EFCOG BEST PRACTICE # 203

Best Practice Title: Risk Assessment / Operation of Overcurrent Protection Devices

Facility: DOE Complex

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Brief Description of Best Practice: The EFCOG Electrical Safety Task Group has developed tools for use in completing a risk assessment to support operation of Overcurrent Protection Devices as described in NFPA 70E 2015.

Why the best practice was used: NFPA 70E recognizes arc flash hazards may exist even when equipment is in an enclosed condition. This includes operators whose only interaction is with the equipment in an enclosed condition. There are situations where opening or closing a switch or breaker has been a contributing factor to an arc flash event.

What are the benefits of the best practice: This best practice provides guidance to establish the minimum level of PPE for those who operate OCPD's based on assessment of risk. Tools are provided to help the DOE complex assess risk associated with verification of proper installation, proper maintenance and evidence of impending failure which are the primary factors for consideration in the risk assessment..

What problems/issues were associated with the best practice: Benchmarking by the EFCOG ESTG revealed there is a lack of consistency in the application of NFPA 70E. Provision of these tools will allow a consistent approach for evaluating risk associated with normal operations

How the success of the Best Practice was measured: This best practice is based upon a careful review of various standards, industry information and input from technical experts in the area of electrical safety.

Description of process experience using the Best Practice: N/A

Risk Assessment / Operation of Overcurrent Protection Devices – Section I

EFCOG Electrical Safety Task Group, Working Group 5 Risk Assessment

The EFCOG Electrical Safety Task Group has developed tools for use in completing a risk assessment to support operation of Overcurrent Protection Devices (OCPDs) as described in NFPA 70E 2015. NFPA 70E recognizes arc flash hazards may exist even when equipment is in an enclosed condition. This includes operators whose only interaction is with the equipment in an enclosed condition. There are situations where opening or closing a switch or breaker has been a contributing factor to an arc flash event. The factors associated with higher risk includes; proper installation, proper maintenance, evidence of impending failure and covers/doors are installed properly.

Employers are responsible for assessing the risk from the arc hazard for employees that interact with electric equipment. The following tools have been developed as a part of this best practice.

- Guidance to establish the minimum level of PPE for those who operate OCPD's based on assessment of risk (Section I page 1 & 2)
- Tool to verify properly installed (Section II page 3-5)
- Tool to verify properly maintained (Section III page 6-42)
- Tool to verify inspection for evidence of impending failure (Section IV page 44-45)

Guidance to Establish the Minimum Level of PPE for Those Who Operate OCPD's Based on an Assessment Of Risk.

Although these tools have been developed and are available for use, the EFCOG ESTG subgroup for risk assessment concluded the following:

- Meeting the bounding criteria for "normal operations" is expected to be very difficult
- Conditions can change over time affecting the risk analysis
- A risk is present if an unknown adverse condition exists
- Systems aged or near end of life are a concern
- Covers may not stay on in some arc events (high fault current)
- Defense in depth is recommended
- Establishing a minimum level of PPE may be impacted by IEEE P 1584 change
- Thresholds for minimum arc flash PPE do not exist
- This is a "go" or "no go" decision
- If "no go" then use of arc rated clothing based on incident energy calculation is recommended

Risk Assessment / Operation of Overcurrent Protection Devices – Section I

Assuming the bounding criteria has been met for risk assessment (as defined in this best practice) and the risk is perceived to be acceptable, the following information was presented by the group:

Meets All Criteria and Incident Energy is 1.2 - 40 cal/cm2

Risk = high consequence/low probability

Controls: Some level of PPE is recommended.

Meets All Criteria and Incident Energy is >40 cal/cm2

Risk = high consequence/low probability

Controls: Additional controls such as engineered controls, remote racking, switching procedures or additional PPE should be applied to control hazards.

With respect to arc flash calculations the following devices are typically ignored (do not interrupt arcing fault currents).

- Breakers downstream of a transformer meeting the criteria in section 4.2 in IEEE 1584-2002 “Equipment below 240 V need not be considered unless it involves at least one 125 kVA or larger low-impedance transformer in its immediate power supply"
- <1.2 cal/cm2

Recommendations:

- All clothing must be non-melting except as allowed in the under layers (elastic in socks and underwear) by NFPA 70E.
- Some level of daily wear (arc rated) clothing is recommended for qualified electrical workers
- Workers should be protected appropriately for the hazard e.g., safety glasses, leather gloves, etc.

Properly Installed – Task Based Risk Assessment - Section II

Electrical safety is influenced greatly by an increasingly sophisticated understanding of factors that affect risk. The National Electrical Code (NEC) mirrors the changes in knowledge incorporating new products and new technologies, but is vastly complex. The hazards NEC is designed to eliminate in general are not obvious, even for qualified, experienced electrical workers. In addition, its complexity, electrical installations are often performed by individuals who are not qualified and lack understanding of safe working practices or legal obligations. When installations are done in jurisdictions with few requirements as to who or what qualifications are necessary to install these systems, it's not surprising that electrical violations are in the top 10 of all OSHA citations.

The General Requirements in Article 110 set the stage for implementation of the following articles in NEC. This article begins with some of the most important and somewhat forgotten part of the NEC. Conductor Terminations, Classification by type, size, voltage, current capacity, and specific use, Marking & Labeling Requirements, Equipment & Working Clearances etc… It is critical that the contents of Article 110 are mastered. Understanding these basic requirements is the key to a safe and compliant installation. In fact, the NEC is to provide the practical safeguarding for electrical installations determined by the any instructions included in the listing or labeling intended use and environment to which it is installed.

Article 110 focuses its intent more on requiring an installation safe for the installer or maintenance electrician, attention to this article is critical. Article 110.2 Conductors and Equipment required by the NEC shall be acceptable only if approved.

Informational note: For a better understanding of product approval, review 90.4, 90.7, 110.3 and the definitions for “Approved,” “Identified,” “Labeled,” and “Listed” in Article 100.

110.3 Examination, Identification, Installation, and Use and Listing (Product Certification) of Equipment.

(A) Examination. In judging equipment, considerations listed in (1) – (8) shall be evaluated.

(B) Installation and Use. Shall be installed an used in accordance with any instructions included in the listing and labeling

(C) Listing. Shall be performed by a recognized qualified electrical testing laboratory and shall be in accordance with applicable product standards.

All electrical installations must have an electrical inspection performed to ensure the installation meets the minimum electrical safety requirements. The goal is to provide a consistent applications of codes and standards. This is achieved when a Qualified NEC Inspector or local AHJ provides an approval and documents the inspection.

Properly Installed – Task Based Risk Assessment - Section II

Electrical Inspection

1. Qualified Person's Initial Observation of Equipment Installation – Real Time Risk Assessment
    1) Covers in place (screws, fasteners are engaged)
    2) All penetrations are closed or sealed
    3) Conduits, Fittings are secured and complete
    4) Handle or Switching mechanism is intact (appears functional)
    5) Equipment meets all field labeling requirements (Equipment Identification, SCC, Retrofit/Refurbished/Reconditioned, Arc Flash)
    6) No Suspect/Counterfeit/Recalls
    7) Field Modifications have been inspected and documented

Electrical Inspection - Program Documentation

1) Permit - Obtain an Electrical Work Authorization Document or Electrical Installation Permit

2) Engineered - Engineering Design Document that has taken into consideration the environment and application of the equipment to be installed.

3) Installation - Qualified person who understands the installation requirements for Method, Sizing and Environment to be installed

3) Inspection or Examination – Inspection performed by a qualified NEC inspector or an AHJ delegated to perform such inspections.

4) Approved or Accepted– The inspection is approved and documented by NEC Inspector or AHJ, & work authorization document or permit is closed. (If violations are cited corrections shall be made, documented and re-inspected for approval)

5) Required Labeling – Visual indication that the installation was performed in accordance with the required by applicable standards. *For examples see figures 1 and 2*

Figure 1

Figure 2

Properly Installed – Task Based Risk Assessment - Section II

Properly Installed - References:

NFPA 70 Definitions: Approved, Qualified Person, Authority Having Jurisdiction (AHJ)

NFPA 70 Article 90.7 & 110.3 Examination, Identification, Installation and Use and Listing (product certification) of Equipment,

NFPA 70 Annex H Article 80.1 Administration and Enforcement (Guidance)

NFPA 70 Article 110.2 Approval of Conductors and Equipment

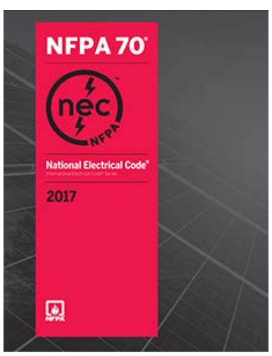
NFPA 70 Article 110.16 Arc Flash Hazard Warning Labels

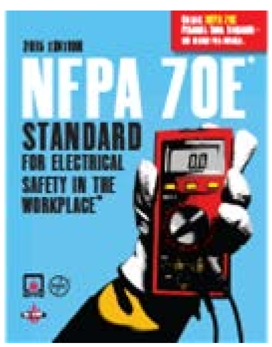
NFPA 70 Article 110.24 (A) Maximum Available Fault Current Labeling & (B) Modifications

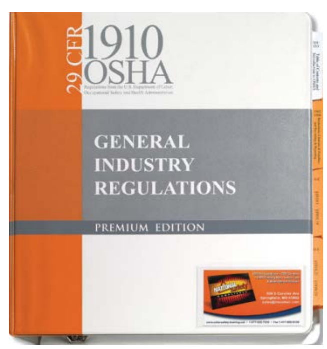
NFPA 70E 2015 Article 130.5 (D) Arc Flash Risk Assessment Equipment Labeling

OSHA 29 CFR 1910.303 (a) Approval (b) Examination, Identification, and Use of Equipment

OSHA 29 CFR 1910.399 Definitions: Acceptable, Accepted, Approved Qualified Person







INTRODUCTION

In 2009, NFPA70E "Standard for Electrical Safety in the Workplace" was changed to include the statement, "Overcurrent protective devices shall be maintained in accordance with the manufacturer's instructions or industry consensus standards" (205.3). This requirement has been consistent in each succeeding edition through the 2015 edition.

It is a known fact, improper or lack of maintenance contributes to increased electrical hazards and risk to employees tasked with working on the equipment. Due to the correlation between maintenance and arc flash risk analysis, the need to perform maintenance of overcurrent protective devices has been emphasized in recent editions of NFPA 70E:

- *NFPA 70E 2015 Edition, Article 130.5(3) "Take into consideration the design of the overcurrent protective device and its opening time, including its condition of maintenance."*

- *Informational Note No. 1: Improper or inadequate maintenance can result in increased opening time of the overcurrent protective device, thus increasing the incident energy. Where equipment is not properly installed or maintained, PPE selection based on incident energy analysis or the PPE category method may not provide adequate protection from arc flash hazards.*

The purpose of this Best Practice is to identify the minimum elements of a maintenance program for overcurrent protection devices to minimize risk associated with arc flash hazard to ensure a high level of safety is achieved.

Manufacturer's instructions and industry consensus standards have been consulted and a compilation of information is referenced in Appendix A describing various maintenance methodology to include mechanical and electrical maintenance. The following paragraphs provide criteria for applying those instructions and standards uniformly across the DOE Complex to meet the requirements of NFPA70E. Professional organizations, such as the Electrical Power Research Institute (EPRI) have published guidance that provided recommendations for the aging and increasing obsolescence of overcurrent protective devices in the Nuclear Power Industry.

The DOE Complex has much in common with the problem EPRI faced, in that many facilities are aging and the over current protective devices in those facilities are at or past their expected end-of-life and are often obsolete and replacements are unavailable. Use of this Best Practice may be used to meet the requirements of NFPA 70E.

DEFINITIONS

Arc Flash Breaker (AFB) – A MCCB that is maintained in accordance with TEV-1100 with the intent of increasing the confidence of arc flash hazard calculations. AFB's are assumed to interrupt arcing fault currents in arc flash hazard calculations. For the purpose of safety related maintenance, all MCCBs shall be considered AFBs unless they meet meet one or more of the exemptions below.

Non-Arc Flash Breaker (NAFB) – Any MCCB that meets one or more of the exemption criteria below can be identified as a NAFB by the system engineer. With respect to arc flash calculations these devices shall be ignored (do not interrupt arcing fault currents).

Exemption Criteria:

1. For systems greater than 240V, any 1 or 2 pole MCCB. Working downstream of devices deemed to be NAFB under this criterion shall require PPE based on NFPA 70E or an arc flash hazard calculation (clearing time of 2 seconds or as limited by an upstream AFB).

2. Any MCCBs downstream of a single transformer (bank) rated less than 125kVA with a secondary voltage <240V.

4. A MCCB where the clearing time is greater than 2 seconds (2 second rule applies) or in cases where a series AFB is in place to limit fault currents.

   A breaker in series with a similarly sized device can be considered an NAFB if the series device adequately interrupts the arcing fault current (as determined by the system engineer).

Molded Case Circuit Breakers (MCCB).

The National Electrical Code defines a circuit breaker as: "A device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined over current without damage to itself when properly applied within its rating."

Molded Case Circuit Breakers (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.

ACRONYMS

AFB	Arc Flash Breaker
EPRI	Electric Power Research Institute
IEEE	Institute of Electrical and Electronics Engineers

MCCB	Molded Case Circuit Breakers
NAFB	Non-Arc Flash Breaker
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
PM	Preventive Maintenance
UL	Underwriters Laboratory

Table 1. AFB/NAFB Scope.

	Arc Fault Breaker (AFB)	Non Arc Fault Breaker (NAFB)
Scope	For breakers graded as AFB, the following maintenance tasks are recommended: • Thermography* • Visual inspection/cleaning • Mechanical operation (cycling) • Electrical testing (including 300% and Instantaneous over current testing) • As specified by regulation	For breakers graded as NAFB, the following maintenance tasks are recommended: • Thermography* • Visual inspection/ cleaning • Mechanical operation (cycling)

*** NOTE:** *Thermography is a nondestructive test method that may be used to detect poor connections, unbalance loads, deteriorated insulation or other potential problems in energized electrical components. Thermography is based on sensing heat emitted from the surface of an object in the form of infrared radiation. NFPA 70B provides a listing of maintenance and equipment testing intervals in Annex I, including thermography. Effective use of thermography requires equipment to be powered up to create the thermal conditions to be monitored. Dead-front removal while at power is desired, which presents a personal safety concern. Data evaluation and retention of data for trend performance over time is desirable. Thermography is recognized as an effective trouble-shooting and predictive tool.*

SUMMARY OF RECOMMENDATIONS AND INFORMATION FROM RELEVANT STANDARDS, GUIDES, WHITE PAPERS, AND EQUIPMENT MANUFACTURERS (See Appendix A for more information)

NFPA-70E-2015, Standard for Electrical Safety in the Workplace.

Maintenance of overcurrent protection is essential to achieve a high level of safety for personnel interacting with electrical equipment. Improper or inadequate maintenance can increase the opening time of the overcurrent protective device, thus increasing the incident energy and concurrent risk to personnel. When performing arc flash analysis, the condition of maintenance must be considered. Assignment of arc rated clothing and PPE is based on an accurate model that has considered the condition of maintenance. Completion of the prescribed maintenance reduces the risk and provides relief from compensatory controls.

NFPA 70E 2015 Chapter 2 Safety-Related Maintenance Requirements.

200.1 Chapter 2 addresses the following requirements:

(1) Chapter 2 covers practical safety-related maintenance requirements for electrical equipment and installations in workplaces as included in 90.2. These requirements identify only that maintenance directly associated with employee safety.

(2) Chapter 2 does not prescribe specific maintenance methods or testing procedures. It is left to the employer to choose from the various maintenance methods available to satisfy the requirements of Chapter 2.

(3) For the purpose of Chapter 2, maintenance shall be defined as preserving or restoring the condition of electrical equipment and installations, or parts of either, for the safety of employees who work where exposed to electrical hazards. Repair or replacement of individual portions or parts of equipment shall be permitted without requiring modification or replacement of other portions or parts that are in a safe condition.

Informational Note: Refer to NFPA 70B, Recommended Practice for Electrical Equipment Maintenance; ANSI/NETA MTS, Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems; and IEEE 3007.2, IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems, for guidance on maintenance frequency, methods, and tests.

205.3 General Maintenance Requirements. Electrical equipment shall be maintained in accordance with manufacturers' instructions or industry consensus standards to reduce the risk associated with failure. The equipment owner or the owner's designated representative shall be responsible for maintenance of the electrical equipment and documentation.

Informational Note: Common industry practice is to apply test or calibration decals to equipment to indicate the test or calibration date and overall condition of equipment that has been tested and maintained in the field. These decals provide the employee immediate indication of last maintenance date and if the tested device or system was found acceptable on the date of test. This local information can assist the employee in the assessment of overall electrical equipment maintenance status.

205.4 Overcurrent Protective Devices. Overcurrent protective devices shall be maintained in accordance with the manufacturers' instructions or industry consensus standards. Maintenance, tests, and inspections shall be documented.

225.2 Molded-Case Circuit Breakers. Molded-case circuit breakers shall be maintained free of cracks in cases and cracked or broken operating handles.

225.3 Circuit Breaker Testing. Circuit breakers that interrupt faults approaching their interrupting ratings shall be inspected and tested in accordance with the manufacturer's instructions.

Mechanical maintenance consists of inspection and adjustment as needed of mechanical mounting and electrical connections, and manual operation of the circuit breaker, which will help keep the contacts clean and will help the lubrication perform properly. Electrical maintenance verifies that the circuit breaker will trip at its desired set point. Manual operation of the circuit breaker helps keep the contacts clean, but none of the mechanical linkages in the tripping mechanisms are moved with this exercise. Still, manual operation of the circuit breaker helps in assuring that the circuit breaker will operate properly. Some circuit breakers have push-to-trip buttons that should be operated periodically to exercise the tripping mechanical linkages.

NFPA-70B, 2016, Recommended Practice for Electrical Equipment Maintenance

NFPA 70B, Paragraph 11.4, Frequency of Tests, states "In General, this cycle can range from 6 months to 3 years, depending on conditions and equipment use." Paragraph 17.10 refers to Table L.1 (70B) which gives the following periodicities:

Table L.1 Molded-Case Circuit Breakers		
Visual inspection/clean	3 years	reference 17.7 through 17.11
Mechanical test	2 years	reference 17.11
Electrical test	3–5 years	reference 11.10.5

Paragraph 17.10 states "Although manual operations will exercise the breaker mechanism, none of the mechanical linkages in the tripping mechanisms will be moved with this exercise." indicating the need for testing the breaker performance.

Paragraph 17.10 also refers to ANSI/NETA MTS for guidance on frequency of exercise as appropriate. Paragraph 11.10.2.1 refers NEMA AB 4, ANSI/NETA MTS and ANSI/NETA MTS for field testing.

Paragraph 11.17.5 Inspection Frequency and Procedures states. "Routine infrared inspections of energized electrical systems should be performed annually prior to shutdown. More frequent infrared inspections, for example, quarterly or semiannually, should be performed where warranted by loss experience, installation of new electrical equipment, or changes in environmental, operational, or load conditions."

NEMA Standards Publication AB 4-2009, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications

NEMA AB 4 Provides detailed mechanical and electrical maintenance and testing procedures for molded case circuit breakers. Maintenance/testing may be performed with the circuit breaker in its equipment in cases where the breaker can be safely isolated.This standard provides tabular tolerances to account for field testing conditions. Removal of the circuit breaker for testing may be desirable for some applications. The mechanical and electrical tests prescribed are considered non-destructive. This standard provides tabular tolerances to account for field testing conditions. No frequency of maintenance is prescribed.

ANSI/NETA MTS-2007, Standard for Maintenance Testing Specifications

Recommends a full suite of mechanical and electrical maintenance and testing with visual at 1 month, visual and mechanical at 12 months, and visual and mechanical and electrical at 36 months with a table of multipliers to be applied depending on breaker condition and reliability requirements. See details in Appendix A.

IEEE STD 1015-2006, The Blue Book™, IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems

Chapter 7 section 7.3 page 173 states "Field maintenance of MCCBs, which includes motor circuit protectors (MCPs), is normally limited to a visual inspection, cleaning, and tightening of connections. However, periodic overcurrent protection testing of MCCBs and MCPs should be completed as indicated below. Per NFPA 70B-2002 (18-4 Frequency of Tests), the optimum testing and maintenance cycle depends on the use of the equipment and typically ranges from 6 months to 3 years."

IEEE STD 1458-2005, IEEE Recommended Practice for the Selection, Field Testing, and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications

Paragraph 8, "Procedure for field testing and determining the remaining life of molded case circuit breakers", is intended to "assist the user in performing required maintenance and in assessing the remaining life of a circuit breaker.", and prescribes a full suite of mechanical and electrical maintenance to evaluate breakers that have interrupted a fault or if the breaker condition is of concern.

IEEE STD 3007.2, Recommended Practice for the Maintenance of Industrial and Commercial Power Systems

This standard covers molded-case, insulated-case, and low-voltage power circuit breakers and recommends following the manufacturer's instructions if available, and in their absence following , NEMA AB 4, IEEE Std. 1458, NFPA-70B-2006, or ANSI/NETA MTS-2007. It also recommends following the manufacturer's time-current curves so that the device will operate as intended and designed. It states in Paragraph 5.3.2 that "The most thorough test for all three types of circuit breakers is by primary injection testing………primary injection testing is the preferred method of maintenance testing, as it tests the entire circuit breaker overcurrent protective system (e.g., CTs, wiring, shunt trip device) in a manner that is similar to how the breaker would operate during a fault condition."

Paragraph 5.7.2 discusses the merits of NFPA 70B-2006 and states "NFPA 70B-2006 offers the core of an excellent EPM program by providing much information for direct use by facility engineers and maintenance personnel. With the addition of specific instructions from the manufacturers' literature, most electrical equipment maintenance needs are covered."

Recommendations from Other Professional Organizations

Emerson - Low Voltage Circuit Breaker Testing Why Test? Series "There is no way to know if a circuit breaker will operate properly under fault or overload conditions unless it is tested, preferably by a primary injection test. (Refer to NEMA Standard AB 4 "Guidelines of Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications.")" Testing is recommended at start-up and every three years thereafter.

EPRI Molded Case Circuit Breaker Application and Maintenance Guide Rev 2 -2004 states "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."

See Appendix A for additional detailed information.

Manufacturer's Recommendations

NFPA 70E, paragraph 205.3, states "Overcurrent protective devices shall be maintained in accordance with the manufacturers' instructions or industry consensus standards". With the wide variety of manufacturers and models it may not be practical to use specific manufacturers' instructions for each breaker. Further it can be difficult, almost impossible, to obtain the instructions for all breakers, especially older breakers installed in the distant past, fifty or more years ago. As an alternative, common maintenance instructions selected from Allen-Bradley, Eaton, General Electric, Siemens, and Square D may be used as representative of typical commercial/industrial electrical power distribution breakers. Other manufacturers and models may be selected as well.

The instructions from the aforementioned manufacturers' typically contain statements that MCCBs "requires little", "almost maintenance-free", or "no maintenance". The reason is, MCCBs have no serviceable internal parts and MCCBs are typically discarded vs. subject for corrective maintenance. Although corrective maintenance is not applicable, preventative maintenance is recommended to include:

- Breakers should be cleaned and inspected for case damage and/or signs of excessive heat. Note: Case damage can compromise the breaker's short circuit current rating.

- Wire connections should be inspected for a secure termination and signs of excessive heat. One manufacturer discourages torqueing the set screws on the terminals. They should be torqued only if found loose.

- The breakers should be mechanically cycled. Three times should be adequate. If the breaker has a push/slide/twist (PST) operator, it should be used. This will exercise the latch/trip mechanisms in the breakers. Simply opening and closing the breaker by the handle does not exercise the latch/trip mechanism. Actuating the PST helps ensure reliable breaker operation.

Frequency of inspection and/or testing is not consistent among the manufacturers. Some say periodically while others say annually. A mechanical or PST switch is normally recommended annually.

When it comes to field testing, the manufacturers make a general recommendation of using the applicable NEMA Standard which is AB4. None of the manufacturers provide specifics on the use of NEMA AB4.

EPRI's "Molded Case Circuit Breaker Application and Maintenance Guide", Revision 2 has several applicable statements on breaker maintenance. In Section 6.1.3 it states "It should be noted that, from the manufacturer's 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 testing." In several places, the EPRI guide references NEMA AB4 as the current industry-accepted standard for maintenance and testing of MCCBs. This reference in the Guide is consistent with the instructions in the selected manufacturers' instructions. Section 6.6.2 states "Manufacturers' literature typically provides little information or guidance regarding frequency of inspections and testing." Again, this is somewhat consistent with the above manufacturers since they may recommend "periodically" or exercise annually.

Summary of manufacturers' instructions

- Mechanically exercise breaker with the handle and/or the PST.
- Visually inspect for case damage
- Visually inspect breaker, conductors, and terminations for excessive heat
- Clean the breaker
- Any field testing should be done in accordance with applicable NEMA standard.

TASK GROUP RECOMMENDATIONS

There is an absence of consistency between the groups (NEMA, NETA, NFPA, IEEE, NUREG, EPRI, and Manufacturer's) with regard to PM Frequencies. This section is the result of combining and organizing the information from various sources to portray frequencies based on; 1) distillation of multiple recommendations from available documentation, 2) consideration given to multiple overlaps and gaps, 3) clearly understanding failure modes and mechanisms and how to mitigate their influence, 4) Site Specific experience for facilities, 5) providing a Graded Approach to maintenance and operational resources, and 6) meeting new federally mandated codes and standards.

A highly rigorous PM is performed on AFB breakers to provide a high level of reliability. The instantaneous feature of the breaker is essential in mitigating the arc flash incident energy. The operation of this feature supports the maintenance and reliability assumptions used in the Arc Flash calculations and the resulting personal protection equipment prescribed. It follows that any breaker credited with interrupting an arc flash current must have the instantaneous feature electrically tested.

Table 2 Circuit Breaker Preventative Maintenance Frequency (suggested)

Maintenance Task	Arc Flash Breaker (AFB)		Non-Arc Flash Breaker (NAFB)	
	Recommended Frequency	Not to Exceed Frequency	Recommended Frequency	Not to Exceed Frequency
Mechanical Cycling	2 yr	4 yr.	2 yr.	6 yr.
Visual Inspection and Cleaning	4 yr	6 yr.	4 yr	6 yr

Electrical Testing (including 300% and Instantaneous)	3-5 yr.	6 yr.	Not specified	Not specified
Thermography*	Annually	Annually	Annually	Annually

Service Life for molded case circuit breakers is estimated by suppliers to be from 25 to 40 years. These life expectancy estimates usually include caveats of a favorable environment and a regular maintenance program. It is expected that as equipment approaches these service life limits, an increased level of rigor should be applied to the equipment monitoring and maintenance. Extreme environmental conditions for molded case circuit breakers include areas of high moisture, temperature or vibration and dusty or environmentally polluted areas (presence of corrosive chemicals or high salinity). Where these conditions exist, additional attention to the equipment monitoring and maintenance is prudent and should include attention to the insulation, case and contacts as well as the device operation. The responsible engineer should adjust testing frequency and content to address both service life and extreme environmental conditions.

Preventive Maintenance frequencies less than those prescribed frequencies in Table 2, for AFB or NAFB should be adequately justified and documented. Otherwise, the breakers cannot be relied upon to provide arc-flash mitigation per the requirements of NFPA-70E or acceptable operation to clear overload conditions in accordance with the requirements of the National Electrical Code. Maintenance extended beyond the “Recommended “frequency prescribed in Table 2 should be approved by the AHJ or other designated authority.

Utilize the appropriate inspection procedures, testing procedures, and acceptance criteria identified in NEMA AB 4 *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications*, for the preventative maintenance tasks identified in Table 2.

BIBLIOGRAPHY

- NFPA 70E “Standard for Electrical Safety in the Workplace” 2015 Edition Chapter 2
- NFPA 70B “Recommended Practice for Electrical Equipment Maintenance” 2016 Edition
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- NEMA AB 4 “Guidelines for Inspection and Preventative Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications” 2009 Edition

- IEEE STD 1015-2006, “The Blue Book IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems”
- IEEE STD 3007.2 “Recommended Practice for the Maintenance of Industrial and Commercial Power Systems” 2010 Edition
- Emerson - Low Voltage Circuit Breaker Testing Why Test? Series
- ANSI/NETA MTS-2007 “Standard for Maintenance Testing Specifications”
- EPRI “Molded Case Circuit Breaker Application and Maintenance Guide” Rev 2 - 2004
- NUREG/CR-5762 Wyle 60101 “Comprehensive Aging Assessment of Circuit Breakers and Relays”
- Schneider Field Testing and Maintenance Guide
- Allen-Bradley Q-Frame Circuit Breaker Instruction Leaflet for Installation of Q Frame Circuit Breakers
- Eaton Cutler Hammer Installation Instructions for DK, KDB, KD, HKD, KDC, KW, HKW,
- KWC, CKD, CHKD Circuit Breakers and Molded Case Switches
- GE Spectra RMS E and F Frame and SG and SK Frame Molded Case Circuit Breakers
- Siemens EM Frame: Types EM6 and EMK Circuit Breakers

Verification of Proper Maintenance for Overcurrent Protection Devices - Section III

Molded Case Circuit Breakers (MCCBs)

Standard or Instruction	Requirement/Guidance	Maintenance/Tests	Frequency of Maintenance/Tests
NFPA 70E Standard for Electrical Safety in the Workplace 2015 Edition	Chapter 2 Safety-Related Maintenance Requirements Chapter 2 Commentary An electrical work environment consists of three interrelated components: installation, maintenance, and safe work practices. Safe work practices are most effective when the installation is code compliant and the equipment is maintained appropriately. The NFPA documents that address each aspect are NFPA 70®, National Electrical Code® (NEC®); NFPA 70B, Recommended Practice for Electrical Equipment Maintenance; and NFPA 70E®, Standard for Electrical Safety in the Workplace®. **200.1 Scope.** Chapter 2 addresses the requirements that follow. (1) Chapter 2 covers practical safety-related maintenance requirements for electrical equipment and installations in workplaces as included in 90.2. These requirements identify only that maintenance directly associated with employee safety. (2) Chapter 2 does not prescribe specific maintenance methods or testing procedures. It is left to the employer to choose from the various maintenance methods available to satisfy the requirements of Chapter 2. Employers must determine a maintenance strategy and then implement the necessary components of that strategy. Some maintenance is necessary to support the implemented electrical safety program. For information on preventive maintenance programs, see NFPA 70B. NFPA 70B provides information on commissioning and on an effective preventive maintenance program. Commissioning, or acceptance testing, verifies that the equipment functions as intended by the design specification. Acceptance testing generates baseline results which can help to identify equipment deterioration or a change in reliability or safety. Future trend analysis is useful in predicting when equipment failure or an out of tolerance condition will occur and can allow for convenient scheduling of outages. All electrical equipment might have a predictable life cycle, and knowing the service life can be crucial in predicting the reliability and safe operation of the equipment. Routine maintenance and maintenance tests can be performed at regular intervals over the service life of equipment or when condition indicators warrant. Maintenance tests help identify changes in overcurrent protective device characteristics and potential failures before they occur. A shutdown can then be scheduled and repairs can be made before equipment damage and with minimum exposure to employees. An alternative method is utilizing Reliability- Centered Maintenance (RCM) techniques. See Chapter 30 of NFPA 70B for further	Refers to other standards such as NFPA 70B and manufacturer's instructions 225.2 Molded-Case Circuit Breakers. Molded-case circuit breakers shall be maintained free of cracks in cases and cracked or broken operating handles. 205.4 Overcurrent Protective Devices. Overcurrent protective devices shall be maintained in accordance with the manufacturers' instructions or industry consensus standards. Maintenance, tests, and inspections shall be documented. Commentary Although molded-case circuit breakers can be in service for years and may never be called upon to perform their overload– or short-circuit–tripping functions, they are not "maintenance- free" devices. They require both mechanical and electrical maintenance. Mechanical maintenance consists of inspection and adjustment as needed of mechanical mounting and electrical connections, and manual operation of the circuit breaker, which will help keep the contacts clean and will help the lubrication perform properly. Electrical maintenance verifies that the circuit breaker will trip at its desired set point. Manual operation of the circuit breaker helps keep the contacts clean, but none of the mechanical linkages in the tripping mechanisms are moved with this exercise. Still, manual operation of the circuit breaker helps in assuring that the circuit breaker will operate properly. Some circuit breakers have push-to-trip buttons that should be operated periodically to exercise the tripping mechanical linkages. See Chapter 17 of NFPA 70B and ANSI/NEMA AB 4, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications, for more information on electrical maintenance of molded-case circuit breakers.	Following the maintenance schedule defined by the manufacturer or by a consensus standard reduces the risk of failure and the subsequent exposure of employees to electrical hazards such as shock, arc flash, or arc blast. Documents such as NFPA 70B and ANSI/NETA MTS, Standard for Maintenance Testing Specification, provide testing and maintenance instructions for some overcurrent devices. ANSI/NEMA AB 4, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications, provides useful information on the type of maintenance, testing, and inspections that should be documented. 225.3 Commentary Circuit breakers should have an initial acceptance test and subsequent maintenance testing at recommended intervals. Following the maintenance schedule defined by the manufacturer or by a consensus standard reduces the risk of failure and the subsequent exposure of employees to electrical hazards such as shock, arc flash, or arc blast. NFPA 70B, ANSI/NETA MTS, and ANSI/NEMA AB 4 are documents that can assist a company in understanding the specific tests and testing intervals required to ensure reliability and safety.

	information on RCM. Informational Note: Refer to NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*; ANSI/NETA MTS, *Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*; and IEEE 3007.2, *IEEE Recommended Practice for the Maintenance of Industrial and Commercial Power Systems*, for guidance on maintenance frequency, methods, and tests. Maintenance is often the most neglected component of a strategy to provide a safe work environment. NFPA 70B provides employees with solutions, techniques, and testing intervals for adequate maintenance to maximize the reliability of electrical equipment and systems. It describes electrical maintenance subjects and issues surrounding maintenance of electrical equipment.		
NFPA 70B Recommended Practice for Electrical Equipment Maintenance 2016	17.7 Types of Maintenance. Maintenance of insulated-case/molded-case circuit breakers generally can be divided into two categories: mechanical and electrical. Mechanical maintenance consists of inspection involving good housekeeping, maintenance of proper mechanical mounting and electrical connections, and manual operation as outlined in Sections 17.8 through 17.10. Electrical testing under field test conditions is covered in 11.10.2. 17.10 Mechanical Mechanism Exercise. Devices with moving parts require periodic checkups, and an insulated-case/ molded-case circuit breaker is no exception. Manual operation of the circuit breaker will help keep the contacts clean and will help the lubrication perform properly. 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 manually operated to exercise the tripping mechanism linkages. (Refer to Annex K, Long-Term Maintenance Guidelines; Annex L, Maintenance Intervals; and ANSI/NETA MTS, Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems, for guidance on frequency of exercise as appropriate.	17.11 Electrical Testing. For further information on testing see 11.10.1, Insulated-Case/Molded-Case Circuit Breaker Testing. 11.10.2 Field Testing in General. 11.10.2.1 The procedures outlined in Sections 2 and 3 of the NEMA publication listed in 11.10.1(2) are intended for checking the condition and basic electrical operation of circuit breakers, but they should not be considered as calibration tests or comparisons to laboratory tests. Section 3 outlines factors to be considered if laboratory accuracy is to be approached. If evaluation indicates operation outside acceptable limits, the circuit breaker should be removed and either replaced or repaired. Refer to the manufacturer's instruction manual to understand appropriate maintenance procedures. If checking indicates maloperation, the circuit breaker should be removed and sent to the manufacturer for investigation and test. Checking the condition and basic electrical operation of circuit breakers can be accomplished by performing field testing, but these tests should not be considered as calibration tests or comparisons to laboratory tests. The applicable industry field evaluation standards include the following: (1) For insulated-case/molded-case circuit breakers, inspection and preventative maintenance performed in accordance with NEMAAB 4, Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications; ANSI/NETA ATS, Standard for Acceptance Testing Specifications for Electrical Power Distribution Equipment and Systems; and ANSI/NETA MTS, Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems. **11.10.5.1 Insulated-Case/Molded-Case Circuit Breakers — General.** **11.10.5.1.1** Insulated-case/molded-case circuit breakers are available in a wide variety of sizes, shapes, and ratings. Voltage ratings, by standard definitions, are limited to 600 volts, although special applications have been made to 1000 volts. Current ratings are available from 10 amperes through 4000 amperes. Insulated-case/molded-case circuit breakers can be categorized generally by the types of trip units employed as described in Section 17.5.	**NFPA 70B** 11.4 Frequency of Tests. Most routine testing can best be performed concurrently with routine preventive maintenance, because a single outage will serve to allow both procedures. For that reason, the frequency of testing generally coincides with the frequency of maintenance. The optimum cycle depends on the use to which the equipment is put and the operating and environmental conditions of the equipment. In general, this cycle can range from 6 months to 3 years, depending on conditions and equipment use. The difficulty of obtaining an outage should never be a factor in determining the frequency of testing and maintenance. Equipment for which an outage is difficult to obtain is usually the equipment that is most vital in the operation of the electrical system. Consequently, a failure of this equipment would most likely create the most problems relative to the continued successful operation of the system. In addition to routine testing, tests should be performed any time equipment has been subjected to conditions that possibly could have caused it to be unable to continue to perform its design function properly. **Table L.1 Molded-Case Circuit Breakers** Visual inspection/clean 3 years reference 17.7 through 17.11 Mechanical test 2 years reference 17.11 Electrical test 3–5 years reference 11.10.5

		11.10.5.1.2 Electrical testing should be performed in a manner and with the type of equipment required by the type of trip unit employed. **11.10.5.1.3** For further information on insulated-case/molded case circuit breakers, see Chapter 17, Insulated-Case/Molded- Case Circuit Breakers. **11.10.5.1.4 Insulation Resistance Tests.** Measure insulation resistance tests for 1 minute on each pole, phase-to-phase and phase-to-ground, with the circuit breaker closed and across each open pole. Apply voltage in accordance with manufacture's published data. Insulation resistance values should be in accordance with manufacture's published data. For further information on insulation resistance testing see 11.9.2.3, Insulation Resistance Testing. **11.10.5.1.5 Contact/Pole Resistance or Millivolt Drop Tests.** Measure contact/pole resistance or millivolt drop. These tests are used to test the quality of the contacts. The contact resistance or millivolt drop should be kept as low as possible to reduce power losses at the contacts with the resultant localized heating, which will shorten the life of both the contacts and nearby insulation. Microhm or millivolt drop values should not exceed the high levels of the normal range as indicated in the manufacturer's published data. **11.10.5.2 Testing Thermal-Magnetic Trip Units.** **11.10.5.2.1** The electrical testing of thermal-magnetic trip units in circuit breakers can be divided into three steps: (1) Overload of individual poles at 300 percent of trip rating (2) Verification of test procedures (3) Verification of manufacturer's published data **11.10.5.2.2** Complete and detailed instructions for testing insulated-case/molded-case circuit breakers in accordance with the steps in 11.10.5.2.1 are outlined in detail in NEMA AB 4, *Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications*. Individual manufacturers also publish recommended testing procedures as well as time–current characteristic tripping curves. **11.10.5.2.3** When circuit-breaker tripping characteristics are tested, it is recommended that the inverse time trip (thermal or long time-delay element) tests be performed on individual poles at 300 percent of rated current. **11.10.5.2.4** The reaction of the circuit breaker to this overload is indicative of its reaction throughout its entire overcurrent tripping range. This load is chosen as the test point because it is relatively easy to generate the required current in the field, and the wattage per pole from line to load is large enough that the dissipation of heat in the nonactive pole spaces is minor and does not affect the test results appreciably.	

11.10.5.2.5 Values for Inverse Time Trip (Thermal or Long Time-Delay Element) Data. Table 11.10.5.2.5 outlines the current and trip-time values as recommended by NEMA. The minimum/maximum range of values in Table 11.10.5.2.5 was developed to encompass most brands. For more specific values, refer to the manufacturer's data for the circuit breaker being tested.

11.10.5.2.6 Testing the instantaneous (magnetic) element of a trip unit requires the use of elaborate constant rate-of-rise test equipment coupled with accurate current-monitoring instrumentation, preferably digital readout, for accurate confirmation of manufacturers' test results. Unless this type of equipment is available, it is recommended that these breakers be referred to the manufacturer, electrical contractor, or other competent service organization when calibration is required. Instantaneous pickup values of insulated-case/molded-case circuit breakers should fall within the manufacturer's published tolerances. In the absence of manufacturer's published tolerances, refer to Table 11.10.5.2.6 with values as recommended in Table 4 of ANSI/NEMA AB4, *Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications*.

11.10.5.3 Testing Instantaneous-Only Circuit Breakers. The testing of instantaneous-only circuit breakers requires the use of elaborate constant rate-of-rise test equipment coupled with accurate current-monitoring instrumentation, preferably digital readout, for accurate confirmation of manufacturers' test results. Unless this type of equipment is available, it is recommended that these breakers be referred to the manufacturer, electrical contractor, or other competent service organization when calibration is required. Instantaneous pickup values of insulated-case/molded-case circuit breakers should fall within the manufacturer's published tolerances.

11.10.5.4 Testing Solid-State Trip Units. Breakers employing solid-state trip units offer testing opportunities not readily available in thermal-magnetic or instantaneous only trip units. These devices have two or more of the following elements.

11.10.5.4.1 Long Time-Delay Element. This element is designed to operate on overloads between its pickup setting and the pickup of a short time delay or an instantaneous element. The long time-delay pickup adjustment is generally within the range of 80 percent to 160 percent of the trip-device rating. Settings higher than solid-state trip-device ampere rating do not increase the continuous-current rating of the trip device, and in no event is the rating increased beyond the breaker frame size. The operating time of this element ranges from seconds to minutes. Determine long-time pickup and delay. Long-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published timecurrent characteristic tolerance band, including adjustment factors.

11.10.5.4.2 Short Time-Delay Element. This element has a time delay measured in cycles and is used to protect against moderate fault currents and short circuits. This element usually can be adjusted to pick up within the range of 250 percent to 1000 percent of the trip-device rating. Determine short-time pickup and delay. Short-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time–current tolerance band.

11.10.5.4.3 Instantaneous Element. This element has no intentional time delay and is used to protect against heavy fault currents and short circuits. The pickup settings for this type of element usually range from 500 percent to 1500 percent of the trip-device rating. Determine instantaneous pickup. Instantaneous pickup values should be within the tolerances of manufacturer's published data.

11.10.5.4.4 Ground-Fault Element. This element is available only on solid-state devices and is used to protect against ground-fault currents at levels below those that would be sensed otherwise. Determine ground-fault pickup and delay. Ground-fault pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time–current tolerance band.

11.10.6 Low-Voltage Power Circuit-Breaker Testing. When low voltage circuit-breaker testing is performed, the criteria in 11.10.6.3 through 11.10.6.3.4 should be utilized.

11.10.6.1 Insulation Resistance Tests. Measure insulation resistance tests for 1 minute on each pole, phase-to-phase and phase-to-ground with the circuit breaker closed and across each open pole. Apply voltage in accordance with manufacturer's published data. Insulation resistance values should be in accordance with the manufacturer's published data. For further information on insulation resistance testing, see

11.9.2.3, Insulation Resistance Testing.
11.10.6.2 Contact/Pole Resistance or Millivolt Drop Tests.
Measure contact/pole resistance or millivolt drop. These tests are used to test the quality of the contacts. The contact resistance or millivolt drop should be kept as low as possible to reduce power losses at the contacts with the resultant localized heating, which will shorten the life of both the contacts and nearby insulation. Microhm or millivolt drop values should not exceed the high levels of the normal range as indicated in the manufacturer's published data.

11.10.6.3 Overcurrent Trip Device. Most low-voltage power circuit breakers are equipped with overcurrent trip devices that sense overload of fault currents and trip the breaker. These devices can be either electromechanical or solid state and usually have two or more of the following types of elements.

11.10.6.3.1 Long Time-Delay Element. This element is
designed to operate on overloads between its pickup setting and the pickup of a short time delay or an instantaneous element. The electromechanical long time-delay pickup adjustment is generally within the range of 80 percent to 160 percent of the trip-device rating. Settings higher than an electromechanical trip-device ampere rating do not increase the continuous-current rating of the trip device, and in no event is the

		rating increased beyond the breaker frame size. The oper-ating time of this element ranges from seconds to minutes. Determine long-time pickup and delay. Long-time pickup values should be as specified, and the trip characteristic shall not exceed manufacturer's published time–current characteristic tolerance band, including adjustment factors. **11.10.6.3.2 Short Time-Delay Element.** This element has a time delay measured in cycles and is used to protect against moderate fault currents and short circuits. This element usually can be adjusted to pick up within the range of 250 percent to 1000 percent of the trip-device rating. Determine short-time pickup and delay. Short-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time–current tolerance band. **11.10.6.3.3 Instantaneous Element.** This element has no intentional time delay and is used to protect against heavy fault currents and short circuits. The pickup settings for this type of element usually range from 500 percent to 1500 percent of the trip-device rating. Determine instantaneous pickup. Instantaneous pickup values should be within the tolerances of manufacturer's published data. **11.10.6.3.4 Ground-Fault Element.** This element is available only on solid-state devices and is used to protect against ground-fault currents at levels below those that would be sensed otherwise. Determine ground-fault pickup and delay. Ground-fault pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time–current tolerance band. **11.10.6.4 Low-Voltage Power Circuit Breakers in General.** For further information on low-voltage air circuit breakers see Section 15.4, Air Circuit Breakers.	
NEMA Standards Publication AB 4-2009 Guidelines for Inspection and Preventive Maintenanc e of Molded Case Circuit Breakers Used in Commercial and	1.2 REFERENCED STANDARDS In this publication, reference is made to the latest edition of the standards listed below. Copies are available from the indicated sources: National Fire Protection Association Batterymarch Park Quincy, MA 02269 NFPA 70 National Electrical Code® NFPA 70B Recommended Practice for Electrical Equipment Maintenance NFPA 70E Standard for Electrical Safety Requirements for Employee Workplace National Electrical Manufacturers Association 1300 North 17th Street Rosslyn, Virginia 22209 AB 1 Molded Case Circuit Breakers, Molded Case Switches and Circuit Breaker Enclosures1 AB 3 Molded Case Circuit Breakers and Their Application	6. TEST PROCEDURES 6.1 GENERAL Some industrial users have indicated that they are required to conduct operational tests of their circuit breakers. The AB 4 Standards Publication is not intended, nor is it adequate, to verify proper electrical performance of a molded case circuit breaker that has been disassembled, modified, rebuilt, refurbished, or handled in any manner not intended or authorized by the original circuit breaker manufacturer. The following non-destructive tests may be used to verify specific operational characteristics of molded case breakers: mechanical operation test, insulation resistance test, individual pole resistance test (millivolt drop test), inverse time overcurrent trip test, instantaneous overcurrent trip test, and rated hold-in test.	References: NFPA 70 National Electrical Code® NFPA 70B Recommended Practice for Electrical Equipment Maintenance NFPA 70E Standard for Electrical Safety Requirements for Employee Workplace AB 1 Molded Case Circuit Breakers, Molded Case Switches and Circuit Breaker Enclosures1 AB 3 Molded Case Circuit Breakers and Their Application

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Industrial Applications			
IEEE STD 1015-2006, The Blue Book ™ IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems.	7.11 Normative references The following referenced documents are indispensable for the application of this standard. (Excerpted) NEMA AB 4-2003, Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers used in Commercial and Industrial Applications.6 NETA, Acceptance Testing Specifications—2003.7 NETA, Maintenance Testing Specifications—2001. NFPA 70B-2002, Recommended Practice for Electrical Equipment Maintenance8. NFPA 70E-2004, Standard for Electrical Safety in the Workplace.	1) *Thermal unit test*. The MCCB is tested by passing 300% of the MCCBs ampere rating through each pole of the MCCB. The test results should be compared with the manufacturer's time-current characteristics (curve sheet). For multi-pole MCCBs, these curve sheets are based on current in all poles of the breaker and are used for coordination purposes; thus, the curve sheet should be examined for maximum single-pole trip time. Not all curve sheets specify a maximum single-pole trip time, but when one is available it should be noted. (In lieu of one not provided, Table 5-3 of NEMA AB 4-2003 provides a maximum trip time for a range of continuous current breakers tested at 300% rated continuous current.) 2) *Magnetic unit (instantaneous) test*. The MCCB (thermal-magnetic, electronic trip, or MCP) is tested by passing the magnetic rated trip amperes through each pole of the circuit breaker. The circuit breaker should trip within the following parameters: Adjustable: +40% to –30% of setting. Nonadjustable: +25% to –25% of manufacturer's trip range The testing of instantaneous trip units usually requires a high current test set for all, but the smallest frame sizes of MCCBs. Care must be taken when checking the instantaneous unit with high current to ensure that the thermal-trip unit is not the cause of the MCCB tripping. The high current should be placed on the MCCB for very short periods of time with adequate cool down time allowed between applications. When testing the instantaneous trip of MCPs, additional consideration may be needed for the proper operation of the overload protective device, such as the overload relay for a motor starter, to assure complete overcurrent protection. 3) *Shunt trip*. Shunt-trip devices are used to trip an MCCB via some external device operation (e.g., ground-fault relay). If an MCCB is equipped with a shunt-trip coil (solenoid), the unit can be verified by applying the rated voltage across the coil, with the MCCB closed. The shunt-trip device trips a mechanical latch (or trip mechanism) that trips the MCCB. 4) *Insulation resistance*. All poles should be tested in accordance with standard insulation resistance testing guidelines at 1000 V dc. Resistance values of less than 1 MΩ should be considered inadequate, and the cause should be investigated. Insulation tests should be performed between the line and load terminals with the MCCB open, between adjacent poles, and from each pole to the grounded parts of the MCCB. 5) *Contact resistance*. Contact resistance should be measured using an ohmmeter capable of measurements into the micro-ohm range. Contact resistance measurements on some of the smaller sized MCCBs are not practical where the test lead clip is larger than the MCCBs' terminal. The manufacturer should be contacted to obtain acceptable contact resistance levels for the breaker under test. 6) *Rated load test*. A rated load hold-in test can be run if there is some doubt of the MCCBs' ability to carry rated load. With the MCCB in free air, all three poles are	Chapter 7 section 7.3 page 173 Field maintenance of MCCBs, which includes motor circuit protectors (MCPs), is normally limited to a visual inspection, cleaning, and tightening of connections. However, periodic overcurrent protection testing of MCCBs and MCPs should be completed as indicated below. Per NFPA 70B-2002 (18-4 Frequency of Tests), the optimum testing and maintenance cycle depends on the use of the equipment and typically ranges from 6 months to 3 years."

		connected in series with jumpers of a short length and adequate capacity. Applying rated load current for a minimum of 30 min should not cause the breaker to trip.	
IEEE STD 1458-2005 IEEE Recommended Practice for the Selection, Field Testing, and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications	2. Normative References The following referenced documents are indispensable for the application of this standard. IEEE Std 242 ™ The Buff Book ™—IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems. 1, 2 IEEE Std 1015, The Blue Book ™ IEEE Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems.	**8. Procedures for field testing and determining the remaining life of molded case circuit breakers** The determination of the remaining life in a molded case circuit breaker is dependent on many factors. This clause will help the user determine the end of the useful life of a circuit breaker. There are two points that cannot be over stressed when determining when a molded case circuit breaker must be replaced. They are as follows: 1) When in doubt about the condition of a circuit breaker, replace it. A circuit breaker replaced at a convenient time is very inexpensive compared to the cost of an unscheduled circuit breaker failure. 2) NEVER reuse a molded case circuit breaker that has been opened. Working with energized electrical equipment is inherently dangerous. All work or testing on equipment that is energized shall only be performed by qualified electrical workers following the safety procedures outlined in NFPA 70E, STANDARD FOR ELECTRICAL SAFETY REQUIREMENTS FOR EMPLOYEE WORKPLACES.[B5] FAILURE TO FOLLOW THESE PROCEDURES CAN RESULT IN SIGNIFICANT PROPERTY DAMAGE, SERIOUS INJURY OR LOSS OF LIFE. The precautions set forth herein, and in NFPA 70E [B5] and other applicable safety guides, assist in minimizing the inherent dangers of working on energized electrical equipment, but do not guarantee safety. The life expectancy of molded case circuit breakers is dependent on many factors. The conditions that affect the life of circuit breakers are as follows: — The number of fault clearing operations of the breaker — How often the breaker is turned on and off — The humidity and ambient temperature where the breaker is located — Corrosive, abrasive, or conductive dust or particles in the atmosphere around the breaker — Loose connections of the power leads on the breaker that result in over heating of connections — Abnormal occurrences such as fire or explosion near the breaker Appropriately selected and maintained circuit breakers will provide many years of trouble free service. Under normal conditions, properly applied molded case circuit breakers require maintenance only to verify the integrity of the installation. However, when inspection is necessary to determine an abnormal condition or determine the possibility of damage, it might be necessary to perform maintenance on a circuit breaker. This clause is intended to assist the user in performing required maintenance and in assessing the remaining life of a circuit breaker. If a circuit breaker has interrupted a fault or its condition is of concern, the following tests should be performed to determine its condition and remaining life.	References the Blue Book normative references which references 70B Chapter 7 section 7.3 page 173 Field maintenance of MCCBs, which includes motor circuit protectors (MCPs), is normally limited to a visual inspection, cleaning, and tightening of connections. However, periodic overcurrent protection testing of MCCBs and MCPs should be completed as indicated below.

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		8.1 Rated current hold in test 8.2 Exposed face and lug temperature check 8.3 Mechanical operation tests 8.4 Insulation resistance test 8.5 Individual pole resistance test (millivolt drop) 8.6 Inverse-time overcurrent trip test 8.7 Instantaneous overcurrent trip test	
IEEE STD 3007.2 Recommended Practice for the Maintenance of Industrial and Commercial Power Systems 2010 Edition	**5.3.2 Low-voltage circuit breakers** Low-voltage circuit breakers come in the following three major types: a) Low-voltage power (air-frame) circuit breakers b) Molded-case circuit breakers (MCCBs) c) Insulated-case circuit breakers (ICCBs) Low-voltage power circuit breakers start with a frame size of 600 A and go up to 5000 A. The sensing unit that operates the breaker on a short circuit or overload may be either an oil-dash pot with springs and copper coils (for older breakers), CTs, and an electronic trip unit or some other current detection and tripping system, such as an external protective relay. With an electronic trip unit, the number of possible settings and trip functions has made it easier to coordinate circuit breakers with other protective devices. MCCBs and ICCBs are similar in mechanical construction and insulation. The circuit breakers' contacts and operating mechanisms are totally enclosed in a molded plastic housing. Both are normally tested and rated in accordance with UL 489 [B51]. The difference between the two is a MCCB has a single-step stored energy mechanism while the ICCB has a two-step stored energy mechanism. For both, the current-carrying parts, mechanisms, and trip devices are completely contained within a molded case of insulating material. _ The cover and base of smaller MCCBs are designed so that the MCCBs cannot be opened for maintenance. The main contacts of MCCBs cannot be removed; however, some MCCBs are available with field-installable accessories. MCCBs are available in stationary or plug-in construction with circuit breaker enclosures that can be flush or surface mounted. They are available in a large number of continuous-current and interrupting ratings. The smaller continuous current ratings are equipped with thermal-magnetic or magnetic-only trip units. A thermal magnetic trip unit is made up of two pieces: a thermal unit to sense overload that uses two dissimilar metals and a magnetic unit to trip on short circuit. Larger sizes of MCCB are available with thermal-magnetic or electronic (static) trip devices. _ The case of the ICCB is designed so that it can be opened for inspection of contacts and arc chutes and for limited maintenance. Most manufacturers offer designs that permit replacement of accessories, and some designs permit replacement of the main contacts. ICCBs are available in both stationary and draw-out construction. They are generally characterized by a two-step stored energy mechanism, larger frame sizes, and higher short-time withstand ratings than MCCBs. Electronic trip units are standard.	5.3.2 (pg 31) The most thorough test for all three types of circuit breakers is by primary injection testing. A special test set that puts out high (fault-level) current at a low voltage (typically 6 V ac to 20 V ac) is used to functionally test the circuit breaker. These test sets have built-in timing functions; therefore, the breaker can be tested at various currents in order to verify that it operates within the published time-current Specifications that are provided by the manufacturer and that it is calibrated to perform in accordance with the arc-flash and coordination study. For circuit breakers that have electronic trip units, it is often possible to do secondary injection testing. This test is usually done with a special test set that is designed for the trip unit. It injects low-level test currents into the trip unit, directly testing the trip unit, its trip output, and the trip coil. For many styles of electronic trip units, it does not test the trip unit's power supply, interconnecting wiring, or CTs. For this reason, primary injection testing is the preferred method of maintenance testing, as it tests the entire circuit breaker overcurrent protective system (e.g., CTs, wiring, shunt trip device) in a manner that is similar to how the breaker would operate during a fault condition. In addition to testing the tripping characteristics of the circuit breaker by injecting fault current, it is also normal practice to test the insulation resistance (usually at 1000 V dc) and the resistance of the current carrying components. Such testing is often referred to as a *contact resistance test* or a *microhmmeter test*. Often the primary source of problems with low- and medium-voltage circuit breakers is the contact pivot point. The pivot is lubricated from the factory. However, after being in service, the lubricant dries out over time, and the pivot area wears rapidly. The contact resistance can be measured directly with a digital low resistance ohmmeter (usually in microhms) or indirectly by performing a millivolt drop test. A millivolt drop test is performed by using a primary injection test set to inject rated continuous current through the breaker while measuring the millivolt drop across the breaker's contacts. It is a comparative test between each phase of the breaker in which the millivolt reading typically should not differ by more than 50% between phases.	5.3 (excerpt) Several issues should be considered when testing any molded-case, insulated-case, and low-voltage power circuit breaker as well as testing any protective relay. It is advisable to follow the manufacturer's instructions, if available. In the absence of the manufacturer's instructions, NEMA AB 4 [B43], IEEE Std 1458 [B36], NFPA 70B-2006 [B45], or ANSI/NETA MTS-2007 [B3] should be consulted. Regardless of the instructions used, the manufacturer's time-current curves should be used so that the device will operate as intended and designed. Validating with the curves is vital to the protective device coordination study (see 5.3.1) as well as the arc-flash hazard analysis (see 4.1). These devices should operate as designed, published, and adjusted or set in order to have an electrical power system that is reliable and maximizes safety. Paragraph 5.7.2 discusses the merits of NFPA 70B-2006 and states "NFPA 70B-2006 offers the core of an excellent EPM program by providing much information for direct use by facility engineers and maintenance personnel. With the addition of specific instructions from the manufacturers' literature, most electrical equipment maintenance needs are covered."

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Emerson - Low Voltage Circuit Breaker Testing Why Test? Series	**"Why Test Circuit Breakers?** They fail. A survey by Hartford Insurance Company found that air circuit breakers represent 19.5% of electrical power system failures. Test results on circuit breakers by NETA (National Electrical Testing Association) firms show over a 15% failure rate. Defective circuit breakers can allow extensive damage, personnel injury, or make an outage more widespread when a fault occurs. They can also trip when they shouldn't causing expensive downtime." Why Do They Fail Or Fail? Current sensors fail because they are mis-wired or broken, or solid state components have failed or are incorrectly programmed. Trip linkages fail because dust, hardened grease, corrosion, misalignment or frozen or broken parts prevent operation (even though the breaker may be operated manually and therefore appear to operate properly). The current-carrying parts and main contacts fail because they have been damaged by fault interruption or operating springs have fatigued such that they no longer provide adequate opening or closing force or because internal connection have become loose. The case or insulation fails because it has cracked or been damaged. Common failures include: dashpots leaking, spurious tripping, linkage not adjusted, no tripping at all, broken cases exposing live parts, loose internal connections, defective or broken parts, metal fatigue, age, overuse or misapplication.	Measure contact voltage drop at rated current, (finds loose connections, improper contact pressure, or damaged main contacts). • Test instantaneous trip function with pulse or higher currents until trip occurs, (tests short circuit protection capability). • Measure overload tripping time at 300% rated current. • Check mechanical operation. Inspect for broken parts. • Test operation of ground fault, short time pickup and delay, shunt trips, undervoltage releases, alarm functions, electrical spring charging mechanism, etc. • Check insulation resistance phase-to-phase and phase- to-ground, closed and across open contacts.	Justifies testing and refers to NEMA AB 4 for methods "There is no way to know if a circuit breaker will operate properly under fault or overload conditions unless it is tested, preferably by a primary injection test. (Refer to NEMA Standard AB 4 "Guidelines of Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications.")" Special Considerations • Testing is recommended at start-up and every three years there after. • Circuit breaker must be de-energized to perform test • For primary current injection testing, a power source capable of supplying 100 amps at 208 or 480 volts is required to power the test set
ANSI/NETA MTS-2007 Standard for Maintenance Testing Specifications	Applicable References NEMA AB4 Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications National Fire Protection Association – NFPA ANSI/NFPA 70 National Electrical Code ANSI/NFPA 70B Recommended Practice for Electrical Equipment Maintenance ANSI/NFPA 70E Standard	7. INSPECTION AND TEST PROCEDURES 7.6.1.1 Circuit Breakers, Air, Insulated-Case/Molded-Case * Optional 1. Visual and Mechanical Inspection 1. Inspect physical and mechanical condition. 2. Inspect anchorage and alignment. 3. Prior to cleaning the unit, perform as-found tests, if required. 4. Clean the unit. 5. Operate the circuit breaker to insure smooth operation. 6. Inspect bolted electrical connections for high resistance using one of the following methods: 1. Use of a low-resistance ohmmeter in accordance with Section 7.6.1.1.2. 2. Verify tightness of accessible bolted electrical connections by calibrated torque-wrench method in accordance with manufacturer's published data or Table 100.12. 3. Perform a thermographic survey in accordance with Section 9. 7. Inspect operating mechanism, contacts, and arc chutes in unsealed units. 8. Perform adjustments for final protective device settings in accordance with coordination study provided by end user. 9. Perform as-left tests. 2. Electrical Tests 1. Perform resistance measurements through bolted connections with a low-resistance ohmmeter, if applicable, in accordance with Section 7.6.1.1.1.	Applicable references NEMA AB4 Guidelines for Inspection and Preventive Maintenance of Molded-Case Circuit Breakers Used in Commercial and Industrial Applications National Fire Protection Association – NFPA ANSI/NFPA 70 National Electrical Code ANSI/NFPA 70B Recommended Practice for Electrical Equipment Maintenance ANSI/NFPA 70E Standard for Electrical Safety in the Workplace

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TABLE 100.7

Molded-Case Circuit Breakers
Inverse Time Trip Test
(At 300% of Rated Continuous Current of Circuit Breaker)

Range of Rated Continuous Current (Amperes)	Maximum Trip Time in Seconds For Each Maximum Frame Rating [a]	
	$\leq$ 250 V	251 – 600 V
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

Derived from Table 5-3, NEMA Standard AB 4-2000, *Guidelines for Inspection and Preventative Maintenance of Molded-Case Circuit Breaker Used in Commercial and Industrial Applications.*

a. Trip times may be substantially longer for integrally-fused circuit breakers if tested with the fuses replaced by solid links (shorting bars).

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2. Perform insulation-resistance tests for one minute on each pole, phase-to-phase and phase-to ground with the circuit breaker closed, and across each open pole. Apply voltage in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table
100.1.
3. Perform a contact/pole-resistance test.
7. INSPECTION AND TEST PROCEDURES
7.6.1.1 Circuit Breakers, Air, Insulated-Case/Molded-Case (continued)
* Optional
*4. Perform insulation-resistance tests on all control wiring with respect to ground. The applied potential shall be 500 volts dc for 300-volt rated cable and 1000 volts dc for 600-volt rated cable. Test duration shall be one minute. For units with solid-state components, follow manufacturer's recommendation.
5. Determine long-time pickup and delay by primary current injection.
6. Determine short-time pickup and delay by primary current injection.
7. Determine ground-fault pickup delay by primary current injection.
8. Determine instantaneous pickup current by primary injection.
*9. Test functions of the trip unit by means of secondary injection.
10. Perform minimum pickup voltage test on shunt trip and close coils in accordance with Table 100.20.
11. Verify correct operation of auxiliary features such as trip and pickup indicators, zone interlocking, electrical close and trip operation, trip-free, antipump function, and trip unit battery condition. Reset all trip logs and indicators.
12. Verify operation of charging mechanism.
3. Test Values
3.1 Test Values – Visual and Mechanical
1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value. (7.6.1.1.1.6.1)
2. Bolt-torque levels should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.12. (7.6.1.1.1.6.2)
3. Results of the thermographic survey shall be in accordance with Section 9. (7.6.1.1.1.6.3)
4. Settings shall comply with coordination study recommendations. (7.6.1.1.1.8)

7. INSPECTION AND TEST PROCEDURES
7.6.1.1 Circuit Breakers, Air, Insulated-Case/Molded-Case (continued)
* Optional
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3.2 Test Values – Electrical
1. Compare bolted connection resistance values to values of similar connections. Investigate values which deviate from those of similar bolted connections by more than 50 percent of the lowest value.
2. Insulation-resistance values should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, use Table 100.1. Values of

APPENDIX B

Frequency of Maintenance Tests (*continued*)

		Inspections and Tests Frequency in Months (Multiply These Values by the Factor in the Maintenance Frequency Matrix)		
Section	Description	Visual	Visual & Mechanical	Visual & Mechanical & Electrical
7.1	Switchgear & Switchboard Assemblies	12	12	24
7.2	Transformers			
7.2.1.1	Small Dry-Type Transformers	2	12	36
7.2.1.2	Large Dry-Type Transformers	1	12	24
7.2.2	Liquid-Filled Transformers	1	12	24
	Sampling	–	–	12
7.3	Cables			
7.3.2	Low-Voltage Cables	2	12	36
7.3.3	Medium- and High-Voltage Cables	2	12	36
7.4	Metal-Enclosed Busways	2	12	24
	Infrared Only	–	–	12
7.5	Switches			
7.5.1.1	Low-Voltage Air Switches	2	12	36
7.5.1.2	Medium-Voltage Metal-Enclosed Switches	–	12	24
7.5.1.3	Medium- and High-Voltage Open Switches	1	12	24
7.5.2	Medium-Voltage Oil Switches	1	12	24
7.5.3	Medium-Voltage Vacuum Switches	1	12	24
7.5.4	Medium-Voltage SF_6 Switches	1	12	24
7.5.5	Cutouts	12	24	24
7.6	Circuit Breakers			
7.6.1.1	Low-Voltage Insulated-Case/Molded-Case CB	1	12	36
7.6.1.2	Low-Voltage Power CB	1	12	36
7.6.1.3	Medium-Voltage Air CB	1	12	36
7.6.2	Medium-Voltage Oil CB	1	12	36
	Sampling	–	–	12
7.6.2	High-Voltage Oil CB	1	12	12
	Sampling	–	–	12
7.6.3	Medium-Voltage Vacuum CB	1	12	24
7.6.4	Extra-High-Voltage SF_6	1	12	12
7.7	Circuit Switchers	1	12	12
7.8	Network Protectors	12	12	24

TABLE 100.8

Instantaneous Trip Tolerances for Field Testing of Circuit Breakers

Breaker Type	Tolerance of Settings	Tolerances of Manufacturer's Published Trip Range: High Side	Tolerances of Manufacturer's Published Trip Range: Low Side
Adjustable [a]	+40% -30%	-----	-----
Nonadjustable [b]	-----	+25%	-25%

Reproduction of Table 5-4 from NEMA publication AB4-2000, *Guidelines for Inspection and Preventive Maintenanc Molded-Case Circuit Breakers Used in Commercial and Industrial Applications.*

NEMA AB4-2000 *Guidelines for Inspection and Preventative Maintenance of Molded-Case Circuit Breaker Used in Commercial and Industrial Applications, Table 5-4.*

a. Tolerances are based on variations from the nominal settings.

b. Tolerances are based on variations from the manufacturer's published trip band (i.e., -25% below the low side of band; +25% above the high side of the band.)

insulation resistance less than this table or manufacturer's recommendations should be investigated.
3. Microhm or dc millivolt drop values should not exceed the high levels of the normal range as indicated in the manufacturer's published data. If manufacturer's data is not available, investigate values that deviate from adjacent poles or similar breakers by more than 50 percent of the lowest value.
4. Insulation-resistance values of control wiring should be comparable to previously obtained results but not less than two megohms.
5. Long-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current characteristic tolerance band, including adjustment factors. If manufacturer's curves are not available, trip times should not exceed the value shown in Table 100.7. (Circuit breakers exceeding specified trip time shall be tagged defective.)
6. Short-time pickup values should be as specified, and the trip characteristic should not exceed manufacturer's published time-current tolerance band. (Circuit breakers exceeding specified trip time shall be tagged defective.)
7. Ground fault pickup values should be as specified, and the trip characteristic should not exceed
manufacturer's published time-current tolerance band. (Circuit breakers exceeding specified trip time shall be tagged defective.)
8. Instantaneous pickup values of molded-case circuit breakers should fall within manufacturer's published tolerances. In the absence of manufacturer's published tolerances, refer to Table 100.8. (Circuit breakers exceeding specified trip time shall be tagged defective.)
9. Pickup values and trip characteristics should be within manufacturer's published tolerances.
(Circuit breakers exceeding specified trip time shall be tagged defective.)
10. Minimum pickup voltage on shunt trip and close coils should be in accordance with manufacturer's published data. In the absence of manufacturer's published data, refer to Table 100.20.
11. Breaker open, close, trip, trip-free, antipump, and auxiliary features should function as designed.
7. INSPECTION AND TEST PROCEDURES
7.6.1.1 Circuit Breakers, Air, Insulated-Case/Molded-Case (continued)
* Optional
12. Charging mechanism shall function as designed

APPENDIX B

Frequency of Maintenance Tests

NETA recognizes that the ideal maintenance program is reliability-based, unique to eac piece of equipment. In the absence of this information and in response to requests for a timetable, NETA's Standards Review Council presents the following time-based mainte matrix.

One should contact a NETA Accredited Testing Company for a reliability-based evalua

The following matrix is to be used in conjunction with Appendix B, Inspections and Tes the matrix is recognized as a guide only.

Specific condition, criticality, and reliability must be determined to correctly apply the of the matrix, along with the culmination of historical testing data and trending, should electrical preventive maintenance program.

MAINTENANCE FREQUENCY MATRIX			
		EQUIPMENT CONDITION	
		POOR	AVERAGE
EQUIPMENT RELIABILITY REQUIREMENT	LOW	1.0	2.0
	MEDIUM	0.50	1.0
	HIGH	0.25	0.50

EPRI Molded Case Circuit Breaker Application and Maintenance Guide Rev 2 -2004

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

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

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

	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. 6-1 EPRI Licensed Material Maintenance Program Development Guidelines 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." 6-2 EPRI Licensed Material Maintenance Program Development Guidelines This approach is supported by statements and correspondence from the NRC and NEMA. NRC IN 93-64 states, "The	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. 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.	(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. 6-7 EPRI Licensed Material Maintenance Program Development Guidelines 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. 6.6 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. 6-12 EPRI Licensed Material Maintenance Program Development Guidelines 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

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	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 safetyrelated 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. 6-3 EPRI Licensed Material Maintenance Program Development Guidelines 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		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.

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. 6-4 EPRI Licensed Material Maintenance Program Development Guidelines 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 6.3.1.1 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. 6-5 EPRI Licensed Material Maintenance Program Development Guidelines 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 industrywide 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-

Table 6-3
Criticality vs. Maintenance Tasks Performed

	Regulatory	Critical	Non-Critical
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 followir maintenance tasks may be considered • Thermography • Visual inspectio cleaning • Mechanical operation (cycli
Frequency	Plant-specific	Plant-specific	Plant-specific

	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 6-6 EPRI Licensed Material Maintenance Program Development Guidelines 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. 3. Establish an inspection program for new and refurbished circuit breakers to include functional testing prior to installation. 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. 6-7 EPRI Licensed Material Maintenance Program Development Guidelines. 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.		

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<table>
<tr>
<td></td>
<td>General Information 2. 3. 4. 5. 6. Testing Thermal-Magnetic Circuit Breakers Overload Testing Considerations Overcurrent Trip Minimum/Maximum Ranges Evaluation of Results Testing Instantaneous-Only Circuit Breakers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOE (EPRI MCCB Guide)</td>
<td>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. 6-8 EPRI Licensed Material Maintenance Program Development Guidelines 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.</td>
<td>
Table 6-1
Aging Management Summary for MCCBs
<table>
<tr><th>Part</th><th>Material(s)</th><th>Aging Effects</th><th>Aging Mechanism</th><th>Typical Aging Management Program</th></tr>
<tr><td>Operating mechanism</td><td>Various</td><td>Binding, sticking of mechanism</td><td>Lubrication failure</td><td>Testing of breaker, clean, inspect, cycle</td></tr>
<tr><td>Current trip device, contacts, lugs</td><td>Various</td><td>Loss of contact, contact erosion, discoloration</td><td>Loose connections, overheating</td><td>Thermography
Testing of breaker, clean, inspect, cycle</td></tr>
<tr><td>Housing</td><td>Plastic</td><td>Cracking, splitting, discoloration, melting</td><td>Overheating, short circuit, premature aging</td><td>Thermography
Clean, inspect breaker</td></tr>
</table>
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<td></td>
</tr>
<tr>
<td>Schneider Field Testing and Maintenance Guide</td>
<td>The standard generally used as a basis for field-testing requirements is the National Electrical Manufacturers Association Standard, NEMA AB 4, “Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications.”

The inspection and preventive maintenance procedures outlined in this publication may be useful in setting up a routine inspection program. Conduct performance tests only if inspection or daily operation indicates that a circuit breaker may not be adequately providing the protection required by its application.</td>
<td>03/2013 Section 3—Performance Tests for Thermal-Magnetic Circuit Breaker
These tests check the performance of thermal-magnetic trip molded case circuit breakers.
General Circuit Breaker Performance Tests
Do the performance tests in the order given to maximize the accuracy of the test results.
NOTE: Never do the contact resistance test before doing the instantaneous primary injection testing. The primary injection testing will ensure the contacts are clear of resistive films, oxidation and foreign material.

The following tests are intended to verify that a circuit breaker is operating properly. Precisely controlled factory testing conditions are used to establish the characteristic</td>
<td>References:
The standard generally used as a basis for field-testing requirements is the
National Electrical Manufacturers Association Standard, NEMA AB 4, “Guidelines for Inspection and Preventive Maintenance of Molded Case
Circuit Breakers Used in Commercial and Industrial Applications.”</td>
</tr>
</table>

		trip curves. If field test results fall outside the characteristic trip curve tolerance band, carefully evaluate the test conditions and methods for accuracy. When questionable conditions or results are observed during inspection and performance tests, consult your local field sales office. Circuit breakers with accessories or factory modifications may require special investigation. If it is necessary to return a circuit breaker to the manufacturing facility, use proper packaging and packing materials to avoid shipping damage. Performance Tests Insulation Resistance Test Severe environmental conditions can reduce the dielectric strength of molded case circuit breakers. Check insulation resistance during electrical system testing. To check the insulation resistance, perform the following steps: 1. De-energize and isolate the circuit breaker. 2. Clean the circuit breaker as described earlier 3. Using a megohmmeter with a capacity of 500–1000 Vdc, apply voltage from: a. Each phase-to-ground with the circuit breaker on (circuit breaker contacts closed). b. Phase-to-phase with the circuit breaker on (circuit breaker contacts closed). c. Between each line and load terminal with the circuit breaker off (circuit breaker contacts open). 4. Record resistance values. Resistance values of less than one megohm (1,000,000 ohm) should be investigated. Thermal-Magnetic Circuit Breaker Performance Tests Inverse-Time Overcurrent Trip Test 1. Completely de-energize and remove the circuit breaker from service. Conduct the following tests at 300% of the circuit breaker ampere rating to verify the performance of the thermal tripping element on thermalmagnetic circuit breakers using a high-current, low-voltage ac power supply of less than 24 V. 2. Test in open air at 25°C (77°F) ambient temperature. 3. Trip times are measured from a “cold start.” A cold start, as defined by Underwriters Laboratories Inc. Standard 489 occurs at 25°C ± 3° (77°F ± 5°). Therefore, before beginning overcurrent testing, the circuit breaker must be in 25°C (77°F) ambient temperature long enough for all parts to reach that temperature. Circuit breakers that have been in higher ambient temperatures may take two to four hours to reach the steady state temperatures mentioned above. 4. Connect the circuit breaker to a power supply by using a minimum of four feet (1.2 m) of cable on each connection. Size the cable according to the ampere rating of the tested circuit breaker. Refer to the National Electrical Code Table 310-16; use the 75°C column for proper conductor sizing. Improperly sized cable will affect test results. 5. Test each pole of the circuit breaker individually at 300% of rated current using a high-current, low-voltage ac power supply.	

		6. Record and compare the trip test values to those in Table 2. As long as the recorded trip times are below the maximum trip times, the circuit breaker is providing acceptable thermal protection. If verification of the manufacturer's data is required, compare the trip times to the 300% trip range shown on the trip curve for the specific circuit breaker. If field test results fall outside the characteristic trip curve tolerance band, the test conditions and methods should be carefully evaluated for accuracy. A small error in test current results in a large error in trip time. Instantaneous (Magnetic) Trip Test This test simulates short-circuit conditions using a low-voltage test supply. To keep stray magnetic fields from affecting test results, test cables exiting the circuit breaker must be parallel with the current path of the circuit breaker for a minimum of 10 in (254 mm). Test results can also be influenced by the wave shape of the supply current. Use a power source with true sinusoidal output and a true RMS or analog ammeter to ensure accurate results. To verify the performance of the instantaneous (magnetic) trip element, proceed as follows: NOTE: Test PA and PH circuit breakers with the circuit breaker mounted on a terminal pad kit (catalog number PALTB). PC circuit breakers should be tested with the circuit breaker mounted on the terminal pad kit provided with the circuit breaker. Test NA and NC circuit breakers in the end-use equipment or lying flat on a piece of 1/8 in. (3 mm) thick steel. 1. Set the circuit breaker instantaneous (magnetic) trip adjustment, if provided, to the high setting. Tests conducted at the high setting ensure instantaneous trip protection exists at all lower settings. 2. Connect the circuit breaker to the low-voltage test source with any convenient length of conductor. 3. Test each pole individually by the pulse method as follows: The pulse method requires that the test equipment have a controlled closing and a pointer-stop ammeter, a calibrated image-retaining oscilloscope, or a high-speed, sampling-rate digital ammeter. The pulse method involves the following steps: a. Connect one pole of the test circuit breaker to the test equipment. b. Set the current control of the test equipment to a value approximately 70% of the instantaneous trip current setting. Example: If the instantaneous (magnetic) trip setting is 2000 A, set the test equipment to 1400 A. c. After the circuit breaker is properly connected and adjusted, apply current in approximately 10-cycle pulses. d. Starting at 70% of the instantaneous trip setting, increase the current of each pulse until the circuit breaker trips. After each pulse, move the circuit breaker handle to the full reset position and then to the on position. e. Repeat step D to recheck and verify this value. Start with the current level below the value measured in step D to ensure a "no trip" on the initial pulse. 4. Record current level and trip time. To ensure protection of the rated conductor, the current necessary to trip the circuit breaker	

		instantaneously must not exceed 140% of the high setting for circuit breakers 250 A frame size and below, and 125% of the high setting for circuit breakers 400 A frame size and above. These settings are printed on the faceplate label of the circuit breaker. If currents higher than these maximum levels are necessary to trip the circuit breaker, consult your local field sales office. If field test results fall outside the characteristic trip curve tolerance band, the test conditions and methods must be carefully evaluated for accuracy. Rated Current Hold-In Test This test should be performed only on circuit breakers that have been nuisance tripping under normal conditions. Conduct the test in a 25°C (77°F) ambient temperature using a high-current, low-voltage ac power supply. Follow the same procedure used in the Inverse-time Overcurrent Trip Test, steps 1-3, page 14. Connect all poles of the circuit breaker in series using cables with the appropriate ampacity for the application. These cables should be 4 ft. (1.22 m) long per terminal (8 ft. [2.43 m] total between poles). All connectors must be properly torqued according to the circuit breaker label specifications. The circuit breaker should not trip when 100% of the device's rated current is applied for one hour for circuit breakers rated less than 100 A, or two hours for circuit breakers rated more than 100 A. If the circuit breaker trips, reset and move the handle from the off to on position several times while under load, then repeat the test. If the tripping condition continues, contact your local field sales office. Contact Resistance Test Circuit breaker pole resistance tests are not reliable indicators of circuit breaker performance because the resistance values are influenced by a number of transient factors including contact surface oxidation, foreign material between the contacts, and testing methods. NEMA AB 4 paragraph 6.4.1 states: "The millivolt drop of a circuit breaker pole can vary significantly due to inherent variability in the extreme low resistance of the electrical contacts and connectors. Such variations do not necessarily predict unacceptable performance and shall not be used as the sole criteria for determination of acceptability." High pole resistance may also be caused by eroded contacts, low contact force, and loose termination. The only one of these factors likely to be present on a new circuit breaker is a loose termination, since the contacts are new and there has been no opportunity for contact pressure to have drifted from the factory setting. A loose termination can be corrected in the field. If a contact resistance test is done, it is important to do it after the contacts have been conditioned by instantaneous primary injection testing to ensure the contacts are clear of resistive films, oxidation and foreign material. If the circuit breaker has been in service with no performance issues, (overheating or nuisance tripping), contact resistance measurements are redundant and of little value. Square D recommends that a DLRO (Digital Low Resistance Ohmmeter) be used, using a 10 A dc test current for circuit breaker ratings below 100 A, and using 100 A dc for circuit breakers rated 100 A and above. the median (middle) value of three readings	

		(toggling the circuit breaker between each reading) should be recorded for each pole tested. If this value is equal to or less than the value listed in Table 3, the pole is acceptable. If the reading is higher, the cause should be investigated and corrected if possible. Contact your local field office for more information. Remove Test Connections Upon completing testing: — Remove test connections from circuit breaker. — Inspect connections for damage caused by testing. Additional Information For more information concerning Square D circuit breakers, refer to the appropriate instruction manual. These manuals contain installation instructions, mounting information, safety features, wiring diagrams, and troubleshooting charts for specific circuit breakers.	
Allen-Bradley Q-Frame Circuit Breaker Instruction Leaflet for Installation of Q Frame Circuit Breakers		**5. INSPECTION AND FIELD TESTING** Q-Frame molded case circuit breakers are designed to provide years of almost maintenance-free operation. The following procedure describes how to do a limited amount of field inspection and testing of a circuit breaker. **Inspection** Circuit breakers in service should be inspected periodically. The inspection should include the following checks 5-1 through 5-8. 5-1. Remove dust, dirt, soot, grease, or moisture from the surface of the circuit breaker using a lint-free dry cloth, brush, or vacuum cleaner. Do not blow debris into circuit breaker. If contamination is found, look for the source and eliminate the problem. 5-2. Switch circuit breaker to ON and OFF several times to be sure that the mechanical linkages operate freely and do not bind. If mechanical linkages do not operate freely, replace circuit breaker. **Note: On molded case switches, there is no PUSHTO-TRIP feature. Omit step 5-3 when installing a molded case switch and proceed with step 5-4.** 5.3 With the circuit breaker in the ON position, press the PUSH-TO-TRIP button to mechanically trip the circuit breaker. Trip, reset, and switch circuit breaker ON several times. If mechanism does not reset each time the circuit breaker is tripped, replace the circuit breaker. 5.4 Check base, cover, operating handle, and handle barrier for cracks, chipping, and discoloration. Circuit breakers should be replaced if cracks or severe discoloration is found. 5.5 Check wire connecting terminals and other type bus bar connectors for looseness or signs of overheating. Overheating will show as discoloration, melting, or blistering of conductor insulation, or as pitting or melting of conductor surfaces due to arcing. If there is no evidence of overheating or looseness, do not disturb or tighten the connections. If there is evidence of overheating, terminations should be cleaned or replaced. Before re-energizing the circuit breaker, all terminations and cable should be refurbished to the originally installed condition.	Schedule not specified

Verification of Proper Maintenance for Overcurrent Protection Devices - Section III

		5.6 Check circuit breaker mounting hardware, and tighten if necessary. 5.7 Exposure to certain types of chemicals can cause deterioration of electrical connections. Check area where circuit breaker is installed for any safety hazards, including personal safety and fire hazards and take required precautionary actions. 5.8 The operation of circuit breakers with electronic RMS trip units can be field tested periodically using the Electronic test kit. Contact Allen-Bradley for details. **Field Testing** Any field testing should be done in accordance with applicable NEMA Standard.	
Eaton Cutler Hammer Installation Instructions for DK, KDB, KD, HKD, KDC, KW, HKW, KWC, CKD, CHKD Circuit Breakers and Molded Case Switches		**5. INSPECTION AND FIELD TESTING** Series C molded case circuit breakers are designed to provide years of almost maintenance-free operation. The following procedure describes how to inspect and test a circuit breaker in service. ***Inspection and Field Testing*** Circuit breakers in service should be inspected periodically. The inspection should include the following checks 5-1 through 5-8. 5-1. Remove dust, dirt, soot, grease, or moisture from the surface of the circuit breaker using a lint-free dry cloth, brush, or vacuum cleaner. Do not blow debris into circuit breaker. If contamination is found, look for the source and eliminate the problem. 5-2. Switch circuit breaker to ON and OFF several times to be sure that the mechanical linkages are free and do not bind. If mechanical linkages are not free, replace circuit breaker. On molded case switches, there is no PUSH-TO TRIP feature. Omit step 5-3 when installing a molded case switch and proceed with step 5-4. 5-3. With the circuit breaker in the ON position, press the PUSH-TO-TRIP button to mechanically trip the circuit breaker. Trip, reset, and switch circuit breaker ON several times. If mechanism does not reset each time the circuit breaker is tripped, replace the circuit breaker. 5-4. Check base, cover, and operating handle for cracks, chipping, and discoloration. Circuit breakers should be replaced if cracks or severe discoloration is found. 5-5. Check terminals and connectors for looseness or signs of overheating. Overheating will show as discoloration, melting, or blistering of conductor insulation, or as pitting or melting of conductor surfaces due to arcing. If there is no evidence of overheating or looseness, do not disturb or tighten the connections. If there is evidence of overheating, terminations should be cleaned or replaced. Before re-energizing the circuit breaker, all terminations and cable should be refurbished to the condition when originally installed. 5-6. Check circuit breaker mounting hardware, and tighten if necessary. 5-7. Check area where circuit breaker is installed for any safety hazards, including personal safety and fire hazards. Exposure to certain types of chemicals can cause deterioration of electrical connections.	Schedule not specified

Verification of Proper Maintenance for Overcurrent Protection Devices - Section III

		5-8. The operation of circuit breakers with Seltronic trip units can be field tested periodically using the Seltronic test kit. (See Frame Book 29-103.) ***Field Testing*** Any field testing should be done in accordance with applicable NEMA Standard.	
GE Spectra RMS E and F Frame and SG and SK Frame Molded Case Circuit Breakers		Generally no maintenance is required, but it is recommended that the following operations be performed annually. 1. Turn off the power to the equipment being servied. 2. Clean the surfaces of te breaker and surrounding area of any dirt, soot, or other debris. 3. Inspect the breaker for signs of damage. 4. Operate the Push To Trip button and toggle the handle several times to exercise the mechanism and test the operation of the breaker. 5. If any sign of damage is found or if the mechaism has a sluggish or sticky operation , replace the circuit breaker This circuit breaker is sealed and contains no user-servicable parts. Opening the breaker vboids any and all warranties.	No schedule specified
Siemens EM Frame: Types EM6 and EMK Circuit Breakers		INSPECTION AND FIELD TESTING EM Frame Circuit Breakers are designed to provide maintenance free service. Any inspection and field testing should be conducted in accordance with NEMA AB2 : Procedures for Field Inspection and Performance Verification of Molded Case Circuit Breakers ; also NEMA AB4 : Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers.	
NUREG/CR-5762 Wyle 60101 Comprehen sive Aging			

Assessment of Circuit Breakers and Relays

EXECUTIVE SUMMARY

This report describes the results of a comprehensi assessment of relays and circuit breakers that was comp part of the NRC Nuclear Plant Aging Research (NPAR) Program and circuit breakers were analyzed because they are i safety-related equipment which perform critical functions operation and control of nuclear power plants.

This is a Phase II NPAR report and the research has the established NPAR strategy described in NUREG-1144, "Nuclear Plant Aging Research (NPAR) Program Plan."

The significant results of this research were:

- The determination that current nuclear plant mai practice for the inspection of certain relays is ine at detecting significant aging degradation; parti significant aging degradation of Agastat 7012, Electric HFA, Westinghouse MG-6, and Struthers-I relays was not detected using current industry pract
- Identified improved inspection, surveillan monitoring (ISM) methods for relays and circuit which are more effective at detecting aging degradat current nuclear plant practice,
- Identified less intrusive ISM methods, which potential for providing predictive maintenance and c based maintenance,
- Recommended that Infrared temperature measure added to the maintenance practices for auxiliary, protective, and timing relays and for molded case a clad circuit breakers,
- Recommended that vibration signature measurement to the maintenance practices for auxiliary, cont timing relays and for molded case and metal clad breakers,
- Recommended that inrush current signature measur added to the maintenance practices for timing relays
- Recommended that the procedures for instantane testing of molded case circuit breakers be clar assure that the instantaneous trip occurs specification limits. A trip below this l significant since false instantaneous trips can preclud performance of safety-related equipment.

5.6 Molded Case Circuit Breakers

Sixteen ISM methods were evaluated on the molded case circuit breakers. The results of the Phase II testing have shown twelve methods to have been effective in detecting and therefore capable of mitigating aging, Table 5-7. They were visual inspection, pole resistance, mechanical actuation, 100% rated current hold-in, 135% rated current, 300% overcurrent, instantaneous trip, infrared pyrometry, infrared scanning, on-contact temperature measurement, vibration testing, and acoustic testing.

Four methods were ineffective. They were insulation resistance, ion detection, 600% overload and dielectric.

The result of the effectiveness in the Phase II testing was compared to the current nuclear practice. The ISM methods, in common nuclear plant practice, were visual inspection, instantaneous trip, pole resistance, insulation resistance, 100% rated current hold-in, 135% rated current hold-in, and 300% overcurrent. All were shown to be effective, when properly performed, at detecting and capable of mitigating aging in Phase II, except for insulation resistance and mechanical actuation, which were ineffective. Insulation resistance is useful to assure connections are of high integrity for personnel and equipment safety, after maintenance is performed. The instantaneous trip test was shown to be effective when tests were performed below and above the instantaneous trip range. Thus, all of these current methods are considered to be useful.

Additionally effective for molded case circuit breakers were the improved ISM methods of infrared temperature measurement with infrared pyrometer or scanner, and vibration testing.

Infrared temperature measurement was sensitive to the degraded condition of loose connections. The advantage of infrared temperature measurement was the detection of significant temperatures before they damaged molded case circuit breaker internals. As was noted in the tests on aged devices, the failure modes caused by overheating of the molded case circuit breakers were non-conservative.

Vibration testing was the only method which exhibited differences with all of the degraded conditions. The vibration signatures are obtainable with a hand held data acquisition computer. Vibration signatures should be obtained during manual actuation, the 300% overcurrent and instantaneous trip tests since these tests check the performance of the three different trip initiating functions. All three of these functions were shown to be mutually exclusive in the tests on aged molded case circuit breakers.

Clearly one of the significant factors in predicting survivability for relays and circuit breakers is temperature. High temperatures were the root cause of the failure of thermal element trip devices and magnetic trip devices in molded case circuit breakers tested in Phase II. Several of the degraded conditions caused excessive temperatures. Temperatures over 600°F were caused by loose connections in auxiliary relays. Dirt accumulation caused temperatures in excess of 470°F on auxiliary relays. Loose connections caused temperatures over 440°F on molded case circuit breakers. It is generally accepted that circuit breakers are more prone to failure if temperatures are excessive. Additionally, it is known that these devices follow an Arrhenius aging relationship in which the expected service life is a direct function of temperature. It was seen in some of the degraded conditions that service life would be reduced to 6% to 25% of expected life due to the temperature increases observed on the devices. These detrimental temperatures were present on several devices. The timing relays were a good example. The higher than normal temperatures were causing a significant reduction in service life. However, this would commonly go unnoticed because the parameter normally tested was pick-up voltage, which was not degrading. Thus, the use of pick-up voltage as the only maintenance method would overlook the increased temperatures and thus failures would not have been predicted. The function of other factors to affect service life are more subtle and less obvious. A basic assumption in the model is that the relay and circuit breaker is inherently a good design which is free from quality control or lot defects.

The major factors which have been shown by this research to impact the service life of relays and circuit breakers in nuclear plant service are :

- Time in service (TS)
- Temperature of the device (T)
- Vibration at the device (V)
- Cleanliness of the surrounding environment (C)
- Propensity for looseness of critical parts (L)
- Propensity to experience overheated conditions (O)
- Propensity for damage during maintenance (M)
- Duty cycle (D)
- Cool down period prior to re-energization (CD)
- Ionizing radiation (R)

Table 5-7. ISM Methods Effectiveness for Molded Case Circuit Breakers

ISM	Initial Condition	Degraded Conditic DA	HP	LC
Current Practice				
Instantaneous Trip	E	E	E	E
135% Rated Current Hold-in	E	E	E	E
Visual Inspection	E	E	I	E
Pole Resistance	I	E	E	E
100% Rated Current Hold-in	I	I	I	E
300 % Overcurrent	E	I	I	I
Insulation Resistance	I	I	I	I
Mechanical Actuation	I	I	I	I
Advanced Methods				
Vibration Testing	P	E	E	E
Acoustic Testing	P	E	E	E
Infrared Pyrometry	E	I	I	E
Infrared Scanning	E	I	I	E
On-contact Temperature	E	I	I	P
Ion Detection	I	I	I	I
600 % Overload	I	I	I	I
Dielectric	I	I	I	I

Legend:
DA : Dirt Accumulation
E : Effective
HP : High Potential
I : Ineffective
LC : Loose Connection
M : Misleading
P : Probably Effective

Evidence of Impending Failure Table--Real Time Assessment – Section IV

Note: Hazard determination does not constitute whether to proceed or not, at any hazard level a re-evaluation and resoultion must be determined prior to operation

Evidence	Possible Causes	Risk	Hazard ID	Controls	Resolution	Resource
Breaker making unusual sounds, e.g. buzzing	Phase loss, under or over voltage, loose connection, failing breaker, mechanical failure, debris	High	Arc flash and Shock	Isolate up-stream disconnecting means	Inspection and testing	Facilities Electrical Division
Not understanding or knowing why a breaker continues to trip, or is in a tripped condition	Overload, equipment failure, ground fault, breaker failure, wrong overcurrent protection settings	Medium	Arc flash	Examine load to determine cause	Troubleshooting, Inspection and testing	Facility Engineer
Water damage	Weather, leak, excessive humidity, condensation, steam heaters, broken pipes	Medium to High	Arc flash and Shock	Isolate up-stream disconnecting means	Inspection and testing	Facilities Electrical Division
Burn marks (arcing)	Historical arc event	Medium to High	Arc flash	Isolate up-stream disconnecting means	inspection and testing	Facilities Electrical Division
Excessive heating, e.g. discoloration, temperature	Overload, loose connection, inadequate design of conductors or breakers, failing breaker	Medium	Fire	isolate up-stream disconnecting means	Inspection and testing	Facility Engineer, Equipment owner
Combustible process contaminants, e.g. hazardous locations	Industrial processes in area	Low to High (dependent on extent of contaminant, environment, and equipment rating)	Arc flash, and fire	Evaluate condition with resource	Removing contaminant if necessary (using appropriate procedure)	IH, Fire protection engineer, facility electrical engineer
Tracking, e.g. phenolic material (spider webbing)	Equipment breakdown, contamination, aging insolation	High	Arc flash	Isolate up-stream disconnecting means	Clean, maintain, and replace if necessary	Facility Engineer, Equipment owner
Evidence of pest infestation, e.g. hornets, wasps, birds, squirrels, mice	Some pests just like electronics	Low to High (dependent on extent of infestation)	Arc flash	Don PPE to Isolate up-stream device to inspect	Remove infestation, clean, and implement preventative controls	Facility engineer, equipment owner, pest control

Evidence of Impending Failure Table--Real Time Assessment – Section IV

Unusual odor	Battery failure, dielectric breakdown, overload, infestation	Medium to High	Arc flash, chemical fumes, fire	Isolate up-stream, evacuate and ventilate area	Troubleshoot and inspect	IH, Facility engineer, Equipment owner, fire dept.
External physical conditions, e.g. fading color (especially if outdoors), blunt trauma, broken handles, evidence of undocumented modifications, visible cracks, un-used openings	Aging, equipment not rated for environment, human error, loose parts or tools, abandonment	Low to High	arc flash, shock	Isolate up-stream	Repair and replace	Facility engineer, equipment owner
Knowledge of manufacturers recall information, and documented previous failures of a certain type or manufacturer of breaker	Inadequate design, manufacturing, history of failure	Low to High	arc flash, shock, fire	Follow manufacturer recommendations	Follow manufacturer recommendations	Contact manufacturer, Recall websites
Environmental deterioration and contaminates, e.g. snow, rain (rust), dirty, radiation, chemical	Aging, equipment not rated for environment, human error	Low to High	arc flash, shock	Isolate up-stream	Repair and replace	Facility engineer, equipment owner
Trending results from maintenance, e.g. IR scans	Aging equipment, poor design	Low	arc flash, fire	Dependent on trending report	Contact resource	Facility engineer
Using the breaker according to manufacturers instructions, e.g. applications of breakers	No products designed for application, and misuse of equipment	Medium	arc flash	Remote operation, and PPE	Re-design if possible, Engineering controls	Facility engineer, equipment manufacturer, equipment owner
Evidence of floating voltages, e.g. equipment not running quite right, loss of phase or ground, meter indicators	Loss of phase, neutral, ground, loose connection	Medium to High	arc flash, shock	Isolate up-stream	Investigate and examine equipment	Utilities, Facility engineering, equipment owner
Trip function does not work	Defective, damaged components	High	arc flash, shock	Replace	investigate and test equipment	Utilities, Facility engineering, equipment owner