Molded Case Circuit Breaker Application and Maintenance Guide

Revision 2

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Technical Report

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Molded Case Circuit Breaker Application and Maintenance Guide

Revision 2

1009832

Final Report, December 2004

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REPORT SUMMARY

Molded case circuit breakers (MCCBs) provide power and circuit protection in nuclear plant electrical distribution systems. Their proper operation is essential to the safe and reliable operation of such systems. This guide applies to both nuclear and non-nuclear power generating facilities and can help improve the maintenance and reliability of MCCBs.

Background

An increased awareness of MCCB performance trends, reliability, and failure effects has led to progressively more sophisticated maintenance practices within the nuclear power industry. A number of plants are establishing or modifying their maintenance programs for MCCBs. Standardized technical guidance in this area is needed.

Objective

- To provide generic and specific recommendations, conveyed clearly and with sufficient detail to allow development and implementation of a practical, cost-effective, and technically sound MCCB maintenance program

Approach

The project team developed this guide to establish a working-level understanding of hardware performance trends, reliability, and failure modes from which maintenance practices could be specified. MCCB application information was included to form, in part, the basis for certain maintenance recommendations. Current industry practices, manufacturers' recommendations, and industry standards were reviewed. The collective information was used to develop MCCB programmatic, maintenance, and test recommendations.

Results

This guide provides many recommendations applicable to MCCB maintenance, including an engineering description of MCCBs and their operation; application information related to MCCBs; an overview of reliability and failure data; program recommendations, including inspection and test periodicity; detailed inspection and test guidance: and corrective maintenance recommendations. Supplementary information includes an overview of industry standards and regulatory documents. This guide is comprehensive in nature and presents practical guidance not readily available in other industry documents.

EPRI Perspective

Circuit breaker maintenance is an ongoing responsibility for nuclear plants. Improper MCCB maintenance practices can decrease electrical system reliability and can lead to expensive problems. Excessive maintenance can expend limited plant resources without achieving commensurate reliability improvements. By understanding the basis for each possible MCCB inspection and test, a maintenance program can be established that ensures acceptable equipment performance in a cost-effective manner.

Keywords

Control equipment
Electrical equipment
Switchgear
Maintenance
Predictive maintenance
Preventive maintenance

ABSTRACT

Molded case circuit breakers (MCCBs) are used extensively at nuclear power plants. Their proper operation is essential to the safe and reliable operation of plant electrical distribution systems. The purpose of this guide is to provide specific recommendations—conveyed clearly and with sufficient detail—to allow development and implementation of a practical, cost-effective, and technically sound MCCB maintenance program. Guidance and background information contained in this report can be used by individual utilities to review their MCCB maintenance programs and improve maintenance practices as appropriate.

The guide was developed primarily for nuclear power plants; however, the underlying principles and recommended practices are applicable to any power generating facility. Additionally, the descriptive information provided in the document can serve as an excellent instructional tool for technical groups involved in the design, application, and maintenance of MCCBs.

An increased awareness of MCCB performance trends and failure effects has led to progressively more sophisticated maintenance practices within the nuclear industry. A growing need for standardized technical guidance in this area has become evident. This document is a comprehensive maintenance guide intended to provide a level of standardization not yet established for MCCB maintenance activities.

This application and maintenance guide provides an engineering description of MCCBs and their operating characteristics; MCCB application information; an overview of reliability and failure data; programmatic recommendations, including inspection and test periodicity; detailed inspection and test guidance; acceptance test guidance; and corrective maintenance recommendations. Design and application information is provided primarily to help establish the basis for the purpose and value of certain inspections and tests.

Development of this guide was approached with the intent of developing a working-level understanding of hardware performance trends, reliability, and failure modes from which to establish appropriate maintenance practices. This information was used to develop programmatic recommendations and, where appropriate, detailed inspection and test guidance. This document is presented with an emphasis on providing readers with a link between hardware performance trends and the recommended maintenance practices. This link reinforces the bases behind the recommendations.

The original version of this guide was issued in September 1991 and has been well received by the industry. Since the original publication, MCCBs have continued to have industry-wide issues develop that warrant further technical discussion. At a December 1993 NMAC conference on MCCBs, users from many plants expressed a desire for additional information, including application-related information. For these reasons, this guide has been extensively revised.

ACKNOWLEDGMENTS

Various individuals and organizations provided substantive contributions to make this report possible. EPRI would like to recognize the following for their contributions, reviews, and support of this document. The time and consideration of each are greatly appreciated. Because this is the second revision of the report, the contributors to each revision are listed in reverse chronological order.

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This document was originally published in 1991 and revised in 1996 (NP-7410-V3, Revision 1). This document, the second revision, was undertaken primarily to

- Revise Chapter 6 to better reflect current industry practices and MCCB program constraints
- Update the document to include the 2003 version of NEMA AB-4

The following provides a description of the changes since the last revision (1996 version of NP-7410-V3).

- Chapter 6, Program Development Guidelines was completely re-written. Chapter 6 now (1) discusses the apparent perspective of the regulator considering recent regulatory action and notices of violation, and (2) cites various industry documents such as NRC Notices and Bulletins (Especially IN 93-64), INPO SOER 98-02, INPO AP-913, NFPA 70-E, and EPRI's PM Basis Software maintenance frequencies.
- Several sections were added or modified in Chapter 8, Overcurrent Tests, including
  - Section 8.5, Pre-Conditioning & As-Found Testing, was modified.
  - Section 8.7, New Testing Methods (based on experience gained at Exelon and Pacific Gas and Electric), was added.
  - Section 8.8, Considerations for Applying NEMA AB-4 Test Criteria, was added based on correspondence with NEMA.
- Appendix F, NEMA Correspondence, was added.

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INTRODUCTION

Molded case circuit breakers (MCCBs) are used extensively at nuclear power plants. Their proper operation is essential to the safe and reliable operation of plant electrical distribution systems. The purpose of this guide is to provide specific recommendations—conveyed clearly and with sufficient detail—to allow development and implementation of a practical, cost-effective, and technically sound MCCB maintenance program. Detailed technical information is provided to assist the user with understanding the basis for recommendations as well as limitations associated with different test methods.

This maintenance guide provides an engineering description of MCCBs and their operating characteristics; MCCB application information; an overview of reliability and failure data; programmatic recommendations, including inspection and test periodicity; detailed inspection and test guidance; acceptance test guidance; and corrective maintenance recommendations.

Figure 1-1 displays the overall scope of this guide. As shown, the scope includes application and maintenance considerations. Application and maintenance are related; a maintenance program should verify the operability of important design and application attributes. Design and application information is provided primarily to help establish the purpose and value of certain inspections and tests.

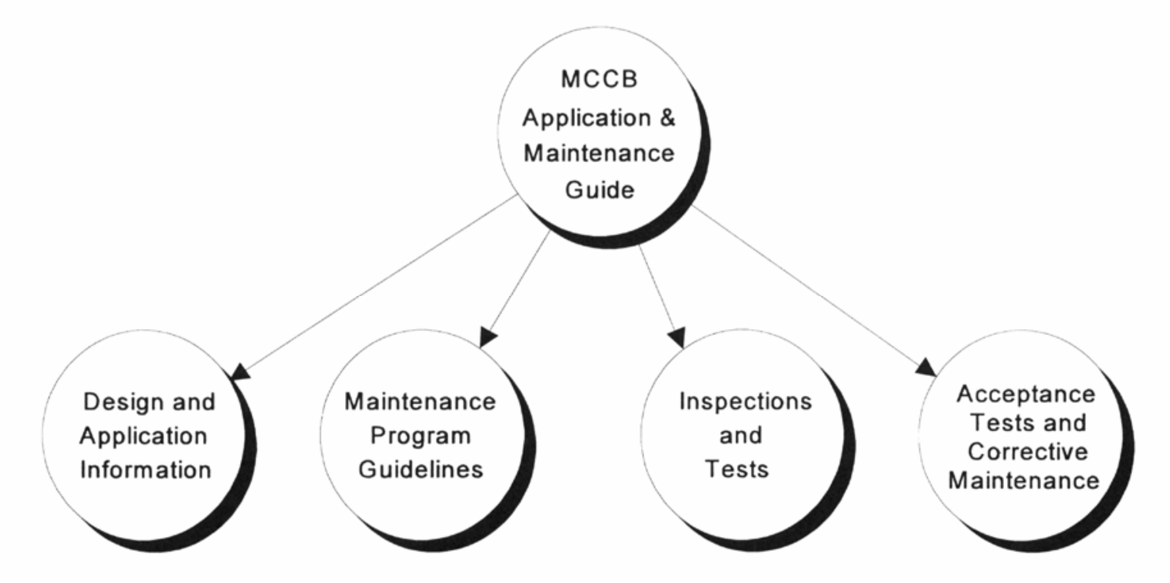


Figure 1-1
MCCB Application and Maintenance Guide Overview

Section 1 provides a road map for the guide. Section 2, “Common Questions and Answers,” addresses commonly asked questions and directs the user to the appropriate section for additional information.

The following sections provide a more detailed explanation of the scope of each functional area.

1.1 Design and Application Information

Design and application information establishes a foundation for understanding why certain inspections and tests are important. Sections 3 and 4 provide the principal design and application information (see Figure 1-2).

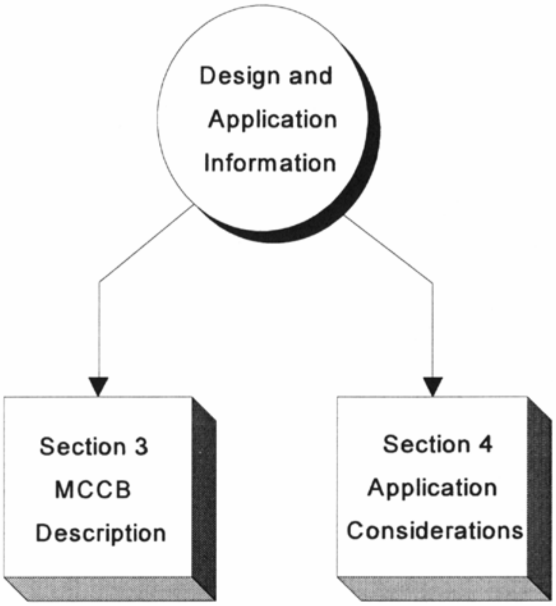


Figure 1-2
Design and Application Information

Section 3 describes MCCB design, rating, and construction. Section 4 provides a more detailed discussion regarding application issues for MCCBs. The following topics are discussed in Section 4:

- Basic requirements
- Types of protection systems
- Current-limiting characteristics of MCCBs
- Sizing MCCBs
- Cable design considerations

- Designing for motor loads
- Short circuit studies
- Interrupting rating considerations
- Selective coordination
- Comparison of DC to AC MCCB characteristics

Appendix D, "Comparison of rms AC Current to DC Current," and Appendix E, "Asymmetrical Current in an Inductive Circuit," provide background technical information for the above application topics.

1.2 Maintenance Program Guidelines

Figure 1-3 shows the sections that cover development of a maintenance program for MCCBs. Development of a maintenance program should be based, in part, on an understanding of how MCCBs age and fail in service. Section 5 presents reliability and failure information applicable to MCCBs.

Section 6 discusses basic program-related issues for MCCBs. The inspections and tests considered most useful are described. Not all MCCBs should necessarily receive the same level or frequency of inspections and tests; the maintenance routine for each MCCB should be based on its function, type, environment, and other factors. Section 6 provides information on prioritizing maintenance for MCCBs.

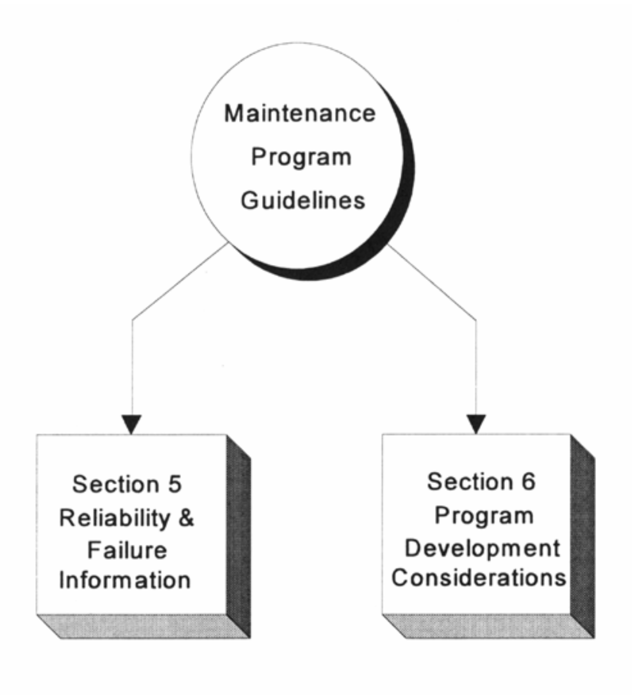


Figure 1-3

1.3 Periodic Maintenance

Periodic maintenance is described in Sections 7, 8, and 9 (see Figure 1-4). These sections provide the following detailed information:

- How to perform the inspection or test
- What the inspection or test may accomplish
- Failure mechanisms that might be detected
- Limitations of the inspection or test
- Acceptance criteria for the inspection or test
- Alternative methods

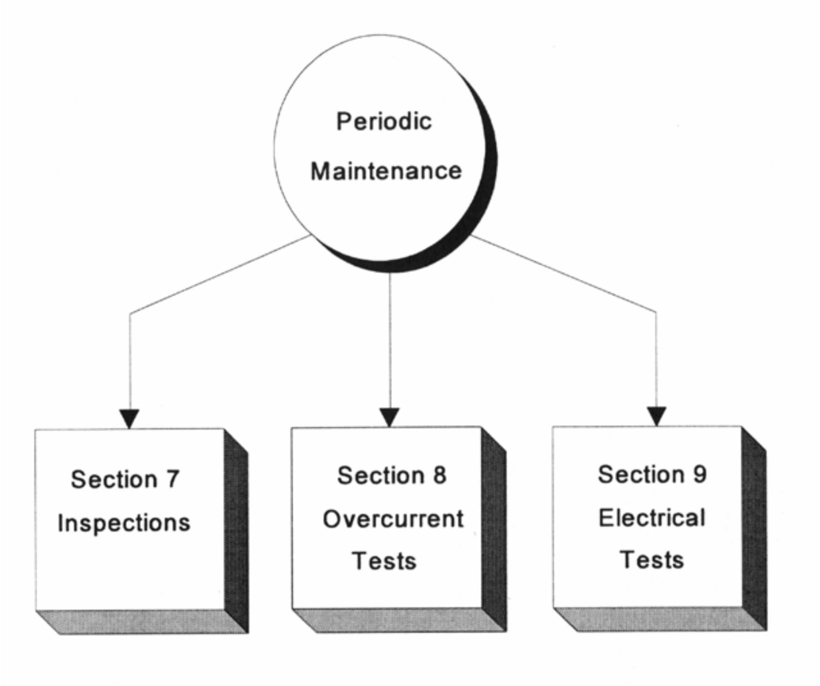


Figure 1-4
Periodic Maintenance

Section 7 describes MCCB inspections and Section 9 describes basic electrical tests. Overcurrent testing is covered in Section 8. Most MCCB test issues are related to overcurrent testing, and the following topics are discussed in detail in Section 8:

- Overcurrent test criteria as specified by NEMA AB-4
- Limitations associated with validating MCCB time-current curves by overcurrent tests
- As-found testing to determine an MCCB's ability to meet design requirements
- Testing of DC MCCBs

1.4 Non-Periodic Maintenance

Non-periodic maintenance refers to acceptance tests or corrective maintenance for MCCBs (see Figure 1-5). Acceptance tests are described in Section 10 and apply to new or replacement MCCBs. Most thermal-magnetic MCCBs used in nuclear plants are obsolete with, at best, limited support from the original manufacturer. New MCCBs often have different physical dimensions and electrical characteristics from the original breaker. For this reason, engineering evaluations are typically necessary to verify that a replacement breaker is compatible with the original installation.

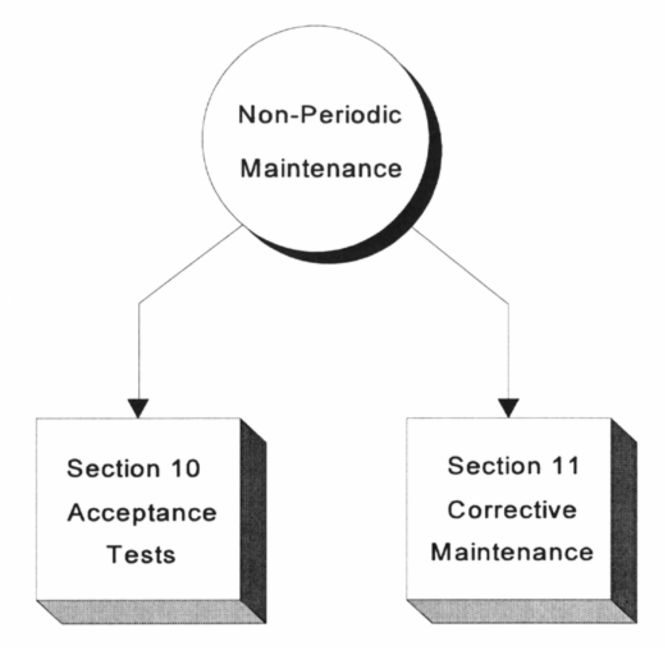


Figure 1-5
Acceptance Tests and Corrective Maintenance

Section 11 discusses corrective maintenance issues associated with MCCBs. In general, most MCCBs are not field-repairable, and damaged MCCBs require replacement. In this regard, Sections 10 and 11 are complementary and should be considered together as part of any MCCB replacement.

2

COMMON QUESTIONS AND ANSWERS

Section 2 provides a quick reference to common questions. Many of the more common MCCB maintenance issues are addressed in this section. A brief answer is provided for each question, and a reference directs the reader to the section in this report that addresses the issue in more detail.

2.1 General Questions

1. Why was NEMA AB-2 rescinded?

NEMA AB-2 (1984) was intended only as a guide for the performance of field testing. It was rescinded because some companies were using it as the basis for acceptance of rebuilt MCCBs. Rebuilt or refurbished breakers are produced outside of the normal UL-489 certification process. Because rebuilt breakers are not subjected to all UL-489 qualification tests, there is less assurance that they will perform required protective functions under all conditions specified by the manufacturer. By withdrawing AB-2, NEMA attempted to eliminate its inappropriate use as a production standard. NEMA AB-4 (1991) was subsequently issued to satisfy the industry need for field testing guidance. See Section 11.3 for more information.

2. How does NRC Bulletin 88-10 apply to a periodic maintenance program?

It does not apply to periodic maintenance. The purpose of this NRC Bulletin was to identify potentially rebuilt or refurbished breakers and establish some level of testing to accept their interim use until replacement. See Section 11.3 for more information.

3. What is the difference between an AC and a DC breaker in a test program?

There is no effective difference between AC and DC breakers with regard to most MCCB inspections and tests. However, overcurrent testing does require some evaluation because the breaker response may vary, depending on whether the test current is AC or DC. Section 4.10 explains the differences between AC and DC overcurrents, and Section 8.6 discusses test programs for DC MCCBs.

4. How many faults can a breaker interrupt?

This is a difficult question to answer without knowing the fault magnitude. Certification testing in accordance with UL-489 verifies that an MCCB can withstand two full magnitude faults. Generally, actual fault levels will be substantially less than the breaker interrupting rating. Any breaker or other protective device that has cleared a faulted circuit should be carefully inspected and confirmed to be operating properly before restoring the circuit to service.

5. Do the manufacturers recommend periodic MCCB replacement?

The manufacturer representatives from ABB, General Electric, Square D, and Westinghouse present at the December 1993 NMAC Molded Case Circuit Breaker Workshop stated that periodic replacement is not recommended. A breaker should be replaced only if a problem is encountered.

6. Should all MCCBs at a plant receive the same level of periodic inspections and tests?

No. The specified level of inspection and testing for a given breaker should be based on its classification, purpose, environment, and other factors. Refer to Section 6 for additional information.

7. Should all nuclear plants have the same requirements for periodic inspections and tests?

Not necessarily. There is not really a single program that fits all plants well. A test program that is acceptable for one nuclear plant might be either inadequate or excessive at another plant. There are several valid reasons for plant-to-plant program variations, including differences in the following:

- Number of MCCBs
- MCCB manufacturers
- Model types and number
- Technical Specification requirements
- Electric power distribution system design
- Available test equipment
- Outage frequency
- Availability of MCCBs during outages
- Regulatory commitments

Refer to Section 6 for additional information.

2.2 Overcurrent Trip Testing

2.2.1 General Issues

1. Why must test cables for overcurrent testing be approximately, but no less than, 4 feet in length and of a particular size?

The cables function as a heat sink when current flows through the breaker. A shorter cable or smaller-than-specified cable size can not dissipate as much heat, possibly causing the breaker to trip sooner than expected. Refer to Section 8.2.2 for more information.

2. How does the MCCB continuous current rating restrict the allowed conductor size?

An MCCB is certified in accordance with UL-489 including is ability to interrupt overloads and faults. The conductor size affects the MCCB's heat dissipation ability and is therefore specified by UL-489 as one parameter controlled during testing. Installing a smaller conductor in a field application means that the MCCB may not dissipate as much internal heat. Refer to Section 4.5 for additional information.

3. Why does NEMA AB-4 specify removal of the breaker from its cubicle before testing?

The NEMA A B-4 criteria are intended to standardize the overcurrent test methods so that consistent results may be obtained. Overload trip test results are sensitive to the ambient temperature variations that may exist inside an enclosure. Instantaneous trip results are sensitive to the magnetic field variations that may occur inside an enclosure. Refer to Sections 8.2.2 (overload trip test) and 8.3.3 (instantaneous trip test) for more information.

4. NEMA AB-4 specifies that the breaker should be tested at 77°F. Is there a correction factor to apply if the test is performed at a different temperature?

No. NEMA and the manufacturers have not published correction factors for test temperatures different from 77°F. MCCBs are certified for use at 77°F. One goal of overcurrent testing should be to establish temperatures as close as reasonable to 77°F without requiring extreme measures. Refer to Section 8.4.2.2 for the typical variation in trip time as a function of temperature.

5. Should the NEMA AB-4 test tolerances be used for solid-state breakers?

Although not explicitly stated in NEMA AB-4, solid-state breakers should not require the large tolerances allowed for either the overload or instantaneous trip tests. Testing in accordance with the manufacturer's curves is usually acceptable for these breakers. Consult with the manufacturer for acceptance criteria for solid-state breakers.

6. What do the tolerances in an MCCB's time-current curve mean?

Each thermal-magnetic MCCB has some variability in its response to an overcurrent condition. The tolerances shown on a typical time-current curve account for manufacturing variations and other uncertainties in the trip actuation time for a specified current and configuration. Refer to Sections 3.6 and 4.9 for additional information.

2.2.2 Instantaneous Overcurrent Trip Testing

1. How are the NEMA AB-4 test tolerances interpreted?

The lower tolerance is subtracted from the lowest value of the vertical instantaneous region shown on the breaker's time-current curve. An additional 5% is subtracted if using the pulse method of testing. The upper tolerance is added to the highest value of the vertical instantaneous region shown on the breaker's time-current curve. Section 8.3.4 provides detailed examples of how to apply the test tolerances.

2. Why are the NEMA AB-4 test tolerances so large?

The large test tolerances allow for potential test uncertainties in field testing, including differences in field test equipment and technique. Even the number of cycles used to perform the test can affect the results if near the trip point. Section 8.3 provides more information.

3. One of our breakers failed the instantaneous trip test by tripping prematurely when we tested it. When the manufacturer tested the breaker, it appeared to perform properly. Why did we get different results from the manufacturer?

Whenever comparing test results with the manufacturer or any other test authority, the test methods, setup, and equipment should also be reviewed. In one instance, an industrial facility identified breakers that tripped prematurely when subjected to a 9-cycle test current pulse. Subsequently, the manufacturer tested the same breakers and declared them satisfactory. Further discussions with the manufacturer revealed that they used only a 3-cycle current pulse. Overcurrent test results are prone to variability, depending on many factors. Refer to Section 8.3 for further information.

2.2.3 Overload Trip Testing

1. Why is the test normally performed at 300% of the breaker rating?

The rescinded NEMA AB-2 (1984) provides the best rationale for an overload test current of 300%:

> When testing circuit breaker tripping characteristics, it is recommended that the overcurrent tests be performed on individual poles at 300% of rated current. The response of the circuit breaker to this overload will be indicative of its response throughout its entire overcurrent tripping range. This load has been chosen as the test point because it is relatively easy to obtain the required current in the field and the wattage per pole from line to load is low enough so that transfer of heat into the nonactive pole spaces is minor and does not affect the test results appreciably.

Manufacturers' literature confirms the above rationale. Section 8.2 provides additional information.

2. NEMA AB-4 establishes the maximum acceptable time to trip at 300% of rated current. Why is a minimum acceptable time not specified?

The purpose of NEMA AB-4 is not to confirm that a breaker meets its published time-current curves. Rather, the purpose of the testing specified by NEMA AB-4 is to determine if the breaker will provide its intended protection—the protection of that part of the electrical circuit in which it is applied. A breaker that trips in less than the minimum time shown by the time-current curves will furnish protection at a lower current level. Unless this results in nuisance tripping, this condition is considered acceptable by NEMA. See Section 8.4 for more information regarding testing to verify performance in accordance with the manufacturer's time-current curves.

2.3 Electrical Tests

1. When should the rated hold test be performed as a field test?

The rated hold test is recommended only if nuisance tripping has occurred. Depending on the breaker size, this test may take anywhere from 1 to several hours to complete. When the time to perform other inspections and tests is considered, a single MCCB may take an entire day to test if the rated hold test is included. Refer to Section 9.3 for additional information.

2. What are the acceptance criteria for the insulated pole resistance test?

NEMA AB-4 does not provide specific acceptance criteria for this test. It states that the results can vary significantly due to inherent variability in the extremely low resistance of the electrical contacts and connectors. Such variations do not necessarily predict unacceptable performance and should not be used as the sole criteria for determination of acceptability. Some manufacturers and other industry documents recommend investigating a variation exceeding 50% from other readings. Refer to Section 9.2 for additional information.

3

MOLDED CASE CIRCUIT BREAKER DESCRIPTION

A molded case circuit breaker (MCCB) is a low-voltage circuit breaker assembled as an integral unit in an enclosing housing of molded insulating material. It is designed to open and close by nonautomatic means and to open a circuit automatically on a predetermined overcurrent, without damage to itself, when applied properly within its rating.

MCCBs are one of the most widely used protective devices for electrical circuits. Often, they are in service for years and rarely, if ever, are called upon to perform a protective function. Yet, when needed, they must rapidly isolate a faulted or overloaded circuit to prevent or minimize equipment damage. A circuit breaker cannot prevent damage to faulted equipment in all cases but can always attempt to minimize damage by removing the fault as quickly as possible.

MCCBs can provide overload protection for conductors as well as short-circuit protection for motors, control equipment, and heating and lighting circuits. These breakers combine the convenience of an on-off switch for circuit isolation with protective elements for circuit protection.

3.1 Breaker Components

Figure 3-1 shows typical MCCBs.

Figure 3-1
Typical Molded Case Circuit Breakers
(Courtesy Square D Company)

The primary components in an MCCB are as follows:

- Molded case
- Operating mechanism
- Contact assemblies
- Arc extinguishers
- Trip device
- Overcurrent trip unit(s)

Figure 3-2 provides a cutaway view of major components. Sections 3.1.1 through 3.1.4 discuss these components in more detail.

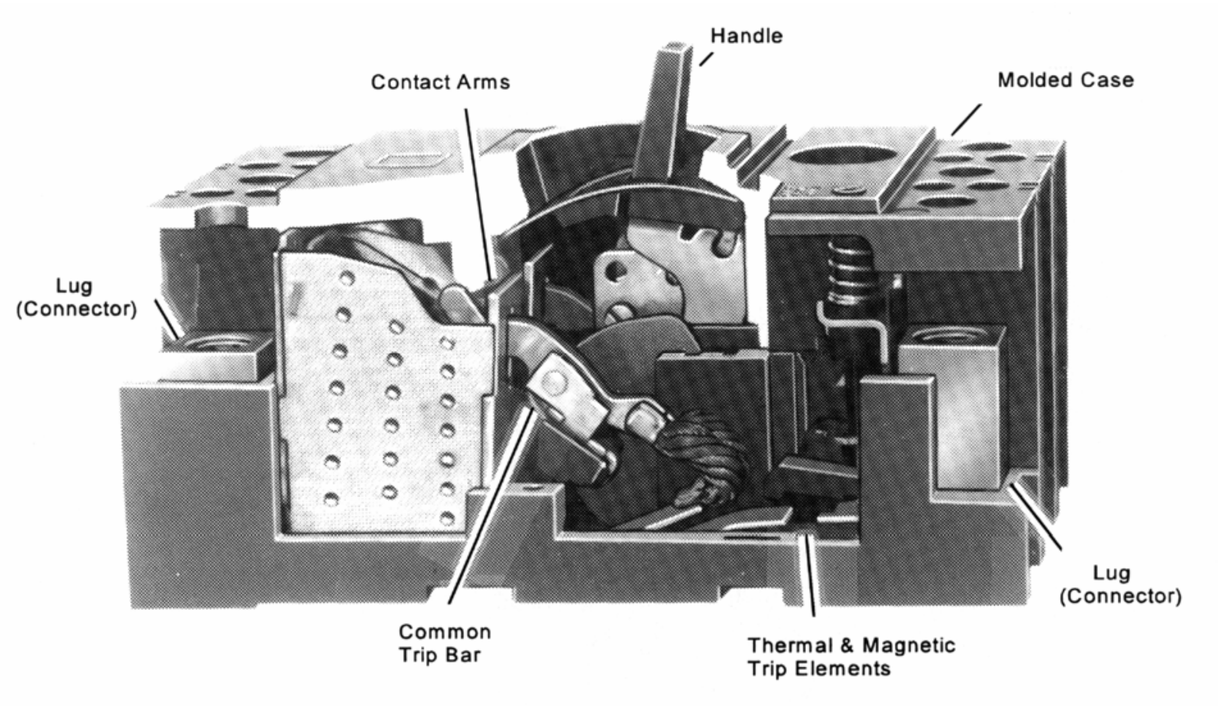


Figure 3-2
Cutaway View of a Molded Case Circuit Breaker
(Courtesy Square D Company)

3.1.1 Molded Case

The molded case is an insulated housing that structurally supports the circuit breaker internal components. The molded case also plays a key role in ensuring that the breaker can withstand and interrupt an electrical fault. The case is usually molded from a plastic characterized by structural ruggedness and high dielectric strength. The case must be strong enough to withstand mechanical forces caused by fault currents, thermal stresses produced during normal operation and fault current interruption, and internal pressure caused by gases produced during arcing.

3.1.2 Operating Mechanism

The breaker operating mechanism is used to manually open and close the breaker contacts. During closing, the operating mechanism also charges a spring that later provides the necessary force for quick opening, initiated either manually or by an automatic trip unit. If equipped with a mid-point trip, the breaker handle position indicates the contact status: closed, open, or tripped. The breaker is in the tripped condition when the handle is approximately midway between ON and OFF.

MCCBs are designed with a trip-free feature for the operating mechanism. This design allows the internal trip unit to open the breaker contacts even if the breaker handle is held in the ON position. A trip-free design ensures that a faulted condition will open the breaker even if an operator is attempting to manually close the breaker.

Some MCCBs include a push-to-trip mechanism (or similar device) that provides a manual means of tripping the circuit breaker. When the push-to-trip button is pressed, a plunger rotates the trip bar, causing the breaker to trip.

3.1.3 Breaker Contacts

The breaker contacts physically make or break the circuit. They allow current flow during normal operation and provide current interruption under fault or overload conditions. The contacts must withstand electrical arcs created during breaker opening and closing operations.

The contacts are usually designed for a quick make or break during closing and opening operations. Typically, the contacts have a toggle mechanism that is actuated independent of the operating mechanism or the trip unit. By this design, the speed at which the breaker handle is operated does not affect the speed at which the contacts open or close. Figure 3-3 shows a typical contact assembly. Each moving contact arm is rigidly connected to a single crossbar member. Manual and automatic breaker operations cause rotation of the crossbar, either opening or closing the breaker.

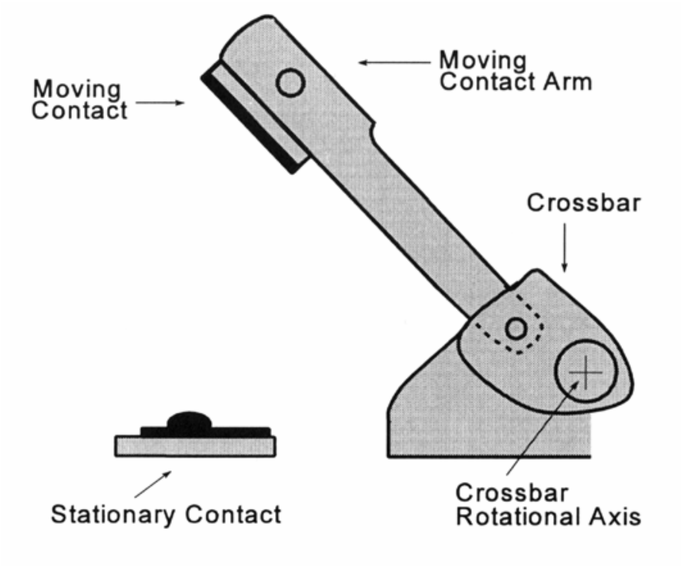


Figure 3-3
Typical Contact Assembly

Contacts are a critical component in the breaker design. When closed, they must have a low resistance so that current is conducted without overheating or excessive voltage drop. When the contacts are opened under normal load, overload, or short-circuit conditions, an arc forms; the contacts must withstand this arc. The ideal contact has a low resistance when closed, high immunity to damage by arcs, and high structural strength to withstand the mechanical impact of closing. A substantial portion of the breaker design is intended to protect the contacts from erosion due to arcing or damage due to mechanical operation.

Figure 3-4 shows the current flow path through a typical breaker. When the breaker contacts are closed, the current flows from the line terminal, through the closed contact assembly, through the thermal and magnetic trip elements, to the load terminal.

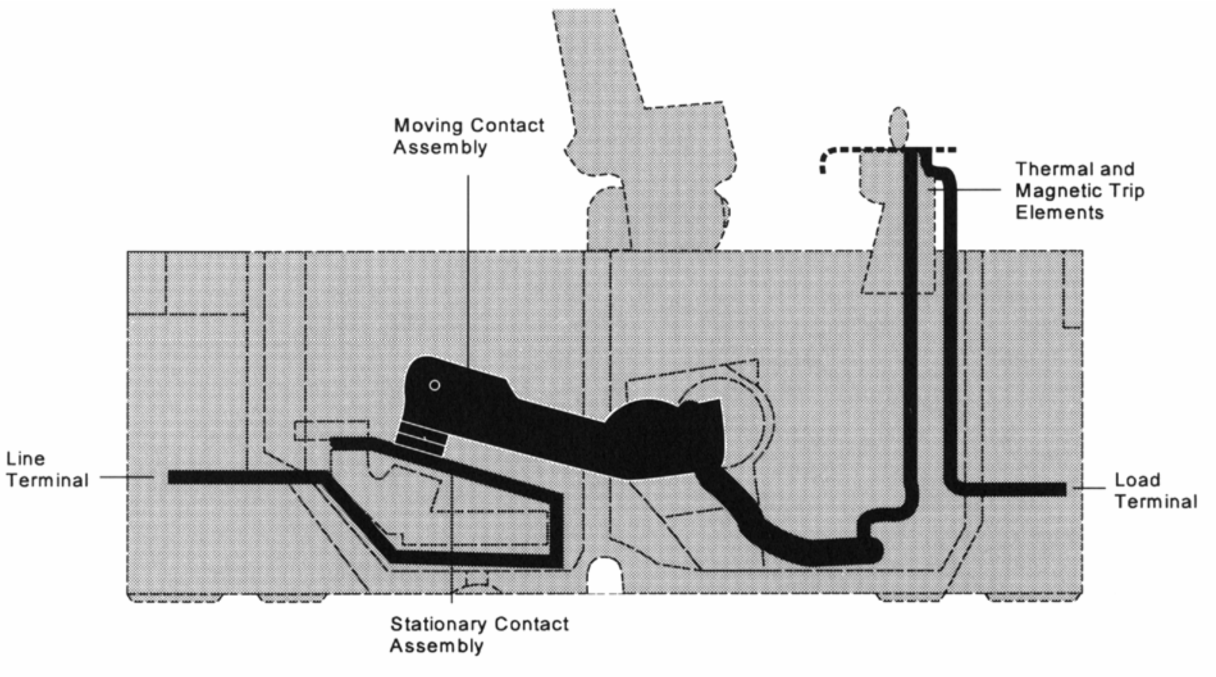


Figure 3-4
Circuit Breaker Current Flow Path

3.1.4 Arc Extinguishers

The arc generated when the breaker is opened under a load or overcurrent condition can damage the contacts. Also, the arc generates a high temperature and pressure within the confined interior of the MCCB. The arc interruption method is an important part of an MCCB design.

Arc extinguishers are designed to channel the arc away from the mating surface of the contacts and into the arc chute, where it can be extinguished safely with minimal contact damage. Figure 3-5 shows a typical arc extinguisher.

The arc chute consists of closely spaced steel plates that cause the arc to cool and dissipate. When the breaker contacts first open, the air space between the contacts ionizes, allowing current (the arc) to continue flowing. The current flow produces a magnetic field around the arc and the arc extinguishers. This magnetic field produces a force perpendicular to the flow of current which forces the arc into the steel plates. The arc extinguishers divide and cool the arc and allow the gas to deionize.

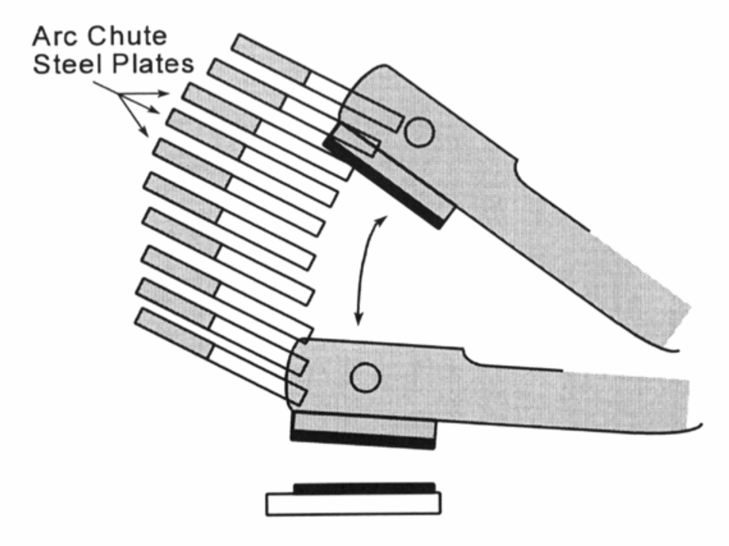


Figure 3-5
Arc Extinguisher

3.2 Overcurrent Trip Units

Overcurrent trip units are intended to sense abnormally high current and initiate a trip to protect electrical systems from damage. Overcurrent trip units may be used in MCCBs to protect against the following conditions:

- Circuit overloads in which the circuit components are exposed to electrical current in excess of the intended design
- Component short circuits that result in high current flow
- Ground faults

Overcurrent trip units open the breaker when current exceeds a preset value for a specified time. This time-current relationship is fundamental to an understanding of how an MCCB protects a circuit and is explained in more detail in the following sections.

Magnetic, thermal, and solid-state trip units may be utilized to sense and actuate the breaker trip mechanism within a predetermined time for a given level of current. Thermal and magnetic trip units are normally used together to provide overload and short-circuit protection. Solid-state trip units provide adjustable protection tailored for overloads and short circuits in specific applications.

3.2.1 Instantaneous (Magnetic) Trip Units

Magnetic trip units protect against short circuits. They are often called *instantaneous trip units* since they are actuated without any intentional time delay. A magnetic trip unit consists of an electromagnet constructed with an armature (movable iron slug) that acts on the breaker trip bar (see Figure 3-6). Line current passing through the electromagnet results in an attractive magnetic force on the magnet armature. When a short circuit occurs, the magnetic force attracts the armature. As the armature is drawn toward the electromagnet, it rotates the trip bar and disengages the latch, allowing the moving contact assembly to rotate under spring force. This tripping action has no intentional built-in time delay; trip actuation is a function of line current only. For any current below the instantaneous set point, the instantaneous trip unit should not actuate (see Figure 3-7).

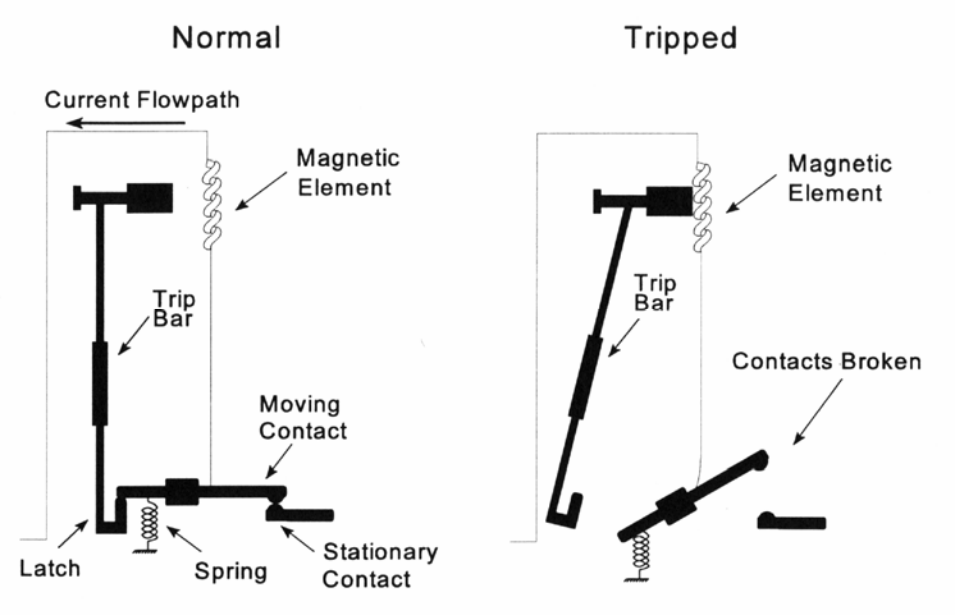


Figure 3-6
Magnetic Trip Unit

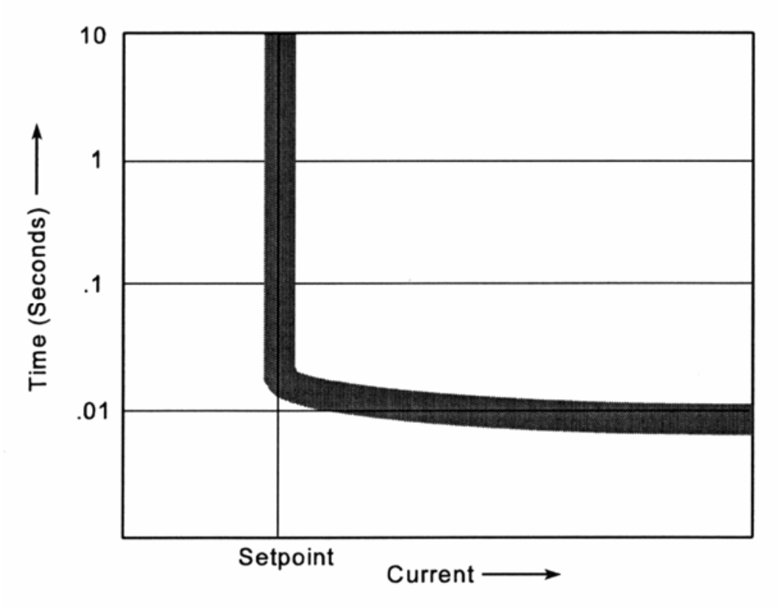


Figure 3-7
Overcurrent Response of Magnetic Trip Unit

An instantaneous trip design is desirable for the following reasons:

- An instantaneous magnetic trip minimizes the duration of a short circuit and therefore provides maximum protection to the breaker and to the upstream and downstream circuit conductors and equipment.
- An instantaneous magnetic trip minimizes damage at the fault location since power is removed as soon as possible.
- An instantaneous trip minimizes the disruption to portions of the electrical system not otherwise affected by the fault.

Magnetic trip units may be either adjustable or nonadjustable. Although MCCBs are available with adjustable magnetic trip units below 150 amperes, most MCCBs rated below 150 amperes generally have nonadjustable magnetic trip units. Breakers rated 225 amperes and above typically have adjustable magnetic trip units. If an adjustment is possible, the magnetic pickup setting is usually adjusted by a linkage that varies the spring tension on the magnet armature or by varying the air gap between the coil and the armature.

MCCBs containing only an instantaneous trip unit are sometimes used in conjunction with thermal overload units for motor circuit protection. This type of MCCB is often referred to as a *motor circuit protector* (MCP).

3.2.2 Time Delay Trip Units

Time delay trip units protect against sustained overloads. The time delay trip function is normally achieved by thermal trip units or, in some MCCB designs, by magnetic trip units. A thermal trip unit is usually a bimetal element consisting of two bonded strips of metal having different rates of thermal expansion (see Figure 3-8). Line current passing through the bimetal element, which is often part of the current carrying path, causes the element to heat and deflect. If the bimetal element deflects sufficiently, it applies sufficient force on the trip bar to disengage the latch, allowing the moving contact assembly to rotate open under spring force.

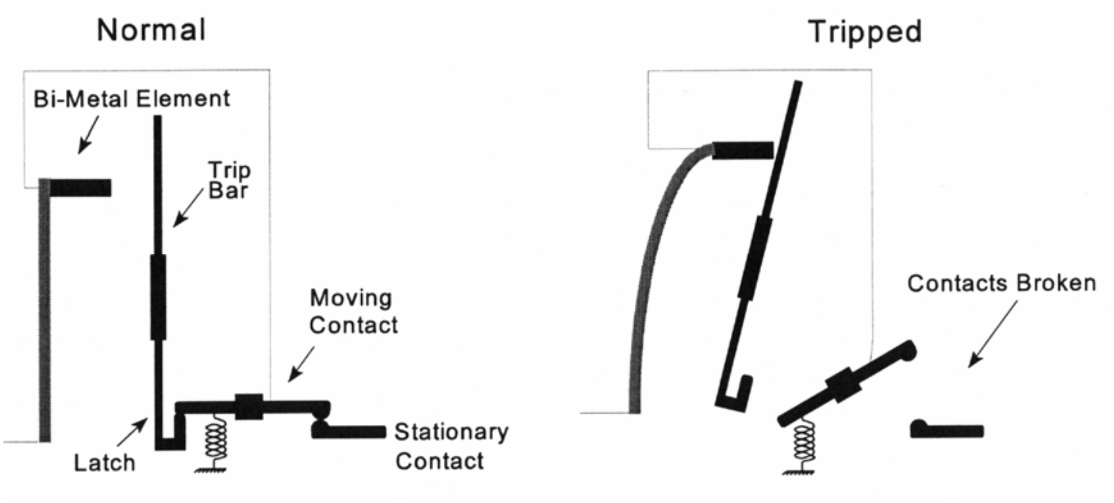


Figure 3-8
Thermal Trip Unit

The time needed for the bimetal to deflect and trip the circuit breaker varies inversely with the current. This inverse-time delay response typically starts at about 125% of rated current and governs the breaker opening time up to the instantaneous trip region. A long time delay is allowed before tripping when a light overload occurs, and a quicker response occurs for heavy overloads. Figure 3-9 shows the expected response of a typical thermal trip unit.

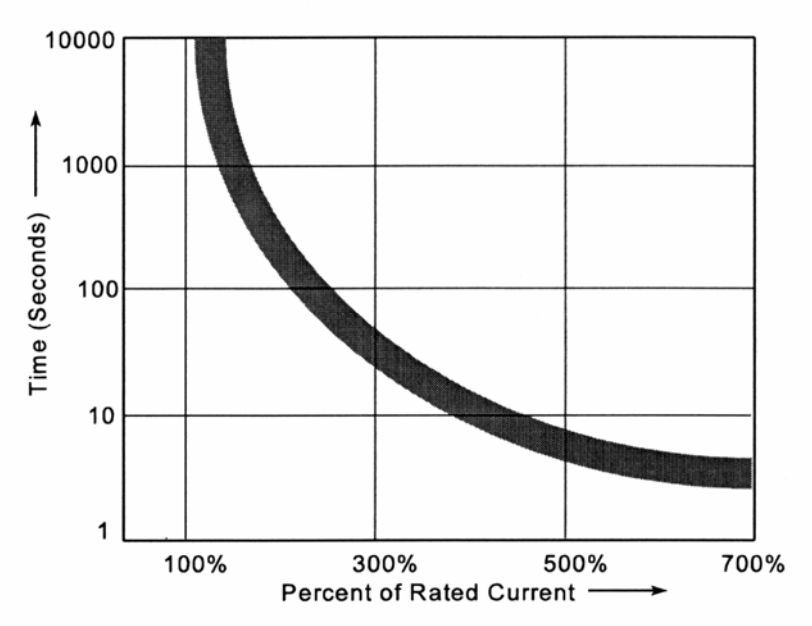


Figure 3-9
Overcurrent Response of Thermal Trip Unit

The inverse-time tripping characteristic of time delay trip units offers the following advantages:

- Under moderate overload conditions, the thermal trip unit allows sufficient time delay to preclude unnecessary trips caused by anticipated transients, such as motor starting and transformer inrush.
- When exposed to severe overloads, the thermal trip unit causes the breaker to trip quickly, so there is adequate protection for the circuit conductors and insulation.

For many MCCBs, thermal trip units are calibrated by the manufacturer and are not adjustable. In some newer breakers, the time-current response is adjustable.

Some fully magnetic breakers are also capable of providing a time delay trip function. Magnetic forces generated in the breaker's coil are concentrated in a movable iron core. In response to overcurrent, the core is drawn closer to the trip mechanism armature until the magnetic force on the armature trips the breaker. The trip time delay is obtained by use of a damping fluid which slows movement in the iron core.

3.2.3 Thermal-Magnetic Trip Units

Thermal-magnetic MCCBs utilize a combination of a magnetic trip unit and a thermal trip unit. A thermal-magnetic configuration is well suited for the majority of general purpose circuit breaker applications.

The combined tripping features of the magnetic and thermal trip units provide:

- Instant tripping action for short circuits
- Discrimination against undesired trips during momentary overloads resulting from normal system operation, such as high starting currents in motors or initial surge currents in lighting circuits
- Protection against abnormal overload conditions

Figure 3-10 shows a typical response of a thermal-magnetic MCCB to overcurrent.

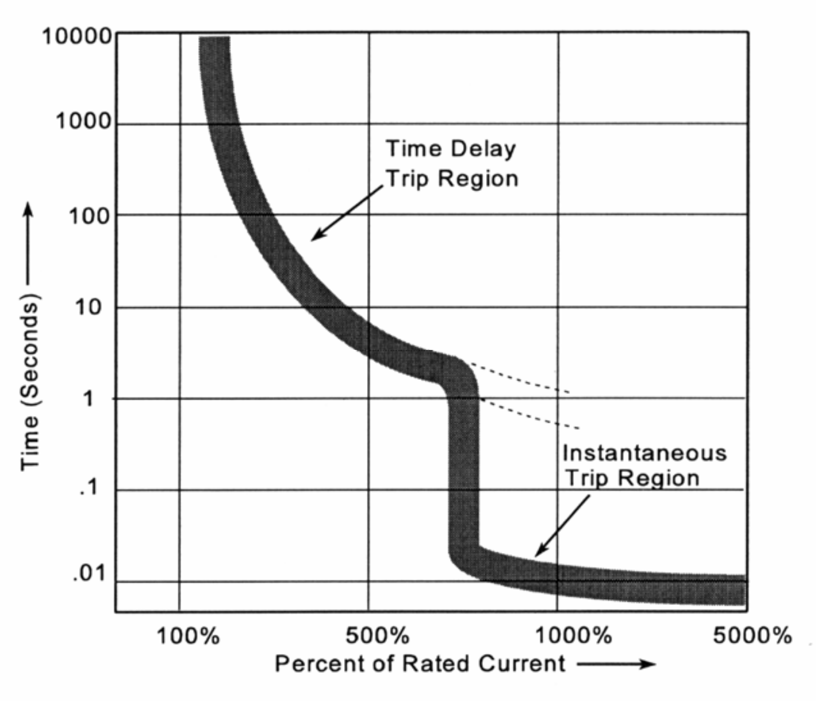


Figure 3-10
Overcurrent Response of Thermal-Magnetic Trip Unit

Note in the above figure that the thermal trip characteristics actually extend into the instantaneous region. However, the instantaneous trip is much faster and its characteristics define the expected trip response time in this region.

3.2.4 Electronic (Solid-State) Trip Units

Solid-state trip units can provide both short-circuit and overload protection. They are adjustable, often over a wide range, so their time-current relationships can be customized for specific applications. The breaker tripping characteristics are adjustable over the entire range of operation; the following adjustments are possible for a typical solid-state trip unit:

- Long time pickup
- Long time delay
- Short time pickup
- Short time delay
- Instantaneous pickup
- Ground fault pickup
- Ground fault time delay

Current transformers are typically used in each pole of the breaker to sense line current. The solid-state circuit in the trip unit monitors the current from the output of the current transformers. When predetermined levels of time and current are reached, the solid-state trip unit sends a signal to an internal tripping solenoid that trips the breaker. Solid-state trip units have a good reputation for accurate and reliable operation. Their overall performance appears to surpass that of thermal-magnetic breakers with regard to accurate and repeatable tripping characteristics. Solid-state trip units are not used for DC applications because the current sensing element can not measure DC current.

Solid-state trip units can also be used for ground fault protection. Thermal-magnetic trip units usually cannot provide ground fault protection without shunt trip devices that are actuated by a separate ground fault protection system.

3.3 Shunt Trip Units

Shunt trip units are accessory devices used to trip an MCCB under conditions other than an overcurrent condition as described previously. They are often used on thermal-magnetic MCCBs to meet ground fault protection requirements.

The shunt trip mechanism typically utilizes a solenoid that is energized by a separate power source in response to a trip signal. The solenoid circuit is closed by an external switch or relay. Shunt trip solenoid coils are usually not rated for continuous current and include a clearing switch to break the solenoid circuit when the MCCB opens.

Nuclear plants require that selected equipment be de-energized upon receipt of certain protective signals, such as safety injection signals. Shunt trip units are used in this situation to open the breaker even though no fault is present. Once the signal is cleared, the breaker may be closed and power restored to the load.

3.4 Breaker Size Ratings

MCCBs are classified by frame size, ampere rating, and interrupting rating. The frame size, expressed in amperes, represents the largest ampere rating available for that particular frame size. Available frame sizes vary among manufacturers.

The ampere rating is the largest current that the breaker is designed to continuously carry without either tripping or exceeding the permissible temperature rise. This rating is usually specified at a temperature of 40°C (104°F). Table 3-1 shows sample standard frame sizes and typical continuous ampere ratings for MCCBs used in distribution circuits. Manufacturers can provide sizes larger than those shown in Table 3-1 for special applications.

Table 3-1
Typical Frame Sizes and Continuous Ampere Ratings

	Frame Size, amperes					
Rating, amperes	**100**	**250**	**400**	**600**	**800**	**1200**
	15	70	100	150	300	600
	20	80	110	175	350	700
	25	90	125	200	400	800
	30	100	150	225	`450	1000
	35	110	175	250	500	1200
	40	125	200	300	600	
	45	150	225	350	700	
	50	175	250	400	800	
	60	200	300	450		
	70	225	350	500		
	80	250	400	600		
	90					
	100					

MCCBs are typically applied in the following voltage ratings:

AC: 120, 120/240, 240, 277, 480Y/277, 480, 600Y/346, and 600 volts
DC: 125, 125/250, 250, 500, and 600 volts

Molded Case Circuit Breaker Description

MCCBs may be used in AC or DC electrical systems to the extent allowed by each manufacturer. The AC breakers are normally rated for 50/60-Hz systems. The manufacturer should be consulted for applications involving frequencies above 60 Hz. Higher frequencies affect the thermal performance, magnetic response, and interrupting rating.

MCCBs are available in one-, two-, and three-pole versions. The number of poles refers to the number of breaker current carrying paths. Figure 3-11 shows how different pole breakers are typically applied. A single-pole breaker is most often used in a low-voltage, single-phase, grounded system. Two-pole breakers are used in ungrounded DC systems and some single-phase applications. Loads requiring three-phase power use three pole breakers.

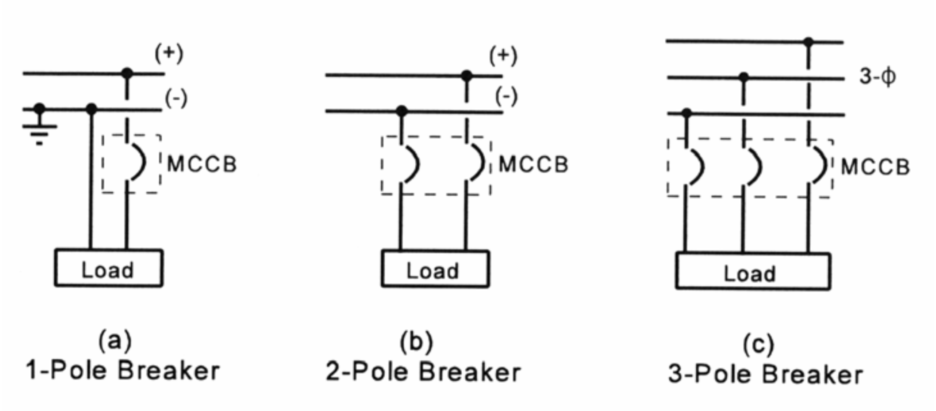


Figure 3-11
MCCB Configurations

MCCB ratings are usually annotated on single-line drawings as shown in Figure 3-12.

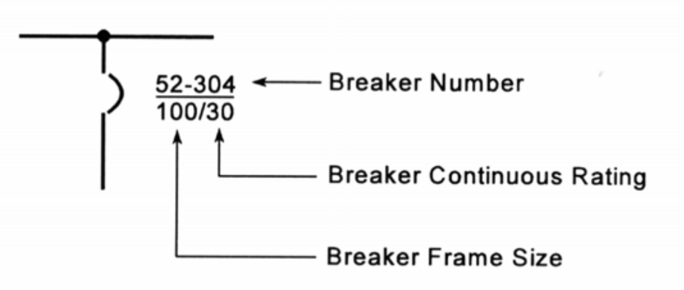


Figure 3-12
MCCB One-Line Designation

MCCBs for DC applications are often identical in design to standard AC breakers. Breakers designed for AC applications, but used in DC systems, may have a higher continuous current capability because of the absence of skin effect, hysteresis, and eddy currents. However, for convenience, the manufacturer may provide the same current rating for both applications.

3.5 Breaker Interrupting Rating

The interrupting rating of a breaker is the maximum root-mean-square (rms) value of current at maximum voltage and frequency that the breaker can safely interrupt.

Short-circuit current causes high mechanical forces within the breaker. These forces are proportional to the square of the current and place a large strain on the breaker components. If the short-circuit current is greater than the interrupting rating of the breaker, these mechanical forces can cause violent destruction of the breaker, including an explosion and fire.

For assured safe operation, the breaker interrupting rating must exceed the available short-circuit current for the application. The ability of MCCBs to withstand and interrupt short-circuit currents has continuously improved. Typical interrupting ratings, expressed in rms symmetrical amperes, are shown in Table 3-2.

Table 3-2
Typical Interrupting Ratings

AC Symmetrical Amps		DC Amps
5,000	45,000	5,000
7,500	50,000	10,00
14,000	65,000	20,000
18,000	70,000	
20,000	85,000	
22,000	100,000	
25,000	125,000	
30,000	150,000	
35,000	200,000	
42,000		

An MCCB's interrupting rating is directly dependent on the voltage rating. The interrupting rating always decreases as the voltage increases.

The maximum current that a DC breaker can interrupt and the maximum voltage that can be applied will be less than for an equivalent design AC breaker because of the nature of DC current. Interruption of DC current is distinctly different and is usually more difficult to accomplish than interruption of AC current at comparable voltages and currents. An AC current interrupter does not have to develop a large voltage drop across the fault current arc between the breaker contacts because the sinusoidal current passes through zero during each half cycle, causing the arc to extinguish naturally. DC current does not pass through a current zero. For this reason, a DC current interrupter must develop an arc voltage drop greater than the applied circuit voltage to force the fault current to zero across the contacts. As a result, the DC breaker must absorb considerably more energy during the fault clearing process than an equivalent AC breaker; a given breaker contact and arc chute design will have a lower DC (compared to AC) voltage and current interrupting rating. For example, a breaker rated for 65,000 rms symmetrical amperes at 480 VAC may be rated only for 10,000 amperes at 250 VDC.

The interrupting rating of a DC breaker requires close review as part of an installation. Multiple breaker poles may have to be wired in series to obtain the specified interrupting rating. Wiring poles in series allows multiple contacts to open in response to an overcurrent condition. The manufacturer should be consulted for specific installation methods that may be necessary to achieve the desired interrupting rating.

Additional factors that can affect an MCCB's interrupting rating are discussed in Section 4.8.

3.6 Time-Current Tripping Curves

Circuit breaker protective devices are often selectively coordinated so that the breaker closest to an overload or fault opens first and the balance of the distribution system is left intact and operational. Time-current curves define an operating region beyond which the overcurrent trip unit is actuated automatically to open the circuit breaker. Examples of how to interpret time-current curves are provided in Section 4.9. Time-current curves are generally divided into categories defined by the type of trip unit(s) used in the circuit breaker and the type of adjustments available. Examples are:

- Nonadjustable overcurrent trip unit
- Fixed time delay trip unit
- Fixed instantaneous trip unit
- Partially adjustable trip unit
- Fixed time delay trip unit
- Adjustable instantaneous trip unit
- Fully adjustable trip unit
- Solid-state trip unit
- Adjustable thermal-magnetic trip unit

3.6.1 Nonadjustable Overcurrent Trip Unit Time-Current Curves

Although MCCBs are available with adjustable magnetic trip units below 150 amperes, most MCCBs rated below 150 amperes generally have nonadjustable magnetic trip units. Figure 3-13 shows a typical time-current curve for a nonadjustable overcurrent trip unit. The thermal trip unit provides protection in the long time portion of the curve. The curve is drawn with the long time curve extending into the instantaneous protection region provided by the magnetic trip unit. In the instantaneous region, no intentional time delay occurs. A tolerance is provided to account for uncertainty in the actual trip values, as shown by the shaded area of the curve in Figure 3-13.

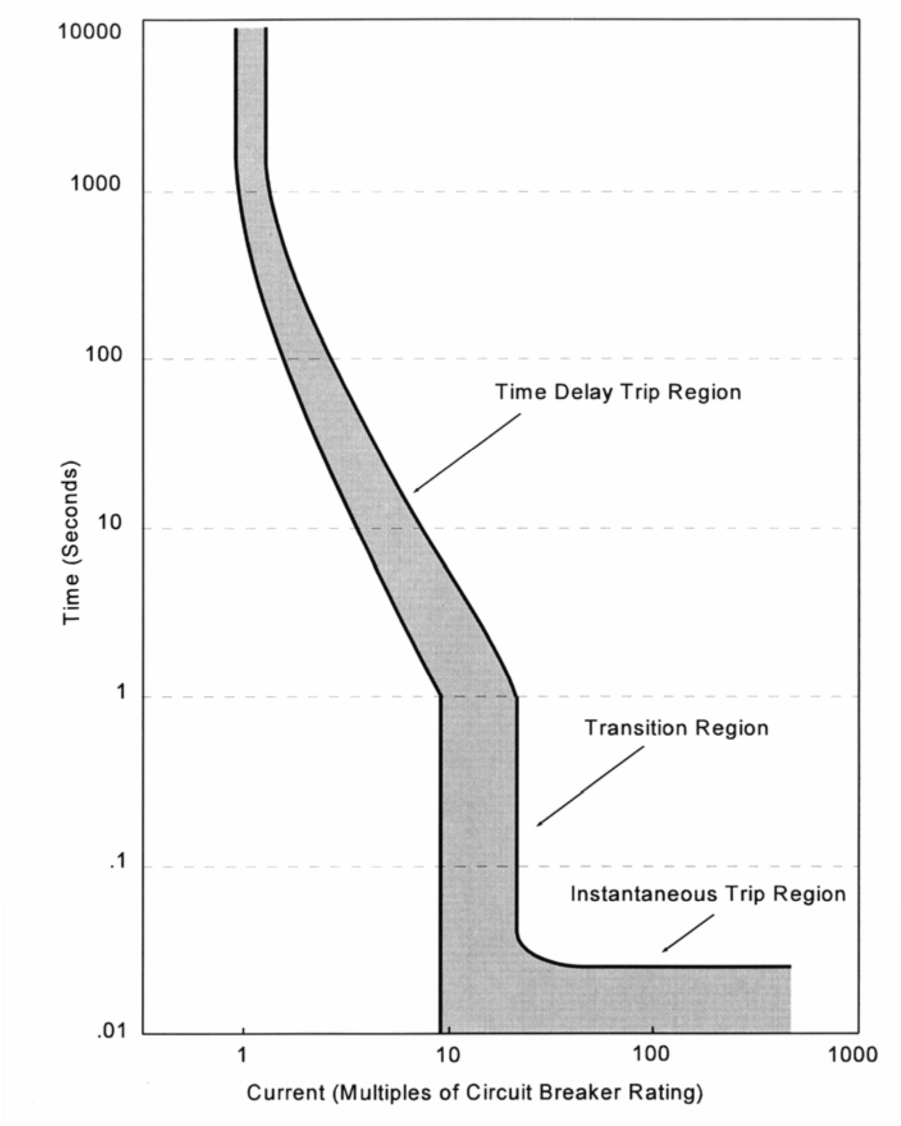


Figure 3-13
Typical Time-Current Curve for a Nonadjustable Overcurrent Trip Unit

The instantaneous trip function shown on time-current curves starts with the vertical band that intersects the time delay region. Trip times inside this vertical portion of the time-current curves are not precisely defined because this region defines the transition from thermal tripping to magnetic tripping. This transition region represents the setpoint tolerance of the magnetic trip unit. Depending on the exact trip point of the instantaneous unit, tripping within this transition region can be thermal, with a short time delay, or magnetic, with no intentional delay. Beyond the transition region is the instantaneous region. In this region, the magnetic trip unit alone should cause the breaker to trip.

3.6.2 Partially Adjustable Overcurrent Trip Unit Time-Current Curves

MCCBs rated 225 amperes and above generally have fixed long time overcurrent trip units and adjustable instantaneous settings. The time-current curve is the same as for the nonadjustable overcurrent trip unit in the long time region, but the instantaneous setting is adjustable over a range as shown in Figure 3-14.

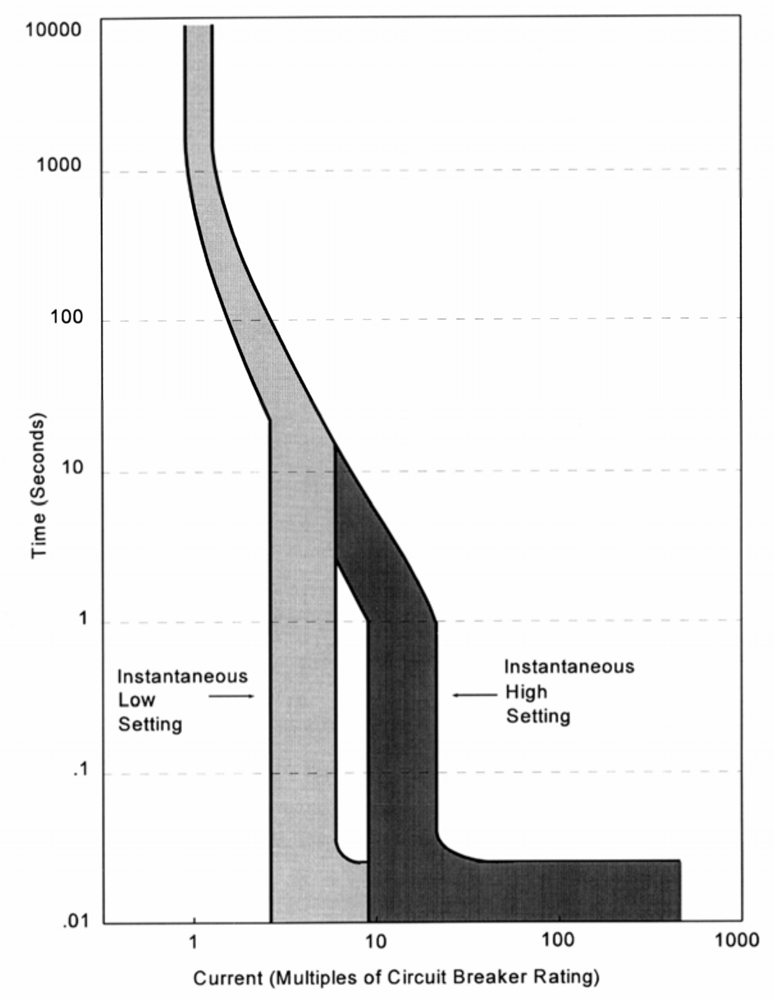


Figure 3-14
Typical Time-Current Curve for a Partially Adjustable Overcurrent Trip Unit

3.6.3 Fully Adjustable Overcurrent Trip Unit Time-Current Curves

Solid-state trip units allow custom setting of MCCB overcurrent protection characteristics. As shown in Figure 3-15, the trip characteristics are adjustable over the entire region of the time-current curve. The following trip characteristics may be adjustable:

- Long time pickup point
- Long time delay
- Short time pickup point
- Short time delay
- Instantaneous pickup

Adjusting the short time characteristics can provide selective coordination between MCCBs. The short time settings provide for a small time delay at higher current levels before allowing the instantaneous trip to actuate. Refer to Section 4.9 for more information regarding selective coordination. Ground fault protection can also be provided by a fully adjustable breaker. Both the pickup point and the time delay can be varied to suit the application as shown on Figure 3-16.

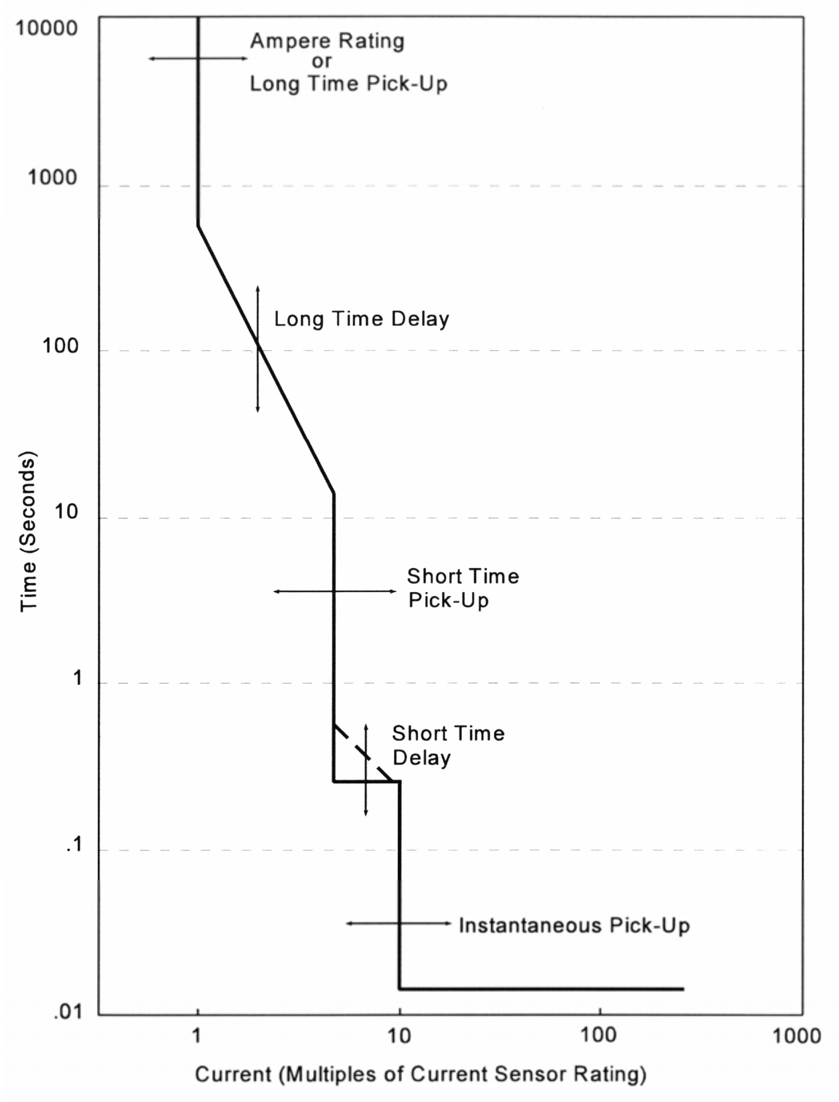


Figure 3-15
Typical Time-Current Curve for a Fully Adjustable Solid-State Overcurrent Trip Unit

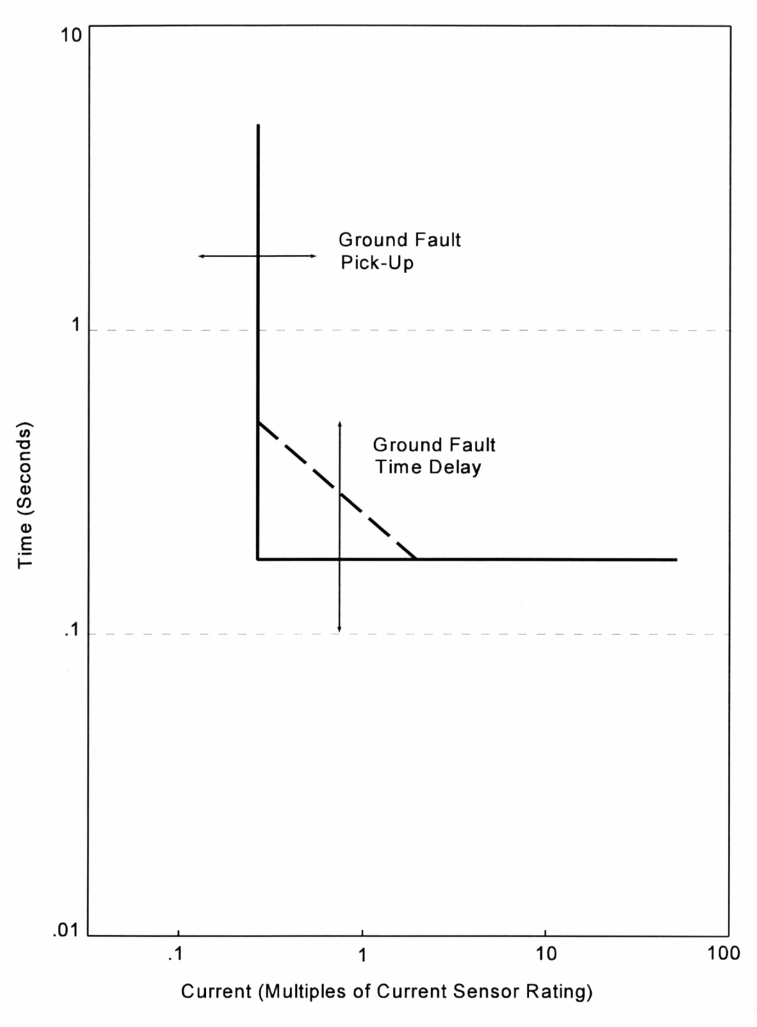


Figure 3-16
Typical Time-Current Curve for Adjustable Ground Fault Pickup and Delay Settings

3.6.4 Development of Time-Current Curves by the Manufacturer

Time-current curves are developed by the manufacturer to describe the expected response of an MCCB throughout its allowed range of operation. The time-current characteristics of thermal-magnetic MCCBs depend on the design and manufacturing variability of the thermal and magnetic trip units. For a given thermal-magnetic MCCB, its response to overcurrent has only limited adjustment capability. Note that this is significantly different than solid-state MCCBs in which the response is typically adjustable throughout its range of operation. For this reason, this section applies mainly to thermal-magnetic MCCBs.

MCCBs are certified in accordance with UL-489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures.* The performance tests specified by UL-489 confirm a breaker's ability to protect properly sized downstream conductors and withstand rated short circuits. However, it is interesting to note that verification of the time-current curves is not a direct part of this qualification process. Instead, manufacturers determine the time-current characteristics of their breakers by in-house testing. The time-current characteristics of each breaker style and size is typically confirmed by a series of overcurrent tests. Each test has a trip time recorded for the applied current. For example, the results for a sequence of tests in the thermal region may appear as shown in Figure 3-17.

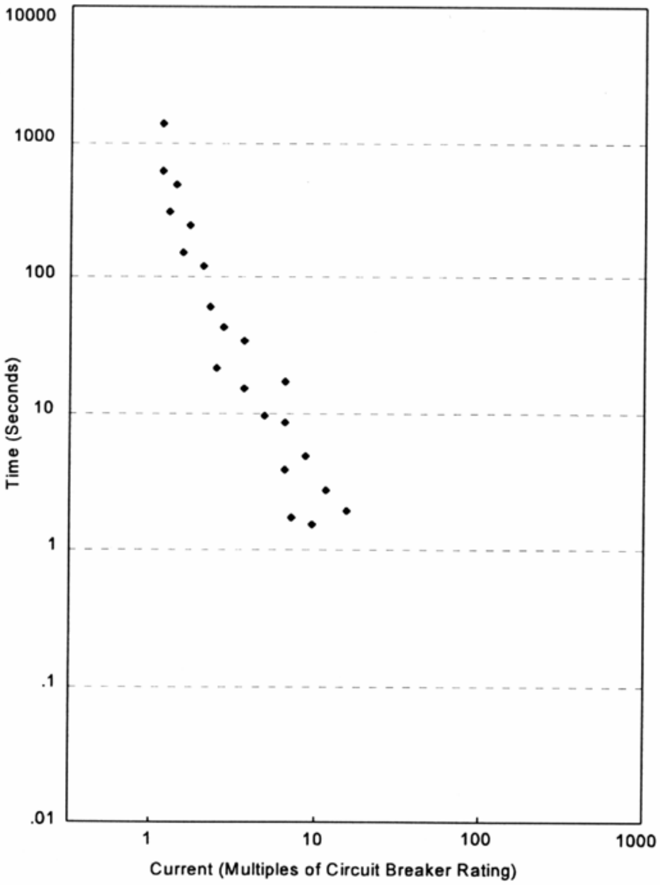


Figure 3-17
Time-Current Curve Testing by the Manufacturer

Many tests will be completed before the time-current curve is determined for a particular breaker style and size. Testing in the thermal region is performed in open air with current flowing in all poles as shown in Figure 3-18. The test temperature is normally maintained at 40°C (104°F) so that the time-current characteristics are determined at the breaker temperature rating. Testing of the instantaneous trip unit may be performed with a single-pole test.

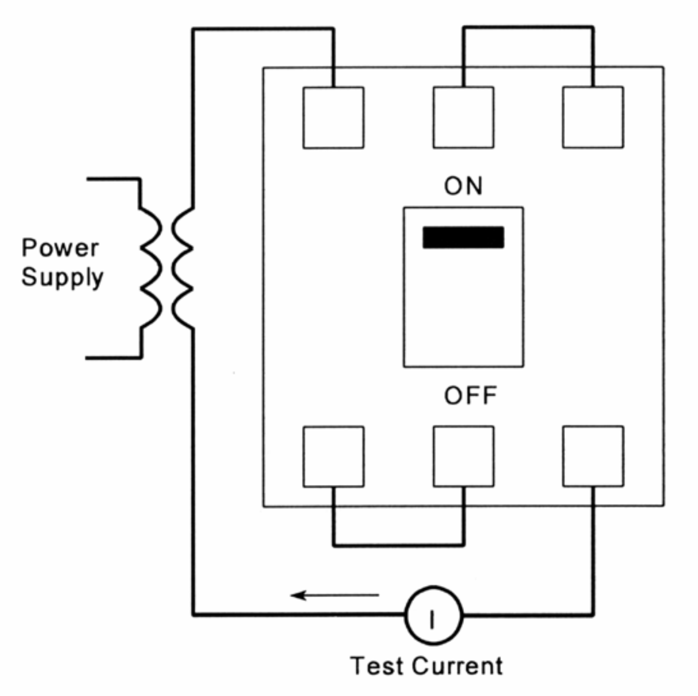


Figure 3-18
Manufacturer's Time-Current Curve Test Setup for the Thermal Trip Response

3.7 Molded Case Switches

A molded case switch is a device assembled as an integral unit in an enclosing housing of molded insulating material, designed to open and close a circuit by nonautomatic means. Molded case switches do not provide overcurrent protection; they are just switches that offer a convenient method of opening and closing a circuit. They are sometimes installed on skid-mounted equipment or local control panels as a local means of isolating power.

Some molded case switches are provided with instantaneous trip units. This protection is intended only to protect the switch against faults above its withstand rating; it is not intended to protect other equipment.

Some MCCBs are essentially used as molded case switches. For example, some control room panels have MCCBs installed for power disconnection at the panel. Although the MCCB inside the panel offers some level of overcurrent protection, this protection may not be a design requirement of the application. Overcurrent protection is typically provided by an MCCB at the power panel or motor control center. MCCBs applied in this manner are effectively used as molded case switches, and their design function is primarily to serve as an on-off switch.

4
APPLICATION CONSIDERATIONS

Section 4 describes application issues relating to MCCBs. The purpose of this section is to discuss MCCB design, application, and qualification features that should be considered when designing or evaluating an MCCB installation. Application and maintenance go hand in hand. With an understanding of MCCB application considerations, a maintenance program can establish a basis for various inspections and tests. Refer to Section 3 for an overview of various MCCB characteristics and additional information regarding MCCB construction and ratings.

4.1 MCCB Basic Requirements

The following standard application requirements must be considered when evaluating an MCCB installation:

- Voltage rating
- Continuous current rating
- Interrupting current rating
- Frequency
- Number of poles
- Trip unit type
- Trip unit functions
- Fixed or interchangeable trip unit
- Accessories, for example, alarm units, shunt trip units, and interlocks
- Type of load, for example, lighting circuit, motor load, and UPS
- Protection scheme type, for example, fully rated, selectively coordinated, and series-combination rated
- System and load classification, for example, Class 1E system with Class 1E loads, Class 1E system with non-Class 1E loads, or non-Class 1E system with non-Class 1E loads

Application Considerations

Depending on the application, other conditions may also require consideration:

- Unusual ambient temperature (high or low)
- Wet conditions or high humidity
- Corrosive atmospheres
- Seismic qualification
- Shock or vibration
- Unusual mounting requirements

An MCCB's continuous current rating is the maximum continuous current that it can carry in a specific ambient temperature. Most manufacturers calibrate MCCBs for an ambient temperature of 40°C (104°F). The ambient temperature is the temperature of the air surrounding the breaker. Thermal-magnetic MCCBs are temperature sensitive. Above 40°C, an MCCB will carry less current than the continuous current rating before nuisance tripping can become a problem, and terminal connections can develop high temperatures. Below 40°C, an MCCB can carry more current than indicated by the continuous current rating and nuisance tripping is not an expected problem. The mechanical operation of an MCCB can be adversely affected by ambient temperatures significantly below 25°C; freezing conditions can cause lubricant failure or binding due to differential contraction of parts. Consult the manufacturer when applying a thermal-magnetic MCCB in unusual ambient conditions.

The interrupting rating of an MCCB is one of its most important characteristics. A short circuit study is normally performed to determine the minimum required interrupting rating. Refer to Section 4.7 for additional information.

4.2 Types of Protection Systems

Not all MCCB installations offer the same level of reliability and protection. Three basic system design approaches are available:

- Fully rated
- Selectively coordinated
- Series-combination rated

In general, nuclear plants tend to have fully rated systems with some level of selective coordination available. The following sections discuss the different types of protection schemes, including their advantages and limitations.

4.2.1 Fully Rated Systems

An electrical distribution system short-circuit analysis typically determines the maximum available fault current at critical locations in the system. In a properly designed fully rated system, each breaker has an interrupting rating greater than the maximum possible fault current available at its location.

When exposed to short-circuit current, MCCBs often exhibit current limiting characteristics (see Section 4.3). The term *current limiting* means that a breaker responds to an overcurrent condition quickly enough that the maximum available fault current is not observed downstream of that breaker. The breaker opening process results in a smaller peak value of current passing through the breaker than would be available if the breaker was not present. Section 4.2.3 discusses a type of protection scheme in which this current-limiting characteristic is used to apply lower rated breakers downstream of the breaker that principally reacts to the short circuit. A fully rated system does not take credit for this current-limiting ability; each breaker is fully rated for the maximum prospective fault current at its point of application regardless of any current-limiting features in upstream breakers.

A fully rated system does not guarantee that selective coordination is assured for all potential fault currents (see Sections 4.2.2 and 4.9 for more information regarding selective coordination). Although equipment protection is maintained in a fully rated system, continuity of service is not always guaranteed. A short circuit might result in the opening of one or both of two breakers in series. A lack of coordination is indicated when two or more breakers in series have overlapping time-current characteristics. A common condition at power plants is for coordination to be assured in the time-delay region of the time-current curves of a load breaker and its upstream feeder breaker; however, the instantaneous trip elements of either or both breakers may actuate in response to a short circuit.

4.2.2 Selectively Coordinated Systems

A selectively coordinated system uses fully rated breakers as described in Section 4.2.1 with the improvement that a coordination time delay is assured for any credible fault. By designing for selective coordination, the breaker closest to the fault actuates first to clear the fault. Should the nearest breaker fail to open, the next upstream breaker is expected to actuate and clear the fault after a suitable time delay, thereby providing backup protection for the system. By this arrangement, maximum service continuity is expected after a faulted condition. Figure 4-1 shows an example of selectively coordinated breakers; a feeder breaker provides power to a motor control center (MCC). Equipment is powered from the MCC through individual load breakers. Notice that a fault downstream of a load breaker should not result in actuation of the feeder breaker; for an overload or fault of any magnitude, there is a coordination time delay that allows the load breaker an opportunity to open first. Thermal-magnetic MCCBs typically do not provide this level of selective coordination in the instantaneous trip region because the instantaneous trip units may respond simultaneously to the fault current. Section 4.9 provides additional information and several examples regarding selective coordination.

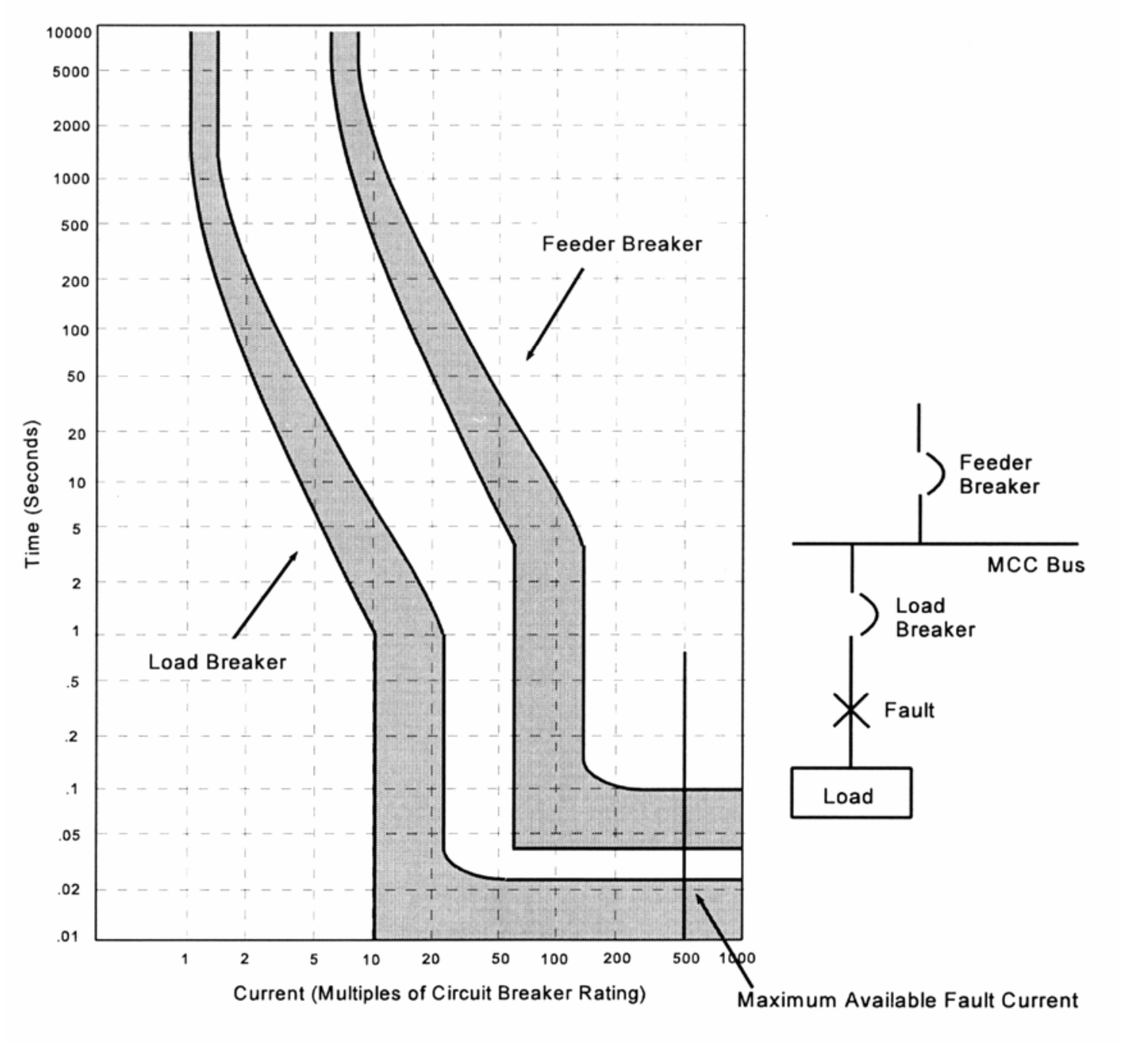


Figure 4-1
Selectively Coordinated Breakers

In order to accomplish selective coordination throughout the entire range of possible fault current, the upstream breaker must incorporate a short time delay trip even in the instantaneous range. The upstream breaker must also be capable of withstanding the magnetic and thermal stresses created by the fault current during the period required for the breaker nearest the fault to open.

4.2.3 Series-Combination Rated Systems

As noted previously, MCCBs often demonstrate a current-limiting capability, allowing the breaker to interrupt and clear a fault before the maximum possible fault current is seen by downstream devices (see Section 4.3 for technical information). A series-combination rated system takes advantage of the current-limiting characteristics of MCCBs and allows the downstream breaker to have a lower interrupting rating due to the current-limiting ability of the upstream breaker. A series-combination rating cannot be obtained by analysis; the breakers must have been tested in a series combination in accordance with UL requirements. Furthermore, a series-combination rating for a pair of breakers cannot be claimed by similarity analysis to another tested pair. Only a test in accordance with UL requirements of the specific combination of breaker types can produce this rating.

A series-combination rated configuration has the economic advantage of being less expensive than a fully rated system or a selectively coordinated system. By relying on the current-limiting characteristics of the upstream breaker, smaller and less expensive breakers can be used downstream.

A series-combination rating has several application limitations that may offset the economic benefits:

- The system design has no selective coordination for large fault currents. Notice that this type of design ensures loss of service continuity in response to a large fault because the upstream breaker must open to clear the fault and limit the magnitude of let-through current. However, smaller faults or overloads might still be cleared by the downstream breaker without the upstream breaker opening. Despite the possible coordination for overloads, the system designer must acknowledge that loss of the entire system downstream of the upstream device is an expected consequence of a large fault.
- The series-combination system is intended only for distribution circuits containing lighting or resistive loads. This configuration should not be used if large motor loads are included because the motor contribution to a fault through the downstream breaker was not verified by UL testing.
- Failure of the upstream breaker to open due to a mechanical failure could result in exceeding the interrupting rating of the downstream breakers since the upstream breaker did not fulfill its current-limiting function.

4.3 Current-Limiting Characteristics of MCCBs

When a large fault current actuates the instantaneous trip element of an MCCB, the breaker is expected to open with no intentional time delay. As the breaker contacts part, an arc is formed between the contacts. This arc has an impedance, called *dynamic impedance*, that is introduced into a circuit by the opening of the breaker contacts during circuit interruption. As implied by the name, the impedance is dynamic, or constantly changing, as the breaker contacts separate.

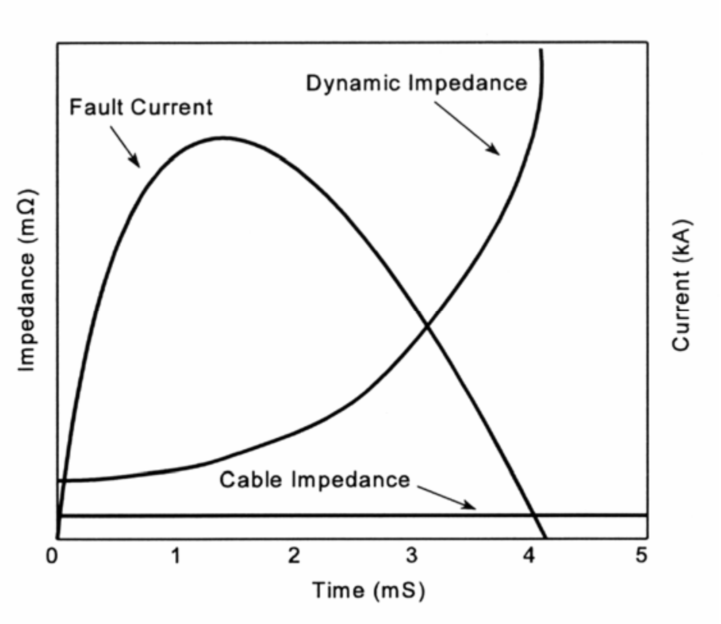


Figure 4-2
Arc Dynamic Impedance Across MCCB Contacts

As the dynamic impedance of the arc increases, the fault current is proportionately reduced. Figure 4-2 illustrates the relationship between the dynamic impedance and fault current as a function of time. This dynamic impedance plays a major role in the current limiting characteristics of some MCCBs. MCCB contact designs usually incorporate features that 1) cause them to open independent of the operating mechanism for fast response and 2) force them to separate quickly because of the magnetic forces created by the current. The result is shown in Figure 4-3 for current-limiting MCCBs. The prospective fault current does not have time to reach its full value; an MCCB's current-limiting feature tends to clear the fault before current can reach its theoretical peak.

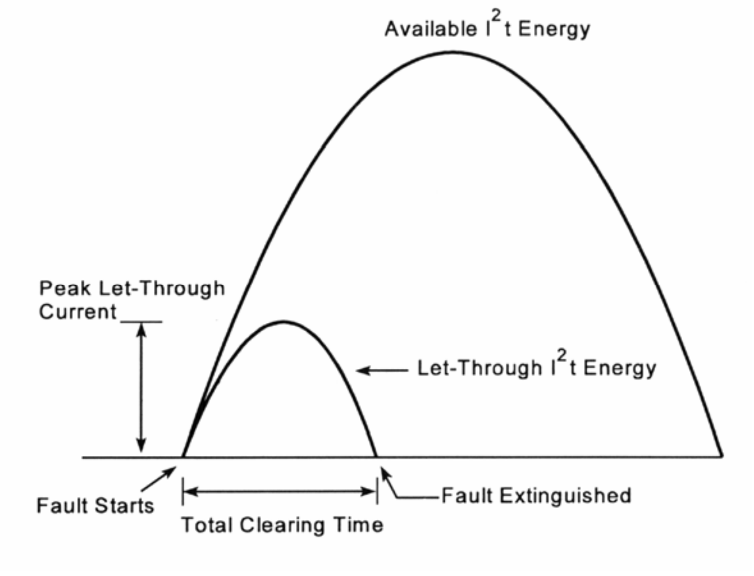


Figure 4-3
Current-Limiting Characteristics

Not all MCCBs are current limiting to the degree shown in Figure 4-3. However, it can be seen that a current-limiting MCCB substantially reduces the peak magnitude of downstream fault current. Section 4.2.3 discusses how current-limiting MCCBs can be used to design a less expensive installation by allowing downstream breakers to have a lower interrupting rating than would be indicated by a conventional short-circuit study.

4.4 Sizing MCCBs

MCCBs should be selected to satisfy the applicable design requirements specified in Section 4.1. Beyond meeting the basic design criteria for an installation, an MCCB should be sized to protect the downstream conductors and equipment from excessive or dangerous temperatures in conductors or insulation.

Breaker sizing and conductor sizing are directly related; the conductor must be capable of carrying the maximum expected load, and the breaker must protect the conductor from carrying current beyond its ampacity. In many cases, MCCBs are relied upon for load protection in addition to cable protection. As an example, a circuit breaker may be credited with providing overload protection of a motor in addition to protecting the cables feeding the motor.

The following sections are not intended to establish definitive design criteria for MCCB sizing; rather, they are intended to briefly introduce the reader to some of the key sizing considerations. The National Electrical Code is used by most facilities as the primary source of guidance for sizing MCCBs.

4.4.1 Continuous Current Rating

Defining the continuous current rating of an MCCB is not as straightforward as it should be. Unless specified otherwise, an MCCB is actually allowed to carry 100% of its rated current for only 3 hours, and is rated to carry only 80% of its nameplate current continuously. This counterintuitive requirement stems from the original qualification testing of the breakers to UL-489, which certifies breakers for 100% continuous current in free air. Since most breakers are installed in a panel or enclosure, the breaker is effectively derated to account for the predictable temperature rise inside the enclosure. This category of breakers is referred to as *80% rated breakers*. Note that most MCCBs are calibrated by the manufacturer at 40°C, which is the presumed air temperature immediately surrounding the MCCB when installed in an enclosure.

Many manufacturers market breakers that are rated for a true 100% continuous current, referred to as *100% rated breakers.* 100% rated breakers are specifically labeled as such, including enclosure requirements. Breakers in this category often have additional limitations on the insulation rating of the connected cables because of the additional temperature rise inherent in the higher rating.

The National Electrical Code requirements applicable to MCCB sizing depend on several variables, including:

- The type of circuit, for example, main service breaker, feeder breaker, and branch circuit
- The types of loads being fed, for example, continuous, non-continuous, motors, and lighting
- Equipment ratings

4.4.2 Interrupting Rating

The interrupting rating of the circuit breaker should be equal to or greater than the maximum available fault current available at the terminals of the breaker. See Section 4.8 for additional information.

4.4.3 Tripping Characteristics

The time-current tripping characteristics of the breaker should meet the design requirements for the breaker, which typically include:

- Protection of downstream conductors
- Protection of downstream equipment
- Selective coordination with other system protective devices
- Avoidance of nuisance trips

Competing design requirements frequently make it extremely difficult to satisfy all the objectives simultaneously. This is especially true for thermal-magnetic MCCBs, which have modest accuracy and limited flexibility. See Sections 4.2 and 4.9 for additional information.

4.4.4 Temperature

MCCBs are typically designed and calibrated for operation at 40°C. Recall that this is the ambient temperature surrounding the breaker and not just the ambient room temperature. Ambient temperatures substantially different from 40°C may require breaker rerating.

4.4.5 Other Factors

Other factors that can affect breaker sizing include frequency and altitude. Applications involving frequencies above 60 Hertz or altitudes in excess of 6,000 feet can influence breaker sizing. Manufacturers should be consulted for any unique application requirements.

4.5 Cable Design Considerations

Although MCCBs are the principal subject here, cable and MCCB design requirements are interrelated. A circuit's cable must simultaneously satisfy several design requirements:

- Continuous current capability – The conductors must have sufficient ampacity to supply the load.
- Short circuit and overload capability – The conductors must be capable of withstanding fault interruption current for the time required for the breaker to open.
- Voltage drop – The conductors must be large enough to provide adequate voltage to the load.
- Size – The conductors must be capable of fitting within the MCCB connectors.
- Thermal conductivity – The conductors must be large enough to conduct heat from the MCCB.
- Cost – The conductors should be as economical as possible.

Meeting the above requirements simultaneously involves a certain degree of compromise. For example, the least expensive conductor may not satisfy the voltage drop limits. Or, a conductor that has virtually no voltage drop for the maximum expected operating current may be too large to fit within the MCCB terminal connections.

Cables must accomplish their primary design function of providing current and adequate voltage to their associated loads. In addition to providing a circuit disconnection capability, MCCBs protect cable conductors from overheating due to overload or short circuit current. During a short circuit, virtually all of the heat generated by the current in the conductor elevates the conductor temperature. Providing adequate cable protection involves understanding the following:

- Maximum available short-circuit current
- Maximum conductor temperature that will not damage the conductor insulation
- Installation features that limit heat conduction to the ambient air, such as conduit or firewrap
- Length of time that a short circuit can be present before interruption

One method of ensuring that the cable conductors are properly protected is to compare the time-current curve of the MCCB to the maximum short-circuit current and short time overload current allowed for the conductor size. Figure 4-4 shows an example of an MCCB's time-current curve compared to the maximum allowed current for a conductor. When plotted on the same graph, the MCCB's time-current curve should be below and to the left of the conductor maximum current curve.

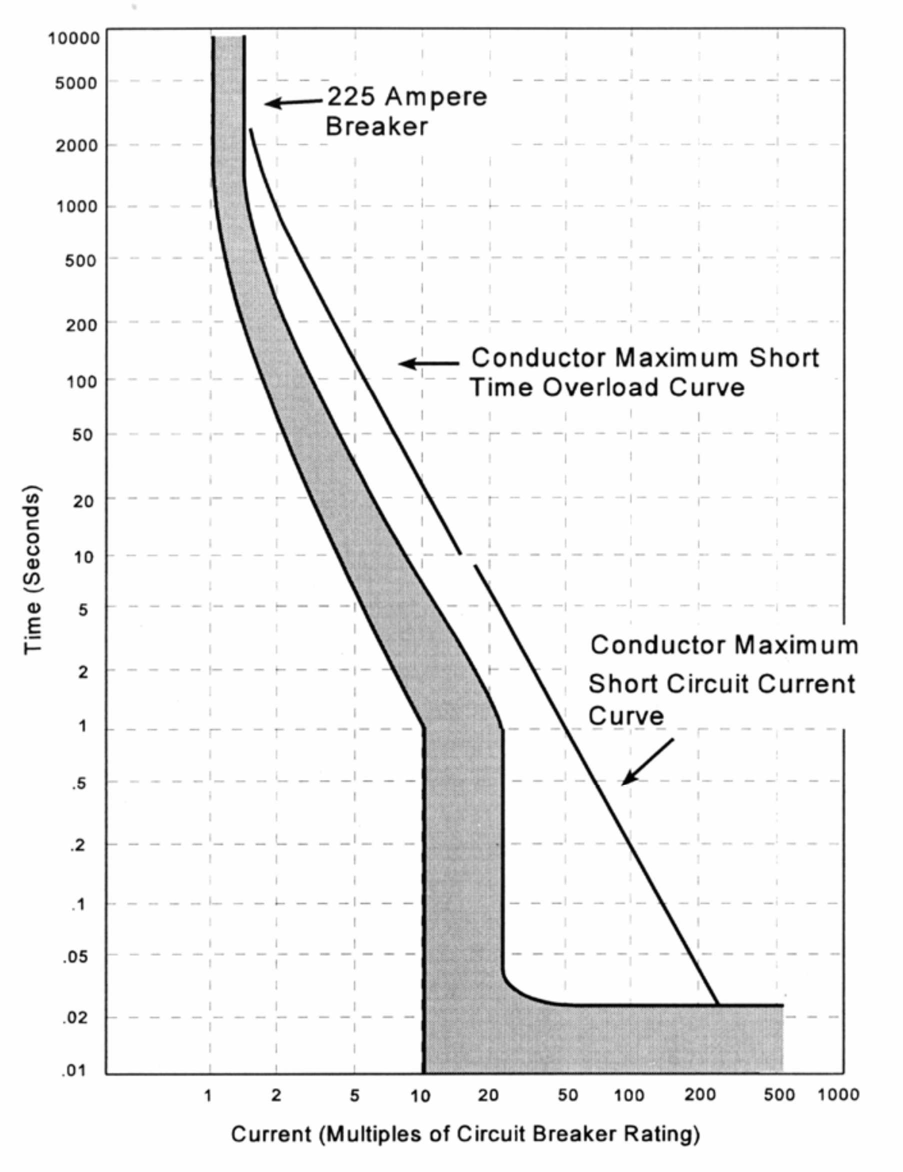


Figure 4-4
MCCB Characteristics Compared to Maximum Allowed Conductor Current

Each MCCB has a minimum conductor size that should be installed based upon the breaker's continuous current rating. MCCBs are tested and certified in accordance with UL-489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures.* Table 8-16.1.4.2.1 of UL-489 specifies the conductor size to use during certification testing as a function of the continuous current rating of the MCCB. The UL-489 conductor sizes for copper conductors are shown in Tables 4-1 and 4-2 (refer to UL-489 for aluminum conductor information). The conductor size is an important attribute because it also acts as a thermal conductor for heat generated within the MCCB. As the conductor size is increased, the MCCB can dissipate a greater amount of internally generated heat. By specifying the test cable size, UL-489 effectively establishes a minimum cable size for installation in the field. If the user chooses to install a cable smaller than the size used in UL-489 certification testing, the MCCB could potentially be exposed to a greater amount of heat during an overload than was confirmed by test. For this reason, the conductor sizes specified in Tables 4-1 and 4-2 are considered the *rated conductor size* for a particular MCCB rating. Generally speaking, a conductor selected in accordance with National Electric Code sizing practices should not be smaller than specified by UL-489.

Table 4-1
Rated Copper Cable Sizes for Smaller Breakers*

Breaker Rating (amperes)	Conductor Size (75°F rating)	Conductor Size (60°F rating)
15 or less	14 AWG	14 AWG
20	12 AWG	12 AWG
25	10 AWG	10 AWG
30	10 AWG	10 AWG
40	8 AWG	8 AWG
50	8 AWG	6 AWG
60	6 AWG	4 AWG
70	4 AWG	4 AWG
80	4 AWG	3 AWG
90	3 AWG	2 AWG
100	3 AWG	1 AWG
110	2 AWG	1 AWG
125	1 AWG	1/0 AWG
150	1/0 AWG	
175	2/0 AWG	
200	3/0 AWG	
225	4/0 AWG	
250	250 MCM	
275	300 MCM	
300	350 MCM	
325	400 MCM	
350	500 MCM	

* For circuit breaker ratings not shown in the table, use the next higher rating.

Table 4-2
Rated Copper Cable Sizes for Larger Breakers*

Breaker Rating (amperes)	Number of Paralleled Conductors	Conductor Size (75°F rating)
400	2	3/0 AWG or
	1	500 MCM
450	2	4/0 AWG
500	2	250 MCM
550	2	300 MCM
600	2	350 MCM
700	2	500 MCM
800	3	300 MCM
1000	3	400 MCM
1200	4	350 MCM or
	3	600 MCM
1400	4	500 MCM
1600	5	400 MCM
	4	600 MCM
2000	6	400 MCM
	5	600 MCM
2500	8	400 MCM, or
	7	500 MCM, or
	6	600 MCM
3000	9	400 MCM, or
	8	500 MCM, or
	7	600 MCM
4000	12	400 MCM, or
	11	500 MCM, or
	10	600 MCM

* For circuit breaker ratings not shown in the table, use the next higher rating.

4.6 Designing for Motor Loads

MCCBs must be sized to withstand motor starting currents while simultaneously protecting circuit conductors. The magnitude of a motor's starting current depends on its size and design. Some motors may have starting currents as low as 6 times the normal running current while others may have starting currents greater than 13 times the normal operating current. Furthermore, the starting current may by asymmetric for the first few cycles (see Appendix E for more information). For these reasons, MCCBs must be carefully sized to satisfy all design requirements when motor loads are involved. Either thermal-magnetic or magnetic-only MCCBs can be used for motor applications.

Magnetic-only MCCBs provide short-circuit and high level ground fault protection. This type of breaker must be used with a combination motor starter. Overload protection for each conductor is provided by the combination motor starter. The instantaneous trip on the MCCB must be adjustable so that it can be set just above the starting current of the motor. This allows for short-circuit protection to be provided for any current slightly above the instantaneous peak starting current of the motor.

The National Electric Code, Section 430-52, states that the instantaneous setting for a magnetic-only breaker can not exceed 13 times the motor's full load current. Unfortunately, this limit may not be adequate to prevent nuisance breaker trips during some motor starting transients. When the circuit is closed to provide power to a motor, the initial current consists of two components, a sinusoidal steady-state current and a transient component current that rapidly decays (see Appendix E for additional information). After a few milliseconds, only the sinusoidal terms remain with a magnitude corresponding to the motor locked rotor current. As the motor accelerates, the current falls to the normal full load current value. Newer, high-efficiency motors may have even higher starting currents, increasing the possibility of a breaker trip during startup.

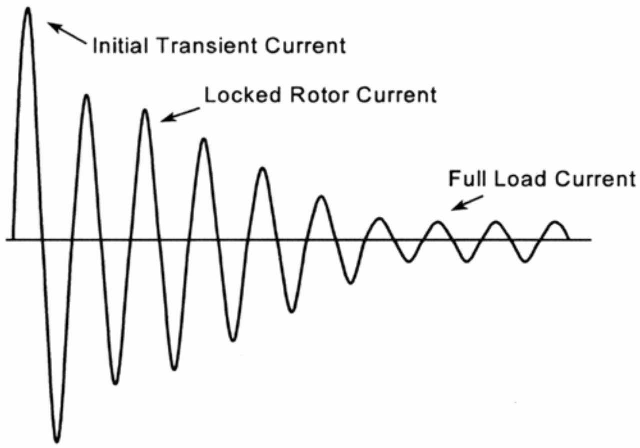


Figure 4-5
Motor Starting Current

An MCCB or other protective device must allow a motor to start, accelerate, and attain its full load current without tripping. Figure 4-6 shows a typical MCCB's time-current characteristics in relation to an example motor starting curve. When voltage is applied to the motor, an initial transient current may peak higher than the motor locked rotor current. As the motor accelerates, the current stabilizes at the locked-rotor current of the motor. After a time interval ranging from several cycles to several seconds, depending on the motor design, the current falls to the full load current of the motor. The MCCB time-current curve must be above and to the right of the motor starting curve. However, notice that the MCCB curve is also below and to the left of the motor damage curve. Whatever protective device is selected must satisfy both design needs: 1) it must allow the motor to start and run under design conditions and 2) it must protect the motor from sustained overload conditions.

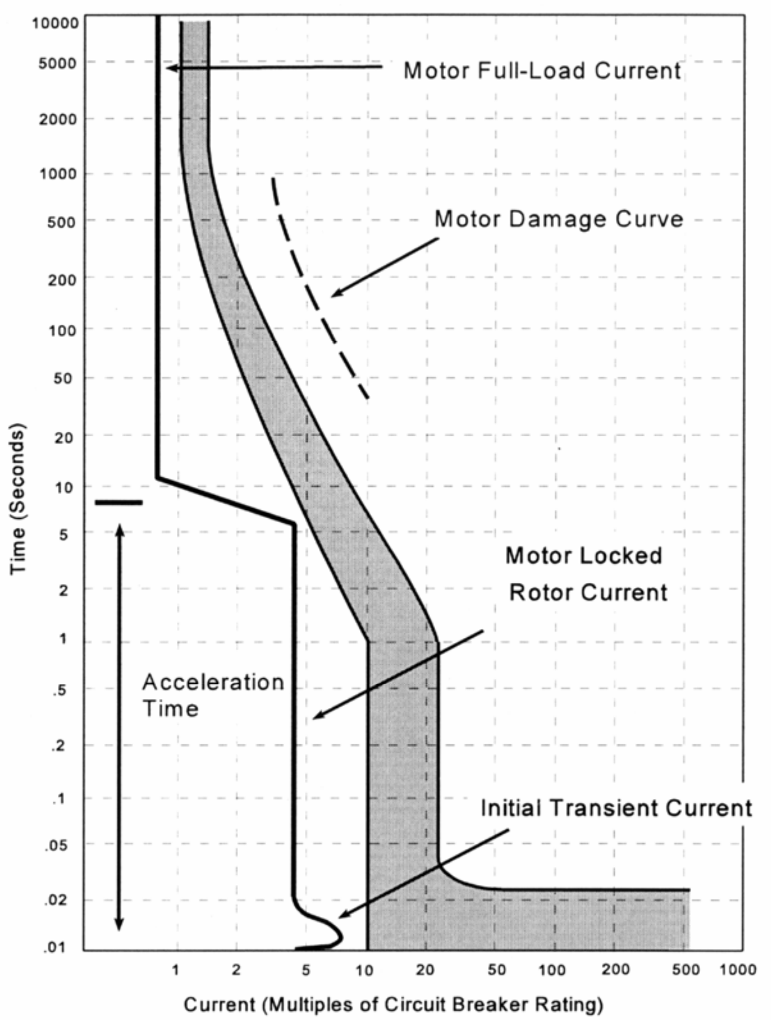


Figure 4-6
Motor Starting Current in Relation to MCCB Time-Current Curve

4.7 Short-Circuit Studies of Low-Voltage Power Systems

A short-circuit study must be performed as an integral part of selecting and sizing electrical distribution components. Even the best and most reliable electrical distribution system is not immune to occasional short circuits. Overcurrent protective devices in the system, including MCCBs, should isolate faults safely with minimal equipment damage and minimal disruption to plant operation. All equipment exposed to the abnormally high short circuit current must be capable of withstanding the mechanical and thermal stresses caused by the current until the short circuit is isolated.

The current that flows during a short circuit depends on the impedance between the fault location and the equipment capable of producing current in response to the fault. As the amount of impedance increases between a source of current and the fault location, the amount of current that this source contributes to the fault decreases; the impedance limits the magnitude of current flow. In general, all rotating electric machinery in the plant may contribute current to a fault. The following types of equipment can supply current to a fault:

- Electric transmission and distribution systems
- Generators
- Motors

Short-circuit studies are normally performed by computer. Hand calculations typically require simplifying assumptions to avoid becoming too time-consuming and burdensome to complete. Unfortunately, the simplifying assumptions in hand calculations can produce erroneous results. Computer programs are readily available for this type of analysis.

Short-circuit currents must be calculated in support of the following equipment selection considerations:

- Verification of interrupting rating of protective devices (see Section 4.8)
- Determination of system components' ability to withstand mechanical and thermal stresses
- Evaluation of time-current coordination of protective devices

Figure 4-7 graphically shows a typical short-circuit study for a simple electrical distribution system. For the fault location shown, the bulk of the short-circuit current is provided by the distribution system through the transformer, with a lesser amount of current provided by each of the motors.

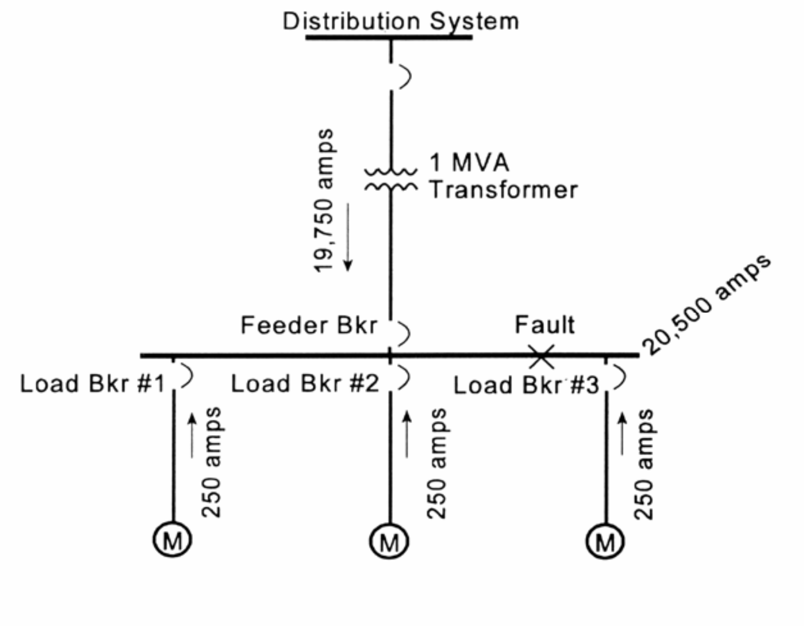


Figure 4-7
Short-Circuit Results for a System Fed by a 1-MVA Transformer

A short-circuit study should not be performed only once as part of initial system design. Instead, it should be a living document, recalculated each time a significant change is made to the electrical distribution system, including equipment replacements or load additions. For example, most plants have experienced significant load additions since original plant construction. Even the simple upgrading of a transformer can affect the short-circuit currents throughout the system. Figure 4-8 shows that upgrading a supply transformer from 1 MVA to 2 MVA can almost double the available downstream fault current (compare to Figure 4-7). The existing equipment, including MCCBs, may not be rated for such an increase in fault current.

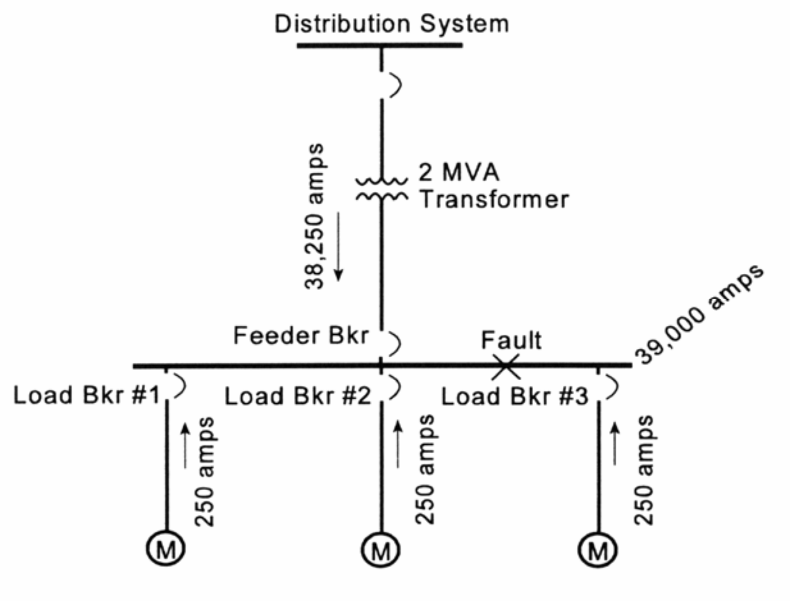


Figure 4-8
Short-Circuit Results when Transformer Size Is Increased to 2 MVA

4.8 Short-Circuit Current X/R Ratio Effect on Interrupting Rating

The ratio of reactance (X) to resistance (R) exhibited by a system during a fault affects the magnitude of short circuit current. The X/R ratio can, under some circumstances, affect a circuit breaker's interrupting rating.

MCCBs are tested per UL-489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures,* to confirm their capability to interrupt rated short circuit current. An understanding of the UL certification process for MCCBs is necessary to apply them properly. The power factor of the short circuit current applied in a UL-489 test varies depending on the breaker rating as shown in Table 4-3.

Table 4-3
UL-489 Test Circuit Power Factor for MCCBs

Breaker Interrupting Rating in Amperes	Test Circuit Power Factor	Equivalent Minimum X/R Ratio
10,000 or Less	0.45 to 0.50	1.73
10,001 to 20,000	0.25 to 0.30	3.18
Over 20,000	0.15 to 0.20	4.90

As shown in Table 4-3, an MCCB with an interrupting rating of 7,500 amperes would be certified by UL test with a circuit power factor of 0.45 to 0.50, and an MCCB with an interrupting rating of 35,000 amperes would be tested with a power factor of 0.15 to 0.20. The net effect is that the tested power factor represents a qualification limit; the MCCB rating must be adjusted if the power factor at the short-circuit current location is less than the tested value.

Before proceeding with the discussion of interrupting rating, some basic terms must be described. Power factor (pf) is defined as the cosine of the phase angle (0) between the voltage and the current.

$$pf = \cos\theta$$

Another useful form of expressing power factor is in terms of the X/R ratio, where X is the reactance in the circuit and R is the resistance in the circuit. The ratio of reactance to resistance equals the tangent of the phase angle 0.

$$\frac{X}{R} = \tan\theta$$

Therefore, power factor can be expressed in terms of X and R as follows.

$$pf = \cos\ (\arctan\frac{X}{R})$$

In a purely resistive circuit, the current and voltage are in phase and the power factor equals 1. In a purely reactive circuit, the current lags the voltage by 90° and the power factor equals 0. A circuit containing both resistance and reactance will have a power factor value between 0 and 1.

Table 4-3 also shows the corresponding minimum tested X/R ratio for different breaker ratings. Sometimes, it is more convenient to convert from a given power factor to the X/R ratio as follows.

$$\frac{X}{R} = \tan\ [\arccos\ (pf)]$$

The term *symmetrical current* refers to the shape of an alternating-current in which the waveform is symmetric about the zero axis. An example of symmetrical current is shown in Figure 4-9.

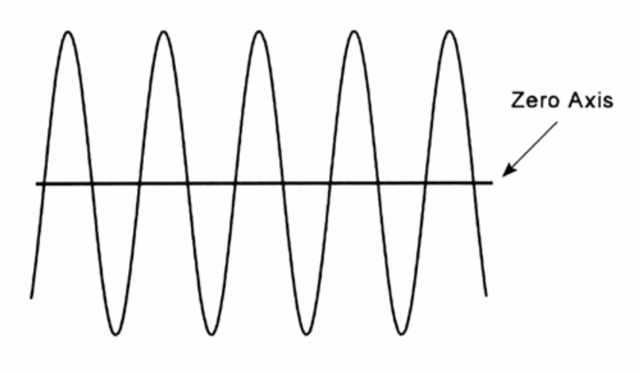


Figure 4-9
Symmetrical Current Waveform

Short-circuit currents are usually asymmetrical, or not symmetric, about the zero axis for the first few cycles (see Appendix E for an explanation of this phenomenon). An example of an asymmetrical current is shown in Figure 4-10.

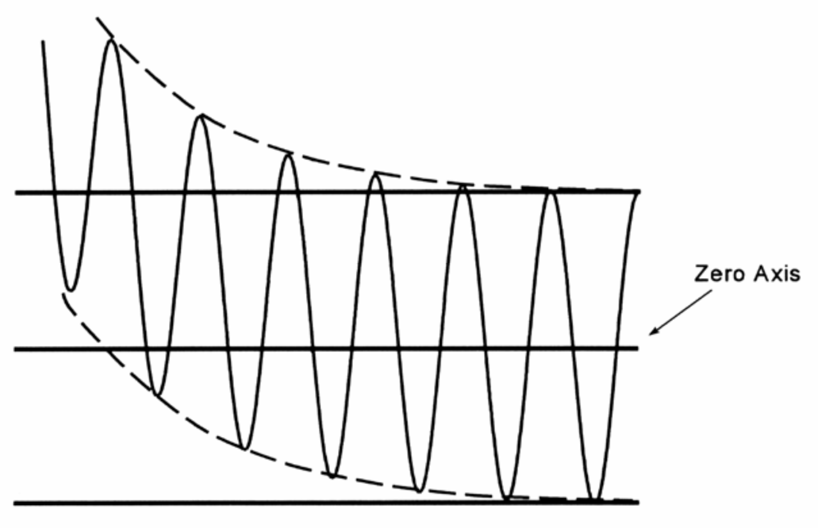


Figure 4-10
Typical Short-Circuit Current Waveform

As shown in Figure 4-10, the asymmetrical current peaks on the first cycle after a short circuit occurs and gradually becomes symmetrical over the next few cycles. Short-circuit current consists of a symmetrical AC component as well as a DC component. The DC component decreases to zero with a rate of decay inversely proportional to the X/R ratio at the point of fault. The rate of decay is more rapid for lower X/R ratios. Higher X/R ratios mean that the decay rate is slower and the breaker is exposed to a higher current for a longer time.

The peak short-circuit current also depends on the X/R ratio. Under normal operating conditions, the alternating-current waveform is sinusoidal about the zero axis. In high-voltage power circuits, the resistance of the circuit back to and including the power source is generally very small compared to the reactance of the circuit. As a result, the short-circuit current may lag the source voltage by almost 90°. If a short circuit occurs at the peak of the voltage wave in a theoretical circuit containing only reactance, the short-circuit current will start at zero since it is 90° out of phase with voltage. It will start at zero and trace a sine wave symmetric around the zero axis. Figure 4-9 shows the resulting waveform.

If the same theoretical circuit suffers a short circuit at the zero point of the voltage wave, the current will start at zero but cannot follow a sine wave symmetrically about the zero axis because the current still must lag the voltage by 90°. This can happen only if the current is displaced from the zero axis as shown in Figure 4-11. Notice that the current peak in Figure 4-11 is twice the peak shown in Figure 4-9 and that it does not decay to a symmetrical waveform about the zero axis because the circuit theoretically has zero resistance.

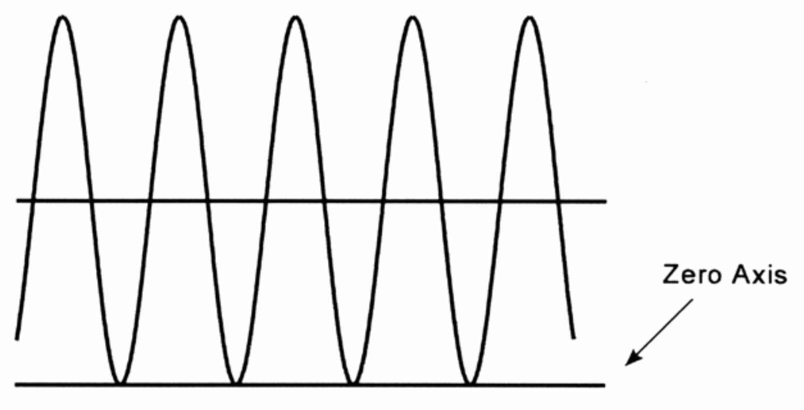


Figure 4-11
Asymmetrical Current Totally Offset from the Zero Axis

The above two examples are theoretical since all circuits have some resistance. However, the examples illustrate how a highly reactive circuit may experience a high peak short-circuit current that persists for some time.

Low-voltage power circuits using MCCBs tend to have a proportionately larger resistance than a high-voltage circuit. Because there is more resistance in the circuit, the current will lag behind the voltage by less than 90°. The peak value of short-circuit current and rate of current decay still depend on the X/R ratio.

Now we are prepared to continue our discussion regarding interrupting ratings. When an MCCB is tested at a specified power factor per UL-489 (see Table 4-3), the breaker is subjected to a certain peak current and rate of decay from the peak current down to a symmetric value about the zero axis. If the system short-circuit current X/R ratio at a particular fault location is larger than this tested value, then the MCCB could be exposed to an asymmetric current greater than it has been certified to withstand per UL-489. To account for this difference, the MCCB is either derated or the symmetrical fault current is increased by a multiplying factor to account for the higher X/R ratio at the fault location. These multiplying factors are shown in Table 4-4 for the different MCCB interrupting ratings.

Table 4-4
MCCB X/R Multiplying Factors

Power Factor	X/R Ratio	Multiplying Factor as a Function of Interrupting Current Rating		
		≤10,000	10,001–20,000	>20,000
0.50	1.73	1.000	1.000	1.000
0.40	2.29	1.078	1.000	1.000
00.30	3.18	1.180	1.000	1.000
0.25	3.87	1.242	1.052	1.000
0.20	4.90	1.313	1.112	1.000
0.15	6.59	1.394	1.181	1.062
0.10	9.95	1.487	1.260	1.133
0.05	19.98	1.595	1.351	1.215

Notice that the multiplying factor is 1.000 for X/R ratios less than the tested value. An MCCB interrupting rating can only be derated for higher X/R ratios; it can not be uprated for a higher fault current due to lower X/R ratios. The multiplying factors shown in Table 4-4 are obtained by the following expression:

$$I_{Adjusted} = I_{Symmetrical} \times \frac{1+e^{(-\frac{\pi}{actual\ \ X/R})}}{1+e^{-(\frac{\pi}{tested\ \ X/R})}}$$

For example, Table 4-4 shows a multiplying factor of 1.215 for a breaker rated above 20,000 amperes when exposed to a short-circuit current with a power factor of 0.05, or an X/R ratio of 19.98. Table 4-3 shows that the minimum allowed X/R ratio for UL certification testing is 4.90 for a test circuit power factor of 0.20. Thus, in accordance with the above equation, the multiplying factor is obtained as follows:

$$I_{Adjusted} = I_{Symmetrical} \times \frac{1+e^{(-\frac{\pi}{19.98})}}{1+e^{-(\frac{\pi}{4.90})}} = I_{Symmetrical} \times 1.215$$

The calculated adjustment to the symmetrical current would then be compared to the MCCB interrupting rating. The adjusted value of short-circuit current should be less than the interrupting rating in order for the MCCB to be applied properly. Computer programs typically perform this calculation directly.

4.9 Selective Coordination

A distribution system is selectively coordinated if the upstream protective device nearest the fault acts first to clear the fault. If the nearest protective device fails to actuate for any reason, the next upstream device then functions as a backup to clear the fault. The difference in actuation time between the protective device nearest the fault and the next upstream device is the coordination time delay. A coordination time delay allows the next upstream device to delay its actuation until it is certain that the device nearest to the fault failed to respond.

Selective coordination is often a basic design requirement so that an equipment fault, overload, or other disturbance has minimal impact on the distribution system. Because only the protective device nearest the disturbance actuates, the rest of the distribution system remains intact, still performing its design function.

Selective coordination is evaluated for a system or particular group of protective devices by overlaying the time-current curve for each protective device onto a single time-versus-current graph. To achieve selective coordination, the nearest protective device upstream from the fault must be given an opportunity to respond first to the fault. The following examples describe how to interpret time-current curves and how to evaluate selective coordination.

4.9.1 Example 4-1: Time-Current Curve

The characteristic curve for a 30-ampere breaker is shown in Figure 4-12. What is the expected breaker trip time for an overload of 150 amperes?

Time-current curves are frequently expressed in terms of percent or multiples of the circuit breaker rating. In this example, the breaker is rated for 30 amperes. Therefore, an overload of 150 amperes is 5 times, or 500%, of the breaker rating. Figure 4-12 shows that the breaker is expected to trip within a range of 6 to 30 seconds. Notice that the breaker trip is initiated by the time delay (thermal) trip unit since the postulated overload is below the instantaneous trip set point.

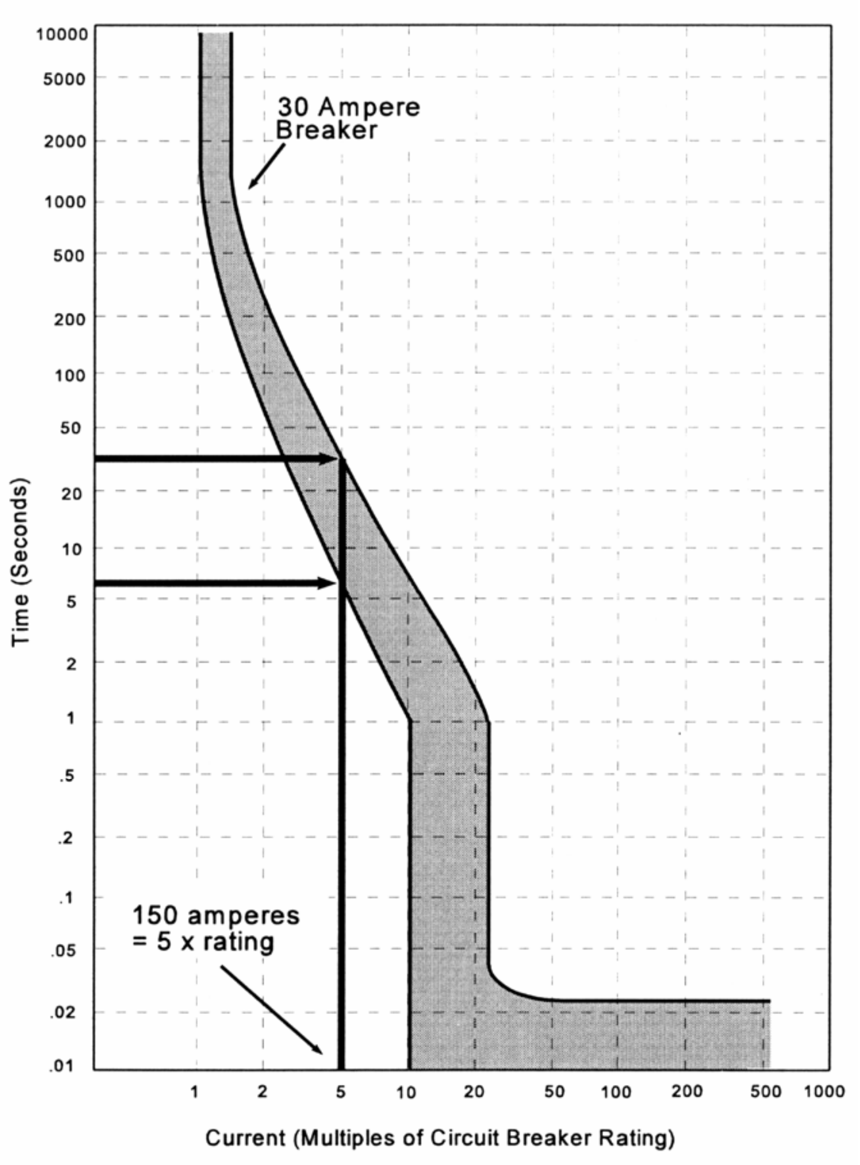


Figure 4-12
Example 4-1: Time-Current Curve

4.9.2 Example 4-2: Time-Current Curve

Assume the starting current for a motor is 120 amperes for 4 seconds. Will the 30-ampere breaker shown in Figure 4-13 allow the motor to start before tripping? The motor starting current of 120 amperes is 4 times the breaker rating of 30 amperes. As shown in Figure 4-13, the breaker is expected to trip within a range of approximately 8 to 45 seconds for an overload of this magnitude. The breaker is not expected to trip when exposed to this motor starting current for only 4 seconds.

MCCBs used for motor applications frequently utilize only an instantaneous trip unit to avoid the possibility of an undesired MCCB trip during a motor start. In this design, overload protection is provided by an overload device, installed in the motor control center, the motor, or in both locations.

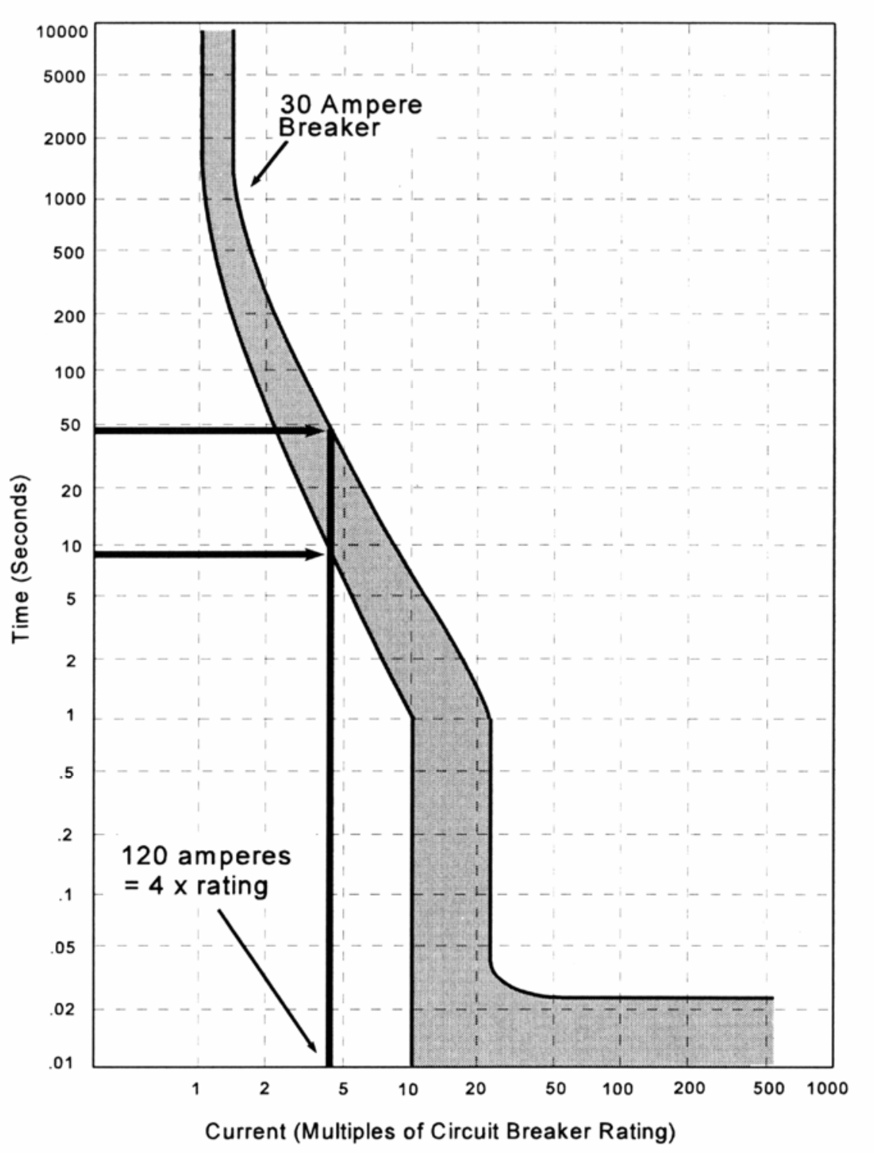


Figure 4-13
Example 4-2: Time-Current Curve

4.9.3 Example 4-3: Time-Current Curve

A 30-ampere rated breaker is exposed to a low-level short-circuit current of 600 amperes. What is the expected response of the breaker?

A fault current of 600 amperes is 20 times the breaker continuous rating. Figure 4-14 shows that this magnitude of fault current is in the transition region of the breaker's time-current curve, and the trip may be caused by either the thermal or magnetic trip unit. In any case, the breaker should trip in less than approximately 1½ seconds.

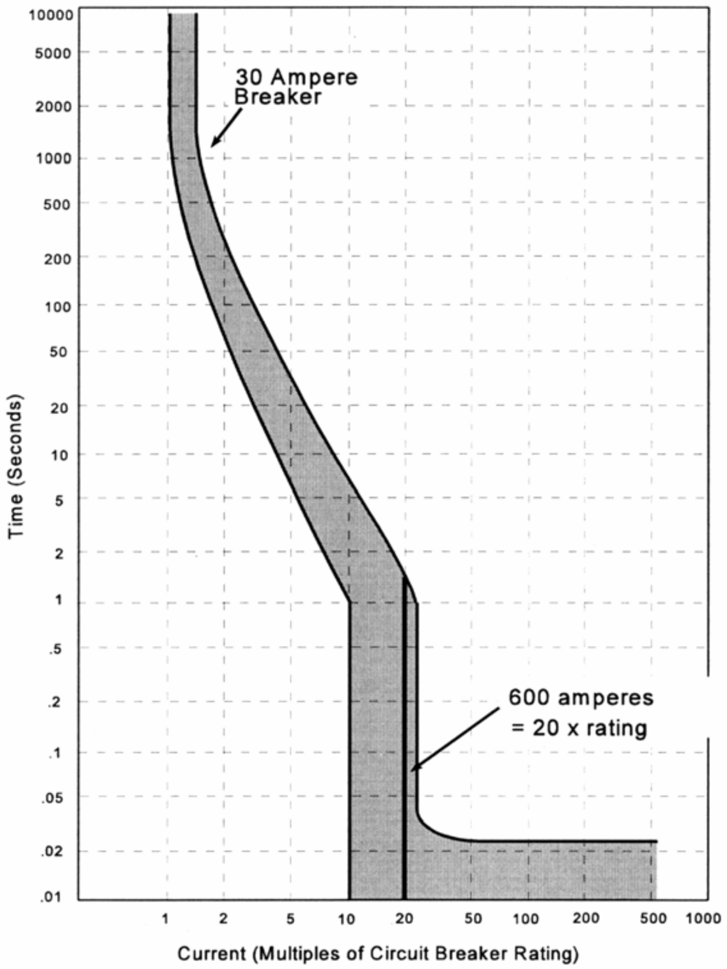


Figure 4-14
Example 4-3: Time-Current Curve

4.9.4 Example 4-4: Time-Current Curve

A 30-ampere rated breaker is exposed to a short-circuit current of 13,500 amperes. What is the expected response of the breaker?

A short-circuit current of 13,500 amperes is 450 times the breaker continuous rating. Figure 4-15 shows that the instantaneous trip unit should be actuated by this magnitude of current. The expected response is for the breaker to open with no intentional time delay and always in less than about 0.025 seconds, or 1½ cycles.

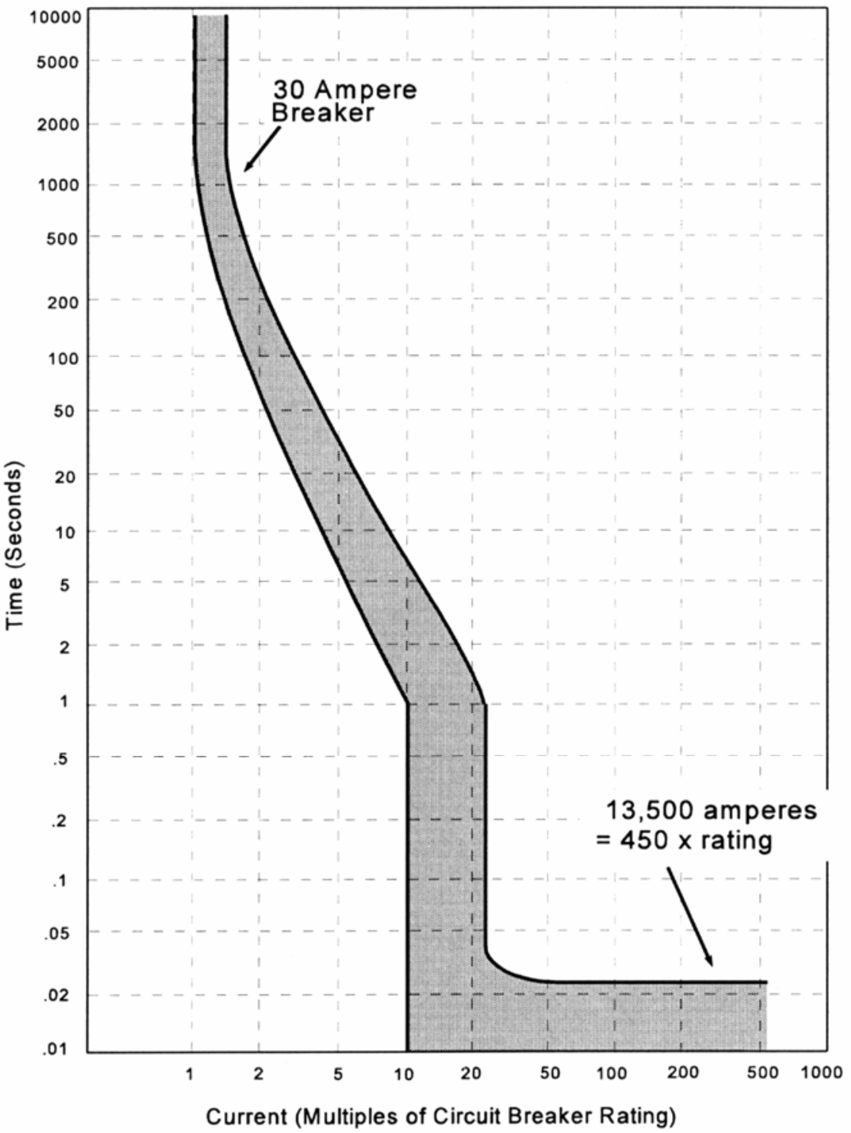


Figure 4-15
Example 4-4: Time-Current Curve

4.9.5 Example 4-5: Distribution System

Consider the case in which a 250-ampere breaker provides power to a motor-control center with individual load breakers rated at 30 amperes, as shown in Figure 4-16.

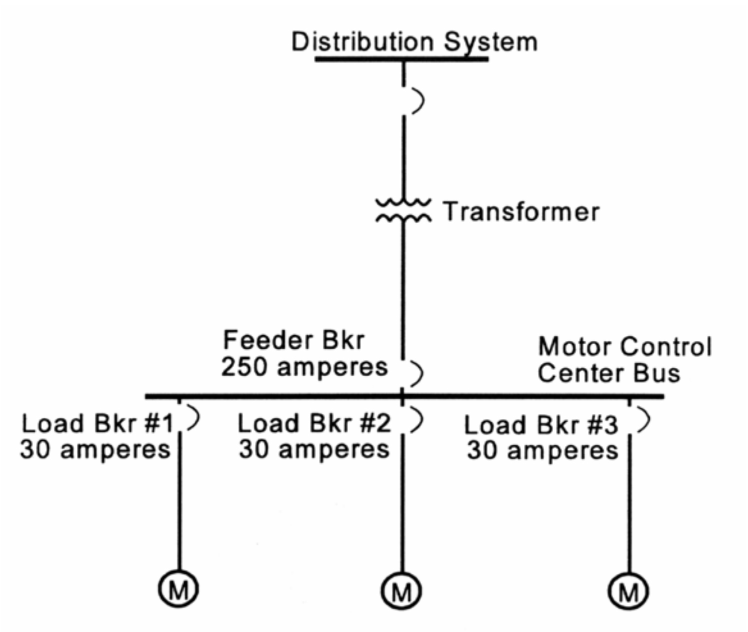


Figure 4-16
Example 4-5: Distribution System

What is the expected response to an overload of 150 amperes downstream of one of the 30-ampere breakers?

The time-current characteristics for the 30-ampere rated breakers have been previously shown in Figure 4-12, and the response of this breaker size to overcurrents was examined in Examples 4-1 through 4-4. The time-current curve for the 250-ampere breaker is shown in Figure 4-17. Notice that the 250-ampere breaker used in this example has an adjustable instantaneous trip setting with two available settings: high and low. Either setting of the instantaneous trip unit might be used for this application.

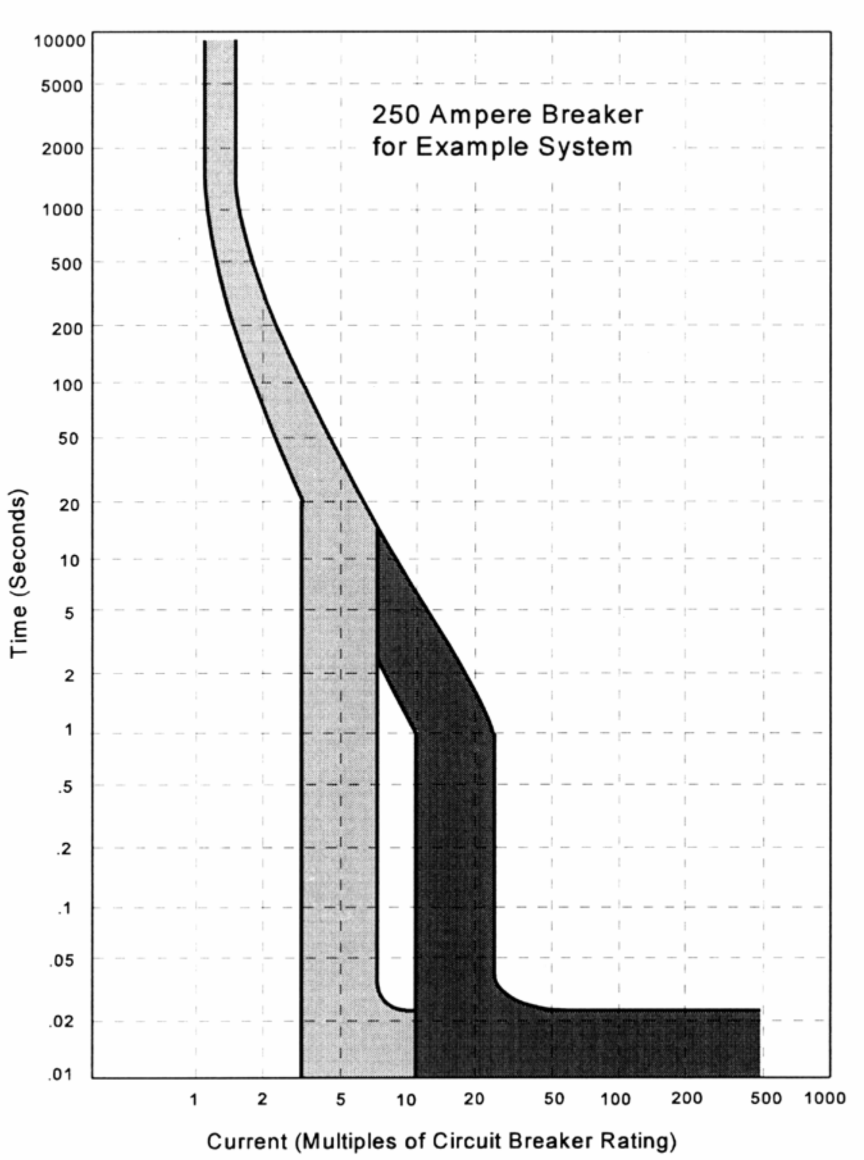


Figure 4-17
Example 4-5: Time-Current Characteristics for the 250-Ampere Breaker

An evaluation of the coordination between the two breakers is accomplished by overlaying the two time-current curves onto a single plot (see Figure 4-18). Note that the x-axis scale, in terms of multiples of breaker rating, applies specifically to the 30-ampere breaker; the 250-ampere breaker time-current curve is shifted to the right by normalizing its trip characteristics to 30 amperes.

As shown in Example 4-1, an overload of 150 amperes is 5 times the rated value of the 30-ampere breaker, and the 30-ampere breaker is expected to trip within a 6 to 30 second range for an overload of this magnitude. Figure 4-18 shows that the 250-ampere breaker should not respond to the overload unless the combined MCC load exceeds 250 amperes.

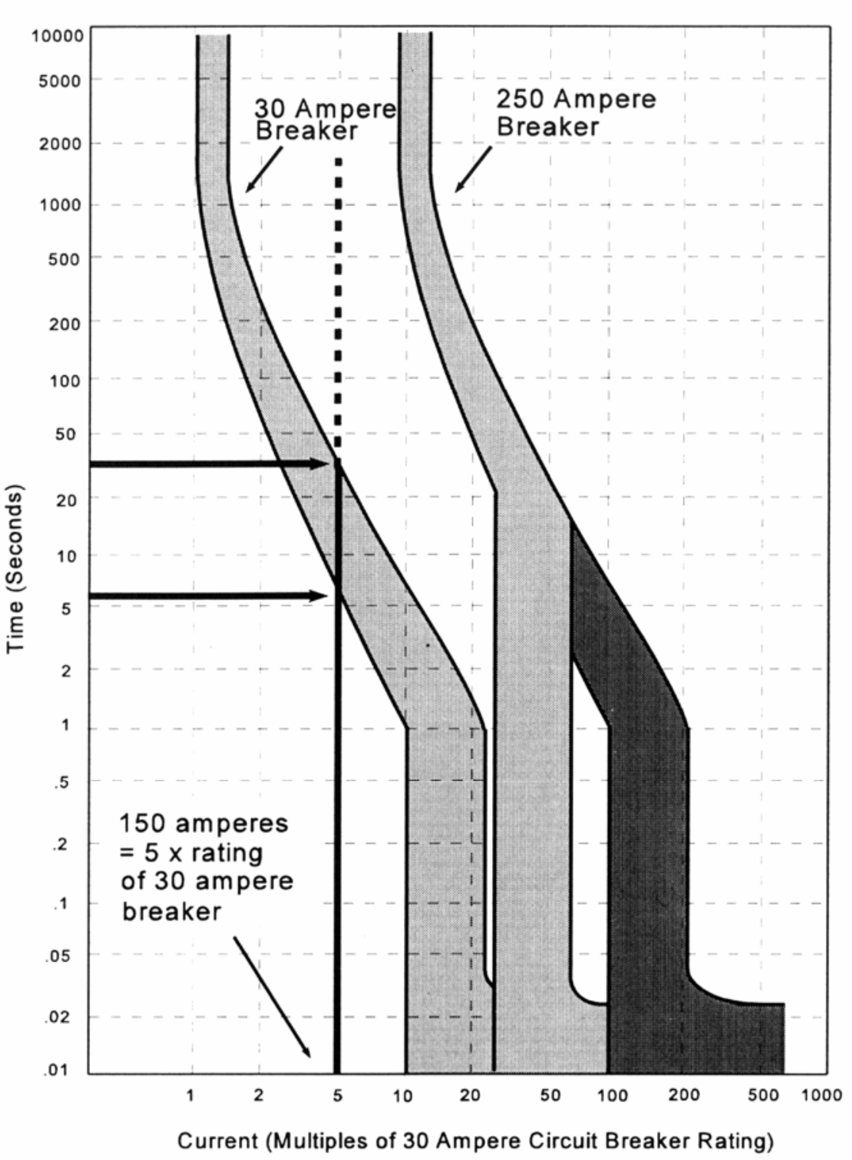


Figure 4-18
Example 4-5: Coordination Analysis

4.9.6 Example 4-6: Coordination Analysis

Suppose that the 30-ampere breaker in Example 4-5 is exposed to a relatively low fault current of 600 amperes. What is the expected response of the 30-ampere and 250-ampere breakers?

A fault of 600 amperes is 20 times the 30-ampere breaker rating. Figure 4-19 shows that this magnitude of fault current is in the transition trip region for the 30-ampere breaker, and it should trip either with no intentional time delay by the magnetic trip unit or within $1^{1}/_{2}$ seconds by the thermal trip unit. In the event that the 30-ampere breaker fails to trip, the 250-ampere breaker is expected to trip within 40 to 225 seconds (see Figure 4-19).

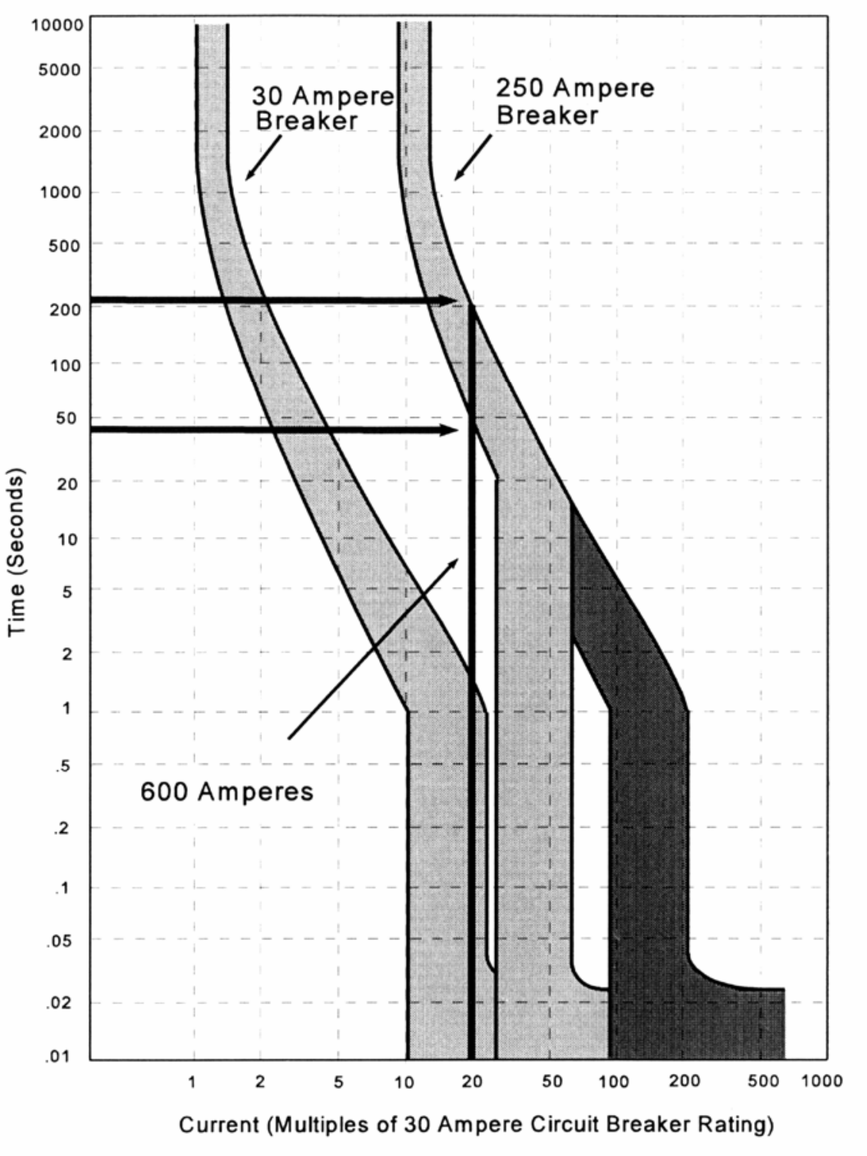


Figure 4-19
Example 4-6: Coordination Analysis

4.9.7 Example 4-7: Coordination Analysis

What is the expected response of the 30-ampere and the 250-ampere breakers in Example 4-6 to an 18,000-ampere fault downstream of the 30-ampere breaker? A fault of 18,000 amperes is 600 times the 30-ampere rating. As shown in Figure 4-20, this magnitude of fault current is in the instantaneous trip region for both breakers. In this case, both breakers are expected to respond; however, either or both breakers may trip. This particular example shows the difficulty in coordinating thermal-magnetic MCCBs in the instantaneous trip region.

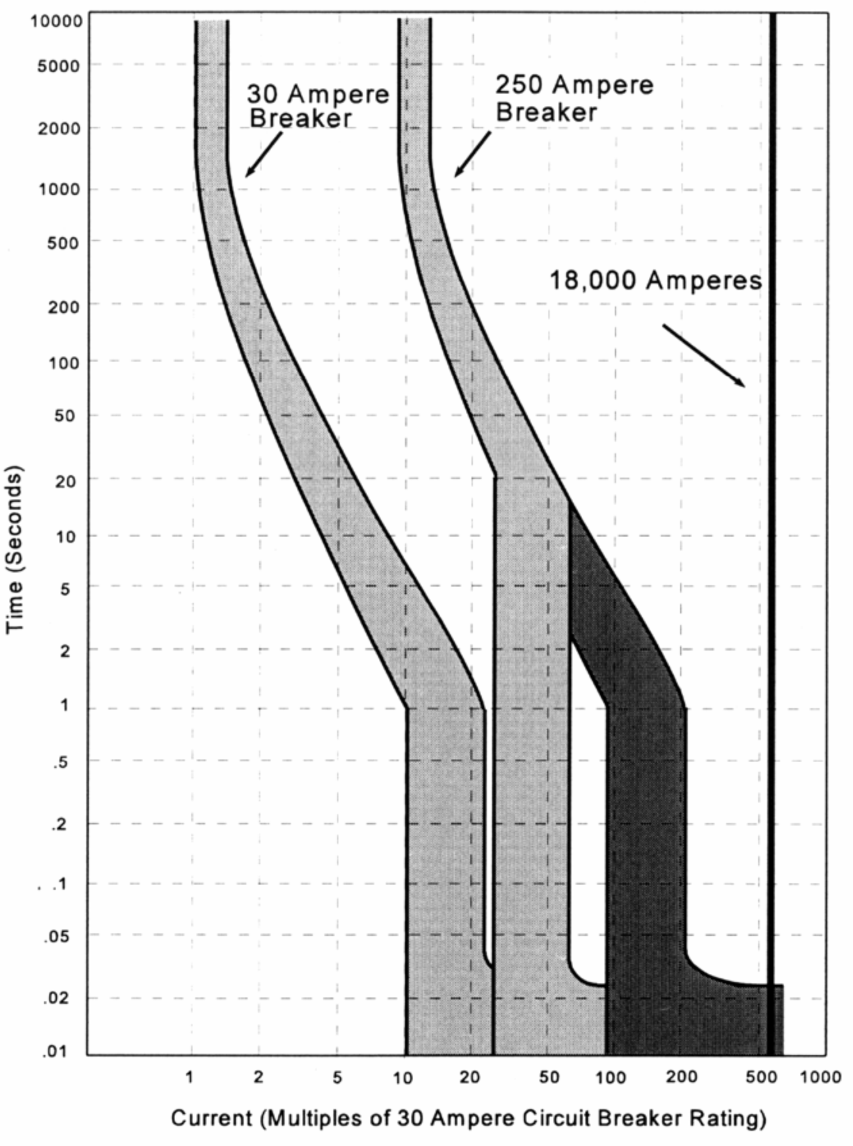


Figure 4-20
Example 4-7: Coordination Analysis

Application Considerations

Examples 4-5 through 4-7 show that the 30-ampere load breaker and the 250-ampere feeder breaker are coordinated for fault currents up to the lower limit of the 250-ampere breaker low instantaneous trip, or approximately 750 amperes at the low setting or 2,700 amperes at the high setting.

4.10 Comparison of DC to AC Characteristics in Overcurrent Trip Units

MCCBs are available for use in both AC and DC applications. In many cases, the MCCB design is the same regardless of whether the end use is for AC or DC; however, the user should understand that an MCCB may respond differently to AC current than to DC current, depending on the magnitude of the current and how the trip unit responds to the current. The following sections describe how MCCB trip units respond to various levels of overcurrent.

4.10.1 Time Delay Trip Units

As discussed in Section 3.2.2, time delay trip units protect against sustained overloads and incorporate an intentional time delay in the tripping function. The time delay trip function is normally achieved by a thermal trip unit, a bimetal element consisting of two bonded strips of metal having different rates of thermal expansion (see Figure 3-8). Line current passing through the bimetal causes the element to heat and deflect. If the bimetal element deflects sufficiently, it trips the latch on the breaker trip mechanism.

The thermal response of the bimetal strip is directly related to the heat energy dissipated in the bimetal element. This energy comes from resistive heating of the element and is therefore a function of power, which in turn is a function of the current flowing through the bimetal strip. Average power is related to the applied current by:

$$P_{AVE} = I_{eff}^{2} R$$

The current in the above expression represents the effective current. In a DC system, the effective current is the steady-state DC current. In an AC system, current varies sinusoidally about the zero axis and alternately reaches a positive and negative peak value (see Figure 4-21). The effective current for an AC signal is defined as the rms current and is related to the peak value by:

$$AC_{RMS} = \frac{AC_{PEAK}}{\sqrt{2}}$$

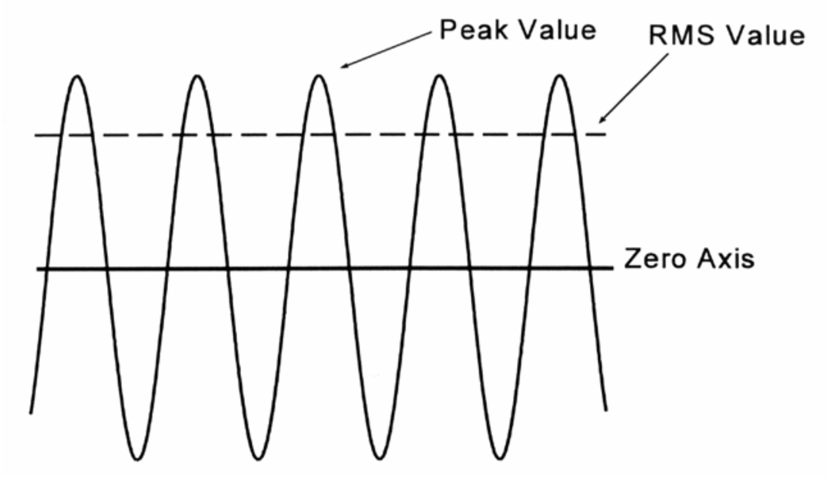


Figure 4-21
Typical Alternating Current

The above relationship between the rms and peak values applies to a single-frequency sinusoidal AC signal. AC current is normally defined in terms of rms rather than its peak value (see Appendix E for a more detailed derivation of the expression for rms current). For example, a 100-ampere current has an rms value of 100 amperes and a peak value of 141.4 amperes.

The rms value of AC current is effectively equal to a DC current of the same magnitude in terms of its power transmission and heating capability, hence the term *effective current*. Based on this relationship, the bimetal strip will respond in virtually the same manner regardless of whether the applied current is AC or DC, provided that the AC rms value equals the DC value. Since the thermal response (deflection) of the bimetal strip is effectively the same for AC rms and DC current of the same magnitude, the time delay trip characteristics depicted by the breaker's time-current characteristic curve represent a breaker's performance in either AC or DC applications.

4.10.2 Instantaneous (Magnetic) Trip Units

Instantaneous trip units contain an electromagnet connected to the breaker trip bar (see Figure 3-6). Line current passing through the magnetic element results in an attractive magnetic force on the magnet armature (a movable iron slug). When a short circuit occurs, the magnetic force generated by the short circuit current is strong enough to overcome internal spring tension. The armature then moves and actuates the latch on the breaker trip mechanism. This tripping action has no intentional built-in time delay.

The instantaneous trip is distinctly different in nature than the thermal trip. The instantaneous trip occurs in response to a magnetic force generated by the current. Current flowing through the magnetic trip unit generates a magnetic force on the trip armature according to the following expression for a simple armature design:

$$Force \propto \frac{(nI)^2}{\mu_0 A \ [R + \frac{2x}{\mu_0 A}]^2}$$

where,

I - Instantaneous magnitude of current

n - Number of effective turns in sensing coil

µ*0* Magnetic permeability of air (47p x 10 Henries/meter)

^{2x} - Effective air gap distance in armature

A - Cross-sectional area of armature

R - Combined reluctance (resistance to magnetic force of all parts of the armature; depends primarily on the armature geometric arrangement)

As shown in the above expression for a simple armature arrangement, the force is a function of

- Instantaneous current magnitude
- Effective number of turns in the current coil
- Air gap distance between the armature contacts
- Cross-sectional area of the armature
- Reluctance of the iron path in the armature

Once an MCCB has been built, the only variable above is current; the other parameters are design dependent and are constant.

As shown, the magnetic force is proportional to the square of the instantaneous current. With AC current, the magnetic force becomes larger as the sinusoidal current varies from zero to its peak value, with the maximum force created at the peak current value. Since the instantaneous trip point depends on the magnetic force exerted on the trip armature of the breaker, the trip point is more dependent on the peak current rather than the rms current. Note that instantaneous DC current has no such distinction between rms and peak values (neglecting rise time and ripple). While the magnetic force from an AC current will vary sinusoidally, the force generated by a DC current should be constant. For this reason, the magnetic trip unit will not respond the same to

AC rms and DC current, and the breaker's performance under DC current is expected to vary by some amount from the AC trip characteristics depicted by the time-current curve.

Another factor differentiating AC from DC current is the cycles of force obtained from AC current. When exposed to an AC overcurrent, the trip armature may "chatter," knocking the latch partially off with each successive electrical cycle. Eventually, with enough cycles, the latch is moved sufficiently to trip the breaker. With DC current, there are no cycles; the magnetic force generated by DC current must be sufficient to trip the armature latch with its single forced motion.

Remember that the peak and rms value of AC current are related by the factor √2. Based on the foregoing discussion, one might expect that the difference in instantaneous trip response between AC and DC current would be about √2, that is, a DC current might be about 1.41 times larger than an AC rms current to initiate an equivalent instantaneous trip. However, this much of a difference will not generally be observed because:

1. The AC peak current is not a sustained value; it is only the peak of a varying sinusoidal current.
2. The DC current is a sustained value even though it is smaller than the AC peak (assuming that the DC current is equal in magnitude to the AC rms value).

For these reasons, the effective difference between AC and DC currents on the instantaneous trip response can vary from 10% to 40%, that is, the value of DC current that will initiate a trip will typically be 10% to 40% higher than the AC rms current that will trip the breaker. For example, a breaker that trips at 1,000 amps AC rms current will trip at about 1,200 amps DC current if the conversion factor is 20%. Figure 4-22 shows the effect on the time-current response.

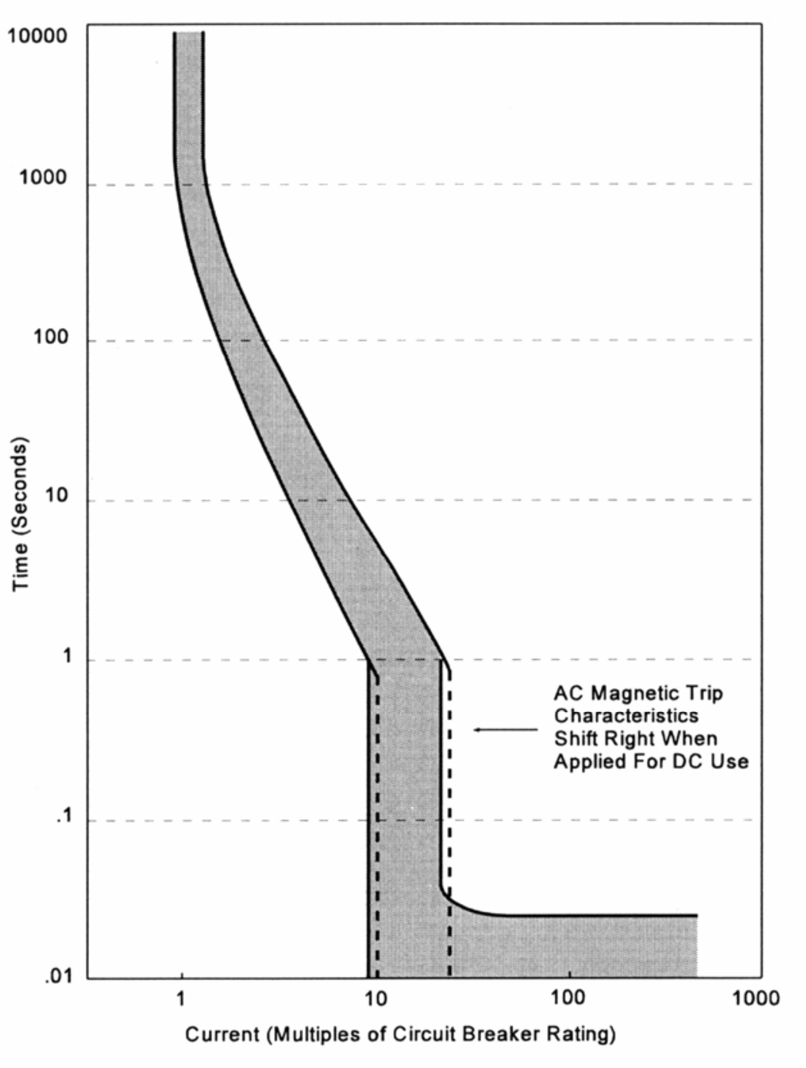


Figure 4-22
Typical Time-Current Curve for an MCCB Modified for DC Applications

The conversion factor between AC and DC current for each to cause an equivalent instantaneous trip is not a constant value that can be applied to all MCCB sizes and ratings. The difference between the two varies with frame size as well as the minimum to maximum ratings within the frame size. Design features that cause these variations include:

- Assembly variations within the magnetic circuit
- Spring constants
- Air gap

Application Considerations

- Armature bias
- Number of turns in sensing coil
- Latch loads
- Trip bar motion

The manufacturer should be consulted to confirm that the information provided on the time-current curves is applicable. Not all manufacturers' time-current characteristic curves readily indicate a difference between AC and DC in the instantaneous region. For example, one manufacturer provides the same curves for AC and DC applications; however, another document must be consulted to determine the correction factor to apply to the instantaneous region for DC applications. Other manufacturers provide the conversion information directly on the time-current curves. Also, each manufacturer may provide a different conversion factor for each MCCB model and rating ranging from as low as 10% to as high as 40%.

5
RELIABILITY AND FAILURE INFORMATION

Section 5 presents reliability and failure information with a focus on the MCCB subcomponents that fail most frequently and the expected failure modes of these subcomponents. A working-level understanding of hardware performance will help clarify the link between recommended maintenance practices and the rationale behind the recommendations.

Failed MCCBs are almost always replaced rather than repaired, and the original manufacturer is not consulted. As a result, manufacturers are usually distanced from the actual in-service failure rates of their products. Additionally, few failure modes for MCCBs result in a loss of equipment or plant conditions that trigger formal reporting in the nuclear industry. Therefore, comprehensive historical failure information is not readily available, and the data that are available are presented in this document in a qualitative rather than quantitative fashion. Avoiding a rigorous statistical analysis of the data probably prevents incorrect conclusions.

The conclusions provided in this section focus on how MCCBs fail and the components most susceptible to failure. The available information does allow insight into MCCB failure mechanisms. The reliability and failure information discussed here came from the nuclear industry, that is, from the Nuclear Plant Reliability Data System (NPRDS), Nuclear Regulatory Commission (NRC) NUREG reports, Licensee Event Reports (LERs), NRC Information Notices and Bulletins, and other miscellaneous sources. Some sources of information outside the nuclear industry were evaluated. Discussions with the major manufacturers also provided insight into breaker reliability.

5.1 Failure Modes

Section 5.1 describes MCCB failure modes, categorized by subcomponent. Based on NPRDS data, Figure 5-1 displays the approximate percentage of failures attributable to each category. Note that NPRDS does not guarantee a full understanding of all failures at each plant since many applications are excluded from the NPRDS scope. Nonetheless, NPRDS information can still offer some insights into the nature of those failures that have been reported.

A few observations about the data in Figure 5-1 are worth noting:

- The single-most common failure type is related to overcurrent trip devices.
- Almost two-thirds of the failures are attributable to the mechanical operating mechanism or the overcurrent trip device. A preventive maintenance program that addresses these two areas would detect the most commonly expected failures.
- None of the reported failures is related to poor or low insulation resistance. By itself, insulation resistance is not considered an important predictor of performance.

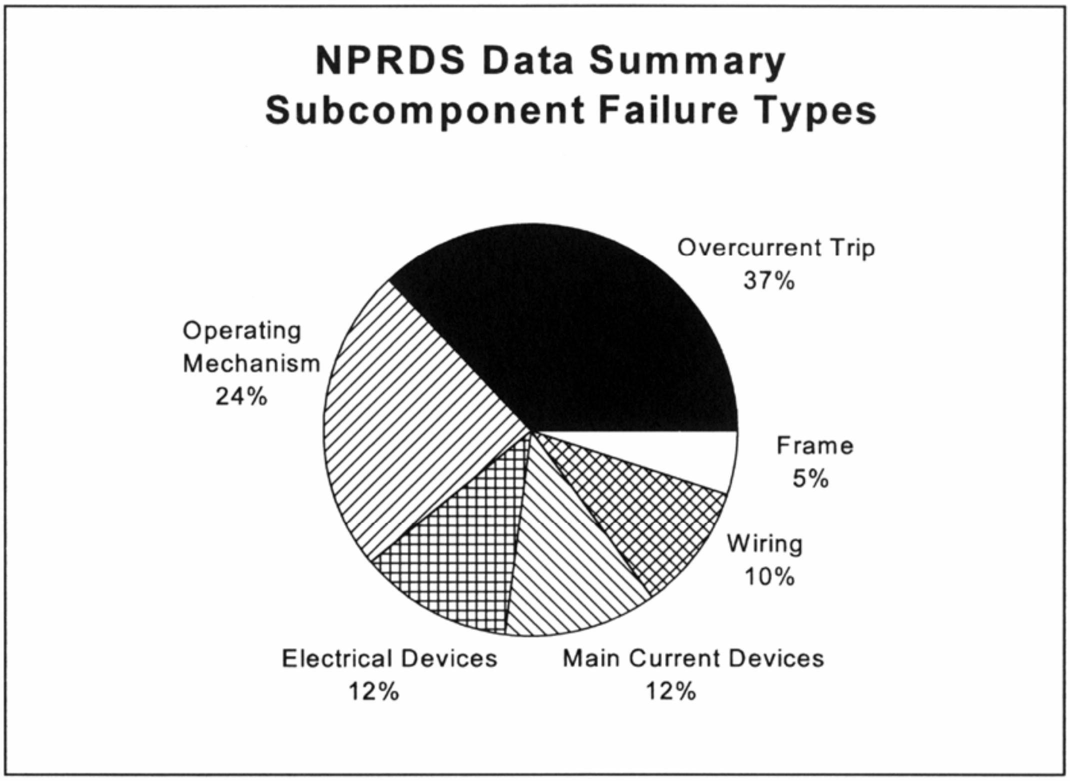


Figure 5-1
Subcomponent Failure Summary

The paragraphs that follow describe the subcomponents in each category shown in Figure 5-1 and their failure modes.

5.1.1 Operating Mechanism

The operating mechanism includes mechanical components used for opening, closing, tripping, and indication. Degradation and failure modes include:

- Dried lubricant
- Out of aligmnent/adjustment
- Worn out, fatigued, damaged, or broken components

Failures typically result in undesired tripping, breaker binding, or an inability to open, close, or reset the breaker. Dried lubricant has been a persistent problem with some older MCCBs, causing the NRC to issue an Information Notice on one particular problem.

5.1.2 Overcurrent Trip Unit

The overcurrent trip unit consists of thermal, magnetic, thermal-magnetic, or solid-state devices/actuators that initiate a trip when an overcurrent condition is sensed. Degradation and failure modes include:

- Damaged or broken components
- Calibration drift
- Improper setpoint
- Degradation in material properties

Failures can result in the breaker not tripping under overcurrent conditions, nuisance tripping, an out-of-calibration state, inability to close or reset the breaker, or undesired tripping free.

5.1.3 Frame

The frame includes the insulated structural case and the operating handle. Degradation and failure modes include:

- Broken handle
- Misaligned handle
- Cracked, chipped, damaged, or broken frame

Failures may cause dielectric breakdown and/or structural weakness that could result in catastrophic failure of the breaker under fault conditions, excessive leakage current, or arcing between poles or to ground.

5.1.4 Wiring and Cabling Terminations

Terminations include line- and load-side cable connections and control wiring connections. Degradation and failure modes include:

- Loose connection
- Dirty connection
- Wrong size of connector or wire
- Damaged or broken wire, terminal, or connector

Failures usually result in a high-resistance connection that generates excessive heat (which may eventually damage the terminations or cause the thermal trip unit to actuate) and creates an excessive voltage drop.

5.1.5 Main Current Components

The main current components include the contact assemblies, arc chutes, and wiring terminals. Degradation and failure modes include:

- Pitted, eroded, welded, or otherwise damaged contacts
- Dirty or contaminated contacts
- Degraded, damaged, or broken arc chutes

Failures include a wide spectrum of events, such as overheating, high contact resistance, excessive arcing, excessive voltage drop, failure to open, and potentially catastrophic failure during a fault.

5.1.6 Electrical Control Devices

Electrical control devices include electrical switches, auxiliary contacts, indicator lights, relays, shunt trips, and undervoltage relays. Degradation and failure modes include:

- Coil winding, rectifier, or relay failure
- Dirty, contaminated, damaged, or broken contacts

Failures may result in an undesired trip or a failure to trip upon the appropriate signal or condition.

5.2 Failure Mechanisms

Although MCCBs are typically placed in mild environments, several mechanisms can stress, age, or degrade breaker components. These mechanisms can cause MCCB degradation or failure in the various ways discussed in Section 5.1.

5.2.1 Thermal Damage

Thermally induced stresses result from resistive heating (ohmic heating) of current carrying components. This includes heating from continuous load currents and from fault currents. Excessive ohmic heating typically occurs at the breaker contacts or cable terminations when resistance at these locations is too high. If the resistance is too high, the contacts or termination and the surrounding insulating material will be degraded.

Even though an MCCB is designed to interrupt a fault within its rating, damage can occur when a heavy fault current is interrupted. The high temperature associated with arcing can rapidly accelerate contact and arc-chute degradation.

5.2.2 Electrical Damage

Electrically induced problems can occur if an MCCB is subjected to extreme voltage or current transients, usually in the form of a voltage spike or fault. Voltage spikes can result in flashover to ground or between phases, short circuiting of components, and a danger of restrike during interruption. Heat generated by the arc drawn between the contacts when an MCCB interrupts a large current vaporizes some metal from the contacts. This metal can be deposited on the surfaces of insulating material, and thereby decrease the insulating capability of the material. This phenomenon can also degrade the performance of the arc chutes.

5.2.3 Mechanical Damage

Mechanically induced stresses result primarily from routine open-close operations, fault interruption, vibration, and friction. These stresses can cause contact degradation, fatigue, wear, loose connections, and ultimately component failure.

5.2.4 Environmental Damage

Environmental factors can significantly affect the performance and reliability of MCCBs. Specific factors include extreme ambient temperatures; humidity; and intrusion of dust, dirt, chemicals, or other contaminants into the MCCB case. These degradation mechanisms can cause increased friction and wear; formation of current leakage paths; stiffening or freezing of mechanical joints; oxidation; hardening or drying of lubricants; and embrittlement of nonmetallic parts.

Operation of some MCCBs in an ambient temperature outside the manufacturer's recommended band can cause a shift in the performance characteristics of the thermal trip unit. Nuisance tripping may occur at higher temperatures, and undesired overloads may be allowed to persist at lower temperatures.

5.3 Method of Failure Detection

Figure 5-2 summarizes the methods by which failures were detected as reported by NPRDS. The majority of failures were detected by either a breaker trip while in service or by a periodic maintenance (PM) test.

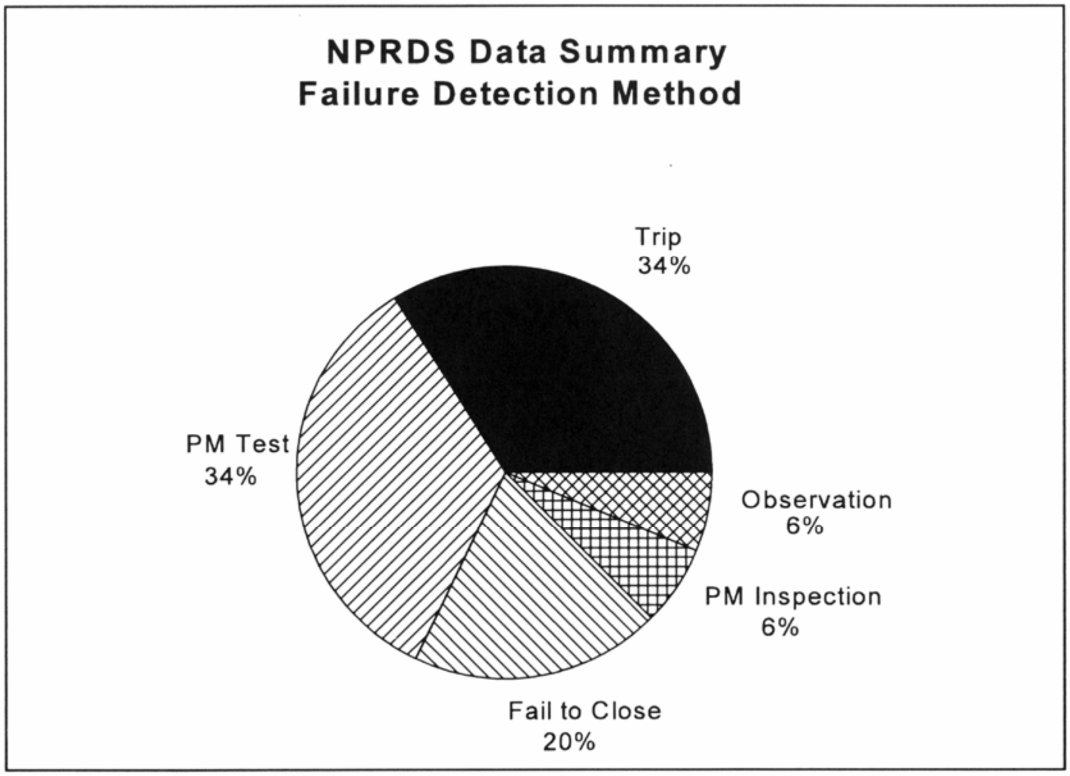


Figure 5-2
Failure Detection Method

5.4 NRC Nuclear Plant Aging Review (NPAR) Program Recommendations

The NPAR program was initiated by the NRC to investigate aging effects on installed equipment in nuclear power plants. The program included a significant research effort into MCCB aging and monitoring methods to evaluate the aging of MCCBs. The general objectives of the NPAR program, as explained in NUREG-1144, Revision 1, *Nuclear Plant Aging Research (NPAR) Program Plan*, include:

- Identify and characterize aging and service-wear effects associated with electrical and mechanical components, interfaces, and systems likely to impair plant safety.
- Identify and recommend methods of inspection, surveillance, and condition monitoring of electrical and mechanical components and systems that will be effective in detecting significant aging effects before loss of safety function so that timely maintenance and repair or replacement can be implemented.
- Identify and recommend acceptable maintenance practices that can be undertaken to mitigate the effects of aging and to diminish the rate and extent of degradation caused by aging and service wear.

Two NUREGs from the NPAR program directly relate to MCCBs. NUREG/CR-4715, *An Aging Assessment of Relays and Circuit Breakers and System Interactions,* provides a reliability and failure assessment of MCCBs based on industry data sources such as the Nuclear Plant Reliability Data System. Although NUREG/CR-4715 does provide failure data for a number of electrical components, it does not provide definitive information regarding MCCBs.

NUREG/CR-5762, *Comprehensive Aging Assessment of Circuit Breakers and Relays,* evaluated several inspection and test techniques that can be used on MCCBs. Currently used methods as well as advanced monitoring methods were evaluated by this NPAR program. Recommendations are provided regarding the effectiveness of the various inspection and test methods. NUREG/CR-5762 evaluated the following traditional methods of inspecting and testing MCCBs:

- Visual inspection
- Mechanical actuation
- Insulation resistance test
- Pole resistance test
- 100% rated hold-in test
- 135% rated current hold-in test
- 300% overcurrent trip test
- Instantaneous trip test

The above inspections and tests were found to be effective, when properly performed, at detecting and mitigating aging—except for the insulation resistance test and mechanical actuation. This maintenance guide is in general agreement with the above findings with the following clarifications:

- **Insulation Resistance Test:** As discussed in Section 5.1, insulation resistance alone is not considered an important predictor of performance. NUREG/CR-5762 does note that insulation resistance measurements are still useful to ensure that connections are of high integrity for personnel and equipment safety after maintenance is performed. Section 9.1 of this maintenance guide recommends performing the insulation resistance test when other tests are scheduled.
- **Mechanical Operation:** Despite the conclusion reached in this NUREG, mechanical operation is still recommended in this guide because it is 1) an integral part of industry standards on MCCB inspection and maintenance, 2) manufacturers recommend periodic cycling of MCCBs, and 3) industry experience has found that MCCBs tend to perform better if periodically exercised. Refer to Section 7.3 for additional information regarding mechanical operation.
- **Rated Hold Test:** The rated hold test is recommended by this maintenance guide only if nuisance tripping is a concern. Refer to Section 9.3 for additional information regarding the rated hold test.

In addition to the more traditional inspections and tests, NUREG/CR-5762 evaluated the following advanced monitoring methods for MCCBs:

- Vibration testing
- Acoustic testing
- Infrared pyrometry
- Infrared scanning
- On-contact temperature
- Ion detection
- 600% overload
- Dielectric strength

Of the above advanced monitoring methods, NUREG/CR-5762 found infrared temperature measurements and vibration testing to be effective for detecting MCCB degradation. Infrared thermography has been included in this maintenance guide and is discussed in Section 7.1.2.

NUREG/CR-5762 recommends performing vibration testing as part of mechanical actuation, 300% overcurrent trip testing, and instantaneous overcurrent trip testing; however, it does not provide any information regarding what equipment to use, how to perform vibration testing, or how to evaluate vibration test results. The recommendation to perform vibration testing has not been incorporated into this guide. Although vibration testing may be useful for evaluating MCCB performance, the series of inspections and tests specified by NEMA AB-4 is considered adequate to confirm MCCB performance.

6

MAINTENANCE PROGRAM DEVELOPMENT GUIDELINES

6.1 Overview

This section discusses the reasons for having an MCCB maintenance program and what such a program should accomplish. Specifically, this section discusses the following:

- Regulatory requirements
- Industry and manufacturers' guidance
- Determining circuit breaker criticality
- Maintenance tasks
- Maintenance task frequencies

6.1.1 Why MCCB Maintenance Programs?

The reason for having a MCCB maintenance program is to confirm the continued reliability of MCCBs during the life of the plant.

A few domestic U.S. nuclear power plants have specific regulatory requirements or commitments regarding MCCB maintenance and testing. An NRC study published in 1992 makes the following point:

> . . . out of the small population of the total number of operating plants that have specific technical specification requirements for the testing of any molded case circuit breakers, only MCCBs used for containment electrical penetration over-current protection are addressed.

Although only a few plants are specifically required to perform testing, recent regulatory actions have referenced CFR Part 50, Appendix B, Criterion XI, as a reason for including safety-related MCCBs in a maintenance program. Criterion XI states, in part, that

> A test program shall be established to assure that all testing required to demonstrate that structures, systems, and components will perform satisfactorily in service is identified and performed in accordance with written test procedures which incorporate the requirements and acceptance limits contained in applicable design documents.

NRC Information Notice 93-64, Periodic Testing and Preventive Maintenance of Molded Case Circuit Breakers, specifically discusses routine testing of MCCBs and cites an NRC study of operational experience (AEOD S92-03), an NRC aging assessment (NUREG/CR-5762), and IEEE Standard 308-1974. When discussing NUREG/CR-5762, Comprehensive Aging Assessment Study of Circuit Breakers and Relays, March 1992, Information Notice 93-64 states:

> The study found that MCCB preventive maintenance practices (such as manual exercising), can mitigate the effects of aging and help ensure continued MCCB reliability. However, manual exercising alone was not found effective in detecting or assessing age-related degradation. Detecting or assessing degradation, the study found, could only be accomplished through appropriate periodic testing and monitoring. Certain standard MCCB tests (such as individual pole resistance, 300-percent thermal overload, and instantaneous magnetic trip tests) performed periodically were found effective along with the additional techniques of infrared temperature measurement and vibration testing.

IN 93-64 also quotes IEEE Standard 308-1974, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations. According to IN 93-64, this IEEE document recommends that

> periodic tests be performed at scheduled intervals to detect the deterioration of the equipment and to demonstrate operability of the components that are not exercised during normal operation.

In addition, ANSI-/IEEE Standard 242-1986 states that

> tripping the circuit breakers electrically must be done “periodically” to assure proper operation. The standard states that experience has indicated that if the circuit breakers are allowed to remain in service for an extended period of time without an electrical operation, the internal mechanism and joints may become stiff such that the circuit breaker will operate improperly when subjected to abnormal current. Therefore, each pole of the circuit breaker should be electrically exercised.

It should also be noted that INPO SOER 98-02 provides recommendations pertaining to circuit breaker reliability. The scope of this SOER includes MCCBs.

6.1.2 Effective Use of Resources

Electric power plants typically have a large number of MCCBs. Routine inspection and testing of all MCCBs would obviously not be an effective use of plant maintenance resources. Using whatever method, plants should determine what MCCBs are critical to plant safety and reliability and perform appropriate maintenance tasks based on the application. Methods for determining criticality are discussed in Section 6.4, “Determining Circuit Breaker Criticality.”

This approach is supported by statements and correspondence from the NRC and NEMA. NRC IN 93-64 states, “The recommendations of these (industry MCCB testing and maintenance) publications may not be applicable in every instance, depending on the specific components installed, their functions, and their environment.”

6.1.3 Manufacturers’ Perspective

It should be noted that, from the manufacturers’ perspective, MCCBs are designed such that they do not require maintenance or testing for their service life. Manufacturers, as a general rule, do not recommend periodic electrical testing.

For critical MCCBs or those used in harsh environments, plant personnel may consider it prudent to periodically determine that these MCCBs remain functional through a combination of inspections, mechanical cycling, and electrical testing based on the application and environment. NEMA considers the mechanical operation test to provide much of the functional indication of a MCCB.

6.1.4 Variations in Plant Programs

This document outlines the considerations that can be used to develop an MCCB maintenance program. However, specific tasks and frequencies may differ from plant to plant and from unit to unit.

6.2 Regulatory Requirements

6.2.1 10CFR50, Appendix B, Criterion XI

Based on the recent enforcement history, the NRC has established an expectation that all safety-related MCCBs be evaluated for the appropriate test requirements. In late 1997, the NRC issued a notice of violation because a plant’s test program failed to meet its original licensing basis for the testing of safety-related MCCBs. The plant’s licensing basis did not explicitly require inspection and testing of MCCBs. However, it did require that tests should be performed at scheduled intervals to demonstrate that components that are not exercised during normal operation are operable. The NRC referenced 10 CFR Part 50, Appendix B, Criterion XI, “Test Control” and the plant’s UFSAR commitment to “Proposed IEEE Criteria for Class 1E Electrical Systems for Nuclear Power Generating Stations” (June 1969) as the basis for the requirement that was violated.

6.2.2 Technical Specifications

As mentioned in Section 6.2.2, only a few domestic U.S. nuclear power plants have specific regulatory requirements or specific regulatory commitments regarding MCCB testing. An NRC study published in 1992 makes the following point:

> . . . out of the small population of the total number of operating plants that have specific technical specifications requirements for the testing any molded case circuit breakers, only MCCBs used for containment electrical penetration over-current protection are addressed.

Standardized Technical Specifications have moved the requirements to test containment penetration MCCBs into Technical Requirements Manuals (TRMs).

6.2.3 Regulatory Commitments

Beyond nuclear plants' license requirements contained in the plant's Updated Final Safety Analysis Report (UFSAR) and Technical Specifications, plants may have made additional commitments in response to NRC generic communications (such as Generic Letters, Bulletins, and Notices) or as a result of an enforcement action. All of these sources may include requirements as to how the MCCBs will be maintained and tested by the plant. These requirements must be considered when developing the plant's program for MCCBs.

6.2.4 Appendix R

The NRC has provided guidance regarding Appendix R impacted breakers and preconditioning prior to testing in Branch Technical Position APCSB 9.5-1. The industry response is contained in NEI 00-01, Guidance for Post-Fire Safe Shutdown Analysis, dated May 2003. The NEI guide addresses design issues to ensure proper equipment operation in the event of a fire. The guidance in NEI 00-01 relative to MCCB maintenance and testing is limited to the following:

> Proper operation of the overcurrent devices shall be ensured by appropriate testing, inspection, maintenance and configuration control.

6.2.5 Maintenance Rule

One NRC regulation that requires particular attention is the Maintenance Rule (10CFR50.65), which provides NRC expectations for trending and monitoring equipment. For the MCCBs in the Maintenance Rule scope, failures are captured within Maintenance Rule reporting requirements. In addition, Maintenance Rule requirements provide for periodic assessments to ensure that all adverse conditions are captured. Plants can either monitor MCCBs within the systems of the loads they supply or within their own system (AC/DC distribution systems). If the MCCBs are monitored within the systems of the loads they supply, specific circuit breaker adverse trends may not become apparent.

6.2.6 10CFR50.49 – Equipment Qualification

An equipment qualification program may provide specific maintenance, testing, or replacement requirements for MCCBs. Equipment qualification requirements should be considered when developing or evaluating a program.

6.3 Industry and Manufacturers' Guidance

This section identifies and discusses industry and manufacturers' guidance that plants may wish to consider when developing an MCCB test program.

6.3.1 NRC Studies

6.3.3.1 AEOD S92-03

AEOD S92-03, Review of Operational Experience with Molded Case Circuit Breakers in US Nuclear Power Plants, June 1992 (Office for Analysis and Evaluation of Operational Data; US Nuclear Regulatory Commission) documents AEOD's review of MCCB operational experience and provides conclusions based on this review. This study makes the following key points:

> . . . out of the small population of the total number of operating plants that have specific technical specifications requirements for the testing of any molded case circuit breakers, only MCCBs used for containment electrical penetration over-current protection are addressed.
>
> . . . none of the industry guidance and standards specify recommended frequencies for testing and maintenance.

6.3.1.2 NUREG/CR-5762

NUREG/CR-5762, Comprehensive Aging Assessment of Circuit Breakers and Relays, describes the results of a comprehensive aging assessment of relays and circuit breakers completed as part of the NRC Nuclear Plant Aging Research (NPAR) Program. The scope of this document includes MCCBs. The significant results of this research included the following recommendation, that

> Infrared temperature measurement be added to the maintenance practices for molded case circuit breakers.

6.3.2 NRC Notices and Bulletins

There are a significant number of NRC Notices and Bulletins related to MCCBs, and a list is provided in Appendix A.

6.3.3 INPO Guidance

6.3.3.1 SOER 98-02

In 1998, INPO issued Significant Operating Event Report (SOER) 98-02 to describe industry-wide breaker reliability problems and to issue a set of recommendations to enhance breaker maintenance. The scope of SOER 98-02 includes MCCBs.

According to SOER 98-02, "The discussions and recommendations in this document (INPO SOER 98-02) apply to safety-related circuit breakers and breakers important to plant reliability, including large and molded case circuit breakers of all voltage ranges."

The recommendations in this SOER addressed the following key topics:

- Receipt inspections
- Vendor recommendations and station and industry operating experience
- Technical guidance from manufacturers' communications, technical communications, and technical manual changes
- Circuit breaker maintenance histories and unique identifiers
- Training

6.3.3.2 INPO AP-913

INPO AP-913, Revision 1, describes an equipment reliability process to efficiently maintain a safe and reliable plant. This document provides criteria for identifying critical, non-critical, and run-to-failure components. This is one method that can be utilized when determining circuit breaker criticality, discussed in Section 6.4, "Determining Circuit Breaker Criticality."

6.3.4 NEIL Standards

Power plants should also consider any insurance standards or requirements that may apply to circuit breakers. In the United States, most nuclear power plants consider *Nuclear Electric Insurance Limited, Boiler and Machinery Loss Control Standard 18* (September 2004) in their circuit breaker maintenance program. This standard deals with inspection and maintenance of circuit breakers and applies to non-Class 1E, low-voltage (600 volts and below) circuit breakers for critical equipment, including the following:

- Turbine-generator lube oil pumps
- Generator seal oil pumps
- Turbine-driven feedwater pump lube oil pumps (and the bus feeder breakers for this equipment)
- Normal and emergency power bus feeder circuit breakers (15 kV and below)
- Circuit breakers for critical equipment (that is, equipment necessary for the protection of the turbine-generator and turbine-driven feedwater pumps)

This standard recommends that U.S. nuclear plants do the following:

1. Establish a preventive maintenance and overhaul program for circuit breakers.
2. Establish an inspection program for new and refurbished circuit breakers to include functional testing prior to installation.
3. Establish an inspection program for MCCBs to verify that breakers are fully functional and that they trip at the set amperage prior to installation.

6.3.5 Industry Standards

A complete list of industry standards is provided in Appendix A. This section highlights key documents that plants should consider when developing or reviewing an MCCB maintenance and testing program.

6.3.5.1 IEEE

The following two IEEE documents are typically cited when discussing MCCB maintenance and test programs.

- IEEE 308
- IEEE 242-1986

6.3.5.2 NEMA AB-4

The current industry-accepted standard for maintenance and testing of MCCBs is NEMA AB-4 (original issue in 1991 with revisions in 1996, 2001, and 2003). NEMA AB-4-2003, Section 3.4, discusses an MCCB maintenance program that includes visual inspection and thermography (Clause 4), cleaning and inspecting terminals and connectors (Clause 5), mechanical operation (cycling) (Clause 6), and electrical testing (Clause 6). Table 6.2 provides NEMA’s recommendations. AB-4 2003 further states that these may be applied independently or in combination to establish a maintenance program.

NEMA and the typical manufacturer's perspective is that MCCBs are designed such that they do not require maintenance or testing for their service life. If some level of MCCB maintenance is deemed to be warranted on the basis of safety, environment, or equipment reliability, then NEMA offers AB-4 as guidance for inspection and testing.

6.3.5.3 NFPA 70-B

NFPA 70-B-2002, Chapter 13, addresses molded case circuit breaker power panels, which includes molded case circuit breakers. Maintenance of molded case circuit breakers is provided for in paragraphs 13.7 (Types of Maintenance) and 13.8 (Inspection and Cleaning), 13.9 (Loose Connections), and 13.10 (Mechanical Mechanism Exercise). Each of these paragraphs describes the steps required to be performed; the periodicity is not addressed.

Paragraph 13.7 discusses mechanical maintenance and refers to paragraph 20.10.2.4 for the electrical testing. Paragraph 20.10.2.4, Molded-Case Circuit Breaker Testing, is composed of 6 subparagraphs:

1. General Information
2. Testing Thermal-Magnetic Circuit Breakers
3. Overload Testing Considerations
4. Overcurrent Trip Minimum/Maximum Ranges
5. Evaluation of Results
6. Testing Instantaneous-Only Circuit Breakers

6.3.6 EPRI Guidance

EPRI's *Preventive Maintenance Basis Database, Version 5.0* (product number 1003282) is a software database that assists power plants in evaluating their preventive maintenance (PM) programs. This software package has many features but also contains maintenance task listings and suggested frequencies. This EPRI software uses criticality, duty cycle, and service conditions to classify a variety of power plant equipment. (This process is somewhat similar in its objectives to the methodology found in INPO AP-913.) The maintenance tasks discussed in this software package are in alignment with the tasks discussed with the current report and with NEMA AB-4. The maintenance frequencies in this software are discussed in this report in Section 6.6, "Maintenance Task Frequency."

6.3.7 DOE Studies

Under a collaborative agreement between the U.S. Department of Energy and EPRI, the Sandia National Laboratory published a series of aging management guides (AMGs). SAND93-7069, *Aging Management Guideline for Commercial Nuclear Power Plants – Motor Control Centers* (February 1994) provides the identification of plausible aging mechanisms and effects as well as recommended aging management methods.

Table 6.1 provides a summary of the principal aging effects and mechanisms, the associated effective aging management methods, and the specific reference, as applicable. The following are descriptions and clarifications for the column headings in the table:

- *Aging Effects* are the manifestations of aging as observed in the field.
- *Aging Mechanisms* are the possible causes of the observed aging effects.
- *Typical Aging Management Programs* consist of those preventive and predictive actions for detection and diagnosis of incipient aging and degradation before failure occurs.

The aging mechanisms and aging effects presented in Table 6-1 reflect the normally benign environment in which the major components are located; that is, the reactor, auxiliary, or turbine building in the plant. The environmental conditions for the equipment are normally controlled and include protection against external environments such as weather, UV light, exposure to rain or water, and temperature extremes. The location of the equipment is such that easy maintenance access is assured and radiation is commensurate with normal access provisions. Some MCCBs may also be installed in unheated plant areas or areas with elevated temperatures (for example, containment, steam tunnel, and the feed pump area). In this case, a plant-specific aging evaluation may be required. The use of caution is also appropriate with MCCBs that are located outdoors with respect to functional concerns affected by freezing, viscosity change for lubricants, moisture intrusion, and condensation. In contrast to the external environment, the local conditions for MCCBs situated in closed cubicles may be significantly different from those in the general surroundings. Temperature rise in cubicles that contain energized equipment (such as transformers, coils, and resistors) leads to premature aging of susceptible materials, such as grease, plastics, and cable/wiring insulation.

Table 6-1
Aging Management Summary for MCCBs

Part	Material(s)	Aging Effects	Aging Mechanism	Typical Aging Management Program
Operating mechanism	Various	Binding, sticking of mechanism	Lubrication failure	Testing of breaker, clean, inspect, cycle
Current trip device, contacts, lugs	Various	Loss of contact, contact erosion, discoloration	Loose connections, overheating	Thermography Testing of breaker, clean, inspect, cycle
Housing	Plastic	Cracking, splitting, discoloration, melting	Overheating, short circuit, premature aging	Thermography Clean, inspect breaker

6.4 Determining Circuit Breaker Criticality

This section discusses how to determine which breakers require routine PM tasks within a maintenance program and provides two examples of methodologies that can be used to classify breakers by criticality.

Not all breakers have the same criticality within a PM program. Some breakers are critical to safe plant operation and/or shutdown while others may supply power to non-critical equipment such as bathroom water heaters.

For non-critical breakers, routine maintenance tasks may not be necessary. This philosophy is supported by the stated positions of the NRC, NEMA, and the manufacturers. For more significant breakers, some routine tasks such as thermography or cycling may be appropriate based on the criticality of the circuit breaker. For critical, risk-significant, safety-significant, or economically significant breakers, a more comprehensive combination of routine tests and inspections may be prudent.

The previous revision of this document (EPRI product number NP-7410-V3, Revision 1; 1996) suggested a simple method by which MCCBs can be prioritized. This method proposed classifying MCCBs into four categories, with category 1 being the most critical and category 4 being non-essential MCCBs that were considered run-to-failure.

Another way of determining circuit breaker criticality is by following the methodology described in INPO AP-913, Revision 1. This document provides criteria for identifying critical, non-critical, and run-to-failure components.

The method used to determine criticality should not be complex or require detailed engineering analysis.

No single prioritization method can be expected to work for all plants. A plant will need to develop a prioritization method that satisfies its particular needs.

6.4.1 What to Consider

Regardless of the method used, the following should be considered when determining which circuit breakers require routine PM tasks within a maintenance program:

- Regulatory Requirements: includes Technical Specifications, regulatory commitments, Bulletins, Appendix R, Licensing requirements, design requirements, and equipment qualification requirements)
- Risk Significance (health and safety of the public): includes failure of a non-safety-related breaker that could take out an entire MCCB (and effectively take out a safety-related breaker)

- Economic significance
- Operating environment
- Industry and plant specific OE

For plants having Class 1E and non-Class 1E equipment powered from the same MCCB or power panel, credit may be taken for the MCCB to function as the isolation device between the Class 1E motor control center and non-Class 1E equipment powered by the MCCB. In this case, the MCCB must open, if necessary, to isolate the Class 1E system from any non-Class 1E equipment failures caused by the design basis event. If a plant has Class 1E equipment powered only from a motor control center or power panel, equipment or breaker failures should be covered by the plant's single failure analysis.

6.5 Maintenance Tasks

The current industry-accepted standard for maintenance and testing of MCCBs is NEMA AB-4. (Revision 2003 was current at the time of this publication.) Table 6-2 outlines the maintenance tasks discussed in NEMA AB-4-2003.

Sections 7, 8, and 9 of this report also discuss these same maintenance tasks.

It should be emphasized that all of these tasks may be not required based on the criticality of the MCCB to be tested. Section 2.4 of NEMA AB-4 states:

> These (inspection, preventive maintenance, and testing) sections may be applied independently or in combination to establish such a (MCCB maintenance) program.

In addition, NRC Information Notice 93-64 states that

> The recommendations of these (industry MCCB testing and maintenance) publications may not be applicable in every instance, depending on the specific components installed, their functions, and their environment.

For non-critical breakers, no routine maintenance tasks may be necessary. For more significant breakers, some routine tasks such as thermography or cycling may be appropriate, based on the criticality of the circuit breaker. For critical, risk-significant, safety-significant, or economically significant breakers, a more comprehensive combination of routine tests and inspections may be prudent.

An MCCB maintenance program should consider the use of infrared thermography as a means to monitor the condition of selected MCCBs within the program.

Table 6-2
NEMA AB-4 Maintenance Tasks

NEMA AB-4 Tasks	
Overheating Inspection	Overheating inspection via infrared thermography (Sec 3.2.2) or exposed face temperature check (tactile-finger touch, 3 seconds), following a 3-hour heat-up. (Section 3.2.2)
Enclosure Inspection	Verify breaker ratings. (Section 3.3.2.3) Examine breaker surfaces for dust, dirt, soot, grease, or moisture and clean it. (Section 3.3.2.4) Examine housing for cracks and replace if cracks are found. (Section 3.3.2.5) If there is evidence of overheating or arcing, investigate the cause. (Section 3.3.2.6 (b)) Verify that conductors are the right size and visually check that all connections are clean and secure. (Section 3.3.2.6)
Mechanical Operation Inspection	Mechanical operation: breaker handle should operate smoothly without binding. Use an ohmmeter (or similar) to verify On-Off positions. (Section 5.2.2) (MCCB installed but electrically isolated.)
Overcurrent Test	Instantaneous overcurrent trip test with the breaker removed from enclosure. (Section 5.6) Inverse time overcurrent trip test. (Section 5.5)
Electrical Tests	Insulation resistance test at 500 VDC minimum. (Section 5.3) Individual pole resistance test (millivolt drop test). (Section 5.4) Rated hold-in test (performed when the breaker is tripping under normal load). (Section 5.7) Shunt trip release test. (Section 6.2)

6.6 Maintenance Task Frequency

This section discusses industry guidance on maintenance task frequency.

6.6.1 NRC

The NRC has no regulations that specify inspection or testing frequencies. Instead, the NRC directs the licensees to the requirements of 10CFR50, Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants,” for testing of components to demonstrate satisfactory performance.

6.6.2 Manufacturers

Manufacturers' literature typically provides little information or guidance regarding frequency of inspections or testing.

6.6.3 NEMA

NEMA AB-4 provides guidance for MCCB testing and maintenance. However, there is little guidance regarding frequency of inspections or testing. NEMA AB-4-2003 does reference NFPA 70B, "National Fire Protection Association's Recommended Practice for Electrical Equipment Maintenance."

6.6.4 NFPA

NFPA 70B, "National Fire Protection Association's Recommended Practice for Electrical Equipment Maintenance," discusses MCCB maintenance. Similar to NEMA's AB-4, it discusses electrical testing of MCCBs, including overload (300%) and instantaneous testing. In the 1998 edition, NFPA provides a "typical frequency" for performing inspections and electrical testing of three to six years.

6.6.5 Determining Maintenance Frequency

Each plant should determine how best to establish breaker maintenance and test periodicity. A plant's inspection and testing program must maintain the plant's licensing basis and regulatory expectations, while ensuring that the MCCBs perform with a high degree of reliability in a cost-effective manner.

As discussed in Section 6.1.1, inspection and test periodicities are plant-specific. Regardless of the technique selected for categorizing breakers, the end goal is to establish a test periodicity and a specific set of inspections and tests for a given breaker. To determine a plant-specific inspection and testing frequency, the plant needs to:

- Ensure that regulatory commitments are addressed
- Determine the criticality of the MCCB with respect to plant and public safety
- Determine the criticality of the MCCB with respect to plant operational reliability
- Review the manufacturer's recommendations
- Review plant and industry operating experience

6.7 Putting It All Together: Critically, Tasks, and Frequency

When developing an MCCB maintenance program, a plant will need to develop a method for prioritizing their MCCBs by criticality, determine what maintenance tasks should be performed given the criticality, and determine an appropriate maintenance frequency. Regardless of the method used to prioritize MCCBs, the criticality assigned to each circuit breaker should establish the tasks and frequency of inspection and testing to be performed.

Table 6-3 provides an example of the process of categorizing MCCBs by their criticality and associating maintenance tasks based on this criticality.

It is possible that all MCCBs within a plant may be accounted for in the MCCB maintenance program. However, it is also possible that the vast majority of these MCCBs may be categorized as run-to-failure.

Table 6-3
Criticality vs. Maintenance Tasks Performed

	Regulatory	**Critical**	**Non-Critical**	**Run-to-Failure**
Testing To Be Performed	As specified by regulation	Depending on the criticality of the equipment, one or more of the following maintenance tasks may be considered: • Thermography • Visual inspection/ cleaning • Mechanical operation (cycling) • Electrical testing (including overcurrent testing)	Depending on the criticality of the equipment, one or more of the following maintenance tasks may be considered: • Thermography • Visual inspection/ cleaning • Mechanical operation (cycling)	No routine maintenance tasks
Frequency	Plant-specific	Plant-specific	Plant-specific	--------

7

INSPECTIONS

MCCB inspections are discussed in Section 7. The main objectives of this section are to:

- Provide a step-by-step description of how periodic inspections should be performed.
- Offer insight into what the inspections accomplish and why they are (or are not) important for ensuring breaker reliability. Discussions of the failure mechanisms that each inspection might detect, as well as any inherent limitations of the inspection, are included.

The emphasis here is on how to perform the inspections and what the inspections should accomplish. See Section 6 for information on periodicity and equipment prioritization.

National Electrical Manufacturers Association (NEMA) Standards Publication AB-4-2003, *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications,* is acknowledged as a principal reference source. NEMA AB-4-2003 represents the manufacturers' consensus regarding how to inspect and test MCCBs.

7.1 Overheating Inspection

7.1.1 Purpose of Inspection

Breaker overheating affects MCCB performance. A breaker overheating inspection is intended to identify hot spots while the breaker carries normal load current. Typical problems that can cause overheating are:

- Loose terminations or connections
- Excessive contact resistance
- Inadequate ventilation

Several failure mechanisms are directly related to breaker overheating. Some possible consequences of overheating are:

- Localized overheating of a loose termination may eventually cause termination failure. Loose terminations have a higher electrical resistance, which results in a higher temperature at the termination and excessive voltage drop. Loose terminations can occur on the line terminals, load terminals, or any internal connections.

- Overheating can damage contacts or other internal components such as thermal trip units. When electrical arcs cause excessive contact pitting or erosion, contact resistance can be greater than normal. This can result in overheating, which affects other internal components.
- If the ventilation is inadequate or the ambient temperature is higher than normal, the breaker will experience a higher-than-desired temperature, which can cause premature breaker tripping. Thermal-magnetic breaker tripping characteristics are usually defined at a given temperature, typically 77°F (25°C) to 104°F (40°C). A higher internal temperature would cause the breaker to trip sooner than shown on the characteristic tripping curves since the thermal trip unit would start out at a higher initial temperature. Nuisance tripping is one possible outcome. For nuclear plants, an important concern is that a safety-related breaker might nuisance trip from the inrush current when its load is initially energized. Breakers should be installed in an environment and configuration in accordance with manufacturers' recommendations.
- Overheating prematurely ages breakers and may contribute to the eventual failure of other internal components.

Although the breaker overheating inspection may provide valuable information regarding potential MCCB problems, this inspection does have its limitations. The inspection is intended to be performed on operating equipment; however, many MCCBs (including motor circuit protectors) in nuclear plants provide power to cycling, intermittent, or normally de-energized loads. For example, motor-operated valves typically operate through their full range of travel in less than 30 seconds, which is not enough time to obtain useful breaker overheating information. A breaker overheating inspection is expected to offer the most benefit for continuously energized loads.

Breakers in lighting and distribution panels are typically exposed only on the front face. A breaker overheating inspection in this case may provide little information since only part of the breaker is accessible.

7.1.2 Overheating Inspection by Infrared Thermography

The overheating inspection may be performed manually or as part of an infrared thermography program. However, infrared thermography is recommended since it provides an objective appraisal that can be used for later trending analysis. Infrared thermography also allows direct checking of the breaker line and load terminations, which cannot be performed manually.

Infrared thermography uses nonintrusive techniques to monitor the operating condition of equipment and components and can be a valuable element of a predictive maintenance program. The images can be stored on a computer for trending comparisons. EPRI report NP-6973, *Infrared Thermography Guide,* provides a comprehensive overview of this subject and should be consulted for further information.

Infrared thermography is a useful tool for verifying hot spots in MCCBs supplying continuously energized loads; however, it is not as useful for a normally de-energized load because little or no current is flowing through the MCCB. Examples of normally de-energized, or effectively de-energized, loads include motor-operated valves and equipment intended for post-accident use. Although a minor amount of current flow may be present for monitoring circuits, it is not adequate to identify hot spots that may exist when equipment is running. In many installations, infrared thermography may not be useful simply because there is little or no visual access to the electrical connections.

The following method is recommended for this inspection:

1. Perform this inspection with the breaker enclosed as in normal use and carrying normal load current. Allow the breaker at least three hours to reach its operating temperature if starting from a de-energized condition.

CAUTION: Although infrared thermography allows noncontact measurements, precautions for working with energized equipment are necessary.

NOTE: Smaller MCCBs are typically installed in a panelboard containing many breakers. Only the front face may be exposed for this inspection.

2. In accordance with plant procedures for infrared thermography inspections, check the following for hot spots:

- The exposed accessible insulated face of the breaker
- All accessible surfaces next to the breaker
- Line and load terminal connections

NOTE: Record all measurements in accordance with the plant infrared thermography program.

3. Investigate any hot spots detected. If necessary, perform a complete breaker enclosure inspection as described in Section 7.2 to identify external problems. Internal problems such as loose connections or damaged contacts may be identified by an insulated pole resistance test (Section 9.2).

CAUTION: Evaluate hot spots with care to avoid erroneous or misleading readings. For example, some breakers may have their load change considerably from test to test.

7.1.3 Manual Overheating Inspection

For manual breaker overheating inspections, the following method is recommended.

1. Perform this inspection with the breaker enclosed as in normal use and carrying normal load current. Allow three hours for the breaker to reach its operating temperature if starting from a de-energized condition.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other electrically energized locations.

NOTE: Smaller MCCBs are typically installed in a panelboard containing many breakers. Only the front face may be exposed for this inspection.

2. Check the following for hot spots by lightly touching the surfaces with hand or fingers:

- The exposed accessible insulated face of the breaker
- All accessible surfaces next to the breaker

NOTE: A contact thermometer may also be used to determine the actual temperature, if desired.

3. Investigate further if contact cannot be maintained for three seconds without discomfort. If further investigation is necessary, perform a complete breaker enclosure inspection (described in Section 7.2) to identify any external problems. An insulated pole resistance test (Section 9.2) may identify internal problems such as loose connections or damaged contacts.

7.2 Enclosure Inspection

7.2.1 Purpose of Inspection

A complete breaker enclosure inspection should accomplish the following:

- Check the condition of the molded case.
- Check for physical indications of overheating.
- Verify that terminals and connecting bus bars are in good condition.
- Verify the breaker application and rating.
- Verify that the MCCB conforms to design drawings.
- Confirm basic operation of the breaker.

In general, this inspection verifies that the breaker and associated hardware have no obvious visual problems and are capable of normal mechanical operation. Most MCCBs are sealed and can only be inspected externally.

7.2.2 Initial Conditions for Inspection

1. Before starting the inspection, deenergize the breaker and electrically isolate it from all other circuits in accordance with plant procedures.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations, conductors, or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.
3. Open the circuit breaker enclosure to perform the inspections described in Sections 7.2.3 through 7.2.7; if necessary, remove the circuit breaker from the enclosure.

7.2.3 Design Verification

1. Verify that the breaker markings and ratings match applicable design documents. If the existing breaker does not match the design drawings, consult engineering personnel for resolution.
2. Verify that the line and load conductors are of the appropriate size and type. If the conductors are too small for the application, consult engineering personnel for resolution. Section 4.5 provides additional information regarding conductor size requirements.

7.2.4 Molded Case Examination

1. Examine the circuit breaker surfaces for dust, soot, grease, or moisture. If there is grease, evidence of moisture, or more than a thin film of dust, dirt, or soot, clean the breaker.

NOTE: MCCBs experience fewer problems if they are kept in a clean environment. Keeping the breakers free of dirt or other contaminants helps prolong their life.

2. If necessary, clean the insulating surfaces of the breaker with a lint-free dry cloth or vacuum cleaner. Do not blow dirt into the circuit breaker or other equipment.

CAUTION: Do not use commercial cleaners or lubricants to clean MCCBs since they can damage labels or insulating materials and can remove breaker date codes.

3. If necessary, eliminate the source of any dirt, grease, or moisture as much as possible.
4. Examine the molded case for cracks. Replace any breaker with cracks in the case.

NOTE: The structural integrity of the case is critical to the overall ability of the breaker to withstand the mechanical stresses caused by short-circuit currents. A crack in the case reduces the short-circuit current interruption ability.

7.2.5 Overheating Checks

Perform the following overheating checks. Engineering should be consulted for any conditions requiring repair or rework.

1. Check all visible electrical components for overheating by looking for discoloration or signs of arcing.
2. Carefully remove and examine plug-on circuit breakers. If the plug-on jaws of the circuit breaker are pitted, discolored, or melted on the surfaces that mate with the connecting bus bars, replace the circuit breaker. No attempt should be made to bend the plug-on jaws or dress their mating surfaces.
3. Examine the plug-on jaws for the presence of a connector compound. If the compound is present, do not remove it unless it is contaminated with dirt or other materials. Before plugging the circuit breaker back on the panelboard bus bars, apply a small amount of new compound to the jaws in accordance with the manufacturer's recommendations.
4. Check the connecting panelboard bus bars for signs of pitting or melting. Replace damaged connecting bus bars, or replace the entire assembly if the bus bars are not replaceable.
5. If necessary, clean and dress external copper circuit breaker terminals and connecting straps, after carefully disconnecting them. Use fine aluminum oxide paper and remove all metal and abrasive particles before reassembling.
6. Clean and dress the electrical connections only if the discoloration or pitting is minor. Replace parts that show extensive damage, or replace the complete breaker and/or bus connections if the parts are not meant to be replaced.

7.2.6 Interchangeable Trip Unit Checks

If the circuit breaker has an interchangeable trip unit, inspect it. Problems noted with these trip units range from incorrect size to incorrect installation.

1. Remove the circuit breaker cover and verify that the trip unit type is in accordance with the applicable design documents.
2. Visually check the connections of the trip unit to the circuit breaker frame for evidence of overheating or looseness. If there is no evidence of overheating or looseness, do not disturb the connections.
3. If there is evidence of looseness, overheating, or arcing at any of the trip unit connections, remove the trip unit and inspect the connecting surfaces. If the connecting surfaces show evidence of overheating, replace the circuit breaker frame and trip unit. If the threaded inserts in the circuit breaker base are stripped or cross-threaded, the circuit breaker frame should be replaced.
4. If there is no evidence of pitting or degradation on the connecting surfaces and the threaded inserts appear to be in good condition, reinstall the trip unit in accordance with the manufacturer's recommendations.

7.2.7 Wiring Inspection

1. Inspect all visible wiring for damage. If wire conductors are damaged, remove or repair the damaged portion in accordance with plant procedures. After installing and tightening stranded conductors in compression type connectors, the conductor should be moved from side-to-side and tightened again to help prevent future loose terminations.
2. Before reinstalling the conductors, examine the wire connectors. Wire connectors that appear to be in good condition may be reused. If the connectors, screws, or their plating appear worn or damaged, or if there is evidence of stripping, cross-threading, or binding, replace the connector assembly.
3. Torque any replaced wire connectors in accordance with the nameplate marking or the circuit breaker manufacturer's instructions.

7.2.8 Mechanical Operation Inspection

Whenever the breaker enclosure inspection is performed, complete a mechanical operation inspection in accordance with Section 7.3.

7.3 Mechanical Operation Inspection

7.3.1 Purpose of Inspection

Periodic exercising of the breaker is one of the most effective ways to ensure operability. Breakers that have not been cycled for many years may be "sticky," that is, may respond to an overload or fault slower than expected. As a consequence, the upstream breaker may clear the overcurrent and thus cause an unnecessary loss of other equipment. Subsequent investigations often are unable to find anything wrong with the breaker, and it may meet all of the original manufacturer’s, specifications after it has been cycled a few times.

The operating mechanism of a breaker is lubricated for a normal life span at the factory, but like any mechanical device, it must be exercised periodically. Exercising can be accomplished simply by opening and closing the breaker and actuating the push-to-trip device if available. This ensures that the mechanism operates freely and redistributes the lubrication. If the ambient environment exposes the MCCB to hot or cold weather extremes, the lubrication can deteriorate or harden.

A review of failure data for MCCBs has confirmed that failure of the operating mechanism is one of the most common failure modes. Manufacturers' documents regarding preventive maintenance, inspection, and testing repeatedly stress the importance of periodically exercising breakers. Manufacturer representatives have also emphasized that periodically exercising the breaker is probably the most important of all inspections or tests. NFPA 99, *Standard for Health Care Facilities,* and NFPA 110, *Standard for Emergency and Standby Power Systems,* specify an annual frequency for critical applications. NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance,* Chapter 13, “Molded-Case Circuit-Breaker Power Panels,” Section

13.10, “Mechanical Mechanism Exercise,” establishes a reasonable basis for periodically exercising a breaker:

> Devices with moving parts require periodic check-ups. A molded-case circuit breaker is no exception. It is not unusual for a molded-case circuit breaker to be in service for extended periods and never be called upon to perform its overload or short-circuit-tripping functions. Manual operation of the circuit breaker will help keep the contacts clean, but does not exercise the tripping mechanism. Although manual operations will exercise the breaker mechanism, none of the mechanical linkages in the tripping mechanisms will be moved with this exercise. Some circuit breakers have push-to-trip buttons that should be operated at the time of manual exercising in order to move the tripping mechanism linkages.

Ensuring that all MCCBs are periodically exercised is considered a vital part of a maintenance program, applicable to all breakers regardless of their safety classification. The maintenance program should require mechanical operation whenever any other inspections or tests requiring breaker de-energization are performed.

7.3.2 Inspection Procedure

CAUTION: Isolate the breaker from its power source before conducting the test. Do not repeatedly cycle the breaker under load.

1. Before starting the inspection, de-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations, conductors, or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

NOTE: If the breaker is equipped with an undervoltage trip unit, the undervoltage trip unit must be energized to allow the breaker to close.

3. Exercise the breaker by manually operating the breaker handle to both the OFF and ON positions to verify its free operation. A minimum of three cycles is recommended. Use an ohmmeter or other device to check continuity, and verify that all circuit breaker contacts are open when the handle is in the OFF position and closed when the handle is in the ON position.

NOTE: If the breaker is equipped with auxiliary or alarm switches, verify that these switch contacts also change state when the circuit breaker main contacts are opened and closed. Alarm switches may be actuated only by a mechanical trip device such as a push-to-trip switch.

4. If the breaker is equipped with a mechanical trip device, operate the tripping mechanism in accordance with the manufacturer's instructions. A minimum of three cycles is recommended. With the breaker in the tripped position, verify that the contacts are open using an ohmmeter or other device capable of checking continuity.
5. Replace the breaker if any of the following occur:

- The breaker handle does not operate freely.
- The contacts are not open with the breaker in the tripped or OFF position.
- The contacts are not closed with the breaker in the ON position.
- The breaker does not reset.
- The mechanical trip does not trip the breaker.
- Auxiliary or alarm switches do not open or close as required. Breaker replacement is required in this case only if the auxiliary or alarm switches are not replaceable.

8

OVERCURRENT TESTS

Section 8 provides a step-by-step description of how MCCB overcurrent testing should be performed. It also offers insight into what each type of test accomplishes and why it is (or is not) important for ensuring breaker reliability. A discussion of the failure mechanisms that each test might detect, as well as any inherent test limitations, is provided.

The emphasis here is on how to perform a test and what the test should accomplish. See Section 6 for information on periodicity and equipment prioritization guidance. Other electrical tests are covered in Section 9.

8.1 Overview of Overcurrent Testing Methods

Most issues regarding MCCB performance seem to revolve around overcurrent testing. In general, two types of overcurrent testing can be performed:

- Verification of trip capability in the time delay region
- Verification of trip capability in the instantaneous trip region

NEMA Standards Publication AB-4-2003, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications, is the principal industry source document regarding how to perform overcurrent testing of MCCBs. It was originally issued in May 1991 and represents the manufacturers' consensus regarding how to perform inspection and testing. The NEMA AB-4 test methods are described in Sections 8.2 and 8.3.

As discussed in the following sections, the NEMA AB-4 test methods and acceptance criteria are intended to verify the functionality of the breaker. The term *functionality* is important here because NEMA and the associated manufacturers have stated that NEMA AB-4 testing will not confirm a breaker's ability to perform in accordance with its time-current curve. Some users have expressed a desire to confirm a breaker's capability to trip within its defined time-current curves. Section 8.4 provides information to consider if testing to acceptance criteria tighter than specified in NEMA AB-4 is desired.

The inspection and test methods described in NEMA AB-4 and this NMAC guide are intended to provide reasonable assurance that an MCCB will perform its design function. Given this goal, little attention has been paid to the inspection and test sequence. However, some users have had to determine if the MCCB would have been capable of performing its design function. Generally, these concerns are associated with Technical Specification requirements for operability. This kind of testing is called *as-found testing*. The main issues associated with as-found testing relate to the sequence in which breakers are exercised and overcurrent tested. Section 8.5 discusses the practical limitations of attempting to confirm the as-found condition of a breaker.

Section 8.6 discusses how to approach overcurrent testing of MCCBs used in DC applications. Little industry guidance has been provided in this area, and Section 8.6 explains the differences between using AC or DC test equipment to test DC breakers.

8.2 NEMA AB-4 Overload Trip Test

8.2.1 Purpose of Test

Several names are commonly used for the overload trip test. These names include:

- Inverse-time trip test
- Overload tripping test
- 300% overload trip test
- Time delay overcurrent trip test
- Overcurrent trip test
- Timing test

The main goal of this test is to obtain objective evidence, within the limitations imposed by field testing, that the thermal trip unit is functioning as expected.

Failure of the overcurrent trip unit is one of the most common failure modes. Several NRC Information Notices in recent years have identified various problems with overcurrent trip units that could have been detected by a periodic test program. The available reliability information indicates that this test is important for confirming basic operability of the MCCB thermal trip unit. For example, ANSI/IEEE Standard 242-1986, *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*, Section 15.3, recommends performance of the overload and instantaneous overcurrent trip tests:

> Periodically, these circuit breakers must be electrically tripped to assure proper operation. Experience has indicated that if they are allowed to remain in service for an extended period of time without an electrical operation, the internal mechanism and joints may become stiff so that the circuit breaker operates improperly when subjected to abnormal current. Therefore, each pole of the circuit breaker should be electrically exercised.
>
> The recommended tests for a molded-case circuit breaker are timing and instantaneous pickup.

This test is not intended to verify that MCCBs exactly meet their applicable time-current trip curves. Published time-current curves for MCCBs are established and verified by testing under laboratory conditions. Under field conditions, it is difficult to account for or control all variables to the degree necessary for a meaningful comparison of test results to the published curves. Therefore, the acceptance criteria for field testing are necessarily less restrictive. Even with the larger acceptance band used for field testing, the overload trip test must be carefully performed to acquire test data accurate enough for comparison.

8.2.2 Test Guidelines

Numerous factors can compromise the test results if not properly controlled. The objective is to establish stable and repeatable test conditions that are similar, but not identical, to the test conditions used by the manufacturer and certifying organization (for example, Underwriters Laboratories, Inc. [UL]) to validate the tripping characteristics represented by published curves. General guidelines considered applicable to field testing are noted below. Following these guidelines will ensure consistency with factory test conditions to the extent considered practical for field testing.

- Each pole of a breaker is tested individually using a test current equal to 300% of the breaker rated current. This value of test current is relatively easy to produce with readily available test equipment and is low enough to ensure negligible heat transfer to adjacent poles. The results of an overload test at a current of 300% are representative of the MCCB response throughout the inverse-time tripping range.

- The MCCB should be removed from its enclosure and mounted so that the test can be conducted with the breaker in open air at a room ambient temperature of approximately 77°F. Temperatures significantly above 77°F may result in a premature trip. Conversely, low temperatures can delay a trip. MCCBs can be located in a variety of enclosures, each with a different heat dissipation characteristic. Therefore, overload testing is normally performed in open air to establish consistency.

- The test should be conducted from a "cold start." A cold start implies that the breaker is approximately at room ambient temperature prior to the test.

- The MCCB should be connected to the test equipment with copper conductors approximately, but no less than, 4 feet in length and of the proper size (refer to Tables 8-2 and 8-3). The conductors act as a heat sink during the test and thus must be standardized to ensure consistent test results. Smaller cable or shorter lengths can shorten the trip time. Larger cables or a heavy bus bar lengthens the trip time. Small frame breakers are particularly susceptible to variations caused by this effect. Test cables should be connected with mounting lugs specifically designed for the MCCB being tested to avoid damaging the terminals.

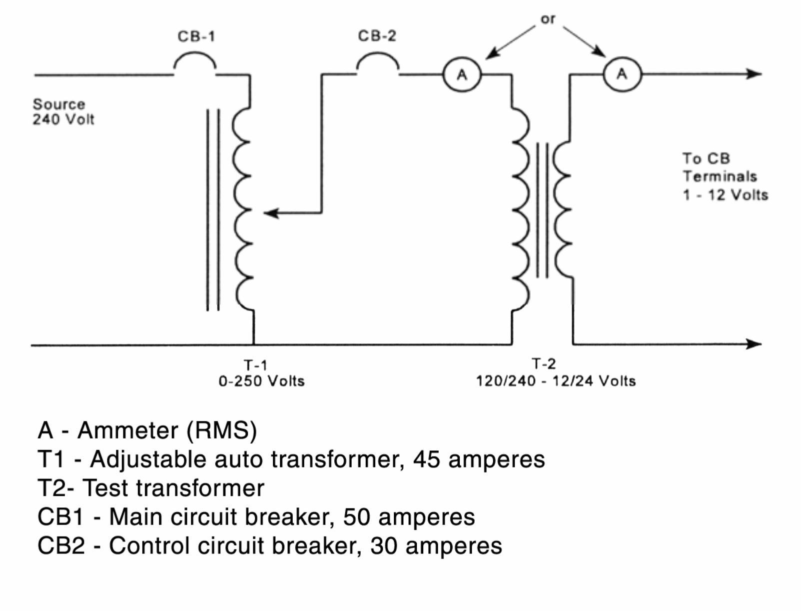
- During the test, it is extremely important to obtain and hold an accurate test current. The heat generated in the bimetal element of the thermal trip unit is proportional to the square of the test current. Thus, a small deviation in test current can result in a large variation in total heat generation. A sufficiently accurate ammeter should be used to monitor current during the test.

The above guidelines do not establish test conditions as tight as those the manufacturer or certifying authority imposes for validating MCCB performance characteristics. Accordingly, the acceptance tolerances for field testing are broader than those depicted by published time-current curves.

8.2.3 Test Equipment

Equipment required to perform this test includes a low-voltage, high-current power source, an ammeter, and a timepiece. High-current test units range from simple to complex.

A simple but effective setup such as that illustrated in Figure 8-1 can be used for breakers rated up to 100 amperes.



A - Ammeter (RMS)
T1 - Adjustable auto transformer, 45 amperes
T2- Test transformer
CB1 - Main circuit breaker, 50 amperes
CB2 - Control circuit breaker, 30 amperes

Figure 8-1
Simple Test Unit

If larger breakers are to be tested or more accurate results are desired, a custom test unit should be used. Figure 8-2 shows a custom high-current test unit capable of testing MCCBs rated up to 1200 amperes. Custom test sets can be purchased with a variety of features and options that greatly reduce the complexity and time required to perform overcurrent testing. These units are typically designed to perform both overload trip testing and instantaneous trip testing. In developing an MCCB test program, one must evaluate the quantity and size of breakers to be tested, the frequency of testing, and the desired accuracy to determine if the expense of a custom test set is warranted.

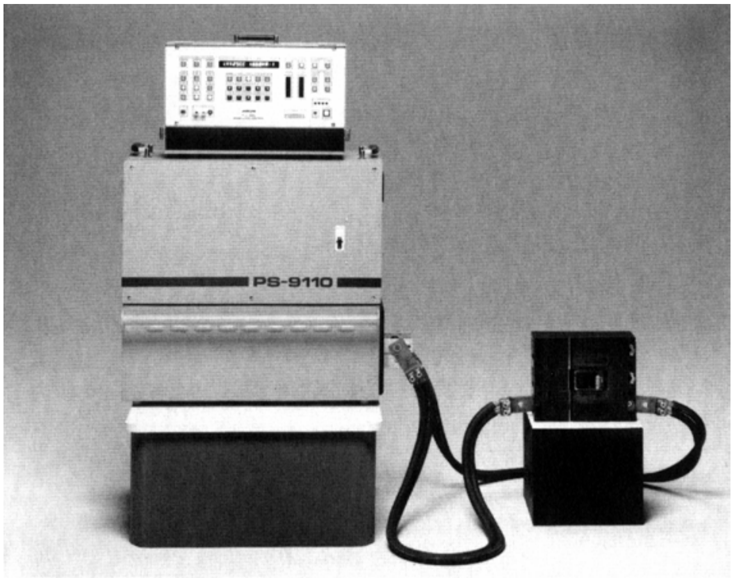


Figure 8-2
Custom Test Unit
(Courtesy AVO International)

8.2.4 Test Tolerances

NEMA AB-4, Table 3, provides recommended tolerances for testing time delay trip units. The tolerances are summarized in Table 8-1.

Table 8-1
Maximum Trip Times

Breaker Rating	≤250 Volts Voltage Rating	251–600 Volts Voltage Rating
(amperes)	Time (seconds)	Time (seconds)
0–30	50	70
31–50	80	100
51–100	140	160
101–150	200	250
151–225	230	275
226–400	300	350
401–600	-	450
601–800	-	500
801–1000	-	600
1001–1200	-	700
1201–1600	-	775
1601–2000	-	800
2001–2500	-	850
2501–5000	-	900
6000	-	1000

Notice that only a maximum trip time is specified. A minimum trip time is not considered part of the NEMA AB-4 acceptance criteria. The purpose of NEMA AB-4 is not to confirm that a breaker meets its published time-current curves. Rather, the purpose of the testing specified by NEMA AB-4 is to provide reasonable assurance that the breaker is capable of protecting the electrical circuit in which it is applied. A breaker that trips in less than the minimum time shown by the time-current curves will furnish protection at a lower current level. Unless this results in nuisance tripping, this condition is considered acceptable by NEMA. Any breaker that trips prematurely, based on the expected trip time shown on its time-current curve, should be evaluated for possible nuisance tripping.

Refer to Section 8.4 for information regarding testing to the manufacturer's time-current curves.

8.2.5 Test Procedure

1. De-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.
2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

3. Remove the breaker from its enclosure and place it in a free air environment.
4. Connect the line and load terminals of the pole to be tested to the test equipment with copper conductors approximately, but no less than, 4 feet in length. Use the conductor size specified in Table 8-2 for smaller breakers or in Table 8-3 for large breakers.

CAUTION: Connect test cables with mounting lugs specifically designed for the MCCB being tested to avoid damaging the terminals.

NOTE: Plug-on or draw-out MCCBs require a special test fixture.

NOTE: If the breaker is equipped with an undervoltage trip unit, energize the undervoltage trip unit to allow the breaker to close.

5. Ensure that the MCCB and surrounding ambient air are at approximately room temperature (77°F).
6. Following the specific instructions for the test set being used, energize the test circuit and establish the required 300% test current as quickly as possible.

NOTE: Set the test current as accurately as possible. Small errors in current result in large errors in trip time.

7. With the test current at the required value, measure the time required to trip the breaker. Record the test current and test time.
8. Repeat the test on each individual pole of the breaker; wait at least 5 minutes between poles.

NOTE: Wait at least 20 minutes before repeating the test on the same pole. Normally, retesting is necessary only if previous results need verification or if an error was made in the previous test.

9. If the MCCB trip time exceeds the time specified in Table 8-1 (Section 8.2.4), allow the breaker to cool to ambient temperature and repeat the test. If the MCCB trip time again exceeds the appropriate time listed in Table 8-1, replace the breaker.

NOTE: Some manufacturers indicate the 300% trip value for single-pole testing at 25°C on their characteristic trip curves, and this value should be used if available. Figure 8-3 provides a typical example.

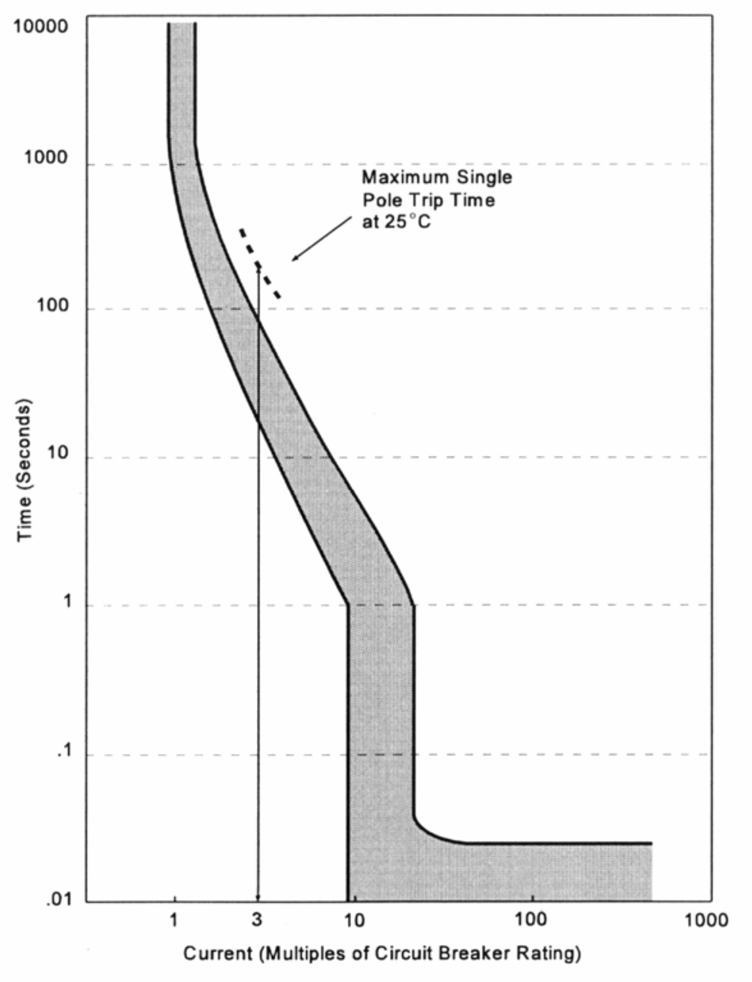


Figure 8-3
Typical Maximum Single-Pole Trip Value

Table 8-2
Test Cable Sizes for Smaller Breakers*

Breaker Rating (amperes)	Conductor Size (74°F rating)	Conductor Size (60°F rating)
15 or less	14 AWG	14 AWG
20	12 AWG	12 AWG
25	10 AWG	10 AWG
30	10 AWG	10 AWG
40	8 AWG	8 AWG
50	8 AWG	8 AWG
60	6 AWG	4 AWG
70	4 AWG	4 AWG
80	4 AWG	3 AWG
90	3 AWG	2 AWG
100	3 AWG	1 AWG
110	2 AWG	1 AWG
125	1 AWG	1/0 AWG
150	1/0 AWG	
175	2/0 AWG	
200	3/0 AWG	
225	4/0 AWG	
250	250 MCM	
275	300 MCM	
300	350 MCM	
325	400 MCM	
350	500 MCM	

* For circuit breaker ratings not shown in the table, use the next higher rating.

Table 8-3
Test Cable Sizes for Larger Breakers*

Breaker Rating (amperes)	Number of Paralleled Conductors	Conductor Size (75˚F rating)
400	2	3/0 AWG
450	2	4/0 AWG
500	2	250 MCM
550	2	300 MCM
600	2	350 MCM
700	2	500 MCM
800	3	300 MCM
1000	3	400 MCM
1200	4 3	350 MCM or 600 MCM
1400	4	500 MCM
1600	5 4	400 MCM or 600 MCM
2000	6 5	400 MCM or 600 MCM
2500	8 7 6	400 MCM, or 500 MCM, or 600 MCM
3000	9 8 7	400 MCM, or 500 MCM, or 600 MCM
4000	12 11 10	400 MCM, or 500 MCM, or 600 MCM

* For circuit breaker ratings not shown in the table, use the next higher rating.

8.3 NEMA AB-4 Instantaneous Overcurrent Trip Test

8.3.1 Purpose of Test

The purpose of this test is to verify proper operation of the instantaneous trip unit. Failure of the overcurrent trip unit is one of the most common MCCB failure modes. This test is considered important for ensuring functionality of the instantaneous trip unit.

Even with the use of sophisticated test equipment, this test must be conducted with great care to obtain accurate and meaningful results. As with overload testing, it is difficult to account for and control all variables to the degree necessary for the published characteristic trip curves to be used as acceptance criteria. Therefore, manufacturers have established a broader tolerance for use in field testing. Refer to Section 8.4 if acceptance criteria tighter than specified by NEMA AB-4 are required.

8.3.2 Test Methods

There are two methods of conducting an instantaneous trip test: the pulse method and the run-up method. The pulse method is more accurate but requires specialized equipment.

8.3.2.1 Pulse Method

The pulse method is performed with a specialized test unit capable of producing a high current pulse of only a few cycles in duration. Because of the short pulse duration, current must be measured with a high-speed sampling rate digital ammeter or a calibrated image-retaining oscilloscope.

A pulsed current (approximately 5 to 10 cycles in duration) is injected through the breaker at a level just below the low tolerance limit for the instantaneous trip. This test method is intended to verify that the breaker is not subject to premature tripping. Next, a pulse of current, again 5 to 10 cycles in duration, is injected through the breaker at a level equal to the high tolerance limit, to verify that the MCCB will trip within the expected band.

The pulse method has several advantages over the run-up method. When it is performed properly, the MCCB is subjected to a small number of short current pulses. Thus, the likelihood that heating of the bimetal strip will compromise the test results is minimized. Once the test parameters are established, performance of the test is largely independent of the operator and operator-induced errors are less probable. Because the number of cycles used for the test is known, there is objective evidence of the time required for the breaker to open.

Overcurrent Tests

A key to obtaining accurate results is the elimination of transient distortions in the current wave shape (referred to as *offset*) that result in an asymmetrical test current. Offset occurs in circuits that contain reactive impedance if the voltage wave shape is at a value other than zero when the circuit is closed (see Appendix E for additional information). Figure 8-4 shows the effect of offset on the current wave shape.

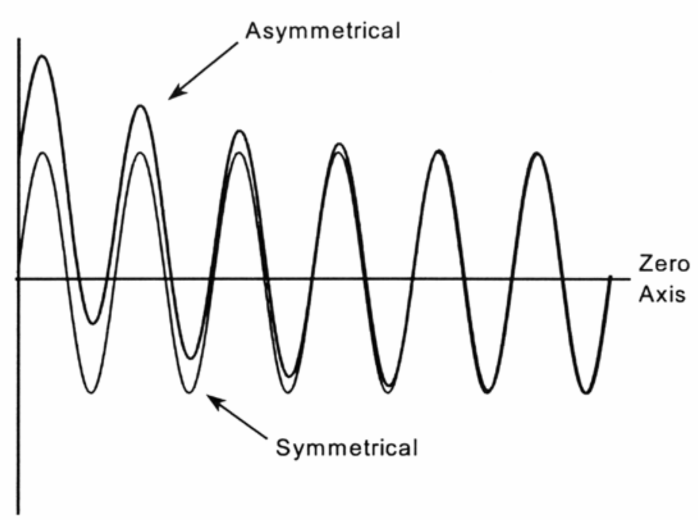


Figure 8-4
Asymmetrical Test Current

The offset can cause a breaker under test to trip prematurely from the offset peak rather than the steady-state current. A complicating factor is that the amount of offset is highly random. Offset largely depends on the instantaneous voltage level at the instant the circuit is closed. Test equipment manufacturers have addressed this problem by incorporating circuitry designed to produce only symmetrical output into their test units.

Not all high-current pulse testers can produce zero offset output. Test equipment incapable of producing zero offset output should not be used to verify the lower-limit instantaneous trip point of MCCBs used in Class WE applications.

As mentioned previously, a pulsed current, approximately 5 to 10 cycles in duration, is injected through the breaker during the pulse test. The number of cycles used should be standardized for all tests. Different results may be obtained at 5 cycles than at 10 cycles if near the trip point. The force required to cause a breaker trip by the magnetic trip unit depends on the current magnitude, trip mechanism geometry, armature spring force, and coefficient of friction between the latching parts. Also, the force applied by the armature spring changes as the armature moves and the spring is extended. At a sufficiently low level of current, the armature will not move. As the current approaches the trip point, the armature will move, but either will not contact the trip bar or will contact it with insufficient force to actuate the trip bar. As the current level is increased further, the armature eventually moves with sufficient force to trip the breaker.

For a given armature design, there may be a range of current that causes the armature to move the trip bar slightly with each successive current cycle, but with insufficient force and displacement to trip the breaker. The armature reacts to the magnetic field generated by the current with the maximum effect achieved as the sinusoidal current reaches its peak value. At the current peak, the armature may move the trip bar slightly. As the current declines from its peak value for that cycle, the armature force will diminish, stopping any further movement of the trip bar. Over several cycles of current, the armature may move the trip bar enough so that the breaker trips. This phenomenon is sometimes termed the *cycles of force* generated by the armature when the current is just approaching the trip point. The breaker might not trip if exposed to 5 cycles of current, but may trip if the current is allowed to persist up to 10 cycles. The NEMA AB-4 tolerances (see Section 8.3.4) used in the pulse test are broad enough that this effect should not be observed. However, if a plant is testing to tolerances tighter than those specified in NEMA AB-4, this effect might impact the test results (see Section 8.4).

Manufacturers do not necessarily test MCCBs before shipment in accordance with NEMA AB-4 criteria. For example, MCCBs at an industrial facility were found to trip prematurely when tested with a 9-cycle current pulse in accordance with NEMA AB-4. The MCCBs were returned to the manufacturer for investigation. Upon testing the MCCBs, the manufacturer concluded that the MCCBs were acceptable and did not trip prematurely. Further discussions between the manufacturer and industrial facility eventually revealed that the manufacturer applied only a 3-cycle current pulse. For such a short-duration current, the cycles of force were not adequate to trip the breaker. But, when 9 cycles were applied at the same current magnitude, the breaker did trip below the NEMA AB-4 tolerance. This example is another illustration of the difficulty in directly comparing field test results to the manufacturer's test data. Comparisons should be made with caution and a full understanding of how tests were performed.

8.3.2.2 Run-Up Method

In the run-up method, the test set is adjusted so that approximately 60% of the expected trip current flows when the test circuit is energized. Once energized, the current is rapidly increased until the breaker trips.

The advantage of the run-up method is that it can be performed with a fairly simple test setup, and it avoids the expense associated with a custom high-current test unit. However, several aspects of this test method limit its usefulness. The method is highly subject to operator variations. If current is increased too slowly, the breaker may actually be tripped by the thermal trip unit or may suffer a premature trip due to an interaction between the thermal trip and the magnetic trip. If current is increased too rapidly, an erroneous current reading may be obtained because the ammeter lags behind the actual current value due to meter damping. This specific problem can be minimized by use of a calibrated oscilloscope instead of a pointer-stop ammeter.

Another inherent limitation is that no information on the actual opening time is provided since the breaker is effectively subjected to a steadily increasing current. The operator can tell that the breaker opened, but not necessarily the true amount of time required for a given test current.

Accurate and repeatable test results are difficult to obtain with the run-up method. Therefore, it is not the preferred approach for precise verification of the trip function. This method may be a cost-effective means of checking functionality of the instantaneous trip when an accurate measure of the trip point is not necessary; however, it is probably better to use the same type of test equipment—a pulse tester—for all MCCB tests.

8.3.3 Test Guidelines

If not properly controlled, numerous factors can adversely influence the test. The objective is to establish test conditions that, as accurately as possible in a field environment, re-create the test conditions used by the manufacturer to establish and validate the MCCB time-current characteristics as represented by published curves. The primary documents governing the manufacture and certification of MCCBs are UL-489 and NEMA AB-1. UL-489 does not impose testing that checks for premature instantaneous tripping; however, premature tripping of safety-related breakers is a concern for nuclear plants.

General guidelines considered applicable to field testing are noted below. Following these guidelines will ensure consistency with factory test conditions to the extent considered practical for field testing.

- The MCCB should be removed from its enclosure. The instantaneous trip characteristics can be influenced by stray magnetic fields caused by the test equipment itself or by steel enclosures, mounting plates, or test conductors. Therefore, it is important to ensure that the test setup minimizes these effects. Since the objective is to establish a test setup that mimics factory testing conditions, the manufacturer should be consulted for product-specific recommendations regarding mounting and wire routing.
- Test results can be affected by the test wave shape. The test unit should be capable of producing a sinusoidal output over the full output range of the equipment.
- The test should be conducted from a "cold start." A cold start implies that the beaker is approximately at a room ambient temperature of 77°F prior to the test. Although temperature does not directly affect operation of the magnetic trip unit, the high test current used for instantaneous trip testing can alone, or in combination with an elevated ambient temperature, cause heating, and thus deflection, of the bimetal thermal element. As the bimetal strip is deflected, it can apply pressure to the trip mechanism that by itself is not large enough to release the trip latch. However, this pressure reduces the force that the magnetic unit must exert against the trip mechanism to trip the breaker. This situation, known as "thermal- magnetic interaction," can result in a premature breaker trip.

- Because of low accuracy and repeatability, the run-up method should not be used to verify MCCB instantaneous trip points that have nuclear safety-related implications. Most likely, erroneous test results would indicate that an MCCB is tripping prematurely. The cost of replacing Class WE equipment is expensive, and to do so because of erroneous test data is obviously not desirable.
- Pulse test equipment incapable of producing a zero offset output should not be used to check the lower tolerance limits that have safety-related implications. The rationale is the same as that discussed above for the run-up method.

8.3.4 Test Tolerances

NEMA AB-4-2003 Section 6.6.4.2.3 Table 4 provides recommended tolerances for testing instantaneous trip units. The tolerances are summarized in Table 8-4.

Table 8-4
Instantaneous Trip Tolerances

Breaker Type	Tolerance of Settings	Tolerance of Manufacturer's Published Trip Range	
		High Side	Low Side
Adjustable(1)	+40%		
	-30%		
Non-Adjustable(2)		+25%	-25%

1. Tolerances are based on variations from the nominal settings
2. Tolerances are based on variations from the manufacturer's published trip band (that is, –25% below the low side of the band; +25% above the high side of the band).

Notice that the instantaneous trip unit is tested with a broad tolerance about the time-current curve settings. The reason for such a large tolerance is to allow for some of the potential test uncertainties in field testing, including differences in field test equipment and technique. Even the number of cycles applied during the test can affect the test results (see Section 8.3.2.1). Refer to Section 8.4 for testing to tolerances tighter than those specified in NEMA AB-4.

As can be seen in Table 8-4, the test tolerances cover a fairly broad region above and below the instantaneous trip setting. The best way to explain how to apply the NEMA AB-4 test tolerances is by an example.

8.3.4.1 Example 8-1: Nonadjustable MCCB

Consider the 100-ampere nonadjustable breaker shown in Figure 8-5. In this case, an instantaneous trip is not expected to occur in response to a current less than 10 times the breaker rating (1,000 amperes), and an instantaneous trip is expected to occur before 25 times the breaker rating (2,500 amperes). Section 3.6.1 refers to the vertical region of the time-current curve between 10 to 25 times the breaker rating as the *transition region*. Inside this region, trip times are not precisely defined because this region describes the transition from thermal tripping to magnetic tripping. Below this vertical region, a trip actuated by the time-delay trip unit is expected. Above this region, an instantaneous trip is expected.

Table 8-4 specifies a trip tolerance of ±25% for a nonadjustable MCCB. Relating this to the breaker used in this example, the upper tolerance limit is 2,500 amperes +25%, or 3,125 amperes. The lower tolerance limit is 1,000 amperes -25%, or 750 amperes. However, one more adjustment is needed on the low side. The test procedure recommended by NEMA AB-4 specifies on the lower end to apply a test current 5% below the lower tolerance limit if testing by the pulse method. Assuming the pulse test in this example, the applied test current on the lower end should be 1,000 amperes -25% - 5%, or 700 amperes. When the test current of 700 amperes is briefly applied to the breaker in this example, it should not trip. When the test current of 3,125 amperes is briefly applied, the breaker should trip. The result is shown in Figure 8-5.

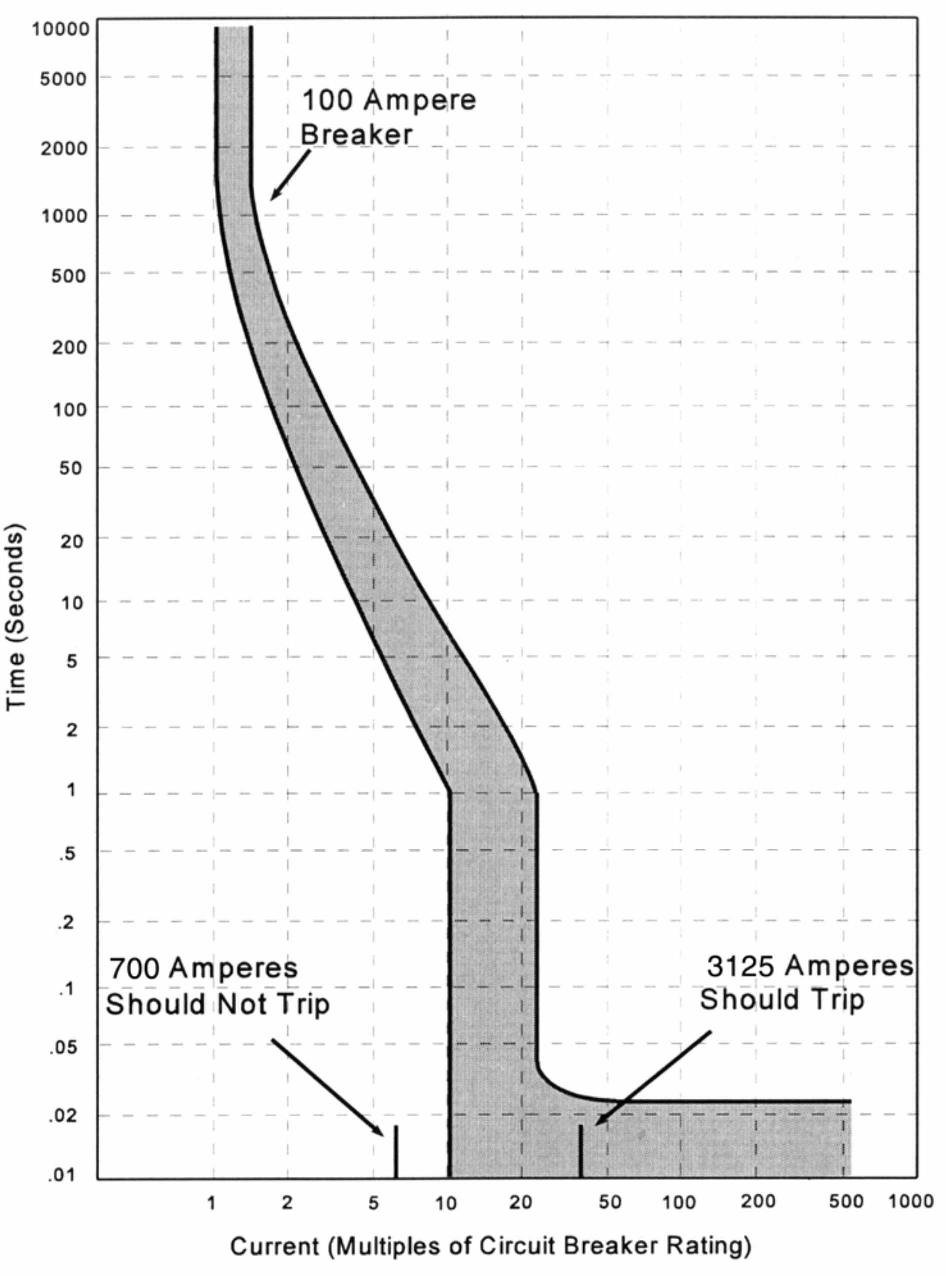


Figure 8-5
Example 8-1: Nonadjustable MCCB

8.3.4.2 Example 8-2:Adjustable MCCB

Consider the adjustable instantaneous-only MCCB shown in Figure 8-6; this type of MCCB is often used for motor applications. In this case, the MCCB has nine adjustable trip settings. As the settings increase from A to I, a greater amount of current is necessary before the instantaneous trip unit will actuate. Notice that each setting has a tolerance band that defines the minimum and maximum expected trip points. For example, the MCCB shown in Figure 8-6 is expected to trip anywhere from 5 to 7 times its rated current on setting H.

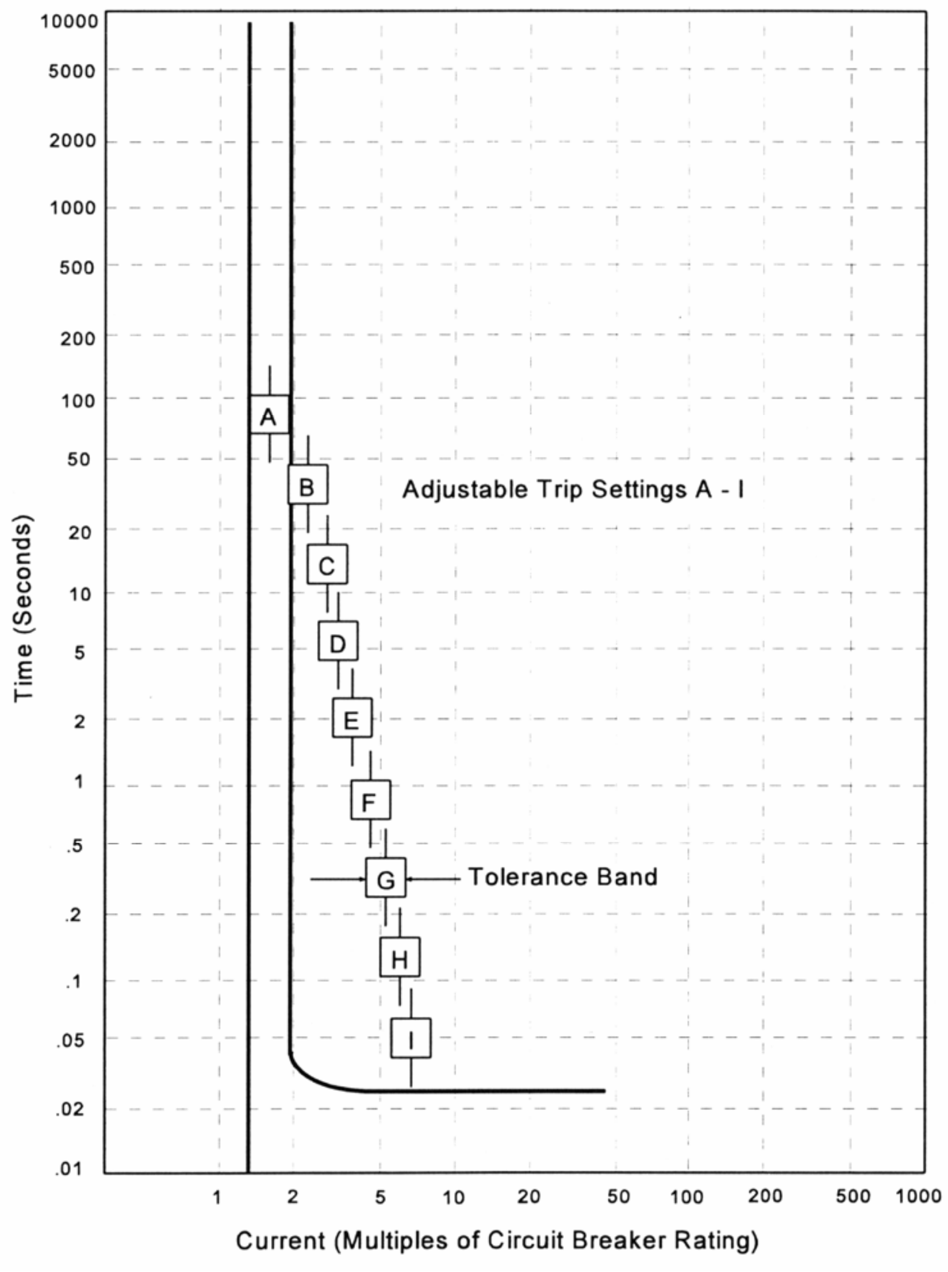


Figure 8-6
Example 8-2: Adjustable MCCB

Suppose the breaker shown on Figure 8-6 is a 100 ampere-rated breaker and the instantaneous trip unit is set on setting H (nominal setting of 600amps). On this setting, the MCCB is expected to trip between 500 to 700 amperes. Referring to the test tolerances provided in Table 8-4, the tolerances for the nominal H setting are +40%/-30%. Assuming that we use the pulse test method, an additional 5% tolerance is applied on the low side of the tolerance band as explained previously. Therefore, the test tolerances for setting H are as follows:

600 amperes -30% = 390 amperes (should not trip)

600 amperes +40% = 840 amperes (should trip)

Figure 8-6 provides the tolerance band for each setting. Some manufacturers may provide only a single line for each setting indicating the nominal trip point. In this case, contact the manufacturer for the appropriate tolerance band about the nominal trip set point for each setting. The test tolerances are then applied to the upper and lower limits of the tolerance band for the appropriate setting as explained above.

8.3.5 Test Procedure

8.3.5.1 Pulse Test Method

In the following test procedure, it is assumed that a test unit capable of producing zero offset output current is used and that the purpose of the test is to verify, within the limits of field testing, the instantaneous trip point within the desired range.

1. De-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.
2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

3. Remove the breaker from its enclosure and place it in a free air environment.

NOTE: Ensure that the test setup minimizes the effects of stray magnetic fields caused by the test equipment itself or by steel enclosures, mounting plates, or the test conductors. Such fields can influence the instantaneous trip characteristics. Because the objective is to establish a test setup that mimics factory testing conditions, consult the manufacturer for product-specific recommendations regarding mounting and wire routing.

4. Use the guidance in Section 8.2.5 (“Overload Trip Testing”) to connect the line and load terminals of the pole to be tested to the test equipment.

Overcurrent Tests

CAUTION: Connect test cables with mounting lugs specifically designed for the MCCB being tested to avoid damaging the terminals.

NOTE: Plug-on or draw-out MCCBs require a special test fixture.

NOTE: If the MCCB contains an undervoltage trip device, energize the device to allow the breaker to be closed.

5. Ensure that the MCCB and surrounding ambient air are at approximately room temperature (77°F).
6. Following the specific instructions for the test set being used, adjust the test current to a value approximately 5% below the lower tolerance limit (specified in Table 8-4 in Section 8.3.4) for the breaker setting. Then apply a current pulse approximately 5 to 10 cycles in duration to the breaker. The breaker should not trip. Record the test current, number of cycles, and test results.

NOTE: Minimize the number of current pulses injected through the breaker when adjusting the current level to prevent bimetal heating. Bimetal heating can cause premature tripping because of thermal-magnetic interaction.

7. Adjust the test current to a value equal to the high tolerance limit specified in Table 8-4 for the breaker setting. Then apply a current pulse approximately 5 to 10 cycles in duration to the breaker. The breaker should trip. Record the test current, number of cycles, and test results.
8. Repeat the test on each individual pole of the breaker.

NOTE: If bimetal heating has occurred, wait at least 5 minutes before repeating the test on the same pole. Normally, retesting is necessary only if previous test results need verification or an error was made in the previous test.

9. If the breaker trip is not within the tolerance specified in Table 8-4, replace the breaker.

8.3.5.2 Run-Up Test Method

For the following test procedure, it is assumed that the underlying purpose is to verify functionality of the instantaneous trip unit and that an accurate measurement of the exact trip setting is not required.

1. De-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.
2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

3. Remove the breaker from its enclosure and place it in a free air environment.

NOTE: Ensure that the test setup minimizes the effects of stray magnetic fields caused by the test equipment itself or by steel enclosures, mounting plates, or the test conductors. Such fields can influence the instantaneous trip characteristics. Because the objective is to establish a test setup that mimics factory testing conditions, consult the manufacturer for product-specific recommendations regarding mounting and wire routing.

4. Use the guidelines in Section 8.2.5 ("Overload Trip Testing") to connect the line and load terminals of the pole to be tested to the test equipment.

CAUTION: Connect test cables with mounting lugs specifically designed for the MCCB being tested to avoid damaging the terminals.

NOTE: Plug-on or draw-out MCCBs require a special test fixture.

NOTE: If the MCCB contains an undervoltage trip device, energize the device to allow the breaker to be closed.

5. Ensure that the MCCB and surrounding ambient air are at approximately room temperature (77°F).
6. Following the specific instructions for the test set being used, adjust the test set to produce an output current of approximately 60% of the expected minimum trip point.

NOTE: Minimize bimetal heating when adjusting the current level. Bimetal heating can cause premature tripping because of thermal-magnetic interaction.

7. Energize the circuit and increase the current until the breaker trips. The current should be increased over a 2- to 5-second period. If the breaker does not trip within 5 seconds, de-energize the circuit.

CAUTION: Do not allow the test circuit to remain energized longer than 5 seconds. Equipment damage may result.

NOTE: This method of testing requires a skilled operator to recognize the relationship between actual test current and indicated current. Do not increase the current too slowly, or the breaker may actually be tripped by the thermal trip unit or may suffer a premature trip due to thermal-magnetic interaction. Do not increase the current too rapidly, or an erroneous current reading may be obtained because the ammeter lags behind the actual current value as a result of meter damping.

NOTE: Use a calibrated oscilloscope to measure current for greater accuracy.

8. Record the indicated test current.
9. Repeat the test on each individual pole of the breaker.

NOTE: If bimetal heating has occurred, wait at least 5 minutes before repeating the test on the same pole. Normally, retesting is necessary only if previous test results need verification or an error was made during the previous test.

NOTE: To verify that the thermal trip unit was not actuated, attempt to close the breaker immediately after the breaker has tripped and the test current has been removed. If the breaker does not reclose, the thermal trip unit may have caused the breaker trip. This technique works well for larger breakers but may not be correct for smaller breakers; the bimetal element of small breakers (15 to 20 ampere size) may continue to move after the magnetic trip has actuated.

10. If the MCCB trip is not within the specified tolerance in Table 8-4 in Section 8.3.4, replace the breaker.

8.4 Validating Manufacturers' Time-Current Curves

8.4.1 Issues Related to Validating Manufacturers' Time-Current Curves

Some users attempt to validate the manufacturer's time-current curve for certain MCCBs as part of a periodic maintenance program. This section discusses issues to consider if a user intends to test to the manufacturer's time-current curves rather than to the NEMA AB-4 acceptance criteria.

NOTE: Testing MCCBs to validate the manufacturer's time-current curves is not an NMAC recommendation. The test methods described in NEMA AB-4 are considered adequate to verify that an MCCB is functional.

Perhaps the most important issue to reconcile is how field testing is conducted compared to the information provided on manufacturers' time-current curves. The following differences between the two should be considered:

- Field testing guidance from NEMA and the manufacturers is based on testing a single pole with the required current. However, time-current curves are based on current in all poles. Using a three-pole breaker as an example, the time-current curve was typically developed with current flowing in all poles with 4 feet of rated wire per terminal. The heat generated inside the breaker with all three poles carrying current will be greater than the heat generated by field testing of a single pole, meaning that it may take longer to trip in the thermal region during field testing.
- The time-current curves are usually based on a 40°C (104°F) ambient temperature. Field testing is recommended to be performed at 25°C (77°F). The difference in current carrying capability before tripping between these two temperatures is typically 10% to 15%.
- The manufacturer's time-current curve is based on testing the breaker in open air. Although NEMA AB-4 field test recommendations also specify testing with the breaker in open air, some users still test the MCCB in its enclosure. Some difference in test results should be expected in this case. See Sections 8.2 and 8.3 for more information.

An MCCB time-current curve usually shows the maximum expected single-pole trip time at 25°C (77°F) at the 300% rated current point (see Figure 8-3 for an example). Notice that the single-pole trip time is well above the design operation range on the time-current curve. The allowed single-pole test time accounts for the above test differences as well as the added variability of field testing.

Manufacturers certify MCCB performance in accordance with UL-489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures.* Perhaps the most important part of this development process to understand is that the time-current curves are not verified by the UL-489 certification process. UL-489 is primarily concerned with the breaker's ability to 1) protect downstream conductors and 2) withstand the rated short-circuit current. Following this rationale, testing in accordance with NEMA AB-4 verifies the functionality of a breaker. The term *functionality* refers to the breaker's ability to eventually open if exposed to an overload or fault so that the downstream conductors and equipment are protected. The test procedures in NEMA AB-4 do not contain acceptance criteria that are intended to confirm that a breaker meets its time-current curves.

As suggested by the above discussion, field testing to confirm that an MCCB performs within the applicable time-current curves is not a straightforward process. NEMA AB-4 provides relatively broad tolerances because of the variability that can occur during field testing and should be attainable for properly functioning MCCBs. Attempting to reproduce laboratory test conditions in the field can become 1) expensive and 2) difficult to achieve despite the expense. As noted above, the manufacturer develops the time-current curve based on different methods and assumptions than used for field testing. See Section 3.6.4 for a discussion of how manufacturers typically develop time-current curves. Figure 8-7 shows the test points to consider checking if trying to validate a manufacturer's time-current curve.

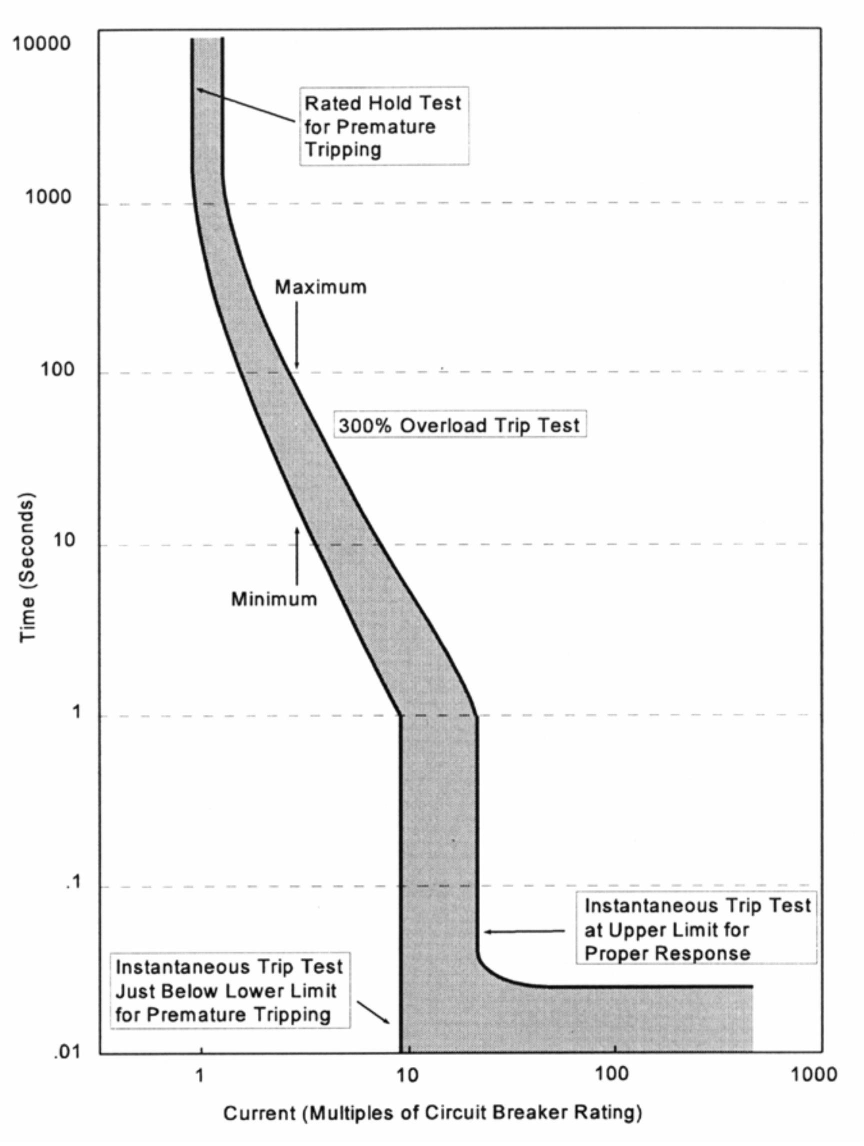


Figure 8-7
Overcurrent Test Points for Validating Time-Current Curves

As shown on Figure 8-7, the following tests are applicable:

- An overload trip test should confirm that the breaker trips at a 300% current within the tolerance shown in the time delay region (plus some added tolerance to account for differences in field test methods and how the time-current curves are developed). See Section 8.4.2 for more information.
- The instantaneous overcurrent test should demonstrate that the breaker will not trip prematurely or too late for large overcurrents. See Section 8.4.3 for more information.
- Although the rated hold test might be performed to confirm that a breaker will not trip up to its rated current, it is not recommended unless nuisance tripping has occurred. See Section 8.4.4 for more information.

The following sections discuss these tests and provide limitations to consider when performing them.

8.4.2 Overload Trip Test

An overload trip test is normally performed at 300% of rated current. The breaker's performance at the 300% level is considered indicative of its expected performance throughout the time delay region. NEMA AB-2 (1984) and manufacturers' literature support this position.

Section 8.2 discusses the NEMA AB-4 recommended method of confirming breaker functionality in the time delay region. As discussed, a maximum trip time acceptance criteria is provided to ensure that the breaker trips in time to protect downstream conductors. However, a comparison to a typical time-current curve for a thermal-magnetic MCCB generally shows that the MCCB is expected to trip in less than half the time allowed by NEMA AB-4.

As previously discussed, field test methods are different than the methods used by manufacturers to develop the time-current curves. The key differences are that field testing is performed on a single pole at 25°C (77°F) while the time-current curve is based on current in all poles at 40°C (104°F). Both of these differences will tend to increase the measured trip time by field testing. Consequently, some variation between field test results and the time-current curve should be expected.

Other field test variations can adversely affect the results. NEMA AB-4 recognizes this inherent variability in field testing in its acceptance criteria for this test. The following sections provide additional information to consider if attempting to validate the time-current curve at the 300% point.

8.4.2.1 Test Equipment Accuracy

The overload trip test is performed by injecting a controlled current into one pole of the breaker and monitoring the time to trip. Particular care must be given to the measurement accuracy of the test equipment. The current must be maintained constant and accurate for the duration of the test. The heat generated in a thermal trip unit is proportional to the square of the current. By this relationship, a small change in current can cause a large variation in total heat generated (and trip delay time). For example, if a desired 90 ampere test current is actually 10% greater (99 amperes), the heat generated in the thermal trip unit has increased by 21%.

$$Heat\ \ Change = -\frac{(I_2)^2}{(I_1)^2} = -\frac{(99)^2}{(90)^2} = 121\%$$

This difference in generated heat can adversely affect the test results. As the above example shows, accurate test equipment is a necessity. In this case, this accuracy requirement refers to the test equipment's ability to produce a stable constant current regardless of load changes as well as its ability to accurately measure the test current. Note that the heating may also cause the test current to fluctuate unless the test equipment is designed to maintain a set current.

The test equipment must be capable of generating a true sinusoidal signal. Harmonics and other distortions of the wave form will change the rms value of current, introducing another source of error into the test.

8.4.2.2 Ambient Temperature Variations

The response of the thermal trip unit depends, in part, on the ambient temperature. NEMA AB-4 specifies that the test temperature should normally be near 77°F, and field testing should strive for an ambient temperature as close to 77°F as reasonable. Temperatures above 77°F should cause the breaker to trip sooner than temperatures less than 77°F. Unfortunately, manufacturers' time-current curves are typically based on a 40°C (104°F) cold start. A review of typical manufacturer breaker rerating data shows that a breaker can typically carry about 10% to 15% more current at 77°F than it can at 104°F before tripping. This means that there is some level of uncertainty in the precise location of the time-current curve as a function of temperature. However, it is clear that a breaker will trip sooner at higher temperatures for a given overcurrent than it will at lower temperatures.

Figure 8-8 shows the typical variation in current carrying ability as a function of temperature for one particular MCCB model. The characteristics shown in Figure 8-8 are illustrative only and do not necessarily apply to all MCCBs; the temperature effect varies among MCCB frame styles. The manufacturer should be contacted for information applicable to a particular MCCB style.

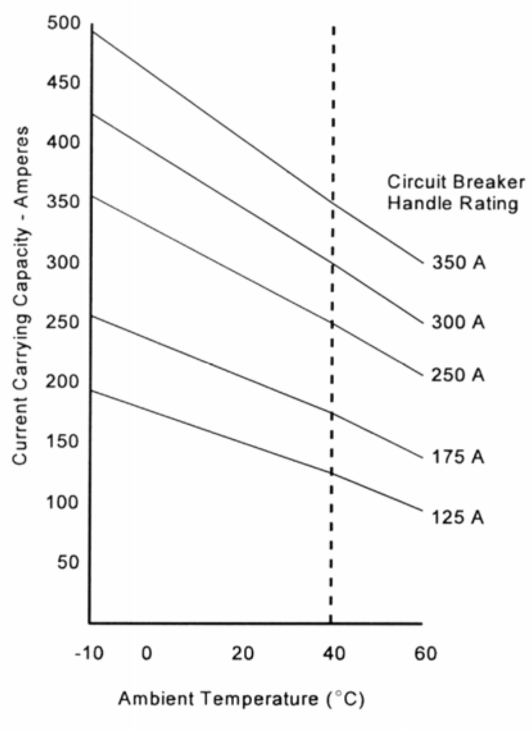


Figure 8-8
MCCB Current-Carrying Capability as a Function of Ambient Temperature

Remember that the ambient temperature is defined as the air temperature surrounding the breaker. Although NEMA AB-4 recommends removal of the breaker from its enclosure to perform this test, some facilities perform the overcurrent testing with the breaker still installed in its enclosure. The temperature inside this enclosure may be higher than the ambient air temperature in the room.

Finally, the breaker must be allowed to cool between testing of each pole. The overload trip test generates heat inside the breaker that can influence the test results on adjacent poles. Also, if a pole is retested for any reason, the breaker should be allowed to cool for at least 20 minutes before retesting.

8.4.2.3 Test Connections

The MCCB should be connected to the test equipment with copper conductors approximately, but no less than, 4 feet in length and of the proper size (refer to Tables 8-2 and 8-3). The conductors act as a heat sink during the test and thus must be standardized to ensure consistent test results. A smaller conductor size or shorter conductor lengths can shorten the trip time. Larger cables or a heavy bus bar lengthens the trip time. Small frame breakers are particularly susceptible to variations caused by this effect. Test cables should be connected with mounting lugs specifically designed for the MCCB being tested to avoid damaging the terminals.

8.4.2.4 MCCBs Found Outside the Manufacturer's 300% Time-Current Range

Given the above considerations, field testing of MCCBs is not expected to be able to duplicate the manufacturer's time-current curves in all cases. If testing to the curves, some amount of tolerance about the curves is still considered practical. For example, ANSI/IEEE Std 242-1986, Section 15.3, suggests a test tolerance of ±15% about the time-current curves. Even if an MCCB is found outside of this tolerance, this does not necessarily mean that the breaker cannot perform its design function. Its performance outside the manufacturer's time-current curve might be completely acceptable given the limitations of field testing or the design requirements for the breaker. An engineering evaluation should be performed to determine if it still meets system design requirements.

8.4.3 Instantaneous Trip Test

NEMA AB-4 specifies a broad tolerance about the lower and upper instantaneous trip points (see Table 8-4). Remember that NEMA AB-4 is not attempting to validate the time-current curve, and its tolerances should be achievable for a properly functioning breaker. If validating the manufacturer's time-current curve, the instantaneous trip will be verified to tolerances less than the NEMA AB-4 criteria. The instantaneous trip test is prone to significant variation, and duplicating the manufacturer's test results is not a straightforward process. The following sections discuss issues to consider if trying to validate the time-current curves in the instantaneous region to a tolerance tighter than specified in NEMA AB-4.

8.4.3.1 Test Method

Section 8.3.2 describes two types of test methods that can be used for instantaneous trip testing: the run-up method and the pulse method. Only the pulse method can be used if trying to validate the manufacturer's time-current curves. As discussed in Section 8.3.2, the run-up test is not accurate and the results are very operator-dependent. Using the run-up test would be similar to using a yardstick to measure some tolerance to 0.001 inch. It simply is not the right tool for the required precision.

The easiest test approach is to use the pulse method and start just below the lower limit of the transition region (see Figure 8-7). The breaker should not trip below the lower tolerance limit. The test current can then be set at the upper limit of the transition region. The breaker should trip at this point. By performing the test in this manner, the breaker is known to trip somewhere within the expected band.

The instantaneous test current should be standardized at a specific number of cycles within the range of 5 to 10 cycles. Section 8.3.2.1 describes an actual situation in which different test results were obtained depending on the number of pulse cycles that were used in the test. Repeatable test results will not be realized if the test is performed with 5 cycles one time and 10 cycles the next. Every portion of the test must be standardized and repeated each time.

Care must be taken with this test. Even though only a short duration current pulse is applied, some heat is still generated inside the breaker. With each successive test, the likelihood of thermal-magnetic interaction is increased if the breaker is not allowed to cool. The result of thermal-magnetic interaction may be a breaker trip at a current level lower than predicted by the time-current curve. The thermal trip unit must not be allowed to participate in the trip function.

Stray magnetic fields inside an enclosure can affect the test results. If trying to validate the manufacturer's time-current curves, the breaker should be tested in a configuration similar to that used by the manufacturer. Remove the breaker from its enclosure and mount it on a steel backplate before performing the test.

8.4.3.2 Test Equipment

Section 8.3.2.1 describes the test equipment requirements for the pulse test. The test equipment must be capable of producing a true sinusoidal waveform with a zero offset. Asymmetry in the test current can cause the breaker to trip prematurely. The current meter must be fast enough to record the peak current.

8.4.3.3 Manufacturer's Tolerances

NEMA AB-4-2003, Section 6.6.4.2.3, Table 4, provides recommended tolerances for testing instantaneous trip units. The tolerances are summarized in Table 8-4. Although NEMA AB-2 has been rescinded from use, it is still a useful reference for the instantaneous test tolerances because it also shows the tolerances recommended for consideration by the manufacturer (see Table 8-5). Notice that the manufacturer's tolerances about the instantaneous region are tighter than the field test tolerances; however, the point to note is that there is still a tolerance. These tolerances are also specified in NEMA AB-1-2002, Section 7.3.1.5.

Table 8-5
NEMA AB-1 and -4 Instantaneous Trip Tolerances

		Tolerance of Manufacturers' Published Trip Range	
Standard	**Location**	**High Side**	**Low Side**
AB - 1	Factory	+30%	-20%
AB - 4	Field	+40%	-30%

8.4.3.4 MCCBs Found Outside the Desired Range

MCCBs found outside the desired range of instantaneous response should be carefully evaluated from several perspectives:

- Was the test setup designed to achieve the most consistent and accurate results possible under field test conditions?
- If the breaker tripped prematurely, is it still acceptable for use?
- If the breaker tripped late, does it still provide the required protection and coordination?

In summary, it cannot be emphasized enough that testing to tolerances tighter than specified by NEMA AB-4 requires carefully establishing accurate and consistent test conditions.

8.4.4 Rated Hold Test

Section 9.3 describes the rated hold test. A purist might contend that the rated hold test is important to complete the validation of the manufacturer's time-current curve. However, performing this test on a routine basis transforms the field test process into a never-ending test program that can become critical path in an outage. The benefit gained is not commensurate with the effort expended.

A properly performed rated hold test can require several hours on a large breaker before the temperature stabilizes. When the other inspections and tests are included, it may take an entire day to test a single breaker. This is not a cost-effective maintenance program. As stated in Section 9.3, this test is recommended only for breakers that experience nuisance tripping during normal operation.

8.5 Pre-Conditioning and As-Found Testing

A typical MCCB inspection and test sequence includes mechanically cycling the circuit breaker to ensure that it is operational prior to performing any electrical testing. The NRC has questioned several plants regarding this practice and has termed this *pre-conditioning* prior to as-found testing for MCCBs with Technical Specification periodic test requirements. The NRC contended that exercising MCCBs prior to performing overcurrent trip testing did not demonstrate operability in the as-found condition. Rather, the NRC perceives manual exercising of an MCCB as satisfactory pre-conditioning prior to verifying its as-found electrical trip characteristics.

8.5.1 Pre-Conditioning

Pre-conditioning of MCCBs prior to performing as-found thermal or magnetic overcurrent trip testing is defined as any action that will result in exercising the circuit breaker’s trip unit linkage or trip sensing elements prior to testing the first phase.

Industry research and experience, however, have proven that pre-conditioning of an MCCB’s trip element can take place only by either tripping the circuit breaker with its “push to trip” test button (if equipped) or from actual electrical overcurrent trip testing. Manually exercising, or cycling MCCBs prior to performing overcurrent trip tests does not influence as-found test results. Research has proven that mechanical operation of an MCCB will simply open and close the breaker contacts by latching or unlatching the normal close latch mechanism, not the electrical trip mechanism. This operation does not involve or actuate any movable linkage of the thermal or magnetic overcurrent trip unit or trip sensing elements. As stated previously, the only way in which a circuit breaker’s trip unit linkage or trip sensing elements could be pre-conditioned is through manipulation of the circuit breaker’s external “push to trip” test button or by performing an actual overcurrent trip test.

8.5.2 As-Found Testing

As-found testing can be defined as performing a test of the electrical trip functions of the circuit breaker prior to disturbing the electrical trip mechanism linkage or trip elements. This definition applies only to the first phase tested on a three-phase circuit breaker. Remaining tests of the other two phases will not verify the as-found condition because the electrical trip mechanism was previously actuated.

As-found testing is not considered to be a test method. Instead it represents a philosophy in which testing is performed to determine if the circuit breaker would have performed its design function, if required. With this approach, testing is performed in a manner that minimizes any pre-conditioning of the breaker by such actions as lubricating, removing the circuit breaker’s instantaneous trip unit or linkages, tripping the circuit breaker with the external “push to trip” test button, or otherwise affecting the circuit breaker’s as-found electrical trip characteristics when performing overcurrent testing to verify a manufacturer’s design trip curves.

A more effective as-found test method would be to conduct the overcurrent testing at a value near anticipated fault current without performing any other inspections or tests. This method would provide a more accurate indication of whether the circuit breaker would perform its design function of clearing faulted circuits in the as-found condition. However, an MCCB is not a precision instrument that can be easily verified for past operability. MCCBs are electromechanical devices, subject to test variability.

8.6 Testing DC MCCBs

Section 8.6 is based on EPRI report TR-104513, *Field Testing of Overcurrent Trip Units for Low Voltage Circuit Breakers Used in DC Applications.* This report was developed because little industry guidance is available with regard to testing MCCBs in DC applications. Refer to Section 4.10 for a technical overview of the differences between AC and DC MCCB applications.

Industry standards and manufacturers' published literature do not provide clear and consistent recommendations for testing DC MCCBs. Industry standards from the following organizations were evaluated as part of this project:

- American National Standards Institute (ANSI)
- Institute of Electrical and Electronics Engineers (IEEE)
- InterNational Electrical Testing Association (NETA)
- International Electrotechnical Commission (IEC)
- Military Standards (MIL STDs)
- National Electrical Manufacturers Association (NEMA)
- National Fire Protection Association (NFPA)

Additionally, investigations included consultation with key manufacturers, test equipment vendors, and users.

8.6.1 Background Information

Ambiguity and controversy exist regarding prudent methods of field testing low-voltage circuit breakers used in DC applications at nuclear power plants. A straightforward solution to the issue has been elusive, primarily due to three factors:

1. A lack of technical information regarding breaker performance characteristics in DC applications
2. Cautious and noncommittal recommendations from manufacturers and industry organizations
3. Little industry effort to resolve the issue due to the small market for DC breakers

Billions of MCCBs have been installed for AC applications. MCCBs for AC applications are well understood, and field test equipment is readily available to verify that AC breakers are functional. The National Electrical Manufacturers Association (NEMA) has issued AB-4, *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications*, to assist users with field testing methods. The test methods described in NEMA AB-4 apply to AC MCCBs; DC applications are not addressed.

Virtually every building or facility contains MCCBs for AC circuit isolation and system protection; however, few, if any, breakers may be installed for DC applications. For example, a nuclear plant may have anywhere from hundreds to thousands of MCCBs installed in AC systems but only a few dozen installed in DC systems.

The information provided in this report is directly applicable to MCCBs in DC applications for the following inspections or tests:

- Overheating inspection
- Enclosure inspection
- Mechanical operation inspection
- Insulation resistance test
- Insulated pole resistance test
- Rated hold test
- Auxiliary device tests

Additional discussion is required for overload and instantaneous overcurrent trip testing. The engineering principles discussed in Section 4.10 provide a technical basis for understanding and implementing field overcurrent test methods for MCCBs used in DC applications. By understanding how these breakers respond to overcurrent, AC and DC, an effective test program can be initiated for DC breakers using either AC or DC test equipment. Either test method is capable of providing satisfactory field test results, if conducted properly.

Overcurrent testing of DC breakers is fundamentally the same as testing AC breakers; there is no technical reason to implement radically different programs for AC and DC MCCBs. For AC breakers, standard industry practice is to perform an overload trip test and an instantaneous trip test. Guidance for conducting these tests on MCCBs is provided in Sections 8.2 and 8.3, respectively. Overload trip testing is generally performed at 300% of rated current, and acceptance criteria for trip times are specified in NEMA AB-4. Instantaneous trip testing is performed based on the low and high tolerance limits specified by NEMA AB-4.

NOTE: Some plants implement more restrictive acceptance criteria than is specified in NEMA AB-4.

DC breakers should be tested in the same general manner and at the same overcurrent points used to test similar breakers in AC applications. The basis for this position is that breaker trip characteristics are either the same (thermal trip units) or differ only by a predictable and measurable factor (magnetic trip units) under equivalent magnitudes of AC or DC current.

Manufacturers' time-current characteristic curves provide the expected response of MCCBs to various levels of overcurrent. Depending on the method of circuit breaker certification and the manufacturer's intended market, available curves may apply to AC only, DC only, or AC/DC. Before establishing test acceptance criteria for a particular DC application, the information provided by the manufacturer's curves should be fully understood.

8.6.2 AC Overcurrent Testing of MCCBs Used in DC Applications

Verifying that a DC MCCB responds properly to an AC test current confirms that it is functional for its design purpose. The test methods described in Sections 8.2 and 8.3 are adequate to verify the breaker's ability to respond to overcurrents in the thermal and instantaneous trip regions. The acceptance criteria do not need to be modified simply because the MCCBs are used in DC applications.

As discussed in Section 4.10, there are not significant design differences between thermal-magnetic MCCBs used in AC or DC applications. Actually, most MCCBs are developed for AC applications and are later tested and rated for DC. The significance of this is that there are not fundamental design differences between AC and DC MCCBs that will cause DC breakers to respond in an unpredictable manner when tested with AC current. Overcurrent test results obtained using AC test equipment can be directly correlated to performance under DC conditions, provided that the expected tripping characteristics for AC and DC current are clearly defined and well understood.

When testing with AC current, the AC time-current characteristics must be known. The test acceptance values should be based on the AC performance characteristics and not the DC performance characteristics. The AC time-current characteristics will certainly be known for AC and AC/DC rated breakers; most time-current curves provided by manufacturers are based on AC performance characteristics. Manufacturer assistance may be needed for rare cases in which an MCCB has only a DC rating. Even in these cases, the manufacturer should be able to provide AC time-current curves or DC/AC conversion information.

Overcurrent Tests

The AC test equipment used should be capable of providing a zero DC offset output current, and the test current should not have a significant harmonic content. DC offset of the AC waveform can occur if the voltage is at a value other than zero when the circuit is closed; the resultant current is called the *asymmetrical current* (see Figure 8-9). The offset can theoretically be as high as 200% under ideal conditions; however, the actual offset depends on the instantaneous voltage at the moment the test is initiated (see Appendix E for additional information). The effect of this offset is that the breaker may trip sooner than expected since the current peak is higher than the expected symmetrical value.

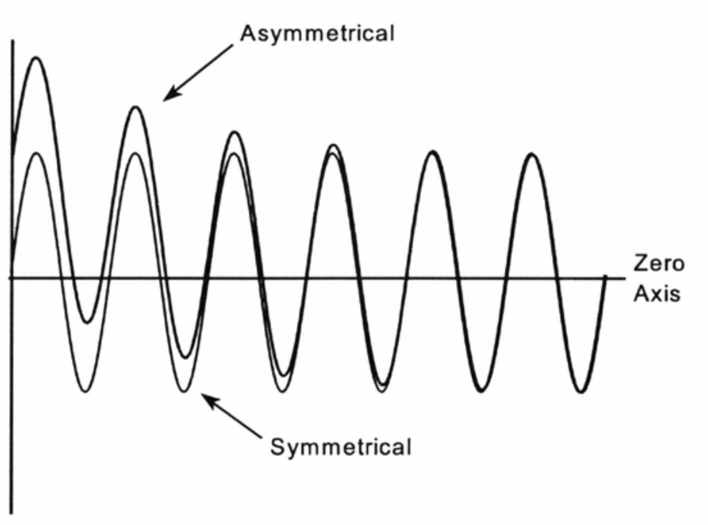


Figure 8-9
Asymmetrical Test Current

When testing the instantaneous trip in accordance with Section 8.3, the offset shown above can influence the test results in two ways:

- A test current applied just below the low tolerance limit for the instantaneous trip might initiate a breaker trip, falsely indicating a tendency for premature tripping. Per NEMA AB-4, the low tolerance is normally -30% below the minimum instantaneous trip point. Some nuclear plants test with a smaller tolerance to ensure that premature tripping cannot occur; a smaller tolerance increases the likelihood of a breaker trip due to asymmetrical test current.
- A test current applied at the high tolerance limit is more likely to trip because of the presence of offset. Thus, the offset might introduce enough additional magnetic force to trip the breaker when the breaker might not have otherwise met the NEMA AB-4 acceptance criteria had the current been only symmetrical.

The DC component of an asymmetrical current decays rapidly and is generally gone within a few cycles. For this reason, asymmetrical current will not measurably affect overcurrent testing of time-delay thermal trip units.

A DC offset in the AC test current may erroneously indicate a potential for premature instantaneous tripping at the low end, and the high end might inappropriately appear to be acceptable. Because the AC trip response is related to the DC trip response by a design-dependent conversion factor, any error in the AC test results will also be present in predictions of the DC trip response.

8.6.3 DC Overcurrent Testing of MCCBs Used in DC Applications

Commercially available DC test equipment can provide the necessary DC current levels to verify the functionality of the thermal and instantaneous trip units. The accuracy and repeatability of DC test equipment is similar to that obtained with AC test equipment. The use of DC current to test DC MCCBs does not guarantee a better correlation between field test results and the factory calibration data represented by the time-current characteristic curves. The following variations in field testing can cause differences from the factory test results:

- Rate of rise
- Ripple
- Initial overshoot

In the instantaneous region, DC test equipment should deliver current with a time constant of 8 ms or shorter to meet the criteria established by UL-489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures.* A longer time constant may yield results different from the manufacturer's predictions.

When testing MCCBs with a DC current source, particular care must be taken to ensure that the correct time-current characteristic curves are used. Many MCCBs mainly have AC time-current characteristic curves, and manufacturers provide conversion factors to adjust the instantaneous trip region for DC applications. As discussed previously, the thermal trip region usually does not require any adjustment for DC testing since AC rms current is equivalent to DC current of the same magnitude.

The manufacturer should be consulted to confirm that the information provided on the time-current curves is applicable. Not all manufacturers' time-current characteristic curves readily indicate a difference between AC and DC in the instantaneous region. For example, one manufacturer provides the same curves for AC and DC applications; however, another document must be consulted to determine the correction factor to apply to the instantaneous region for DC applications. Other manufacturers provide the conversion information directly on the time-current curves. Also, each manufacturer may provide a different conversion factor for each MCCB model and rating, ranging from as low as 10% to as high as 40%.

8.6.4 Conclusions Regarding Testing of DC MCCBs

Key conclusions and recommendations are summarized below:

1. The response of MCCBs to AC and DC overcurrent is readily characterized:

- Thermal trip units will respond equally to a DC current or AC rms current of the same magnitude.

- Magnetic trip units may respond differently to AC rms and DC current. The AC rms and DC current that will produce equivalent tripping characteristics are related by a manufacturer-specified conversion factor.

2. Overcurrent testing of MCCBs used in DC applications may be accomplished using either AC or DC test methods. Technically valid verification of breaker functionality can be obtained using either method as long as the user fully understands and accounts for the inherent potential differences in a breaker's response to AC or DC current.

3. The purchase of DC test equipment solely for the purpose of testing DC system breakers is not recommended. The initial and recurring expense associated with equipment purchase, separate test procedures, additional training, and equipment upkeep is not justifiable given that technically valid test results can be obtained using AC test equipment. By the same rationale, if DC test equipment is already owned and in use, there is no compelling reason to switch to AC testing.

4. The acceptance criteria for testing DC MCCBs are based on NEMA AB-4. The acceptance criteria in NEMA AB-4 are generally considered adequate for verifying the functionality of AC MCCBs. By understanding the difference in breaker trip response for AC and DC currents, the NEMA AB-4 acceptance criteria can be applied with equal validity to DC applications.

5. When testing DC breakers with AC equipment:

- The acceptance criteria should be based on the breaker's AC trip characteristics. If desired, DC equivalent performance can be determined using the manufacturer-specified conversion factors. The conversion factor used for a specific breaker model and size should be confirmed by the manufacturer.

- The instantaneous trip test should be conducted using test equipment capable of providing a zero DC offset output current. A DC offset may result in erroneous test results.

6. When testing DC breakers with DC equipment:

- The acceptance criteria should be based on the breaker's DC trip characteristics. Users should consult with the manufacturer to confirm the DC characteristics since most time-current curves are based on AC applications.

- Test equipment rise time, ripple, and overshoot may impact test result accuracy. Users should confirm that DC test equipment provides current with a sufficiently short rise time to meet the original test criteria established by UL-489.

7. In addition to overcurrent testing, other inspections and tests are recommended for MCCBs to ensure continued high reliability. With regard to these other inspections and tests, existing guidance for AC breakers is considered adequate for DC breakers.

8.7 New Testing Methods

Electrical testing of MCCBs has traditionally been a time-consuming activity and is expensive in terms of the labor required to perform the testing.

The testing method used by many utilities is to remove the circuit breaker from the motor control center (MCC), take it to the shop, connect it to test equipment, perform the test, return the circuit breaker to the field, and reinstall the breaker. This process of removing, testing, and reinstalling can take up to one shift per breaker.

A new testing method is being used by some utilities to test MCCBs in place, without removing them from the MCC. This new test methodology significantly reduces the time required to test MCCBs in an MCC and has resulted in significant cost savings. One utility using this test equipment has been able to test 30 breakers in the time it previously took them to test a single one. This new methodology does require that the entire MCC be taken out of service.

The new methodology requires more portable test equipment, which has become available in recent years. This test equipment is a high-current test set designed primarily to perform primary injection testing on circuit breakers. The equipment incorporates digital signal processing technology along with variable firing angle (which minimizes DC offset) and pulse duration control with specially designed low-voltage, insulated, hand-held probes to connect to the breaker being tested.

Once a motor control center is electrically isolated, low-voltage hand-held test probes connect the test set to the load and line sides of the breaker to be tested. If the MCC has a spare “bucket” or the bus bars are accessible, then the line side test lead can be connected to all three phases—requiring only the load-side lead to be connected using the hand-held test probe.

The new testing method has two process variations from AB-4 test methods, which are described here.

The first variation is that the breaker is tested *in situ* versus being removed and tested in a maintenance shop area. Advocates of this new methodology have stated that testing the MCCB *in situ* provides for a more realistic test because the breaker is tested in its operating environment. The test results, therefore, more accurately reflect the true operating environment.

The second variation is the use of a probe versus a specified length and size of wire. The use of the probe rather than a certain length and size of wire is considered acceptable because the thermal heat transfer and impedance are insignificant (less than 2%). For each breaker size, AB-4 provides for using a predefined wire size and minimum length to have the same approximate impedance and thermal heat sink conditions for each test.

8.8 Considerations for Applying NEMA AB-4 Test Criteria

The purpose of electrical testing is to determine if a circuit breaker will perform its intended function. The trip tolerance criteria provided in Table 4 of NEMA AB-4 is often used as pass/fail criteria for instantaneous trip testing. Utility personnel have observed that, in certain cases, MCCBs have been deemed not functional and discarded when instantaneous test results are just outside NEMA criteria. However, in these cases, utility personnel have noted that the electrical system's coordination and protection are maintained because the actual trip value is well below the damage curve of the breaker's load. Utility personnel questioned the rational for discarding what appeared to be circuit breakers that would have performed their function.

These observations led to a set of questions posed to NEMA in 1999; these questions and NEMA's response are provided in Appendix F. NEMA's response was that a measurement slightly above or below the AB-4 tolerances still indicates functionality. There no reason to think that the MCCB has degraded if it trips consistently and especially if it is consistent with its own history. Decisions related to the ability of the MCCB to protect the load must be made after an engineering evaluation. It would be wise to verify the continuation of the functionality by performing the test several times. History based on previous tests may also be useful in indicating whether the MCCB measurements have been reasonably consistent. If the MCCB fails to operate or shows erratic behavior, it should be replaced. If measurements are clearly beyond the tolerance levels indicated, the MCCB should be considered suspect and should be replaced.

This communication resulted in some utilities taking a closer look at their position on NEMA criteria or calculating new criteria. Rather than using the NEMA criteria as "pass" or "fail," utilities have used engineering evaluation and judgment and have taken into account cable protection, short-circuit current limitations, and circuit breaker coordination to determine whether a breaker is functional.

9

ELECTRICAL TESTS

Section 9 provides a step-by-step description of how MCCB electrical tests should be performed. It also offers insight into what each test accomplishes and why it is (or is not) important for ensuring breaker reliability. A discussion of the failure mechanisms that each test might detect, as well as any inherent test limitations, is provided.

The emphasis here is on how to perform a test and what the test should accomplish. For information on periodicity and equipment prioritization guidance, see Section 6. Overcurrent testing is discussed in Section 8.

NEMA Standards Publication AB-4, *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications*, is acknowledged as a principal reference source. NEMA AB-4 was originally issued in May 1991 and represents the manufacturers' consensus regarding how to perform inspection and testing.

9.1 Insulation Resistance Test

9.1.1 Purpose of Test

An insulation resistance test is performed to assess the adequacy of the insulation between poles of a circuit breaker and between each pole and ground. A low insulation resistance might indicate contaminated, flawed, or cracked insulating material.

Low insulation resistance is not a common failure mechanism or failure predictor for MCCBs. Manufacturers' documents state that extreme atmospheres and conditions may reduce the dielectric strength of the insulating material. MCCBs at nuclear plants typically are not exposed to such harsh environments.

Because of the design and construction of MCCBs, a low insulation resistance is not an expected occurrence under normal conditions; other problems would likely show up first. Therefore, the insulation resistance test alone is not considered an important test for a periodic maintenance (PM) program. This test should normally be performed only when other tests are scheduled.

9.1.2 Test Procedure

1. Before starting the test, deenergize the breaker and electrically isolate it from its power source in accordance with plant procedures.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.
3. If the breaker requires removal from the enclosure, mount the breaker in a test location that simulates its installation in actual use.
4. Make sure that any exposed metal parts other than the line, load, and accessory terminals are electrically connected to a metal baseplate.

CAUTION: Isolate accessory terminals from any test connections since the test voltage could damage accessory components.

5. The test should be performed using a standard insulation resistance tester with a minimum of 500 volts DC. Record the following insulation resistances:

- Between line and load terminals of each individual pole with the circuit breaker in the OFF position
- Between terminals of adjacent poles with the circuit breaker in the ON position
- From line terminals to the metal baseplate with the circuit breaker in the ON position

6. If any resistance measurement is less than one megohm, replace the circuit breaker or consult the manufacturer before restoring the circuit breaker to service.

NOTE: The above minimum acceptance criteria was obtained from NEMA AB-4. Manufacturers' literature also specifies one megohm as a lower limit. However, given the nature of an MCCB design, an insulation resistance near one megohm indicates a substantial problem with the insulation. Under normal conditions, the insulation resistance should exceed 50 megohms. The InterNational Electrical Testing Association (NETA) specifies a minimum acceptance criteria of 100 megohms in NETA MTS-2001, *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems.*

9.2 Insulated Pole Resistance Test

9.2.1 Purpose of Test

Several other names are commonly used for the insulated pole resistance test. These include:

- Millivolt drop test
- Contact resistance test
- Breaker resistance test
- Watts loss test

The purpose of the test is to evaluate the electrical quality of the connections and contacts in a circuit breaker. A higher-than-normal contact resistance may indicate that the contacts are damaged. The effect of a high resistance on breaker operation is that the breaker may overheat while carrying load current or cause an unacceptable voltage drop in the circuit.

NEMA recommends measurement of the millivolt drop across the breaker while supplying a substantial DC current because the test data best represent the MCCB performance when carrying rated load. However, the test is difficult to perform, and test results can be affected by differences in the test connections, type of equipment, and test personnel. Industry recommendations have not been consistent with regard to the method for measuring pole resistance, and some manufacturers have allowed a simple measurement with a resistance bridge.

Acceptance criteria for this test should be obtained from the manufacturer. In general, the pole resistance varies inversely with breaker continuous current rating—larger breakers have smaller pole resistances. The typical variation in pole resistance is shown in Figure 9-1.

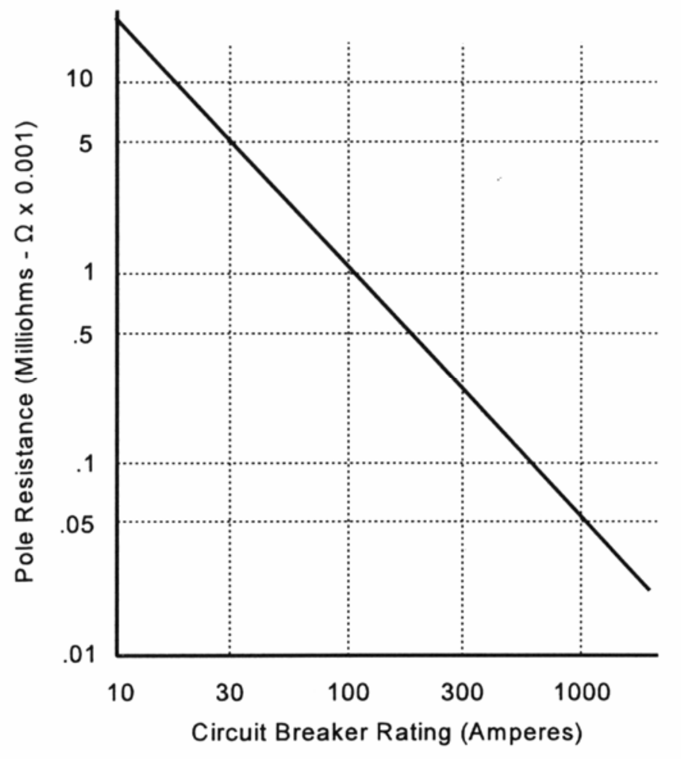


Figure 9-1
Typical Pole Resistance Variation

Two techniques for performing the Insulated Pole Resistance Test are presented here: the millivolt drop test and the precision bridge resistance check. A description of each, including its advantages and disadvantages, follows.

1. Millivolt Drop Test

A custom test unit applies rated current to the breaker, and the millivolt drop across the breaker is measured. This test best determines the contact resistance under the operating condition of concern while actually carrying load current. Its disadvantage is that it is complicated and requires specialized equipment. In most cases, maintenance departments would probably just replace the breaker if overheating were a concern.

2. Precision Bridge Resistance Check

A precision bridge ohmmeter capable of accurate milliohm readings is used to measure contact resistance while the breaker is de-energized. This check provides a quick appraisal of any significant variations between contacts. For example, if one contact in a three-pole breaker has a contact resistance twice that of the other two contacts, there might be degradation of the high resistance contact. Measurements taken with a precision bridge should be evaluated with care. De-energized contact resistances do not necessarily correlate with the expected contact resistance when the breaker carries rated current. Consequently, the data from this check should be used only to compare contact resistances, not to verify some absolute acceptance limit.

Given the nature of the most common failure modes for these breakers and the fact that the test results are prone to considerable variation, this test is not as important as other preventive maintenance such as the mechanical operation inspection. Factors influencing the insulated pole resistance test results include:

- Breaker frame type, ampere rating, and manufacturer
- Quality of connection of test leads, including surface resistivity
- Test current value
- Test system voltage
- Temperature

The point here is that insulated pole resistance measurements should be evaluated with care, and any trending of the data should be viewed with caution. This test is not recommended as the sole basis for MCCB acceptability, and would normally be performed only for troubleshooting if overheating were suspected. Performance of this test on a periodic basis is not recommended.

If performed, the order in which this test is conducted is important. As a practical consideration, this test should be performed before overcurrent testing of thermal-magnetic MCCBs. After an overcurrent test, the thermal trip unit bimetallic strip has absorbed significant energy and is at a higher-than-ambient temperature. This temperature increase will cause errors in a contact resistance measurement. If overcurrent testing is performed first, the MCCB should be allowed to cool completely to ambient before taking insulated pole resistance measurements (at least 20 minutes).

9.2.2 Test Procedure

9.2.2.1 Millivolt Drop Test

1. Before starting the test, de-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.
3. If the breaker must be removed from the enclosure, mount it, if possible, in a test location that simulates its installation in actual use.

NOTE: The following steps specify the breaker rated current, not the load current, for the test. If the test current is limited to less than this amount by the available test equipment, apply the maximum current possible with the existing equipment.

4. Connect the test leads to the line and load terminal connections for the pole to be tested.
5. Apply test current across the pole equal to the breaker rating. If the breaker rating exceeds 500 amperes, apply a minimum of 500 amperes.

CAUTION: Do not apply test current for more than 10 seconds.

6. Record the test current and the millivolt drop on a data sheet.
7. Deenergize the test circuit and manually cycle the breaker to the OFF and then ON positions.
8. Repeat steps 5 through 7 for a total of three readings on the pole being tested.
9. Repeat steps 4 through 8 for each of the remaining poles on the breaker.
10. Average the three readings recorded for each of the tested poles.
11. Compare the results to the values recommended by the manufacturer for the particular type and size of breaker. Also, compare the average readings for the three poles with each other. If any average set of readings is unusually high, review the results of recent overheating inspections.

9.2.2.2 Precision Bridge Resistance Check

1. Before starting the test, de-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.
3. If necessary, remove the breaker from the enclosure to gain access to the breaker terminal connections.
4. Close the breaker.
5. Attach the precision bridge test leads to the line and load terminals; record the milliohm measurements for each pole.

CAUTION: The quality of the connection of the test leads is crucial. Poor connections cause unacceptable variations in the test results.

6. Open and then close the breaker.
7. Repeat step 5 several times to ensure a consistent reading.
8. Compare the readings for the three poles with each other. An unusually high resistance for any contact could confirm that breaker overheating is due to contact degradation. Typically, a 50% deviation between poles should be investigated. Consult the manufacturer for specific criteria for acceptable contact resistance percent variations.

9.3 Rated Hold Test

9.3.1 Purpose of Test

The purpose of this test is to verify that an MCCB can carry its rated current without tripping. This test is usually performed only for breakers that are nuisance tripping during normal operation. For some breaker applications, nuisance tripping may not be tolerable, for example, for ensuring that a safety-related load is energized upon receipt of an automatic initiation signal.

If breaker tripping has occurred, the rated hold test may confirm breaker operability for the specific application.

9.3.2 Test Procedure

1. Deenergize the breaker and electrically isolate it from its power source in accordance with plant procedures.
2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

3. Remove the breaker from its enclosure and place it in a free air environment, with a room ambient temperature of approximately 77°F.
4. Establish the test circuit by connecting all breaker poles in series and terminating to a low-voltage power supply using copper conductors not less than 4 feet in length per pole (see Figure 9-2). The size of the conductor should be as specified in Table 8-2 or 8-3.

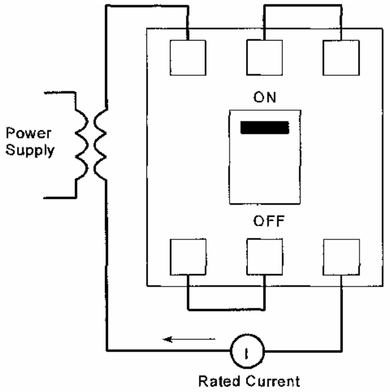


Figure 9-2
Rated Hold Test Setup

CAUTION: Connect test cables with mounting lugs specifically designed for the MCCB being tested to avoid damaging the terminals.

NOTE: Plug-on or draw-out MCCBs require a special test fixture.

NOTE: If the MCCB contains an undervoltage trip device, energize the device to allow the breaker to close.

5. Energize the power supply and establish a test current equal to the breaker rated current.
6. Allow the MCCB temperature to stabilize. Successive temperature measurements (approximately 10 minutes apart) taken at the same place on the breaker can be used to verify that the temperature has stabilized. Monitor the temperature at a connector or terminal lug.

NOTE: Temperature stabilization typically occurs within 1 hour for breakers rated 100 amperes or less. Larger breakers may take several hours to stabilize.

The breaker should not trip during the test. If a trip occurs, reset the breaker and reestablish the test current. The breaker is not capable of carrying the rated load current if it continues to trip before the temperature stabilizes.

9.4 Shunt Trip Test

9.4.1 Purpose of Test

Shunt trip units are accessory devices used to trip open an MCCB under conditions other than overcurrent. In nuclear plants, shunt trips are sometimes used to trip open selected breakers upon receipt of protective signals.

The purpose of this test is to confirm that, when energized, the shunt trip unit will trip open the breaker.

9.4.2 Test Procedure

1. Before starting the test, de-energize the breaker and electrically isolate it from its power source in accordance with plant procedures. De-energize control power to the shunt trip unit.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

NOTE: The test may be performed with the breaker mounted inside its enclosure. Removal is not necessary specifically for this test.

3. Disconnect the control power wires from the shunt trip unit and connect the shunt trip unit to a power supply capable of delivering the shunt trip unit rated current and voltage.

CAUTION: Isolate accessory terminals other than the shunt trip unit from any of the test connections. Ensure that the proper test connections are made before energizing the test power supply source.

4. Close the breaker by operating the handle to the ON position.

NOTE: If the breaker is equipped with an undervoltage trip unit, energize the undervoltage trip unit to allow the breaker to close.

5. Energize the shunt trip unit by turning on the power supply. The breaker should trip.

CAUTION: The breaker should trip without any intentional time delay once the shunt trip unit is energized. If the breaker does not trip within approximately 2 seconds, turn off the power supply to prevent damage to the shunt trip unit.

6. If the shunt trip occurs properly, restore the circuit to normal. If the breaker fails to trip, verify that all connections are correct and repeat the test. If the breaker still fails to trip, replace the shunt trip unit, or replace the breaker if the shunt trip is not replaceable.

9.5 Undervoltage Trip Test

9.5.1 Purpose of Test

Undervoltage trip units are occasionally used to trip open an MCCB under loss of voltage conditions. The purpose of this test is to confirm that, upon a loss of voltage, the breaker trips open and cannot be reposed until voltage is restored.

9.5.2 Test Procedure

1. Before starting the test, de-energize the breaker and electrically isolate it from its power source in accordance with plant procedures.

CAUTION: Follow precautions for working with energized equipment. Do not touch terminations or other potentially electrically energized locations until verifying that all components in the enclosure are de-energized.

2. Open the enclosure and verify that there is no voltage on the incoming conductors or any control power conductors, if present, and between these conductors and ground.

NOTE: The test may be performed with the breaker mounted inside its enclosure. Removal is not necessary specifically for this test.

3. Disconnect the control power wires from the undervoltage trip unit and connect a power supply capable of delivering rated current and voltage to the undervoltage trip unit.

CAUTION: Isolate accessory terminals other than the shunt trip unit from any of the test connections. Ensure that the proper test connections are made before energizing the test power supply source.

4. Turn on the test power supply to the undervoltage trip unit.
5. Close the breaker by operating the handle to the ON position.
6. De-energize the undervoltage trip unit by turning off the power supply. The breaker should rip.
7. Reset the breaker and attempt to shut the breaker. The breaker contacts should not close.
8. If the undervoltage trip unit and breaker operate properly, restore the circuit to normal. If the breaker fails to perform as required by steps 6 and 7, verify that all connections are correct and repeat the test. If the breaker still does not perform as required, replace the undervoltage trip unit, or replace the breaker if the undervoltage trip unit is not replaceable.

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10
ACCEPTANCE TESTS

Acceptance tests apply to new or replacement breakers. The basic considerations for installation of a new or replacement breaker include:

- Evaluation to confirm that engineering design and application requirements are met
- Verification of origin
- Receipt inspection
- Acceptance tests prior to installation

Section 10 describes the inspections and tests that should be performed as part of a receipt inspection at the warehouse and the tests that should be performed before a new breaker is installed. Engineering evaluations that should be performed as part of accepting a new breaker are also described.

10.1 Engineering Evaluations

New breakers are often of a different make and model from the breaker being replaced. The principal reason for installing a different type of breaker is that the original model is obsolete and no longer available from the manufacturer. However, a different type of breaker may have problems in the following areas:

- Fit
- Coordination
- Ratings

MCCBs are often provided by the original equipment manufacturers as commercial grade products. A third-party qualification source may be required to perform the dedication process and certify a breaker for safety-related use.

An engineering evaluation of the replacement breaker is recommended either prior to or as part of the breaker acceptance process. The following sections provide an overview of issues to consider.

10.1.1 Fit Considerations

Simply stated, the new breaker may not fit in the desired location without some modification to the mounting arrangement. If the original breaker is no longer supported by the OEM, involvement by a third-party qualification source may be needed to develop a mounting arrangement compatible with the desired location.

Height, Width, and Depth

The new breaker may not occupy more volume; however, the height, width, and depth may vary. The new breaker installation should conform to the manufacturer's recommendations regarding distance requirements to grounded metal, control wire, and power wire in the proximity of gas vents and other openings in the breaker.

Mounting Footprint

The new breaker may have a different mounting arrangement than the original breaker. New mounting holes may be required. Templates can be made to determine the new mounting footprint.

Operator Handles

In most cases, switchboard and panelboard handles come directly through a front plate. Generally, this plate can be cut or rebuilt for the new handle.

Motor control centers (MCCs) require more planning to ensure a proper fit with a new operator handle. New breakers are usually not designed to accept old operator designs. The handle designs may allow some flexibility for depth into the MCC but generally have minimal capability for side-to-side or up-and-down adjustment. Also, new handles may operate entirely different from the old design. Resolving operator handle issues for an MCC may require 1) the fabrication of a new door or 2) attaching a plate over the original door with the new cutout requirements.

Line and Load Terminations

Most MCC breakers are cable in and cable out. For this reason, terminations are usually not a significant problem with replacement breakers for MCCs. However, switchboards and panelboards often mount directly on the panel bus. For these breaker types, the mounting configuration should be reviewed carefully. The bus connections may require modification as part of the replacement process.

Accessories

Ensure that adequate space is available for any accessories. Also, access to each accessory device should be provided as part of the installation.

10.1.2 Time-Current Characteristics

A new breaker may not have time-current characteristics identical to the old breaker. Even if the new breaker is the same model, the time-current characteristics should be verified because manufacturers have occasionally changed the trip characteristics over the years without changing part numbers. The time-current curves for the new and old breakers should be directly compared. If the characteristics are essentially identical, no further review may be necessary. However, if the curves are different, coordination with upstream and downstream devices should be confirmed. In this case, the following should be checked:

1. Does the new breaker coordinate with upstream protective devices?
2. Does the new breaker coordinate with downstream protective devices?
3. Does the new breaker let through more current in any region of the time-current curve when compared to the old breaker? If so, are downstream cables and devices adequately protected?
4. Does the new breaker let through less current in any region of the time-current curve when compared to the old breaker? If so, is nuisance tripping a possibility?

10.1.3 Ratings

The ratings for the new breaker must satisfy the design requirements for the application. Section 4 provides an overview of application-related considerations for a new breaker.

10.1.4 Seismic Qualification

If the new breaker is used in a safety-related application, seismic qualification documentation will be required as part of the commercial grade dedication process. A third-party qualification source may be needed to perform seismic qualification testing.

10.2 Receipt Inspection

A new breaker should be inspected upon receipt to ensure that the purchase requirements have been met. Each MCCB should be inspected for the following:

- Date code
- Proper manufacturer labeling
- UL label
- Canadian Standard Association label (may be present)
- Manufacturer seals
- Proper rating
- Proper terminals
- Physical condition

The inspection should confirm that the breaker is traceable to the original equipment manufacturer (OEM). The simplest method of performing this verification is to review the OEM packing slip provided with the shipment. Rebuilt or refurbished breakers are not acceptable for use for the reasons explained in Section 11.3.

10.3 Acceptance Tests

Acceptance testing is different from field testing only in that baseline data should be obtained for later trending. Tests significantly different from or in addition to the tests previously described in this guide are not recommended; acceptable performance of safety-related breakers can be verified with the following inspections and tests:

- Breaker inspection
- Mechanical operation
- Insulation resistance test
- Insulated pole resistance test
- Overload trip test
- Instantaneous trip test
- Rated hold test
- Accessory device tests

Frequently, acceptance tests are required to be performed by the supplier prior to shipment. Based on this testing, the tests listed above may not be necessary before placing breakers into warehouse stock; however, the tests are still recommended to be performed on site prior to installation. The rated hold test should not need to be performed again if the breaker was previously tested.

11
CORRECTIVE MAINTENANCE

Periodic inspection and test recommendations have already been discussed. Section 11 deals with corrective maintenance to be performed when a breaker does not perform as intended. In this regard, corrective maintenance includes the following conditions:

- A breaker fails during operation and must be replaced.
- A breaker fails a routine inspection.
- A breaker fails a routine performance verification test.

11.1 Repair Versus Replacement Considerations

Unless specifically allowed by the manufacturer, MCCBs are not intended to be customer repaired. MCCBs are normally manufactured and/or certified in accordance with the following standards:

- UL 489, Underwriters Laboratories Inc. Standard for Safety, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures*
- AB-1, NEMA Standards Publication, Molded Case Circuit Breakers, Molded Case Switches, and Circuit-Breaker Enclosures

Manufacturer certification to the above standards indicates that the breaker was manufactured and tested in accordance with a formal set of criteria to ensure acceptable performance. Manufacturers do not certify or warrant a breaker that has been modified or repaired outside their recommendations or control. In general, opening the case of an MCCB voids the UL listing and any manufacturer's warranty. Unless specifically allowed by the manufacturer, MCCBs should never be opened. Broken, damaged, or defective MCCBs should be repaired only by the original manufacturer.

The periodic inspection and testing sections in this guide cover corrective actions to be taken whenever a problem is encountered during an inspection or performance test. Acceptance criteria are also provided. For some inspections or tests, additional evaluation or testing may be possible to verify that an MCCB no longer meets acceptable standards. In summary, any of the following conditions should prompt a breaker replacement:

- The breaker rating is not appropriate for the installed application.
- Cracks exist in the molded case.
- Plug-on jaws are pitted, discolored, or melted on bus bar mating surfaces.

- Physical indications of overheating such as severe discoloration are observed.
- The breaker handle does not operate freely.
- The breaker does not reset, or the mechanical trip mechanism does not trip the breaker.
- Insulation resistance is below minimum.
- The breaker fails an instantaneous or overload trip test.
- The breaker fails a rated hold test.
- Accessory devices fail specified tests.
- Contacts or auxiliary switches are not open with the breaker in the tripped or OFF position or are not closed with the breaker in the ON position.

The trip unit or accessory device may be replaceable. Replacement questions should be referred to the manufacturer.

11.2 Spare Parts Inventory Considerations

Unless the manufacturer has specifically authorized such repairs, MCCBs are not field-repairable. Failed MCCBs must be replaced. Therefore, the spare parts inventory for MCCBs should primarily consist of replacement breakers, not replacement parts.

As part of a complete periodic maintenance program for MCCBs, the various models and sizes of breakers should be determined, with a suitable stocking level established for each size and type. This inventory is especially important if the maintenance department is just starting or is expanding the scope of a maintenance program for MCCBs. Particular emphasis should be placed on obsolete breaker styles with a low available inventory on site.

Many nuclear plants have encountered difficulty obtaining replacement breakers of the exact make and model as the originals. In these cases, equivalent substitutions are necessary. Refer to Section 10 for a discussion of the issues potentially encountered with replacement breakers.

11.3 Rebuilt or Refurbished Breakers

Rebuilt or refurbished MCCBs should not be used as replacements. Such breakers should be removed from service if they are discovered anywhere in the plant. The reason for this position is as follows. Manufacturers design, produce, and test MCCBs in accordance with UL and NEMA standards. The accepted industry standard for manufacturing test acceptance of MCCBs is UL-489, *Molded-Case Circuit Breakers and Circuit-Breaker Enclosures.* In order for a breaker to obtain a UL listing, it must pass a series of tests. In particular, the overload, endurance, and short-circuit tests defined in UL-489 are destructive to the breaker. After initial UL acceptance, the quality of the manufacturing process is periodically confirmed by UL inspectors, who check samples from the manufacturing line in accordance with the established test criteria.

To obtain and maintain the UL label, manufacturers must produce breakers that pass a rigorous test series, including destructive tests. In addition, the manufacturing process must be capable of producing breakers representative of those tested.

Rebuilt or refurbished breakers are produced in a manner outside the normal UL certification process. Since refurbished breakers are not subjected to all UL-489 tests, there is less assurance that they will perform required protective functions under all conditions originally specified by the manufacturer. These MCCBs should be avoided since their ability to operate properly and safely clear rated faults has not been completely verified. The following problems have been noted with these breakers:

- Incorrect calibrations
- Wrong parts installed, parts omitted, or parts incorrectly installed
- Mismatch between the ampere rating on the breaker handle and the trip unit
- Improper labeling for a higher voltage rating
- Use of solvents to clean the breaker interior (solvents remove factory lubrication and can subsequently result in breaker binding)

Rebuilt and refurbished MCCBs have received considerable attention throughout the electrical industry. In response to this issue, NEMA rescinded and withdrew Publication AB-2-1984, *Procedures for Field Inspection and Performance Verification of Molded Case Circuit Breakers Used in Commercial and Industrial Applications.* AB-2 was withdrawn because it was being used inappropriately by some companies as the basis for acceptance of rebuilt breakers.

This issue was brought to the attention of the entire nuclear industry by NRC Bulletin 88-10, *Nonconforming Molded-Case Circuit Breakers.* This Bulletin required a number of actions related to breakers used in safety-related applications without verified traceability to the circuit breaker manufacturer.

The Nuclear Management and Resources Council, Inc. (NUMARC), now the Nuclear Energy Institute (NEI), served as the industry interface with the NRC and coordinated the industry response to NRC Bulletin 88-10. The final NUMARC report, NUMARC 90-14, *Summary of the NUMARC Initiative to Address Substandard Non-Safety-Related Molded Case Circuit Breakers*, was issued in November 1990. This report recommends the replacement of such breakers, if currently installed, and provides guidance to prevent their future procurement.

A
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B

GLOSSARY OF TERMS AND ACRONYMS

A

AC - Alternating Current.

Acceptance Criteria - Specified limits placed on the characteristics or performance of an item, process, or service as defined in codes, standards, or other requirement documents.

Accessories - Auxiliary devices that may be installed in or on a circuit breaker that perform a secondary function to the primary function of a circuit breaker.

Adjustable Instantaneous Trip - An overcurrent trip element that contains an adjustable device that allows tripping a breaker instantaneously at various values of current within a predetermined range of currents.

Alarm Switch - An auxiliary switch that operates to open or close another circuit upon the automatic opening of the circuit breaker with which it is associated.

Ambient-Compensated Circuit Breaker - A breaker that has the capability to partially or completely counteract the effect of ambient temperature upon the tripping characteristics.

Ambient Temperature - The average temperature of the surrounding medium in contact with the breaker. For an enclosed device, it is the average temperature of the surrounding medium outside the enclosure.

Ampere Rating - The largest current a given breaker will continuously carry without either tripping or exceeding the permissible temperature rise, usually specified at an ambient temperature of 40°C.

Arcing - The discharge of electric current across a gap between two points. Arcing occurs across breaker contacts each time a breaker interrupts current.

Asymmetrical Current - A current wave that is not symmetrical about the zero axis. The current is offset from the zero axis with the magnitude of current above and below the zero axis unequal.

Auxiliary Switch - A switch that is mechanically operated by the breaker for alarming, interlocking, or other purposes.

B

Bolted Fault - The highest magnitude short circuit current for a particular fault location. The impedance at the fault location is typically very low or zero for a bolted fault.

Branch Circuit - The circuit conductors and components between the final overcurrent device protecting the circuit and the equipment.

Bus - The conductor or conductors, usually made of solid copper or aluminum, that carries the current and serves as a common connection for two or more circuits.

C

Calibration Setting - Adjustment of the breaker trip device(s) so that the breaker performs in accordance with its established characteristics.

Calibration Test - A test performed at a selected percentage or multiple of the current rating of the breaker to verify its tripping characteristics.

Circuit Breaker - A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically upon a prespecified current, without damage to itself when properly applied within its rating.

Circuit Breaker Enclosure - An enclosure intended to house a single circuit breaker.

Circuit Breakers Incorporating Ground Fault Protection - Circuit breakers that perform all normal circuit breaker functions and also trip when a current to ground exceeds some predetermined value.

Class HE - The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing significant release of radioactive material to the environment.

Clearing Time - The total elapsed time between the beginning of an overcurrent and the final interruption of the circuit at rated voltage. For a fuse, the clearing time is typically considered the sum of the melting time and the arcing time. For a breaker, the clearing time is the elapsed time between the actuation of a release device and the instant of arc extinction on all poles of the primary arcing contacts.

Continuous Current Rating - The maximum current the device is designed to carry on a continuous basis and remain within the applicable guidelines for the breaker.

Continuous Load - A load where the maximum current is expected to continue for three hours or more.

Current Limiting Circuit Breaker - A circuit breaker that does not utilize a fusible element, and that when operating within its predetermined current-limiting range, limits the let-through I^2t to a value less than the It of one-half cycle of the expected symmetrical current.

Current Limiting Fused Circuit Breaker - A circuit breaker in combination with integral current-limiting fuses that, when it interrupts a current within its specified current limiting range, purposely introduces an impedance so as to reduce the current magnitude and duration.

D

DC - Direct Current.

Dielectric Withstand Voltage Test - A test intended to determine the ability of insulating materials and spacings to withstand overvoltages without flashover or breakdown under a specific set of conditions.

Direct Current - The current that flows continuously in one direction through a closed circuit from a negative terminal to a positive terminal (usually produced by a battery or battery charger).

Downstream Device - A device beyond a particular point in the circuit and farther away from the source. An upstream device is closer to the source.

E

Electrical Operator - An electrical controlling device used to open, close, and reset a breaker.

Enclosure - A surrounding case constructed to provide a degree of protection to personnel against accidental contact with the enclosed equipment and to provide some degree of protection to the enclosed equipment for specified environmental conditions.

Equipment Qualification - The generation and maintenance of evidence to ensure that the equipment will operate upon demand to meet the system performance requirements.

F

Failure - Termination of the ability of an item to perform its required function.

Failure Mechanism - The physical, chemical, or other process that results in failure.

Failure Mode - The effect by which a failure is observed.

Failure Rate - The expected number of failures of a given type, per item, in a given time interval or a given number of operating cycles.

Feeder - The circuit conductor and components between the main and the branch protective devices.

Fixed Instantaneous Trip - The portion of an overcurrent trip element that contains a nonadjustable means of tripping a breaker instantaneously at or above a predetermined level of current.

Fixed Mounted Circuit Breaker - A breaker bolted into a fixed position with bus or cable mechanically bolted to breaker terminations.

Frame - An assembly consisting of all parts of a circuit breaker with the exception of an interchangeable trip unit.

Frame Rating - The maximum continuous current rating for a given frame size.

Frame Size - A classification for a group of molded case circuit breakers that are physically interchangeable with one another. Frame size is expressed in amperes and corresponds to the largest ampere rated breaker within the given group.

Front Removable Circuit Breaker - A breaker capable of easy removal from a stationary frame with the bus connection to the breaker termination typically accomplished by a manual compression fitting.

G

Grounded - An electrical connection that gives a circuit a direct positive path to ground.

H

Handle Lock - A device that provides a positive means of retaining a breaker handle in a desired position.

I

I^2t Response - A measure of the heating effect or thermal energy of a fault current.

IEEE - Institute of Electrical and Electronics Engineers, Inc.

Infrared Thermography - A nonintrusive method of determining surface temperature by measurement of the radiated infrared heat.

Inspection - Examination or measurement to verify whether an item or activity conforms to specified requirements.

Installed Life - The interval from installation to removal, during which the equipment or component thereof may be subject to design service conditions and system demands.

Insulated Pole Resistance Test - A test to assess the electrical integrity of connections and contacts in a circuit breaker by measurement of the millivolt drop across the connections under an applied voltage and current.

Integrally Fused Circuit Breaker - A circuit breaker with coordinated fuses connected in series with the trip elements of the circuit breaker that are mounted within the housing of the circuit breaker.

Instantaneous - A term used to indicate that no delay is purposely introduced in the automatic tripping of the circuit breaker.

Interchangeable Trip Unit - A trip unit that can be interchanged among circuit breaker frames of the same design.

Instantaneous Trip Circuit Breaker - A circuit breaker intended to provide short circuit protection with no overload protection.

Inverse Time - A term used to indicate that there is a purposely introduced delayed tripping time that decreases as the current magnitude increases.

L

Let-Through Current - The maximum instantaneous or peak current that passes through a protective device.

Load Center - An assembled piece of equipment housing circuit breakers and connections. It accepts an incoming power connection and controls the power flow to branch circuits while providing circuit protection.

Low Level Fault - A fault that typically ranges from just above acceptable full load current to 10 or more times normal current. This type of fault does not generally cause immediate damage. But, if left undetected, a low level fault will eventually lead to damage or equipment problems.

M

Magnetic Trip Unit - An electromagnet connected to the breaker trip bar that actuates upon the set current level without any intentional time delay.

Main - The circuit conductors and components that supply an electrical system between the main overcurrent device to the feeder overcurrent devices.

Maintainability - The ease with which equipment can be maintained, including the ease with which maintenance can be performed in accordance with prescribed requirements.

Maintenance - The combination of all technical and corresponding administrative actions intended to retain an item in, or restore it to, a state in which it can perform its required function.

Maintenance Interval - The period, defined in terms of real time, operating time, number of operating cycles, or a combination of these, during which satisfactory performance is required without maintenance or adjustments.

Mandatory Maintenance - Periodic maintenance required by insurance, operating license, vendor warranty, government regulations, or other safety regulations.

MCC - Motor Control Center.

MCCB - Molded case circuit breaker.

Mean Time Between Failure - A measure of reliability giving either the time before first failure or, for repairable equipment, the average time between repairs.

Mechanical Interlock - A device that interlocks two or more breakers so that only selected ones can be closed at the same time.

Mild Environment - An environment that would at no time be significantly more severe than the environment that would occur during normal plant operations, including anticipated operational occurrences.

Millivolt Drop Test - A test to assess the electrical integrity of connections and contacts in a circuit breaker by measurement of the millivolt drop across the connections under an applied voltage and current.

Molded Case Circuit Breaker - A low-voltage circuit breaker assembled as an integral unit in an enclosing housing of insulating material. It is designed to open and close by nonautomatic means and to open a circuit automatically on a predetermined overcurrent, without damage to itself when applied properly within its rating.

Molded Case Switch - A device assembled as an integral unit in an enclosing housing of molded insulating material, designed to open and close a circuit by nonautomatic means.

Motor Control Center - A piece of equipment that centralizes motor starters, associated equipment, bus, and wiring in one continuous enclosed assembly.

Multipole Circuit Breaker - A breaker with two or more poles that provide a corresponding number of conducting paths in which the poles are insulated from one another.

N

NEC - National Electric Code.

NEI - Nuclear Energy Institute (formerly NUMARC).

NEMA - National Electrical Manufacturers Association.

Neutral - An assembly consisting of an appropriate number of terminals providing for the connection of the grounded neutral conductors. Typically, this includes a means for making the termination between the neutral and the enclosure and a terminal for the service grounding conductor.

NFPA - National Fire Protection Association.

NPAR - Nuclear Plant Aging Research.

NRC - Nuclear Regulatory Commission.

Nuisance Trip - An unintentional trip at below set pickup conditions.

NUMARC - Nuclear Management and Resources Council, Inc.

O

OEM - Original Equipment Manufacturer.

Operable - For a given point in time, a device or piece of equipment that has been demonstrated by testing at that time to have met a set of functional performance requirements under specified test conditions.

Overcurrent - A current that exceeds a continuous current rating, including overloads, short circuits, and ground faults.

Overcurrent Trip - A component that detects overcurrent and transmits the energy necessary to trip the breaker automatically.

P

Panelboard - A metal enclosed assembly designed for low-voltage power distribution.

Peak Current - The maximum magnitude of current in an alternating current cycle.

Periodic Test - A test performed at scheduled intervals to detect failures and verify operability.

Pickup Point - The rms current level at which the circuit breaker tripping function is initiated.

PM - Periodic maintenance.

Pole - The portion of a circuit breaker associated exclusively with one electrically separated conducting path of the main circuit.

Power Factor - The cosine of the phase angle
(0) between the voltage and current for a sinusoidal circuit.

$$pf = \cos\Theta$$

Power factor is also commonly expressed as the ratio of total watts to the total rms volt-amperes.

$$PF = \frac{total\ watts}{total\ volt - amperes} = \frac{active\ power}{reactive\ power}$$

Preventive Maintenance - Regularly scheduled inspections, tests, servicing, repairs, and replacements intended to reduce the frequency and impact of equipment failures.

Q

Qualified Life - The period of time for which satisfactory performance can be demonstrated for a specific set of service conditions.

R

Rated Current - The maximum current the equipment is rated to carry under a specific set of conditions.

Rated Frequency - The service frequency of the circuit for which the breaker is designed and tested.

Rated Insulation Voltage - The voltage to which dielectric voltage tests and creepage distances are referred.

Rated Operational Voltage - The maximum voltage, rms for ac voltage, for which the breaker can be applied.

Rated Short-Time Withstand Current Rating - The value of current specified by the manufacturer that the device can carry, under prescribed conditions, without damage when properly applied within its rating.

Rating - The designated limit for a given parameter for the operating characteristic of the device.

Reactance - The imaginary part of impedance.

Reliability - The characteristic of an item expressed by the probability that it will perform a required function under stated conditions for a stated period of time or operating cycles.

Reluctance - A material's or assembly's resistance to magnetic force.

Resistance - The real part of impedance.

rms - Root-mean-square.

S

Service Conditions - The conditions under which the breaker is to be applied.

Short Time Delay - A term indicating that there is a purposely introduced delayed tripping action of either finite or inverse time characteristics.

Short Time Withstand Rating - The maximum value of current a breaker is designed to let through and handle safely for a short period of time in the closed position without the contacts welding or any other type of damage.

Shunt Trip Device - A breaker tripping mechanism that may be actuated by signals associated with the circuit breaker or by an independent source.

Solid-State Trip Unit - An electronic overcurrent trip unit capable of time-current adjustment over a wide range.

Symmetrical Current - A current wave symmetrical about the zero axis.

T

Thermal-Magnetic Interaction - An overcurrent condition of sufficient magnitude and duration that the thermal trip unit and magnetic trip units jointly respond. Thermal-magnetic interaction may occur during instantaneous trip testing if the test current is repeatedly applied such that the bimetal element is heated and not allowed to cool.

Thermal Trip Unit - A bimetal element connected to the breaker trip unit to provide protection with an inverse time characteristic.

Thermography (Infrared) - A nonintrusive method of determining surface temperature by measurement of the radiated infrared heat.

Time-Current Curve - A graphical representation of the expected time of a breaker to open in response to overcurrent.

Trip - The opening of a circuit breaker by actuation of the breaker release mechanism.

Trip-Free Circuit Breaker - A circuit breaker designed so that the contacts cannot be held in the closed position by the electrical operator during trip command conditions.

Trip Unit - A self-contained portion of the breaker that actuates the mechanism that opens the circuit breaker contacts automatically.

U

UL - Underwriters Laboratories, Inc.

Undervoltage Trip - A trip mechanism that causes a circuit breaker to open automatically if the control voltage falls below a prescribed value.

W

Watts Loss Test - A test to assess the electrical integrity of connections and contacts in a circuit breaker by measurement of the millivolt drop across the connections under an applied current and calculation of the total watts based on the applied current.

Withstand Current - The specified rms symmetrical current that a circuit breaker can carry in the closed position for a specified time.

X

X/R Ratio - The ratio of reactance to resistance in a circuit.

C

OVERVIEW OF INDUSTRY STANDARDS AND REGULATORY DOCUMENTS

Industry standards are used to define accepted practices for system or product design, application, installation, service, operation, or maintenance. For MCCBs, several standards are available. Some are devoted solely to MCCBs, whereas other standards address MCCBs as part of a broader subject. NRC documents provide insight into specific past problem areas with MCCBs.

C.1 American National Standards Institute (ANSI)

ANSI/IEEE Std 141-1 986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (IEEE Red Book)

The IEEE Red Book provides guidance on the design, construction, and continuity of an electrical system. Maintenance considerations applicable to MCCBs are discussed.

ANSI/IEEE Std 242-1986, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book)

The IEEE Buff Book deals with the proper selection, application, and coordination of components that constitute system protection for industrial plants and commercial buildings. Section 15.3 provides specific recommendations regarding maintenance and testing of MCCBs; it also allows for testing in accordance with NEMA procedures.

ANSI/IEEE Std 308-1974, IEEE Standard Criteria for Class HE Power Systems for Nuclear Power Generating Stations

Circuit breakers, overload devices, and relays are defined as actuation equipment by IEEE 308 when their proper operation is required to support a safety system in the performance of its safety function. Defined as such, this equipment is Class WE and subject to the relevant requirements for the Class 1E electrical distribution system.

Periodic testing of Class WE equipment is discussed in Section 7.4.1 of IEEE 308, which states that periodic tests shall be performed at scheduled intervals to (1) detect within practical limits the deterioration of the equipment toward an unacceptable condition and (2) demonstrate operability of components that are not exercised during normal operation.

MCCBs are actuation equipment as defined by IEEE 308. It is intended that periodic testing include Class WE equipment that could, as a result of otherwise unnoticed degradation, cause a safety system to perform its safety function improperly. IEEE 308 does not define the tests or test frequencies necessary to verify operability. Instead, it states that the specific tests and their frequencies depend upon the specific components installed, their function, and their environment.

ANSI/NFPA 70-1990, National Electric Code

This code is a nationally accepted guide for the safe installation of electrical conductors and equipment, and is the basis for all electrical codes used in the United States.

ANSI/NFPA 70B-1990, Recommended Practice for Electrical Equipment Maintenance

(See ANSI/IEEE Standards listed in the American National Standards Institute section for other IEEE standards.)

IEEE Std 384-1977, IEEE Standard Criteria for Independence of Class IE Equipment and Circuits

The purpose of IEEE 384 is to establish the criteria for implementation of the independence requirements of IEEE Std 279-1971, *Criteria for Protection Systems for Nuclear Power Generating Stations,* and IEEE Std 308-1974, *Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.* With regard to circuit breakers, IEEE 384 allows circuit breakers tripped solely by fault current to be used as Class 1E electrical isolation devices, provided the following coordination criteria are met:

- The breaker time-overcurrent trip characteristic for all circuit faults will cause the breaker to interrupt the fault current before initiation of a trip of any upstream breaker. Periodic testing shall demonstrate that the overall coordination scheme remains within the limits specified in the design criteria. This testing may be performed as a series of overlapping tests.
- The power source shall supply the necessary fault current for sufficient time to ensure proper coordination without loss of function of Class 1E loads.

Simply stated, IEEE 384 allows MCCBs to be used as Class 1E electrical isolation devices if the time-overcurrent trip coordination is applied properly for the circuit and the coordination is periodically confirmed by testing. The above position in IEEE 384 is not endorsed by Regulatory Guide 1.75. Instead, it states that circuit breakers must also trip upon receipt of a signal other than one derived from fault current. This statement implies the use of shunt trip devices actuated by an accident or emergency signal.

C.2 Institute of Electrical and Electronics Engineers (IEEE)

The purpose of this document is to reduce the hazards to life and property that can result from failure or malfunction of industrial electrical systems and equipment. MCCB inspection and testing is addressed in detail.

ANSI/NFPA 70E-1988, Standard for Electrical Safety Requirements for Employee Workplaces

This standard addresses electrical safety requirements that are necessary for the practical safeguarding of employees in the workplace. It does not cover electrical generation facilities under the exclusive control of electric utilities. However, NEMA Standards Publication No. AB 4 does refer to NFPA 70E in some of its recommended practices.

C.3 National Electrical Manufacturers Association (NEMA)

NEMA Standards Publication No. AB 1-2002, Molded Case Circuit Breakers, Molded Case Switches and Circuit-Breaker Enclosures

This publication provides standards and guidance for ratings, performance requirements, verification tests, applications, accessories, enclosures, and markings for MCCBs. The intent is to assist purchasers in selecting the proper circuit breakers for specific needs and to minimize potential misunderstandings between manufacturers and purchasers.

NEMA Standards Publication No. AB 2-1984, Procedures for Field Inspection and Performance Verification of Molded Case Circuit Breakers Used in Commercial and Industrial Applications (Rescinded)

This publication was issued to recommend procedures for field inspection and performance verification of MCCBs. NEMA rescinded this publication in 1989 because of some companies misapplying it to certify refurbished, used, and surplus MCCBs. This publication has since been replaced by NEMA Standards Publication No. AB 4; however, AB 2 is listed here as a cited publication since other industry standards, textbooks, and documents still refer to it.

NEMA Standards Publication No. AB 3-1991, Molded Case Circuit Breakers and Their Application

This publication recommends test and inspection procedures for returning a motor controller to service after a short circuit or ground fault. Recommended inspection and test instructions are provided for MCCBs.

C.4 National Fire Protection Association (NFPA)

This publication explains the proper application of MCCBs.

NEMA Standards Publication No. AB 4-1991, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications

This publication supersedes and fully replaces NEMA Standards Publication No. AB 2. It provides field test methods to verify specific characteristics of an MCCB that was originally built and tested in accordance with NEMA Standards Publication No. AB 1.

NEMA Standards Publication No. ICS 2.2-1983 (R 1988), Maintenance of Motor Controllers After a Fault Condition

C.5 Underwriters Laboratories, Inc. (UL)

UL 489, Molded-Case Circuit Breakers and Circuit-Breaker Enclosures, 1988 Edition including revisions through October 1990

This standard for safety provides requirements for construction, performance, ratings, and markings for circuit breakers, accessories, and enclosures. Circuit breaker manufacturers normally list their equipment in accordance with this standard.

C.6 Regulatory Documents

NRC Generic Letter 81-12 establishes a review method deemed acceptable to the NRC for verifying that the safe shutdown capability can be maintained in the event of a severe fire. The generic letter does not explicitly establish expectations for "associated circuits" as defined by 10 CFR 50. To clarify expectations, the NRC staff issued a follow-up memorandum (NRC Staff's Clarification Memorandum to Generic Letter 81-12, dated March 22, 1982) that provided refined definitions and specific requirements related to associated circuits.

The NRC clarification memorandum requires that a study be performed to verify the absence of common power supply associated circuits. Common power supply associated circuits are defined as follows:

> Those cables (safety-related, non-safety-related, Class WE, and non-Class WE) that: (1) have a physical separation less than that required by Section III.G.2 of Appendix R. and (2) have a common power source with shutdown equipment (redundant or alternative) and the power source is not electrically protected from the circuit of concern by coordinated breakers, fuses, or similar devices.

Satisfactory electrical protection in this context is achieved when a load-side overcurrent device clears a downstream fault before the line-side (or backup) device is actuated. This is commonly referred to as selective tripping. The NRC memorandum further establishes specific criteria for device acceptability. Enclosure 2, Section B.2.2.iii of the NRC clarification memorandum delineates the requirements for MCCBs. It is specifically stated that credit cannot be taken for these devices unless:

> They are periodically exercised and inspected for ease of operation, and (1) (2)
> On a refueling outage basis, a sample of these breakers is tested to verify that drift is within the allowed design limits.

NRC Bulletin 88-10, Nonconforming Molded-Case Circuit Breakers, November 22, 1988 and Supplement 1, August 3, 1989.

This Bulletin was issued because certain MCCBs could not be traced back to the original manufacturer. See NUMARC 90-14.

NRC Generic Letter 81-12, Fire Protection Rule, February 20, 1981.

NRC Information Notice 85-16, Time/Current Trip Curve Discrepancy of ITE/Siemens-Allis Molded Case Circuit Breaker, February 27, 1985.

This Information Notice highlights the need to verify time-current characteristic curves for replacement MCCBs. In this instance, the instantaneous trip range had been changed from 400–700 amperes on the older model to 600–1000 amperes on the newer model.

NRC Information Notice 86-62, Potential Problems in Westinghouse Molded Case Circuit Breakers Equipped With a Shunt Trip, July 31, 1986.

This Information Notice is similar to Information Notice 85-16. The instantaneous band of a particular MCCB was changed from 600–1000 amperes to 1200–2000 amperes. Although product literature usually contains the appropriate curves, the curves are not routinely provided with the breaker.

NRC Information Notice 90-43, Mechanical Interference With Thermal Trip Function in GE Molded-Case Circuit Breakers, June 29, 1990, and Supplement 1, March 13, 1991.

Inadequate MCCB test procedures, test acceptance criteria, test equipment, and test control are discussed. Identified issues include 1) testing dc breakers with a procedure for ac breakers without established acceptance criteria, 2) testing in accordance with NEMA acceptance criteria that are less stringent than the manufacturers' time-current curves, and 3) testing solid-state MCCBs trip units without including the current transformer and associated wiring in the scope of the test.

NRC Information Notice 92-03, Remote Trip Function Failures in General Electric F - Frame Molded-Case Circuit Breakers, January 6, 1992.

This Information Notice discusses actions or conditions that can cause failure of the shunt trip unit on certain MCCBs.

NRC Information Notice 89-21, Changes in Performance Characteristics of Molded-Case Circuit Breakers, February 27, 1989.

This Information Notice describes a mechanical interference problem on one MCCB phase that could prevent a thermal trip. The mechanical interference appeared to be the result of an installed undervoltage trip unit.

NRC Information Notice 91-29, Deficiencies Identified During Electrical Distribution System Functional Inspections, April 15, 1991.

This Information Notice describes a potential trip function failure for certain MCCBs with undervoltage or shunt trip devices.

Regulatory Guide 1.75 endorses IEEE 384-1974 as a means acceptable to the NRC for complying with IEEE 279-1971 and General Design Criteria 3, 17, and 21 with respect to the physical independence of safety-related circuits and electric equipment. Exceptions are taken to the recommendations in IEEE 384 (see discussion related to IEEE 384 in Section C.2).

Nuclear Regulatory Commission (NRC) Special Study AEOD/S92-03, Review of Operational Experience With Molded Case Circuit Breakers in U.S. Commercial Nuclear Power Plants, June 1992.

This report determined whether any type of regulatory action was required to provide assurance that licensees were adequately addressing the question of MCCB reliability in safety-related applications. Nuclear Plant Reliability Reporting System (NPRDS) data from January 1985 to December 1990 was examined. The analysis of specific MCCB failure modes found that most of the failure rate data fell below the estimated range for the generic failure rate contained in IEEE STD 500-1984, with no discernible trend. The report concludes that operational experience does not support any specific regulatory initiative at the time of its publication. The report also notes that, despite manufacturer recommendations and industry standards, many plants do not perform periodic testing or preventive maintenance on safety-related MCCBs, and for the few that do, frequency and procedures differ widely.

NRC Information Notice 92-51, Misapplication and Inadequate Testing of Molded-Case Circuit Breakers, July 9, 1992.

Sizing of MCCBs for potential motor inrush currents to avoid unwanted trips is discussed. Thermal-magnetic trip interaction is described; high currents affect both the thermal and the magnetic trip units and, in some instances, the mutual effect can result in premature tripping.

NRC Information Notice 93-26, Grease Solidification Causes Molded Case Circuit Breaker Failure to Close, April 7, 1993.

Regulatory Guide 1.32 endorses IEEE 308-1974 as an acceptable method of complying with General Design Criteria 17 and 18 (see discussion related to IEEE 308 in Section C.1).

NRC Regulatory Guide 1.75, Physical Independence of Electric Systems, Revision 2, September 1978.

Some MCCB greases can solidify with age, resulting in an inability to operate the breaker. This Information Notice discusses an instance in which a breaker failed to close because of grease solidification.

NRC Information Notice 93-64, Periodic Testing and Preventive Maintenance of Molded Case Circuit Breakers, August 12, 1993.

This Information Notice discusses the wide variation in MCCB test programs at nuclear plants and identifies industry standards and publications that contain recommendations for testing and maintenance of MCCBs.

NRC Regulatory Guide 1.32, Criteria for Safety-Related Power Systems for Nuclear Power Plants, Revision 2, 1977.

C.7 NUMARC (Nuclear Energy Institute) Documents

Nuclear Management and Resources Council (NUMARC) 90-14, Summary of the NUMARC Initiative to Address Substandard Non-Safety-Related Molded Case Circuit Breakers, November 1990.

NUMARC coordinated the industry response to NRC Bulletin 88-10. This report summarizes information relating to substandard breakers and contains recommendations for resolving the issue.

D
COMPARISON OF RMS AC CURRENT TO DC CURRENT

An MCCB thermal trip unit is expected to have an essentially identical response regardless of whether the applied current is AC or DC, provided that the rms value of the AC current is equal in magnitude to the DC current. This appendix provides a technical overview of AC and DC currents with regard to their ability to deliver power to a resistive load such as a thermal trip unit. The effective value of a single frequency sinusoidal AC current capable of providing the same energy as a DC current is calculated.

The power delivered by a DC current, I_{DC} Through a resistance, R. is given by

$$P_{dc} = I_{dc}^2 R$$

The power delivered at any instant in time by an AC current through the same resistance, R. is given by

$$p(t) = i^2 R$$

where,

$$i(t) = I_{\max} \cos(\omega t + \theta)$$

The lower case letters for power and current above indicate that these are the values at a particular instant in time. I_{max} represents the peak value of the sinusoidal current. The cosine term is present due to the sinusoidal nature of the current which may be out of phase with the applied voltage by the phase angle 0. In summary, the power delivered at any instant in time by a sinusoidal AC current can be expressed as

$$p(t) = I_{\max}^2 \cos^2(\omega t + \theta) \ R$$

Comparison of rms AC Current to DC Current

The average power associated with a sinusoidal current is the average of the instantaneous power over one complete period, T. In equation form, the average power is expressed by integrating the instantaneous power starting at some time, t over a full period, t_0 + T.

$$P_{ave} = \frac{1}{T}\int_{t_0}^{t_0+T} p(t)\ dt$$

or,

$$P_{ave} = \frac{1}{T}\int_{t_0}^{t_0+T} I_{\max}^2 \cos^2(\omega t + \theta)\ R\ dt$$

This integral can be simplified by expanding the squared cosine function by the trigonometric identity

$$\cos^2(\alpha) = \frac{1}{2} + \frac{1}{2}\cos(2\alpha)$$

Using this identity, the expression for instantaneous AC power is given by:

$$p(t) = I_{\max}^2 \cos^2(\omega t + \theta)\ R = \frac{I_{\max}^2 R}{2} + \frac{I_{\max}^2 R}{2}\cos\ (2\omega t + 2\theta)$$

Returning to the integral relationship for the average power, the second term in the above expression will integrate to zero since it is symmetrical about the zero axis over one complete period. Thus, the average power in a sinusoidal circuit is given by:

$$P_{ave} = \frac{1}{T}\int_{t_0}^{t_0+T} \frac{I_{\max}^2 R}{2} dt$$

Solving the integral yields

$$P_{ave} = \frac{I_{\max}^2 R}{2}$$

Now, we can return to the original question regarding the required relationship between AC and DC current to provide the same power. If the DC power equals the AC power, then

$$P_{dc} = P_{ave}$$

or

$$I_{dc}^2 R = \frac{I_{\max}^2 R}{2}$$

Simplifying this equality yields

$$I_{dc} = \frac{I_{\max}}{\sqrt{2}}$$

The peak AC current, $I_{\max}$, divided by √2 is called the AC rms current. Notice the AC and DC currents supply the same power when the magnitude of the DC current equals the AC rms current.

E

ASYMMETRICAL CURRENT IN AN INDUCTIVE AC CIRCUIT

The terms *symmetrical* and *asymmetrical current* refer to the shape of an alternating-current about the zero axis. During transient conditions such as a short circuit or motor start, the current is not initially symmetric. This appendix provides technical background information regarding asymmetrical current and its impact on MCCBs under transient conditions.

E.1 Current Flow in an Inductive Circuit

Consider a typical AC voltage that varies sinusoidally similar to the shape shown in Figure E-1. The magnitude of voltage varies with time by

$$v(t) = V_p \sin(\omega t + \Phi)$$

where,

v(t): Instantaneous voltage as a function of time.

$V_{p:}$ Maximum or peak voltage value.

l: Time.

ω: A term used to represent the angular frequency of the sinusoidal function. For a 60 hertz system, ω = 2πf where f is the frequency.

Φ: Initial phase angle of the sinusoidal voltage. This shifts the sinusoidal function along the time axis.

A typical sinusoidal voltage is shown in Figure E-1. This voltage waveform is also a steady-state waveform because it is symmetric about the zero axis. The voltage varies sinusoidally between $\pm V_p$. One full cycle is known as a period, T, and is related to the frequency by T = 1/f.

Asymmetrical Current in an Inductive AC Circuit

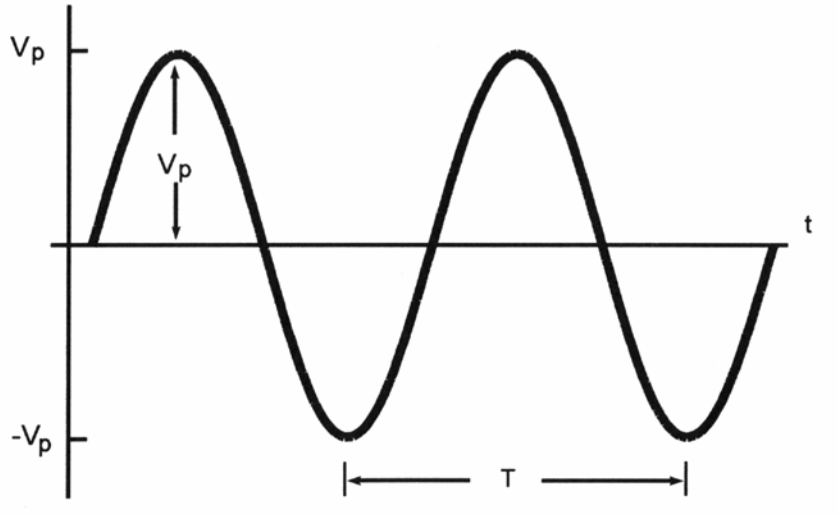

Figure E-1
Sinusoidal and Symmetrical Current Waveform

Power system circuits contain resistance, inductance, and capacitance. However, the inductance in a power system normally is substantially greater than the capacitance. Consider the simple RL (resistance and inductance) circuit shown in Figure E-2. We can develop an understanding of asymmetrical current by evaluating the current in this circuit at time t=0 when a switch is initially closed.

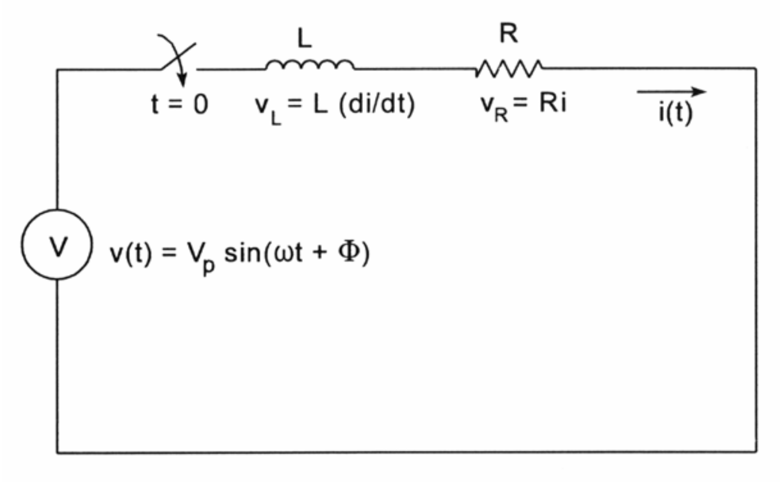

Figure E-2
RL Circuit with Sinusoidal Voltage Applied

As shown in Figure E-2, the source voltage, v(t), generates a current flow at time t=0 that results in a voltage across the inductance, L, and the resistance, R. or

$$v(t) = v_L + v_R$$

Referring to Figure E-2, this leads to the differential equation

$$V_P \sin(\omega t + \Phi) = L\frac{di}{dt} + Ri$$

We are interested in the current as a function of time. The solution to the above differential equation is given by

$$i(t) = \frac{V_P}{|Z|}[\sin(\omega t + \Phi + \theta) - \sin(\Phi - \theta)\ e^{-\frac{Rt}{L}}]$$

where,

$$|Z| = \sqrt{R^2 + \omega^2 L^2}$$

and

$$\theta = \arctan(\frac{\omega L}{R})$$

As can be seen, the current is described by the sum of two terms. The sum of the two currents is the total current, I(t), and is shown in Figure E-3.

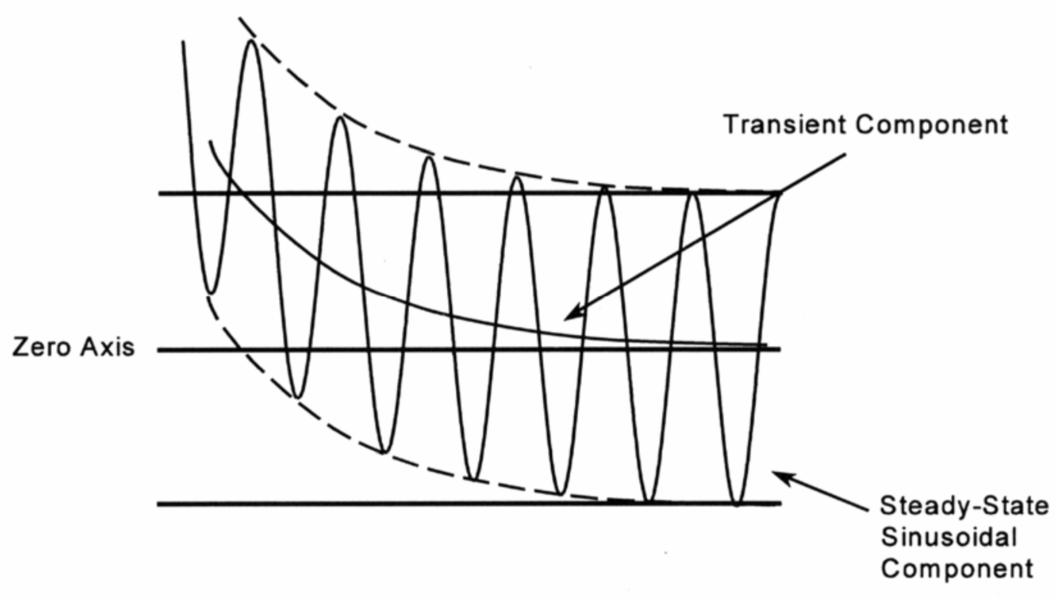

Figure E-3
Current Waveform After Closing Switch at Time t = 0

Notice in Figure E-3 that the current is not initially symmetric about the zero axis. This is referred to as *asymmetric current* and it is significant in that the positive magnitude of current can be significantly larger than only the sinusoidal component of current at time t=0.

Before proceeding with further analysis of asymmetrical current, the concept of X/R ratio will be introduced. Current as a function of time in an RL circuit was described in terms of inductance, L, and resistance, R.

$$i(t) = \frac{V_p}{|Z|}[\sin(\omega t + \Phi + \theta) - \sin(\Phi - \theta)\ e^{-\frac{Rt}{L}}]$$

The term X/R simply refers to the ratio of the magnitude of inductive reactance to the resistance. In the above equation, current is expressed in terms of inductance rather than inductive reactance. The magnitude of inductive reactance is

$$X_L = \omega L = 2\pi f L$$

or

$$L = \frac{X_L}{\omega} = \frac{X_L}{2\pi f}$$

We will simplify by using X rather than XL to describe inductive reactance. For analysis purposes, the power factor in a circuit is often expressed as the X/R ratio. Power factor is defined as the cosine of the phase angle between voltage and current and the X/R ratio is defined as the tangent of this phase angle. Therefore, the relationship between power factor and X/R ratio is:

$$\frac{X}{R} = \tan\ (\arccos\ (Power\ \ factor))$$

Expressing the current in an RL circuit in terms of X yields

$$i(t) = I_p[\sin(\omega t + \Phi + \arctan\frac{X}{R}) - \sin(\Phi - \arctan\frac{X}{R})e^{\frac{(\frac{-\omega t}{X})}{R}}]$$

where,

$$I_p = \frac{V_p}{|Z|}$$

The total current in an RL circuit depends on two terms. The first term is sinusoidal or periodic with time and is known as the *steady-state component* of current, i_5. The second term is nonperiodic and decays exponentially with time. The second term is known as the *transient component* or the *dc component* of current, i_{dc}. Notice that within a few cycles the transient component has effectively decayed to an infinitesimal value, leaving only the steady-state component. The total current in the circuit is the sum of the two components:

$$i(t) = i_s + i_{dc}$$

The magnitude of the peak asymmetrical current just after time t = 0 when a switch is closed depends on two parameters: the initial phase angle, ϕ, of the source voltage and the X/R ratio. The transient component has a maximum value when (ϕ - arctan X/R) = $\pm \pi/2$, equal to the sinusoidal steady-state component. This means that the total initial current is twice the steady-state component value. Similarly, the transient component is at its minimum value of zero when (ϕ - arctan X/R) = $\pm\pi$, Because the initial phase angle, f, can assume any value, the transient component of current must beassumed to have any value between 0 and I_p

The rate at which the transient component of current decays to zero depends on the X/R ratio. As the X/R ratio in the denominator of the exponential term becomes very large, a proportionately larger amount of time must elapse before the numerator has the expected effect of driving the exponential decay component to zero. Notice that an infinitely large X/R ratio, i.e., a circuit that is entirely inductive, would not decay and the transient component would maintain a constant value equal to the steady state component. In this case, the total current would have twice the steady state value and would always be positive as shown in Figure E-4.

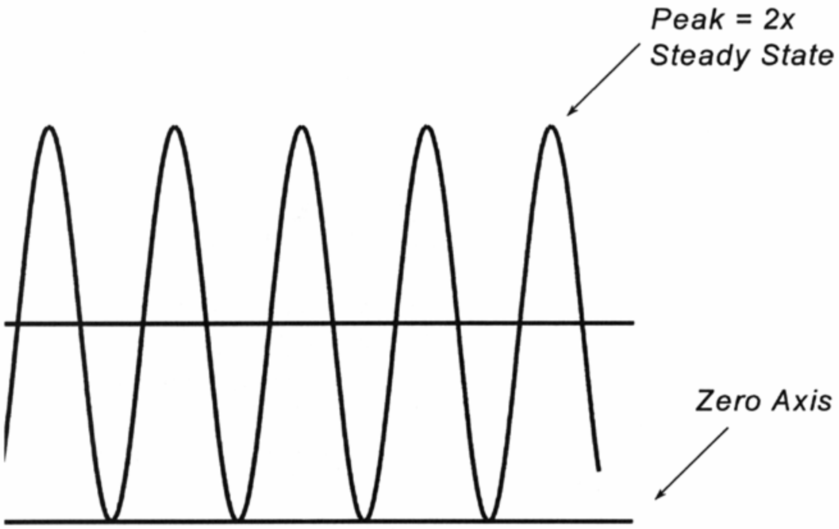

Figure E-4
Current Waveform for a Purely Reactive Circuit

E.2 Asymmetrical Current During Motor Starting Transients

A motor circuit can be modeled as an RL circuit. Following the rationale in Section E.1, a motor starting transient is expected to have an initial asymmetric current resulting from the transient or dc component contribution. The difference in this case is that the sinusoidal steady-state component should be considered the locked rotor current. As the motor accelerates, the total current will decrease to the steady-state full load current as shown in Figure E-5.

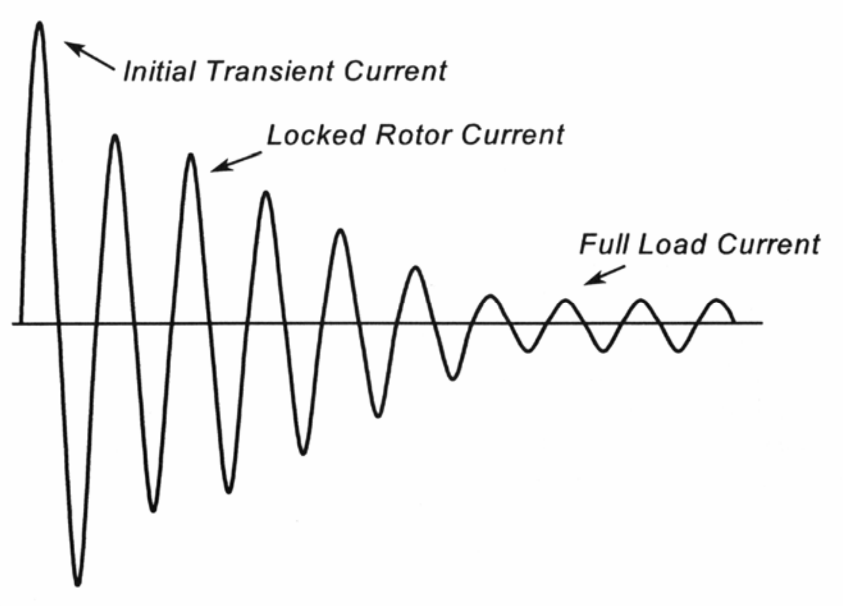

Figure E-5
Motor Starting Current

As described in Section E.1, the initial asymmetrical current peak can be as high as twice the motor starting current. This high of an initial current peak can cause undesired actuation of an MCCB instantaneous trip unit. Refer to Section 4.6 for additional information.

E.3 Asymmetrical Current During Short-Circuit Transients

A short-circuit transient consists of a steady-state sinusoidal component and a transient, or dc, component of current. The current waveform shown in Figure E-3 is similar in shape to a short-circuit waveform. Section 4.8 provides additional information regarding MCCB design requirements to interrupt this asymmetrical short-circuit current.

F
NEMA CORRESPONDENCE

November 29, 1999

Mr. Vince Baclawski
NEMA
1300 N 17th Street, Suite 1847
Rosslyn, VA 22209

Mr. Baclawski:

Attached you will find a list of questions and issues developed by personnel from the nuclear power industry.

It is the desire of these nuclear industry personnel and EPRI's Nuclear Maintenance Applications Center that this list be reviewed by both the members of the IEEE committee on molded case circuit breakers and the NEMA committee responsible for NEMA AB-4. It is our hope that these committee participants may be able to respond to some or all of these issues.

If you or anyone on either of these committees wishes to contact me, I can be reached at (office) 704-547-6057, (Fax) 704-547-6035, or e-mail: jsharkey@epri.com.

For your information, a listing of EPRI-NMAC working group participants is attached. The working group plans to have another meeting next summer to discuss (1) any progress on these issues and (2) a proposed nuclear industry meeting on molded case circuit breaker testing. Any industry-wide meeting would not occur before the winter of 2000/2001. Thanks in advance for your efforts.

Regards,

Jim Sharkey
EPRI-NMAC Project Manager and
Project Manager for All Nuclear Power Industry Circuit Breaker Users Groups

cc. MCCB Working Group
cc. Mr. George Gregory, Chair, NEMA Molded-Case Circuit Breaker Section

Questions and Issues on Molded Case Circuit Breakers

Raised by the Nuclear Power Industry

Developed by EPRI's Nuclear Maintenance Applications Center (NMAC)
and its Working Group on MCCBs

Jim Sharkey, Project Manager, EPRI
Revision: November 11, 1999

Note: Questions are listed in order of relative importance as determined by EPRI-NMAC

The Meaning of AB-4 Tolerances

Plant personnel within our industry have noted the following scenario. An adjustable MCCB is tested using the instantaneous test. The MCCB does not trip (on the high side) within the +40% tolerance specified within NEMA AB-4 Table 5-4, but rather trips just above this value. However, the electrical system's coordination and protection is maintained as the actual trip value is well below the damage curve of the breaker's load.

Our questions are:

1. Is there any reason to believe this MCCB is degraded?
2. Is there any reason to replace this MCCB? If so, why?
3. Is this an engineering judgement call? If so, what should the engineer consider when making his/her determination?
4. Is cable protection a consideration?

With regard to this question, we have noted the following.

NEMA AB-4 states "AB-4-1996 may be used to verify specific characteristics of a molded case circuit breaker . . ." The AB-4 document also goes on to state "these methods cannot be used to verify all performance capabilities of a molded case circuit breaker . . ."

In the nuclear industry, we consider NEMA AB-4 as a way to "verify the functionality of the breaker.

NEMA AB-4, Section 5.6.5 discusses the results of instantaneous testing (pulse method). AB-4 states, "If the results differ significantly from those values (the tolerances in table 5-4), . . . consult the circuit breaker manufacturer."

AB-4 Tolerances and System Design

When designing electrical systems, designers typically use the MCCB's nominal trip value combined with some small design tolerance provided by the manufacturer in the breaker's literature. This nominal trip value combined with the manufacturer's design tolerance produces a trip band, which designers use when designing a system. These design tolerances are (typically) smaller (narrower) than the NEMA AB-4 testing tolerances.

Some utility personnel have raised the following two questions.

- If your system's design is based on the manufacturer's curve (plus the design tolerances), should you not test to the manufacturer's curve rather than to the NEMA AB-4 testing tolerances?
- If your testing to the NEMA AB-4 tolerances, should you not take these testing tolerances into consideration when evaluating your design?

(The second question is actually the converse of the first)

We feel the consensus within the nuclear industry is described below.

NEMA AB4-1991 is intended to demonstrate the functionality of a MCCB; not to validate performance within published design specifications. We feel that it is the functionality testing of NEMA AB4-1991 in combination with the manufacturer's quality assurance programs that provide reasonable assurance that a MCCB will operate within its design tolerances. Consequently, it is not necessary to test to the curve rather than to the NEMA AB-4 testing tolerances. Conversely, it is not necessary to take NEMA AB-4 testing tolerances into consideration when evaluating your design. In other words, NEMA field testing tolerances should not be considered in a system's design and an electrical system design should not consider NEMA AB-4 tolerances.

We realize that testing to NEMA AB-4 does not verify that the breaker will operate within the design tolerances, as this is not our objective.

Our question is:

Do you feel our understanding (as stated above) is correct?

If you agree with our position, what other information or considerations would support this position?

Are there other valid considerations in addition to the manufacturer's QA program?

Are Instantaneous Tests Destructive?

NEMA AB-4-1996, page 11, refers to instantaneous tests as “non-destructive tests”. An Aging Management Report (AMR) issued by US Department of Energy (SAND93-7069) states that MCCB’s internal component parts are susceptible to various forms of induced stresses generated during periodic testing, and these stresses accelerate the normal age-related degradation associated with MCCBs. Several nuclear plants do not see the benefit of instantaneous testing of MCCBs and have elected not to perform this type testing. Other nuclear industry personnel feel that degradation during testing can be minimized by the way the test is done and how many times the test is done.

Our questions are:

1. Are instantaneous tests on MCCBs destructive?
2. If instantaneous tests are potentially destructive, what can be done to minimize this effect?
3. What are the reasons and motivations to perform instantaneous testing?
4. Can the 300 % test give you high reliability that the breaker would perform its function?

The UL Label and Larger Frame MCCBs

The nuclear industry’s has taken the position that MCCBs are factory-sealed units and should not be opened during maintenance activities. This position is in agreement with NEMA AB-4 and other industry guidance. No internal adjustments or lubrication of pivot points are allowed. An exception is allowed for the installation of accessory devices such as shunt trip or under-voltage release units only when done in accordance with the manufacturer’s recommendations.

Some plant personnel assert that larger frame/ amperage breakers exist that are designed to be opened up for the purposes of cleaning the contacts. They maintain the manufacturer recommends cleaning of the contacts.

Our questions are:

1. Are there instances where it is acceptable for certain models or types of MCCB’s to be opened for any reason?
2. If so, what guidance can we provide to the nuclear industry on this issue?
3. Is any type of cleaning, lubrication, or adjustment allowed on any type MCCB?
4. What is the practical meaning of the UL label?

Do MCCB Testing Programs Exist Within Other Industries?

Are you aware of a specific company, manufacturer, or industry that has testing programs for large populations of molded case circuit breakers? In the nuclear industry, we generally assume that other industries simply replace molded case breakers upon failure and do not have detailed testing programs. Is this assumption correct? If not, can you elaborate?

Test Program Justification

What conditions would warrant testing of MCCBs as discussed in Section 5 of NEMA AB-4, 1996? NEMA AB-4, Section 5, “Test Procedures, page 11, states “Some industrial users have indicated that they are required to conduct operational tests of their circuit breakers.” As you know, the nuclear industry requires a high degree of equipment reliability, and consequently requires testing of MCCBs in critical applications at some plants. However, some plant personnel have noted that they have found no vendors who recommend periodic testing of MCCBs.

Our questions are:

1. Does guidance exist on what conditions warrant testing of MCCBs?
2. Are there any instances where manufacturer’s recommend periodic testing?

Interpretation of NEMA AB-4 Guidance

Are there any documents in existence which provide insights on the interpretation of NEMA AB-4 guidance?

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1300 North 17th Street, Suite 1847, Rosslyn, Virginia 22209

April 17, 2000

Mr. Jim Sharkey
Project Manager
EPRI-NMAC
1300 W.T. Harris Blvd.
Charlotte, NC 28262

Dear Mr. Sharkey:

This letter is in response to your November 29, 1999 letter to NEMA, which contained questions and issues on molded case circuit breakers raised by the nuclear power industry. The AB1 Standards Task Subcommittee of NEMA's Molded Case Circuit Breaker Section has addressed the questions and issues raised by the nuclear power industry and developed the attached responses.

I hope that the response adequately addresses the industry's questions. If you have any questions or comments on the response, please call me at 703/841-3236 or send e-mail to vin_baclawski@nema.org.

Sincerely,

Vince A. Baclawski
Technical Director
Power Distribution Products

Attachment

Cc: AB1 Subcommittee members
Frank Kitzantides
Larry Miller
Clark Wilcox

Responses to "Questions and Issues on Molded Case Circuit Breakers" Raised by the Nuclear Power Industry

I. The Meaning of AB-4 Tolerances

1. Is there any reason to believe this MCCB is degraded?

As NMAC has pointed out, the intent of the AB-4 tests is to verify the functionality of the MCCB in the area of performance tested. The tolerances of the Instantaneous Overcurrent Trip Test are set wider than those used to verify the design for certification (see UL 489). The reason for this wider tolerance is to account for differences in testing methods as well as differences related to magnetic field losses and influences in various test set-ups. A measurement slightly above or below the AB-4 tolerances still indicates functionality. As NMAC has indicated, it would be wise to see how such a measurement would affect the load to be protected. Also, it would be wise to verify the continuation of the functionality by performing the test several times. History from previous tests may also be useful to indicate that the MCCB measurements have been reasonably consistent. There no reason to think that the MCCB has degraded if it trips consistently and especially if it is consistent with its own history.

2. Is there any reason to replace this MCCB? If so, why?

The AB-4 tests are indicators of functionality rather than precision measurements of performance. If the MCCB fails to operate or shows erratic behavior, it should be replaced. If measurements are clearly beyond the tolerance levels indicated, the MCCB should be considered suspect and should be replaced. Decisions related to the ability of the MCCB to protect the load must be made by engineering judgement.

3. Is this an engineering judgement call? If so, what should the engineer consider when making his/her determination?

Engineering judgement is certainly useful in determining whether operation slightly outside of tolerance provides needed protection for the load. Factors noted in response to question 1 should also be considered.

4. Is cable protection a consideration?

Cable or wire protection will not be adversely affected by operation slightly above tolerance for cables sized for the rating of the MCCB.

II. AB-4 Tolerances and System Design

1. Do you feel our understanding (as stated above) is correct?

The NMAC statement is accurate.

2. If you agree with our position, what other information or considerations would support this position?

UL Listed products must be within the narrower UL 489 tolerances when they leave the factory. Each pole of each circuit breaker is tested as it is calibrated on the production line. Samples are periodically taken by UL inspectors from production and tested to the UL 489 requirement and must be within tolerance for production to continue. These UL inspections are in addition to the quality assurance program in place by each manufacturer.

As stated above, differences in test procedures and in magnetic field losses make field test results variable.

III. Are Instantaneous Tests Destructive?

1. Are instantaneous tests on MCCBs destructive?

When performed at low voltage, such as below 40 Vac, the instantaneous overcurrent trip test is not destructive. Having said this, we all must recognize that an excessive number of operations on any mechanical device will wear parts of the device. It is NEMA's position that this test is not destructive if performed as described in AB4. Extracting and reinstalling conductors in pressure wire connectors in order to perform tests may leave the connection in an unknown condition due to distortion of the parts. Replacement of wire connectors is recommended under conditions indicated in Section 4.4 of AB4.

2. If instantaneous tests are potentially destructive, what can be done to minimize this effect?

See response to question 1 above.

3. What are the reasons and motivations to perform instantaneous testing?

MCCBs are designed such that they do not require maintenance or testing for their service life. This test was included in AB4 because of reports that users were testing MCCBs and this test description may help to provide guidelines for these users. It is not in AB4 because of a requirement of manufacturers. For any installation, but especially where MCCBs are used in corrosive or high temperature environments, this test may help to assure that the MCCB remains functional. Much of the same functional indication can be determined by the mechanical operation test in Section 5.2 of AB4.

4. Can the 300% test give you high reliability that the breaker would perform its function?

As mentioned above, the mechanical operation test will provide much of the indication of functionality. The 300% inverse-time overcurrent trip test will also demonstrate functionality of the latching system, contact opening and closing and mechanical operation. Either of these tests will provide good indications of the MCCBs continued functionality.
IV. The UL Label and Larger Frame MCCBs.

1. Are there instances where it is acceptable for certain models or types of MCCBs to be opened for any reason?

Here it is important to recognize three categories of low-voltage circuit breakers.

Low-voltage Power Circuit Breakers (LVPCB). LVPCBs are certified to ANSI C57 Standards and sometimes to UL 1066. They are frequently designed to be opened and maintained according to detailed instructions provided by the manufacturer. Some of the operations may include replacement of contacts, arc chutes, springs and trip units as well as field installation or replacement of accessory devices. There may be other detailed instructions for dressing of contacts and for lubrication or similar maintenance functions.

Insulated Case Circuit Breakers (ICCB). ICCBs are actually larger forms of the MCCB. They exist in frame sizes similar to those of the LVPCBs. They are certified to UL 489. They may be provided with detailed instructions for installation or replacement of motor operators, accessory devices or trip units. They may even be provided with instructions for replacement of arc chutes. However, they are not intended to be opened to the extent that the contacts or operating mechanism be maintained.

Molded Case Circuit Breakers (MCCB). MCCBs are certified to UL 489. They may be designed to be opened for installation or replacement of trip units or accessory devices. Contacts should not be dressed and mechanisms should not be maintained.

Where ICCBs or MCCBs are sealed by means of sealing compound or labels over fasteners, they are not intended for internal maintenance.

2. If so, what guidance can we provide to the nuclear industry on this issue?

ICCBs and MCCBs are not designed or intended for any maintenance of internal parts. Dressing of contacts could remove needed metal and/or leave undesirable film or coating on the contacts. Follow manufacturer's instructions for maintenance, if any.

3. Is any type of cleaning, lubrication, or adjustment allowed on any type of MCCB?

See above comments.

4. What is the practical meaning of the UL label?

The use of the UL label means that the product design has demonstrated compliance with UL requirements including compliance with the applicable UL Standard. It also means that the product was manufactured in a factory and under a process that is consistent and from which products are shown on a periodic basis to comply with all UL requirements. In other words, the UL label means that the product complied with all requirements for listing when it left the factory.

V. Do MCCB Testing Programs Exist Within Other Industries?

We are not aware of other industries with testing programs for MCCBs. Some large companies operate their individual testing programs, but we do not have access to their policies or procedures.

VI. Test Program Justification

1. Does guidance exist on what conditions warrant testing of MCCBs?

We confirm that we do not know of a manufacturer who recommends periodic electrical testing of MCCBs. However, we all recognize that a circuit breaker will eventually reach end of useful service life. Especially for circuit breakers used in critical applications, it is useful to periodically determine that installed MCCBs remain functional. Any or all of AB4 is useful for such evaluation depending on the application and conditions of use.

Conditions that would most likely cause early end of service life are installation in hot, humid or corrosive environments or circuit breakers that have been exposed to high level short circuits or to many overload interruptions.

2. Are there any instances where manufacturers recommend periodic testing?

It is noted of course that when a circuit breaker trips it is essential to investigate the cause of trip before the circuit it re-energized. With respect to periodic testing see comments under question 1 above.

VII. Interpretation of NEMA AB-4 Guidance?

NEMA is not aware of documents that would provide insights on the interpretation of AB4 guidance. Perhaps our response to your questions in this document will provide some of that insight.

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ORGANIZATION(S) THAT PREPARED THIS REPORT

EPRI

レポートの概要

目的

- 実用的、経済的、かつ技術的に健全なMCCBの保全プログラムを開発し、実施することが、明確にかつ十分詳細にできるように、一般的また特定の提言を提供すること

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RESUMEN DEL REPORTE

Objetivo

- Para ofrecer recomendaciones genéricas y específicas, transmitida claramente y con suficiente detalle para permitir desarrollo y implementación de una practica, baja en costo y un programa de mantenimiento de sonido técnico de MCCB

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