitate a proper and safe operating sequence. Metal-enclosed interrupter switchgear is designed and tested in accordance with IEEE Std C37.20.3™-2001.

5.3.5 Arc-resistant switchgear

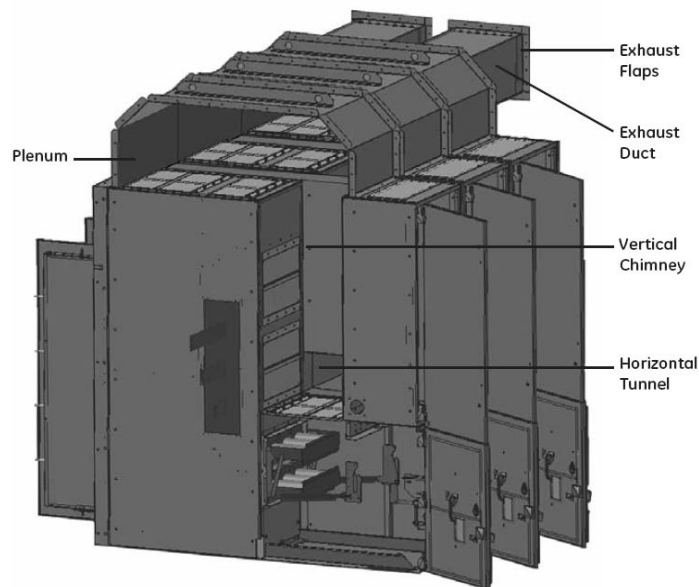
Arc-resistant switchgear may be available to an extent in all forms of switchgear, low- and medium-voltage, metal-enclosed and metal-clad. It is most common in medium-voltage, but low-voltage designs have recently begun to be furnished by a few suppliers.

The goal of arc-resistant switchgear is to guard the heat and blast effects of an arc flash from causing injury to persons standing in close proximity to the enclosure. It does not necessarily do anything to prevent the arc from occurring or to limit the damage done to internal components. Arc-resistant switchgear is characterized by a heavy outer enclosure. Arc byproducts are allowed to escape in a controlled manner by specially designed vents located either on the top or the side of the enclosure. Since arc exhaust can contain toxic gasses, the vents on arc-resistant switchgear that is located indoors should be connected to ducts or plenums to direct the arc exhaust outside the building. These ducts must be specially designed so that they do not impede venting in any way, and they must be strong enough to contain the pressure exerted by the arc gases.



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Figure 8—Fused load interrupter switch



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Figure 9—Arc-resistant switchgear showing the plenum and exhaust system

All covers must be secured in place with all intended fasteners supplied by the manufacturer. Loss of a fastener could jeopardize the integrity of the enclosure. Opening a cover to perform a diagnostic test or other service work will also violate the arc-resistant design.

IEEE Std C37.20.7™-2007 defines the methods by which switchgear shall be tested for resistance to the effects of arcing due to internal faults. The test involves initiating an arcing short-circuit within the

switchgear assembly to see if the enclosure can contain the arc to the criteria listed in the standard. The arcing current is to be driven by preferably the rated maximum voltage of the equipment, although reduced voltages are permitted due to laboratory constraints. However, there are further stipulations that must be followed to prevent premature arc extinguishment should a reduced voltage test be performed. The test value of the short-circuit is calibrated by shorting out the incoming terminals of the equipment, and the shorting conductors are then removed for the test. The arc is initiated using a small metal wire that has been placed directly on the phase bus bar. The size of the wire will vary depending on the ANSI standard to which the switchgear is designed, but it will be either 2.6 mm diameter (#10 AWG) or 0.55 mm diameter (#24 AWG). The thermal effects of arc gasses are determined through indicators constructed of black cotton fabric mounted in a metal frame and placed both vertically and horizontally around the switchgear enclosure. No indicators may ignite as a result of escaping arcing gasses for the switchgear sample to pass the test. In addition, all covers and doors must remain latched and not open, although some bowing or distortion is allowed. No fragmentation of the enclosure during the duration of the test is allowed. The arcing must not burn through the enclosure. All ground connections must remain effective following the test.

IEEE Std C37.20.7™-2007 defines two accessibility types. Type 1 defines switchgear with arc-resistant designs or features at the freely accessible front of the equipment only. Type 2 defines switchgear with arc-resistant designs or features at the freely accessible exterior (front, sides, and rear) only.

A Canadian standard that defines similar accessibility types was developed by Electrical and Electronic Manufacturers Association of Canada (EEMAC). EEMAC standards are no longer actively supported, but neither have they been formally withdrawn. EEMAC Std G14-1 [B16] lists three accessibility types:

Type A, Switchgear with arc-resistant construction at the front only (corresponds to IEEE Std C37.20.7™-2007 Type 1)

Type B, Switchgear with arc-resistant construction at the front, back, and sides (corresponds to IEEE Std C37.20.7™-2007 Type 2)

Type C, Switchgear with arc-resistant construction at the front, back, and sides, and between compartments within the same cell or adjacent cells, with an exception that a fault in a bus bar compartment of a feeder cell is allowed to break into the bus bar compartment of an adjacent feeder cell.

Arc resistance must be qualified for both arcing short-circuit current and arc duration. The preferred rating for arcing short-circuit current is the rated short-time current of the equipment. The preferred time duration rating is 0.5 s. Any value is permitted, but the recommended minimum duration is 0.1 s and it is considered unnecessary to test for longer periods than 1.0 s. These ratings may be further qualified by the use of current limiting breakers or fuses and this must be so stipulated on the equipment nameplate.

5.4 Switchgear design features

The enclosures of switchgear, both low-voltage and medium-voltage types will be supplied with hinged covers on the front, but standard covers on the rear may be bolted in place. Rear covers may be supplied as one-piece, but two-piece covers, arranged vertically, may also be available. The smaller sized cover on the two-piece design is easier to remove and replace. Hinged rear covers are also an available option and the fastening methods available can vary from bolted fasteners to three-point latches. Hinged covers are preferred for making the equipment safer should it be necessary to open the rear covers while the equipment is energized. Thermal scanning of power cable terminations is a common reason for doing this. However, infrared camera ports can be mounted on the rear covers to make opening the doors for this task unnecessary.

Breaker lifting devices (Figure 10) are often required for the removal of breakers from their rails once they have been moved to the withdrawn position. Low-voltage switchgear assemblies can be supplied with a

top-mounted hoist that can travel the length of the switchgear. These hoists are available on indoor enclosures and protected-aisle type outdoor enclosures. They are not possible on drip-proof indoor enclosures or non-walk-in outdoor enclosures. For these applications, a floor-mounted hoist can be furnished.



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Figure 10—Using an integrally-mounted hoist to more safely remove a circuit breaker from its drawout rails

“Racking” a breaker back and forth from the Connect to the Disconnect positions is typically performed manually with a detachable handcrank. However, there can be a risk of arc flash occurring during this operation, so optional remote racking operators have been developed by equipment suppliers to allow the operator to stand outside the flash protection boundary while performing this task. The remote racking operator (Figure 11) is a motor operator that is temporarily latched into place to the breaker where the racking operation is desired. The motor operator is plugged into a convenience outlet and has a pushbutton module for running the motor from a suitable distance, limited by the length of the cord that connects the pushbutton module to the motor operator.

Local operation of circuit breakers and switches also has some inherent risk to arc flash. Giving the operator the means to open or close the breaker from a distance outside the flash protection boundary makes the operation safer. To this end, electrically operated devices are preferred over those that are only manually operated. Control switches should be located away from the section containing the device being operated. Remote control panels are better, but the necessary wiring adds complexity and cost. However, the addition of network input/output modules to the switchgear and their connection to a supervisory control system can allow an operator the ability to monitor and control the switchgear from any location where there is a network jack into which a laptop computer can be plugged.



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Figure 11 —Remote racking a low-voltage circuit breaker

5.5 Ratings

The ratings of switchgear assemblies are designations of the operational limits of the particular equipment under specific conditions of ambient temperature, altitude, frequency, duty cycle, etc. Table 6 lists the rated voltages and insulation levels for ac switchgear assemblies discussed in this section. Rated voltages and insulation levels for dc switchgear assemblies can be found by referring to IEEE Std C37.20.1TM-2002, IEEE Std C37.20.2TM-1999, and IEEE Std C37.20.3TM-2001. The definition of the ratings listed in Table 6 and others subsequently discussed, can be found in IEEE Std C37.100TM-1992.

The short-circuit withstand level and duration capabilities of switchgear assemblies and metal-enclosed bus must be completely coordinated with the operating characteristics of the power system line-side interrupter.

The continuous-current rating of the switchgear main bus must be no less than that of the highest rated overcurrent device or through current to which it must be subjected. The rated continuous current of a switchgear assembly is the maximum current in rms amperes, at rated frequency, that can be carried continuously by the primary circuit components without causing temperatures in excess of the limits specified in IEEE Std 37.20.1TM-2002. The standard ratings of the main bus in ac low-voltage switchgear are 600 A, 800 A, 1200 A, 1600 A, 2000 A, 3000 A, 3200 A, or 4000 A, and in dc low-voltage switchgear are 1600 A, 2000 A, 2500 A, 4000 A, 5000 A, 6000 A, 8000 A, 10 000 A, and 12 000 A (IEEE Std C37.20.1TM-2002).

The continuous-current rating of the vertical and section bus riser shall be equal to the frame size of ac low-voltage power circuit breaker used except any modification required for cumulating loading of multiple breakers (IEEE Std C37.20.1TM-2002).

The momentary and short-time short-circuit current ratings of power switchgear assemblies shall correspond to the equivalent ratings of the switching or interrupting devices used.

The limiting temperature for a power switchgear assembly or metal-enclosed bus (where applicable) 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.