

FUSES VERSUS CIRCUIT BREAKERS FOR LOW VOLTAGE APPLICATIONS

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A circuit breaker (left) and Class L fuse (right)

I. Introduction

This paper discusses the differences between fuses and circuit breakers rated 600V and less. Understanding the differences will help you determine which is better for your application.

II. Definitions

Circuit breaker: “A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating.” [1]

Circuit breaker, current-limiting: “A circuit breaker that does not employ a fusible element and, when operating within its current-limiting range, limits the let-through I^2t to a value less than the I^2t of a 1/2-cycle wave of the symmetrical prospective current.” [2]

Circuit breaker, insulated case: “A circuit breaker with a supportive housing of insulating material and with a stored energy mechanism.” [3]

Circuit breaker, low voltage power: A circuit breaker other than a molded case circuit breaker and which has a stored energy mechanism and a 30 cycle withstand rating.

Circuit breaker, magnetic only: A circuit breaker without a thermal element.

Circuit breaker, molded-case: “A circuit breaker which is assembled as an integral unit in a supportive and enclosed housing of insulating material.” [2]

Circuit breaker, thermal magnetic: A circuit breaker with a thermal element providing overload protection and an instantaneous element responding to higher level overcurrents.

Fuse: “An overcurrent protective device with a circuit-opening fusible part that is heated and severed by the passage of overcurrent through it.” [1]

Fuse, current-limiting: “A fuse that, within a specified overcurrent range, limits the clearing time at rated voltage to an interval equal to or less than the first major symmetrical current loop duration; and limits the peak current to a value less than the available peak current.” [4]

Fuse, fast acting: A term not defined in standards but which is often used to describe a fuse that is not a time-delay fuse.

Fuse minimum melting I²t: The minimum I²t causing melting of the fuse element

$$\text{where } I^2t = \int_0^t i^2 dt$$

Fuse peak let-through current (I_p): “The maximum instantaneous current through a fuse during interruption in its current-limiting range.” [4]

Fuse prospective current: “The current that would flow in a circuit if a fuse therein were replaced by a shorting bar of negligible impedance. The prospective current is also referred to as the available current and is the quantity to which the interrupting rating, I²t, and peak let-through current are normally referred.” [4]

Fuse threshold current: “The lowest prospective rms symmetrical current above which a fuse is current limiting.” [4]

Fuse, time-delay: “A fuse capable of carrying a specified overcurrent for a specified minimum time. Time-delay characteristics are verified by the overload and operation tests in the relevant subsequent parts for certain fuse classes.” [4]

Fuse total clearing I²t: The maximum I²t passed by a fuse operating above its threshold current

$$\text{where } I^2t = \int_0^t i^2 dt$$

Instantaneous pickup setting: “The nominal value of current that an adjustable circuit breaker is set to trip instantaneously.” [2]

Instantaneous trip: “A qualifying term indicating that no delay is purposely introduced in the tripping action of the circuit breaker.” [1]

Interrupting rating, circuit breaker: “The highest current at rated voltage that a device is intended to interrupt under standard test conditions.” [2]

Interrupting rating, fuse: “The highest prospective rms symmetrical alternating current or direct current which a fuse will interrupt under specified conditions verified by operation at rated voltage tests.” [4]

Long-time delay: “An intentional time delay in the overload tripping of an adjustable circuit breaker’s inverse time characteristics. The position of the long time portion of the trip curve is normally referenced in seconds at 600 percent of the current setting (I_r.)” [2]

Selective coordination: A branch circuit overcurrent protective device and its upstream feeder overcurrent protective device are selectively coordinated when any possible overcurrent passing through the branch circuit device is cleared by the branch device before the upstream feeder overcurrent device operates.

Series-rated (series connected): “A group of overcurrent devices, connected in cascade, comprised of a circuit breaker or main fuse and one or more downstream circuit breakers that have been tested together to permit the branch or downstream circuit breakers to be applied on circuits where the available short circuit current exceeds the marked interrupting rating on the branch circuit breaker.” [2]

Short Circuit Current Rating: “The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding the defined acceptance criteria.” [5]

Short-time delay: “An intentional time delay in the tripping of a circuit breaker between the overload and the instantaneous pickup settings.” [2]

Short-time pickup: “The current at which the short-time delay function is initiated.” [2]

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III. Interrupting Ratings

When an overcurrent protective device (OCPD) interrupts a short circuit, a high energy arc is created within the OCPD. The OCPD must withstand the heat energy and pressure created by the internal arcing. The current, voltage, and clearing time determine the energy associated with the event. If the arc is not quickly extinguished, catastrophic failures leading to arc flash events can occur. The National Electrical Code® (NEC) addresses this safety concern in Article 110.9. "Equipment intended to interrupt fault levels shall have an interrupting rating not less than the nominal circuit voltage and the current that is available at the line terminals of the equipment." [1] An understanding of interrupting ratings is necessary for compliance with this section of the code.

Fuse Ratings

Current-limiting fuses listed to UL 248 standards are tested at rated voltage with a single fuse in a single-phase circuit capable of producing currents equal to the full interrupting rating of the fuse. The closing angle of the test circuit is selected so that the fuse is clearing during the peak portion of the voltage sine wave. Fuses are also tested at lower current values selected to subject the fuse to maximum internal energy during high current interruption. These tests confirm that a single fuse is capable of interrupting worst case conditions without assistance from other fuses that may be included in real world circuits, i.e., two fuses clearing a phase-to-phase fault in a three-phase system. UL Class CC, J, L, R, and T fuses have an alternating current interrupting rating of at least 200,000 amperes rms symmetrical.

Circuit Breaker Ratings

Circuit breaker interrupting current ratings varies by manufacturer. UL acknowledges the following standard rms symmetrical ratings: 5kA, 7.5kA, 10kA, 14kA, 18kA, 20kA, 22kA, 25kA, 30kA, 35kA, 42kA, 45kA, 50kA, 60kA, 65kA, 70kA, 85kA, 100kA, 125kA, 150kA, and 200kA.

In terms of voltage, multi-pole circuit breakers may be fully rated, e.g., 480V or slash rated, e.g., 480/277V. In the latter case the single pole rating of the breaker is 277V while its three-phase rating is 480V.

There are three situations where particular attention must be paid to the single pole rating of the OCPD.

1. Power systems with high resistance grounding (HRG).

2. Power systems with a corner grounded leg of a delta service.
3. Power systems with ungrounded delta service.

Article 240.85 of NEC-2011 requires circuit breakers have a straight voltage rating (e.g. 480V) for these three situations. Slash ratings (e.g. 480/277V) are only intended for solidly grounded wye systems.

Series Ratings

It is possible to enhance the ampere interrupting rating of circuit breakers with a higher rated upstream circuit breaker or with an upstream current-limiting fuse. Although this can allow the use of less expensive downstream circuit breakers there are three issues that need to be considered. First, NEC 240.86(C) limits the motor load connected to the load side of the higher rated device to less than 1% of the interrupting rating of the lower rated device. Second, selective coordination at high fault levels is not possible for the series rated parts of the power system because the upstream device must clear before or with the downstream device in order to protect it. Finally, NEC 110.22 addresses the field labeling required to ensure the proper application and proper replacement of components throughout the life of the series rated system.

Ratings Summary

By specifying current-limiting UL Class fuses you can ensure that you have a fully rated system that is capable of safely interrupting fault currents now and in the future. When applied according to the manufacturer's coordination ratios you will have a selectively coordinated system as well.

IV. Component and System Protection

Motor Circuit Protection

A motor branch circuit consists of a disconnecting means (switch or circuit breaker), a branch-circuit short-circuit and ground-fault protective device (fuses or circuit breaker), motor circuit conductors, a motor controller, and a motor. A motor branch circuit needs both overload and short-circuit protection. Both types of protection may be provided by a single OCPD or there may be a device providing overload protection and a second device providing short circuit protection. The controller may be a full voltage starter, a reduced voltage starter (soft start), or an AC or DC variable speed drive. The controller often includes an overload relay.

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In a typical industrial application involving a full voltage start, the motor draws an inrush current of up to 8 times full load current during acceleration. The OCPD(s) must not nuisance trip during this start-up period (usually 0.5 to 2 seconds), but must be able to interrupt the current in the event of an extended overload or a short circuit. Soft starts and AC and DC drives are power electronics devices. Protection of power electronics devices are discussed later in this section of the paper.

Fuse – Motor Circuit Protection

Under short-circuit conditions, fuses generally provide a superior level of current-limitation, even when compared to current-limiting circuit breakers. In addition to providing short-circuit protection, time-delay Class J or Class R fuses can be sized to back-up the overload relay should it fail to operate as expected. Properly coordinated, the overload relay responds to overcurrents up to and including locked rotor current. The fuses only open when a short circuit occurs.

Circuit Breaker – Motor Circuit Protection

Circuit breaker protection is often accomplished using a circuit breaker in which the overload element has been omitted. This device, called a Motor Circuit Protector (MCP), provides short circuit protection only. The MCP is sized to prevent nuisance tripping due to motor inrush. An overload relay is included in the circuit to provide overload protection for the motor and branch circuit components. Properly coordinated, the overload relay opens the motor contactor on overcurrents up to and including motor locked rotor. The MCP is expected to clear short circuits. In the event of a trip, an MCP can be reset. However, the MCP should be reset only after the cause of the short circuit has been identified and corrected and after it has been determined that the MCP is suitable for continued service. If an MCP opens on an overload, it is defective or the overload relay setting needs to be adjusted. Current-limiting circuit breakers are available at a premium cost.

Single Phasing Protection

Utility induced single phasing is not uncommon and utilities recommend proper single-phase protection. Single phasing of a downstream motor(s) within a facility can be caused by the opening of one fuse. A properly maintained circuit breaker is unlikely to cause single phasing. Critical motors should have single phasing protection. Electronic overload relays and IEC type mechanical overload relays are available with a differential function for protection against single phasing.

Short Circuit Current Ratings

Short Circuit Current Rating (SCCR) requirements can have a significant influence upon the selection of OCPDs. Equipment SCCR must be greater than the available fault current at its point of connection. [1]

Fuse – SCCR

At both branch and feeder levels, installing current-limiting fuses may be a cost effective way to achieve the desired panel SCCR while also reducing hazards under fault conditions. UL 248 requires a 200kA interrupting rating for Class J, L, RK1, RK5, T, and CC fuses. These fuse classes are current limiting, satisfy NEC requirements for branch circuit protection, and are suitable for virtually all applications at 600VAC and below.

Many circuit components have been type tested with Class J or Class CC fuses to establish a high SCCR for the component (100kA typical). [15] A higher panel SCCR can often be obtained by using these type tested combinations. Class J or Class CC fuses can also be applied as sub-feed fuses protecting branch circuits containing low rated components.

Circuit Breaker – SCCR

Circuit breakers are available with relatively high SCCR; however, the cost is typically higher than for a fusible switch at the feeder level, and higher than the fuse and holder at the branch level. Current-limiting circuit breakers may have low enough peak let-through currents to protect control equipment with inadequate SCCR. Some circuit components have been type tested with current-limiting circuit breakers to establish component SCCR that are higher than the minimum allowed by UL.

Type 1 versus Type 2 Protection

The IEC standard for motor starters and contactors, 947-4-1, defines two levels of coordination (protection) for the motor starter (contactor and overload relay) under short circuit conditions.

Type 1 Coordination

Under short circuit conditions, the contactor or starter shall cause no danger to persons or installation but may not be suitable for further service without repair and replacement of parts. [6]

Type 2 Coordination

Under short circuit conditions, the contactor or starter shall cause no danger to persons or installation and shall be suitable

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for further use. The risk of contact welding is recognized, in which case the manufacturer shall indicate the measures to be taken in regards to equipment maintenance. [6]

Each level of coordination is achieved by using a specific combination of motor starter and OCPD. Type 1 coordination provides a reasonable level of confidence that the controller will not cause danger to persons under short circuit conditions provided the enclosure door is properly closed. However, the controller may not be suitable for further use. [16] Under test conditions defined in the standard, Type 1 damage may include vaporized heater elements and permanently welded contacts. [6]

In situations where available fault currents are higher and downtime is crucial, it is important to understand that Type 1 coordination may not prevent damage to the motor starter components, and that a higher degree of protection may be desirable. In order to reduce downtime it may be prudent to specify Type 2 coordination when selecting low voltage motor controllers and their OCPDs. Type 2 coordination, as defined by IEC and tested by UL, does not permit damage to the starter beyond light contact welding, easily separated by a screwdriver or several coil operations, thus reducing the likelihood that lost production and unscheduled disruptions will result from a need to replace or repair a starter that has passed fault current.

Fuse or Circuit Breaker for Type 2 Protection

The availability of circuit breaker starter combinations providing Type 2 coordination with SCCRs above 5kA is limited. Generally speaking, Class CC and Class J fuses provide Type 2 coordination with SCCRs of 50kA to 100kA.

Type Testing

UL standards may require minimum SCCRs for listed components. These ratings are determined during UL witnessed testing. The component is tested in combination with the least protective OCPD allowed by UL. The short circuit current level at which the combination is tested and the pass and fail criteria are specified by UL.

Component manufactures have the option of establishing higher SCCRs than the minimum required by UL. This is accomplished by type testing. The component manufacturer tests the component in combination with a specific type of OCPD at a higher short circuit current level. The pass and fail criteria are specified by UL.

Type Testing with Fuses

The UL standard for fuses (UL 248) contains specific maximum peak let-through current and clearing I^2t limits for current-limiting fuses at various prospective current levels. A test limiter is a calibrated fuse that passes a peak let-through current and a clearing I^2t that is higher than the maximum allowed by UL for a given fuse class and ampere rating. [7] Test limiters are used only for short circuit testing and facilitate the establishment of high SCCRs for fuse protected electrical components such as contactors, starters, power distribution blocks, switches, etc.

Type Testing with Circuit Breakers

The UL standard for circuit breakers (UL 489) does not contain specific numeric limits for peak let-through current or clearing I^2t . Therefore circuit breaker test limiters do not exist. To establish a high SCCR for a circuit breaker protected component, that component must be tested in combination with a specific circuit breaker catalog number.

Power Electronics Applications

The protection requirements for power electronics devices are much different than for electromechanical devices. Overload protection is often incorporated within power electronics products. Providing NEC-required branch circuit protection may not provide an acceptable level of protection for the power electronics device under short circuit conditions. External protection for short circuit conditions may be appropriate. Prospective fault current often exceeds 20X normal current rating. Under these conditions heat buildup occurs quickly and healthy components can fail in milliseconds. "Heating effect cannot be characterized by rms value of the prospective current as in the case of overloads, because it depends upon the waveform of the current. In this case the requirement for the protective devices is to limit the energy associated with the fault, which depends upon the integral

$$\int_0^t i^2 dt$$

where i is the instantaneous current [i.e. $i = i(t)$]. This integral is usually called the " I^2t " and is a measure of the thermal energy delivered to each ohm of the circuit by the short-circuit current during the time t ." [8]

Fuses for Power Electronics

High-speed fuses, commonly referred to as semiconductor fuses, have been developed for power electronics applications. In addition to continuous current, voltage, and interrupting ratings, these fuses are rated in terms of their melting and

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clearing I^2t . When subjected to high fault currents, high-speed fuses open faster and let through less energy than standard UL class fuses. High-speed fuses are chosen to limit I^2t and peak arc voltage to values the power electronics equipment can withstand.

Circuit Breakers for Power Electronics

From an I^2t standpoint, circuit breakers do not compare favorably with the low clearing I^2t provided by high-speed fuses. The clearing I^2t of the fastest circuit breakers is one to two orders of magnitude greater than the clearing I^2t of high-speed fuses.

V. Arc Flash Mitigation

Workers need to be protected from the well-documented hazards of arc flash. The physical makeup of the equipment, the distance from the worker to the arc, the magnitude of arcing current, and the clearing time of the upstream OCPD are key factors to consider when determining the potential energy exposure. Third degree burns are possible when workers are exposed to incident energy exceeding 1.2 cal/cm². [12]

Fuse – Arc Flash Mitigation

Current-limiting fuses are energy limiting. Current-limiting fuses clear a short circuit in less than 1/2 cycle and prevent the current from reaching the first prospective peak provided the arc current is above the fuse threshold current. During arc flash events, fuses can drastically reduce the electrical energy delivered to the arc.

To achieve the best possible results, specify fuses with a threshold current that is lower than the arcing current. Within the same fuse class, fuses with smaller ampere ratings will have lower threshold currents. A load study may show that it is possible to reduce fuse ampere rating; doing so will result in lower incident energy. Incident energy below 1.2 cal/cm² is typical provided the arcing current exceeds fuse threshold current.

The best choice for new specifications is the Class J family of fuses. Class J fuses have the lowest let-through energy and the lowest threshold currents of any general purpose current-limiting fuse. The unique dimensions of the Class J make it unlikely that it will be replaced with a lesser performing fuse. For existing facilities, the Class RK1 family of fuses is the best upgrade choice.

Circuit Breaker – Arc Flash Mitigation

Circuit breakers provide their best arc flash performance when tripping instantaneously. With arcing currents just beyond instantaneous pickup, incident energy below 4 cal/cm² is likely and incident energy below 1.2 cal/cm² is possible. As arcing current increases so does incident energy. High incident energy can be expected if arcing current is below instantaneous pickup, or if short-time delay or non instantaneous is in place to achieve selectivity with downstream circuit breakers. Circuit breakers with low instantaneous pickup may outperform fuses if device ratings are large (over 600Amps) and if fault currents are low. Circuit breakers that are not properly maintained may not perform as expected and this can result in incident energy levels that exceed expectations.

VI. Selective Coordination

Selective Coordination between Fuses

Selective coordination or lack thereof is relatively easy to determine for fused circuits. For events lasting 0.01 seconds or longer, fuses will selectively coordinate if the minimum melting curve of the upstream fuse falls to the right of the total clearing curve of the downstream fuse. For currents causing operation of one or both fuses in 0.01 seconds or less, the fuses will selectively coordinate if the total clearing I^2t of the downstream fuse is less than the melting I^2t of the upstream fuse.

The minimum melting I^2t of a fuse is a function of the fuse element material (copper, silver, etc) and the minimum cross-section of the fuse element. Total clearing I^2t is determined by testing the fuse under short circuit current conditions.

To simplify selective coordination evaluations, fuse manufacturers publish selective coordination ratio tables. These tables show the minimum ratios in terms of fuse current rating that must be maintained to ensure selective coordination between upstream and downstream fuses (examples shown below).

*Fuse Selective Coordination Ratio Table – 600 and 480V
Up to 200,000 rms Symmetrical Amperes*

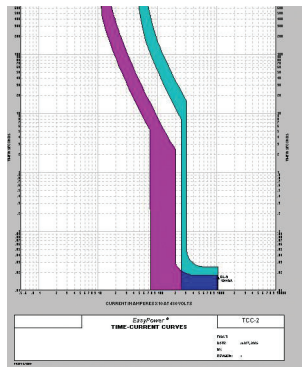
Branch Fuse	Main Fuse		
	A4BQ	A6D	TRS
A4BQ	2:1	--	--
A6D	2:1	2:1	1.5:1
TRS	4:1	4:1	2:1

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Selective Coordination between Circuit Breakers

Time current curves are used to evaluate the selectivity of circuit breakers over their long-time and short-time operating currents. Time current curve comparisons should not be relied upon to provide accurate results for instantaneous circuit breaker tripping. [11] Circuit breakers relying on the magnetic force created by instantaneous current can unlatch in less than 0.01 seconds.

These same circuit breakers may take 1-1/2 cycles or longer to clear. If the downstream circuit breaker is not able to limit the instantaneous current to a value below that required to unlatch the upstream circuit breaker, both devices will open and selective coordination will not be achieved. This is shown in the following graph.



Time current curves showing partial selectivity between circuit breakers

For this reason circuit breaker manufacturers publish instantaneous selectivity capability tables. These tables show the range of prospective currents over which various circuit breaker combinations will selectively coordinate. These tables may be supported by analytical techniques as well as by actual testing. System changes may increase future fault currents and render the initial coordination study obsolete.

Selective Coordination Summary

A fusible system can generally be selectively coordinated without compromising system or component protection. More effort is required to selectively coordinate a circuit breaker system. Circuit breakers with short time delay or without instantaneous trips have been used to achieve selective coordination but at the cost of higher arc flash incident energy for faults occurring between the two circuit breakers. Circuit breakers incorporating zone selective interlocking may provide selective coordination with less compromise to system protection.

VII. Maintenance Requirements

It is hard to overstate the importance of an effective OCPD maintenance program. NFPA 70E requires that an arc flash hazard analysis be performed to assess the potential for employee exposure to dangerous electrical arcing hazards and states that, “the arc flash hazard analysis shall take into consideration the design of the overcurrent protective device and its opening time, including its condition of maintenance.” [12] Article 205.3 of NFPA 70E requires OCPDs be maintained in accordance with the manufacturers’ recommendations or per an industry consensus standard. Article 205.4 states that OCPD “maintenance, tests, and inspections shall be documented”. [12]

The Occupational Safety and Health Administration (OSHA) 29CFR 1910 General Industry Regulations, requires every employer protect employees from hazards that can seriously injure or cause death and notes that a deficient maintenance program for OCPDs can increase hazards when work is performed on or near energized electrical equipment.

Unfortunately many end users do not have adequate maintenance programs for the OCPDs installed in their facilities. A 2008 NETA survey of over 340,000 protective devices found that approximately 23% of the installed circuit breakers tested failed to perform to initial specifications. [13] Other surveys have shown that a significant percentage of failures are attributable to a lack of maintenance.

The following is a list of standards and guides addressing maintenance of OCPDs:

- NFPA70B Recommended Practices for Electrical Equipment Maintenance
- NEMA AB4 Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications
- ANSI/NETA ATS Standard for Acceptance Testing Specifications for Electrical Power Systems and Equipment
- ANSI/NETA MTS Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems
- IEEE 1458 Recommended Practices for the Selection, Field Testing, and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications

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Fuse Maintenance

While circuit breakers act both as disconnects and OCPDs, fuses provide overcurrent protection only and are installed in or with a disconnect switch. This may be beneficial to the fuse user from a maintenance standpoint. Fuses are not subject to mechanical wear from the making and breaking action that circuit breakers are subject to.

Unlike circuit breakers, fuses do not require periodic electrical testing to ensure effective operation when system or component failures occur. This does not mean that a fusible protection scheme is maintenance free. Periodic visual inspection of fuses for loose connections, signs of overheating, corrosion, or cracked ferrules is recommended. Removing dust, dirt, soot, or other contaminants from fuses and fuse holders using a lint-free dry cloth or vacuum cleaner is recommended. See NFPA 70B for details.

Circuit Breaker Maintenance

There are two basic components to an effective circuit breaker maintenance program. They are:

- 1) Inspection and preventive maintenance
- 2) Electrical performance and verification tests (field testing)

Inspection and preventive maintenance involves good housekeeping techniques, verifying proper mounting, inspecting electrical connections, looking for loose hardware, checking for signs of overheating or a cracked casing, and exercising the circuit breaker. Removing all dust, dirt, soot, grease, or moisture from the surface of the circuit breaker using a lint-free dry cloth or vacuum cleaner is recommended. Exercising the circuit breaker is an important preventive maintenance activity and involves more than just turning the circuit breaker off and then back on. NEMA AB4 Section 6.2 outlines how a breaker should be operated and tested during this mechanical operation test.

Many end users do not have the in-house ability to carry out an effective electrical performance and verification test program. This service is typically provided by a circuit breaker manufacturer or by a circuit breaker testing and service company. NEMA AB4 outlines the testing requirements starting in section 6.3. This is also covered in NFPA 70B starting with section 11.10.1. Requirements include:

1. Insulation resistance test
2. Individual pole resistance test (millivolt drop)

3. Inverse-time overcurrent trip test
4. Instantaneous overcurrent trip test
5. Rated current hold-in test

The frequency of these tests is best determined by the end user and the testing company and is based upon conditions of use, the physical environment, age of the equipment, and past history.

Maintenance Summary

It is important to note that the effective operation of all OCPDs is dependant on several key factors including proper application and installation, environmental conditions, and preventive maintenance. The maintenance requirements for fuses are significantly less onerous than for circuit breakers.

VIII. Resetting or Replacing OCPDs

The ability to reset circuit breakers is often viewed as an advantage. However, OSHA CFR 29 1910.334(b)(2) states, “after a circuit is de-energized by a circuit protective device, the circuit may not be reenergized until it has been determined that the equipment and circuit can be safely energized.” Before a circuit breaker is reset or before blown fuses are replaced, a qualified person should determine the cause of the protective device operation. If the opening was caused by an overload, the circuit breaker has the advantage of being resettable. If the device opening was caused by a short circuit, the circuit breaker is at a disadvantage. Article 225.3 of the NFPA 70E states, “circuit breakers that interrupt faults approaching their interrupting rating shall be inspected and tested in accordance with the manufacturer’s instructions.”

Replacing Fuses

If a fuse opens during either an overload or short circuit it can be replaced with a new fuse. If one or two fuses open in a 3-phase circuit it is generally best to replace all three fuses, thus assuring that a weakened fuse is not left in the circuit. All three fuses in a 3-phase circuit should have the same catalog number and the same ampere rating.

Replacing Circuit Breakers

A circuit breaker that has cleared a short circuit should be inspected and tested by a qualified person in accordance with the circuit breaker manufacturer’s instructions before it is returned to service.

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IX. Diagnostics

OSHA CFR 1910.334(b)(2) requires a qualified electrical person determine the cause of opening of an OCPD. If the opening was caused by an overload, the circuit may be re-energized. If the opening was caused by a short circuit, additional steps need to be taken before the circuit is re-energized. Repairs need to be made. If the OCPD is a circuit breaker, it needs to be evaluated and deemed suitable for continued use before the circuit is re-energized. If the OCPD is a set of fuses, they need to be replaced before re-energizing the circuit.

Fuse Diagnostics

An open fuse provides a permanent record of the overcurrent condition that caused the fuse to open. A fuse engineer can dissect or X-ray an open fuse to determine the level of current that caused the fuse to open. A trained electrician can dissect a fuse and often determine whether the fuse opened on an overload or on a short circuit.

Some fuses contain blown fuse indicators showing the status of the fuse, i.e., blown or not blown. Fuse holders and fusible switches with built-in or add-on blown fuse indicators are available.

Circuit Breaker Diagnostics

A circuit breaker provides visual indication showing the status of the circuit breaker, i.e., open, closed, or tripped. Some electronic trip units have the option of recording the magnitude of the current that caused the circuit breaker to trip.

External power system monitors can record current interruption magnitude, harmonics, power, voltage waveform, power factor and other diagnostic tools. External instrumentation can be effective with both circuit breakers and fusible gear.

X. Reliability

Reliability has been defined as “The ability of a component or system to perform required functions under stated conditions for a stated period of time.” [14] The primary function of an OCPD is to open when an overcurrent exceeds current and time limits. The reliability of both circuit breakers and fuses is high when equipment is new. Reliability for both remain high when properly maintained.

Fuse Reliability

Fuses require minimal maintenance (see section 7 of this paper for details). Fuses are calibrated at the factory. If a fuse opens it is replaced by a new, factory-calibrated fuse. If one or two fuses open in a 3-phase circuit, all three fuses should be replaced thus reducing the likelihood that a weakened fuse will open prematurely.

Circuit Breaker Reliability

Circuit breaker reliability can be affected by environmental factors like corrosion and contamination and by previous interruptions of overloads or short circuits. Circuit breakers can open prematurely or they can fail to open. First opening times can be significantly slower if circuit breakers are not adequately maintained. Circuit breaker reliability decreases with service time when circuit breaker maintenance programs are substandard. [14]

Refurbished Equipment

Cost concerns have led to the replacement of circuit breakers and fuses with devices that have been refurbished, modified, or rebuilt by a 3rd party. Such devices may not operate as the original manufacturer intended. Buyers beware.

XI. Obsolescence

Aging Equipment

The UL Class fuse standards (UL 248 series) define the critical mechanical and electrical characteristics of UL Listed fuses. This allows for interchangeability between brands. Should one manufacturer discontinue production of a UL Class fuse, end users can be confident a replacement will be available from another fuse manufacturer.

The same cannot be said for circuit breakers. When a circuit breaker manufacturer discontinues a model, end users cannot be confident a drop-in replacement will be available from the original or from a competing manufacturer.

Interrupting Rating Obsolescence

Both the NEC and OSHA require OCPDs have interrupting ratings adequate for the available fault current. Though OCPDs may have had adequate interrupting ratings when a system was originally commissioned, over time fault currents can increase and render existing OCPDs overdutied and hence unsafe.

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Increases in available fault current may be caused by:

- Utility changing supply transformer
- Utility changes to distribution system
- Adding a facility generator that could be used in parallel with the utility source
- Adding a facility tie bus for distribution reliability
- Replacing an existing transformer within the facility

UL Class J, L, RK1, RK5, T, and CC fuses have a 200,000 ampere interrupting rating. The probability of these devices becoming overdutied is extremely low. Contrast this with circuit breaker systems. The typical practice for designing a circuit breaker system is to satisfy the initial interrupting rating requirements. This is driven by the reality that higher circuit breaker interrupting ratings increase initial system cost. If the available fault current is increased over time due to future changes as noted above, the circuit breakers may become overdutied and this may result in expensive upgrades or may require a new distribution system.

Series Rating Obsolescence

The original system may have been designed with more economical series-rated circuit breakers. Code requirements are very particular requiring the high-rated and low-rated OCPDs to be specifically tested and listed together. If a UL Class fuse was used as the high-rated device, you can be confident future replacements will be available for the life of the distribution system. If a circuit breaker was used as the high-rated device, exact replacements become problematic as the equipment ages.

This potential for obsolescence can be eliminated by specifying a fully rated system. If the budget mandates a series-rated system, using UL Class fuses as the higher rated device extends the potential useful life of the equipment.

Obsolescence by Panel SCCR

Panel SCCR must exceed the available fault current at the point of installation. If the available fault current exceeds panel SCCR, excessive equipment damage may result and the likelihood of personal injury will increase.

The SCCR is calculated based on established component testing. All OCPDs have characteristics that are considered in the overall rating. If an overcurrent device is substituted, there could be a safety issue. Fuses are built to meet or exceed minimum UL Standards incorporated into the SCCR rating. So, listed fuses of the same UL classification and current rating can be safely substituted. However, a circuit breaker replacement should be of the same manufacturer and model as the original. When the exact circuit breaker model becomes unavailable, the panel SCCR becomes problematic.

Obsolescence by Impedance Grounding

Fuses have a full voltage rating and are UL tested as a single pole device. A 600 volt rated fuse is fully capable of safely opening any voltage up to a maximum of 600 within its interrupting rating. The same can be said for the majority of circuit breakers.

However, small circuit breakers used in motor controls often have a slash voltage rating. These circuit breakers are rated 480/277 volts. The second number refers to the maximum voltage that any pole can open with respect to ground. As noted in section 3 of this paper, slash-rated circuit breakers are only suitable for use in solidly grounded wye systems. Should a facility decide to upgrade to impedance grounding, slash-rated circuit breakers will become obsolete and will need to be replaced with fully rated devices.

XII. Cost of Ownership

Initial Cost

Initial system cost is strongly affected by interrupting rating requirements, by selective coordination requirements, and by the designer's or end user's tolerance for arc flash hazard. When these three considerations are not demanding, molded case circuit breakers can be expected to provide the lowest installed cost.

Fusible distribution equipment typically provides high interrupting capacity and selective coordination at a lower installed cost than low voltage power circuit breakers (LVPCBs) and insulated case circuit breakers.

Fusible equipment offers a cost effective solution to those interested in lowering arc flash hazards while maintaining selective coordination.

Obsolescence Cost

Fuses are typically backward compatible with older designs. Older UL designs, such as Class H, and Class K fuses can be replaced with Class RK5 or Class RK1 fuses. The Class RK5 and Class RK1 fuses fit into the older fuse clips and provide improved performance while virtually eliminating the likelihood that fuses will force the obsolescence of associated equipment.

Conversely, when circuit breakers become obsolete, the associated electrical equipment is often replaced. This incurs an added capital cost that needs to be factored into the total cost of ownership.

Circuit breaker obsolescence can be caused by:

- Increases in available fault current
- Discontinuing of a circuit breaker model
 - Series-rated equipment becomes obsolete
 - Panel SCCR becomes problematic
- Upgrading to an impedance grounding system (obsoletes slash-rated circuit breakers)

Product obsolescence can shorten the useful life of a circuit breaker system

Maintenance Costs

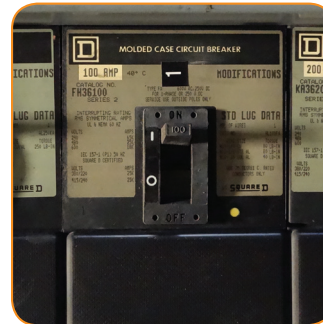
The importance of an effective OCPD maintenance program was discussed in the maintenance requirements section of this paper. Electrical performance verification testing is not needed for fuses but is recommended for circuit breakers. This testing adds to the cost of maintenance for a circuit breaker protected system. If this testing is not performed, failure of circuit breakers to perform as expected exposes the owner to the potential for significant additional operating costs resulting from possible equipment failure, downtime, or hazard to personnel.

Spare Parts Costs

Both fuse and circuit breaker spares are required for maintenance. More fuse than circuit breaker stocking units are generally kept on hand since fuses are replaced more frequently than are circuit breakers. However, three fuses cost considerably less than a three pole circuit breaker. Properly stored, fuses have a long shelf life. A specific fuse item is more likely to be useable in a number of pieces of equipment than is a specific circuit

breaker item. When a circuit breaker switchboard becomes obsolete, the associated spares often become obsolete as well.

Standardized fuse maintenance programs can reduce the cost of using fusible gear. The Mersen Fuse Control™ program makes extensive use of the backward compatibility feature of fuses and reduces the fuse types and quantities required for maintenance thus reducing cost and complexity.



Circuit breaker



Class J Fuses

XIII. Summary

There are significant differences between fuses and circuit breakers.

Fuses operate individually clearing only the problem circuit, thus minimizing unnecessary outages. Fuses offer a higher degree of current limitation than do circuit breakers. A higher degree of current limitation allows for higher equipment SCCRs, better component protection, reduced arc flash energy, and better serves power electronics applications. Fuses allow selective coordination under both overload and short circuit conditions without compromising system, component, or personnel protection. Fuses provide the highest degree of reliability in terms of clearing short circuit currents. Maintenance requirements for fuses are minimal. UL Class current-limiting fuses have a 200kA interrupting rating or higher thus future increases in available short circuit current are unlikely to exceed fuse ratings.

Circuit breakers can be reset. Although this can be an advantage when the opening is caused by an overload, it is a disadvantage when the opening is caused by a short circuit. Circuit breakers clear all poles simultaneously; minimizing the likelihood of OCPD initiated single phasing. Circuit breakers offer advanced protection and monitoring features, however this comes with a significant product cost. Lastly, some circuit breakers can be set to trip instantaneously at multiples as low as 5x continuous current rating which can be advantageous in circuits where arcing fault current is low.

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XIV. References:

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Recommended Fuses and Their Ratings

A4BQ - Class L

Current-Limiting Fuses

Voltage Rating: 600VAC / 500VDC

Current Rating: 100A up to 6000A



AJT - Class J

Current-Limiting Fuses

Voltage Rating: 600VAC / 500VDC

Current Rating: 1A up to 600A



ATDR - Class CC

Current-Limiting Fuses

Voltage Rating: 600VAC / 300VDC

Current Rating: 0.25A up to 30A



A2D-R / A6D-R - Class RK1

Current-Limiting Fuses

Voltage Rating:

A2D-R: 600VAC / 600VDC

A6D-R: 250VAC / 250VDC

Current Rating: 0.1A up to 600A



TR-R / TRS-R - Class RK5

Current-Limiting Fuses

Voltage Rating:

TR-R: 600VAC / 600VDC

TRS-R: 250VAC / 250VAC

Current Rating: 0.1A up to 600A



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