FESHM 9121: SAFETY-RELATED ELECTRICAL MAINTENANCE

Revision History

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David Mertz	Initial release Chapter 9121	July 2020

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1.0 INTRODUCTION AND SCOPE

Work procedures intended to allow personnel to work safely on electrical equipment that has not been proven to be de-energized, including testing equipment to verify that de-energization was successfully performed (zero voltage verification, or ZVV), are based on an expectation that fuses and circuit breakers will interrupt fault currents in accordance with manufacturers specifications. Deterioration from age, environment, and conditions of use can alter the response of fuses and circuit breakers to fault conditions. The deterioration of fuses is far less likely to produce conditions that increase hazards for workers than the deterioration of circuit breakers. This chapter focuses on preventative maintenance for circuit breakers to ensure that the hazards present in electrical systems that have not been proven to be de-energized are accurately assessed.

This chapter applies to all electrical systems at the Fermilab site and in its leased spaces. Nearly all of the equipment covered is facility power distribution equipment as covered by FESHM Chapter 9120. There may also be places where personnel exposure to arc flash energy is limited by, and electrical hazard PPE is selected based on, fuses or circuit breakers contained within utilization equipment. In such cases this chapter applies to that utilization equipment as well.

While this chapter does address a limited scope of electrical equipment maintenance that may also result in improved electrical system reliability, the purpose of this chapter is personnel safety. It is not intended to guide or specify overall electrical system maintenance. Compliance with chapter alone will not fully address electrical system reliability concerns.

2.0 DEFINITIONS

Arc-Flash Circuit Breaker (AFB) – An AFB is circuit breaker that limits the duration of a fault event to a piece of equipment that may reasonably be expected to require servicing or maintenance. Where an arc-flash study has been done, these are the circuit breakers that are identified as the primary overcurrent device that acts to limit the duration of an arc-flash. Where an arc-flash study has not been performed, all circuit breakers that supply a piece of equipment that can reasonably be expected to be accessed for servicing, maintenance, or troubleshooting activities are considered to be AFBs, unless exempted as a Non-Arc-Flash Breaker. Note that these activities do not have to be electrical in nature.

Circuit Breaker – An electromechanical device for interrupting a circuit. It consists of two parts, a switch to open the circuit, and one or more relays to cause the switch to automatically open under overload or fault conditions, or only under fault conditions. These parts are most often combined in a single assembly or may be separate units.

Cycling – Mechanical operation, either using manual force or an electric actuator, to move the circuit breaker switch between the open and closed positions.

Direct Injection – A circuit breaker testing procedure which passes current through the normal phase conducting paths of the circuit breaker. Direct injection confirms that the entire protective mechanism from current sensing to circuit interruption works as intended.

Molded Case Circuit Breaker (MCCB)- A circuit breaker certified to UL 489, typically consisting of both current sensing and interrupting equipment in a single case that is not designed to be serviced or permits only limited servicing. (An Insulated Case Circuit Breaker is an industry designation for a type of MCCB. The distinguishing characteristic is an ICCB has a two step process to close the circuit breaker. It is certified to the same standards as an MCCB and is included as an MCCB for this purpose of this chapter.)

Non-Arc-Flash Breaker (NAFB) – A circuit breaker that meets one of the exemption criteria below:

1. For systems under 600 volts nominal, any one or two pole MCCB rated 60 amperes or less

2. For systems under 250 volts nominal, any three pole MCCB rated 60 amperes or less that serves a branch circuit dedicated to a single receptacle or piece of equipment

3. For systems under 600 volts, a MCCB that is in series (both always carry the same current under normal and fault conditions) with another circuit breaker(s) that is not slower to clear a fault. If two series MCCB are equally fast to clear a fault, this chapter designates the upstream MCCB as the AFB and the downstream MCCB(s) as NAFBs

Opened and Closed – Because this has been misunderstood by those without electrical technical knowledge, "Opened" is defined as a switch or circuit breaker in a non-conducting position, and "Closed" is defined as a switch or circuit breaker in a conducting position. These terms are used this way because they describe the condition of the circuit in which the switch or circuit breaker is located. This definition extends to "open," "opening," "close," and "closing" as well.

Power Circuit Breaker (PCB) – A circuit breaker which operates above 600 volts nominal, or which operates at 600 volts or less that is certified to UL 1066. PCBs are located in switchgear or custom enclosures and typically have extensive provisions for servicing.

Push-to-Test (PTT) – A mechanical control on some circuit breakers that uses the mechanical trip linkage between the current sensing trip unit and the switch mechanism to open the circuit breaker.

Secondary Injection – A circuit breaker testing procedure which passes current through the conducting paths of the circuit breaker normally driven by the current transformers (CTs). Secondary injection confirms that the entire protective mechanism, except for the CTs, works as intended.

Thermography – Infrared imaging used in electrical maintenance to identify components that are operating at abnormally high temperatures, which is indicative of deficient equipment or connections. Because heat rapidly dissipates when equipment is de-energized, the best thermography results are obtained while equipment is energized and operating.

3.0 RESPONSIBILITIES

3.1 Chief Operating Officer

Determine if deferring safety-related electrical maintenance more than one year beyond the not-to-exceed interval is permitted.

3.2 Division, Section, or Project (D/S/P) Heads

Ensuring that maintenance of electrical equipment in facilities for which they have responsibility is performed and documented, including access to equipment, accommodating adequate outages, and providing personnel and equipment. Ensuring adequate staffing of laboratory personnel or subcontract workers with the requisite training and experience that are available to perform the safety-related maintenance work.

Determine if deferring safety-related electrical maintenance more than four months beyond the not-to-exceed interval is permitted.

Determine if deferring correction of deficient conditions that affect electrical safety are acceptable risks, based on written risk assessments.

3.3 Electrical AHJ

Develops and maintains the safety-related electrical maintenance program in conformance with requirements and effectiveness in implementation.

3.4 Electrical Coordinators

Develop and maintain a list of AFBs in the facilities for which they are responsible and record when and what servicing is performed on them. These duties may be integrated into other documents or systems, such as identifying AFBs on single line diagrams and tracking servicing on a maintenance management system. As Fermilab transitions to centralized maintenance program, this responsibility may be assigned to a role identified by the centralized maintenance program.

4.0 PROGRAM DESCRIPTION

Adequate maintenance of electrical distribution equipment has multiple benefits, among them improved system reliability, reduction in unscheduled outages, and lower overall long-term mission costs. This chapter only addresses the maintenance needed to ensure that the incident energy and arc-flash boundary, whether from electrical system modeling calculations or tables for specific types of equipment and tasks, are sufficient to protect personnel. A more rigorous electrical maintenance program can meet the goals of this chapter and achieve further objectives as well.

Two values determine the amount of energy delivered into an arc-flash event and the location of the flash protection boundary, which are the magnitude of the fault current and the time that elapses between the onset of the event and when the first fuses or circuit breaker upstream of the fault interrupt the current. Maintenance of electrical equipment does not have a significant effect on the magnitude of the fault current. With the exception of gross degradation of a current-limiting fuse body to the point that it may fail to contain the arc suppressant, degradation of fuses will not increase the arc duration. Circuit breakers, however, use mechanical components and linkages to clear faults, and sticking, seizing, and failures of these mechanical components may increase the fault clearing time. This program therefore addresses primarily circuit breaker preventative maintenance.

Failure of fuses or circuit breakers to pass inspections and tests shall result in the generation of work orders to correct the deficient condition(s). The failed overcurrent protective device must be replaced or repaired prior to work being performed on equipment that is protected by it. Where a decision to defer correction of a deficient condition is made, a written risk assessment, as described in FESHM Chapter 12030, must be performed and be accepted by the D/S/P Head.

4.1 Fuses

When electrical enclosures with fuses inside are opened for other work, the fuses should be given a quick visual inspection for discoloration due to overheating, rust or corrosion on barrel ends or blades, and condition of the insulating portion of the barrel and label integrity. If an enclosure or other components in the enclosure exhibit signs of overheating, corrosion, or water damage, the fuses should be inspected, and replaced if damaged. A required fuse visual inspection interval is not specified. As a guide, an interval of not more than 10 years is recommended for fuses in a benign environment. For those exposed to outdoor, corrosive, or high temperature conditions, or that have exhibited degradation in the past, the recommended interval is not more than 5 years.

4.2 Circuit breakers

Similar to fuses, when electrical enclosures with circuit breakers are opened for other work, the circuit breakers should be given a quick visual inspection.

4.2.1. Circuit breakers with manufacturer's preventative maintenance directions available

At a minimum, Fermilab shall follow the directions of the circuit breaker manufacturer for preventative maintenance activities and schedules. The electrical AHJ shall approve any tasks recommended by the manufacturer or reduction in the frequencies of tests or inspections, other than as permitted in 4.7 below.

4.2.2. Circuit breakers without manufacturer's preventative maintenance directions available

For equipment which the manufacturer's preventative maintenance directions cannot be located, the following schedule shall be followed. The not-to-exceed interval should only be used for circuit breakers which are less than 40 years old, operating in a benign environment, and for which no problems with circuit breakers of the same model or manufacturer and frame size equipment have been identified. See section 4.9 for a description of maintenance tasks.

	Arc-flash Circuit Breaker (AFB)		Non-Arc-flash Circuit Breaker	
Maintenance Task	Recommended Interval	Not-to-Exceed Interval	Recommended Interval	Not-to-Exceed Interval
Visual Inspection and Thermal Check	When enclosures are accessed for other service	Not Specified	When enclosures are accessed for other service	Not Specified
Mechanical Cycling and Visual Inspection	2 Years	4 Years	2 Years	6 Years
Cleaning & Tightening	4 Years	6 Years	4 Years	6 Years
Electrical Testing*	3 to 5 Years	6 Years	Not Specified	Not Specified
Thermography**	1 Year	1 Year	1 Year	1 Year

* Not applicable to Molded Case Circuit Breakers (MCCBs) or Insulated Case Circuit Breakers (ICCBs).

** See section 4.9.5

4.2.3. Secondary-side circuit breakers in yard (Compad) transformers

Due to the importance of these circuit breakers for limiting arc-flash durations in Fermilab facilities and their exposure to outdoor conditions, these circuit breakers shall receive safety-related maintenance at the minimum of the recommended intervals for arc-flash circuit breakers in the table in section 4.2.2.

4.3 Inspection documentation and archive

Records of safety-related electrical maintenance are preferably maintained in a Computerized Maintenance Management System (CMMS), which will also help drive scheduling of the inspections as well. In the absence of a CMMS, the building manager is responsible for recording maintenance performed on each AFB in a manner of her or his choosing. This record is to be archived in a separate Fermilab location from the primary record to ensure a loss of either copy will not cause a loss of data.

4.4 Inspected equipment labeling

In addition to the inspection documentation and archive, it is recommended but not required that equipment that has successfully passed inspections and tests be labeled noting the successful tests and inspections. At a minimum, the label should list the tests performed, the date(s) on which they were performed, and if performed by a subcontractor, the name of the subcontractor firm. The label may also include the Fermi ID number of the lead person performing the tasks, and the CMMS task identification number.

4.5 Disposition of failed equipment

Action shall be taken to address any additional or changed hazards due to its failure. Most equipment will fail into an inoperative state. Equipment that fails in an operative state, such as a circuit breaker that fails to trip, or has one or more contacts that fail to open, should be taken out of service and locked out using LOTO or configuration control as required by FESHM 2100. Configuration control tags placed on failed equipment should specifically describe the equipment that has failed and the type of failure.

If operational necessity would have the failed equipment remain in service, a written risk assessment must be completed. If continued use of the failed equipment results in increased hazards, the risk assessment must be approved by the D/S/P Head to permit its continued use, and the increased hazards documented so that anyone working on equipment with increased hazards will be informed of those changed hazards while planning such work.

4.6 Equipment that is salvaged, excessed, abandoned in place, or removed

Equipment that is salvaged, excessed, abandoned in place, or removed is no longer required to receive safety-related maintenance. Labels on the equipment indicating previous inspections may be left in place.

4.7 Equipment retrieved from salvage, excess, or abandonment

Equipment retrieved from salvage, excess, or abandonment shall be visually inspected prior to re-energization. If deficiencies are found during the inspection, including mechanical damage, corrosion, water damage, or infestation, all damage shall be corrected and safety-related maintenance performed prior to energization. If no deficiencies are found, safety-related maintenance beyond its repetition interval shall be performed prior to energization; safety-related maintenance that is still within its repetition interval may resume following the intervals from its prior use.

4.8 Extension of testing and inspection intervals to accommodate operations

Operation schedules for the laboratory's accelerator, experiments, special events, or force majeure conditions are permitted to postpone safety-related maintenance activities. For postponements less than 4 months, the building manager and electrical coordinator for each area served by the equipment affected by the activity shall be notified. Postponements of over 4 months require that the D/S/P head(s) be notified and give approval. Postponements of over 12 months require that the Chief Operation Officer be notified and give approval.

4.9 Types of safety-related maintenance tasks

4.9.1. Visual Inspection

A visual inspection observes the condition of fuses or circuit breakers for signs of deterioration and damage. Most deterioration and damage to fuses and fuseholders will increase resistance-caused heating, causing the fuses to clear prematurely. Damage to the body of a current-limiting fuse that allows loss of the arc-extinguishing media found within it can extend clearing times. For the purposes of this chapter, inspection for this type of fuse deterioration or damage is specified.

Visual inspection of circuit breakers observes for discoloration due to overheating, rust or corrosion, condition of the insulating cases, leaking of fluids, and an auditory observation for any abnormal noise the breakers might make.

The importance of visual inspection of the circuit breaker case or frame is often unrecognized. The case or frame provides the structure against which the mechanical parts operate, especially the springs used to separate the main contacts against the magnetic forces from a fault current that hold the contacts closed. A deficient case condition can result in the breaker being unable to open to clear a fault current.

4.9.2. Thermal Check

Thermal checks are a less rigorous, and less precise, thermal inspection than thermography. Thermal checks are performed on switchboards, panelboards and disconnect switches with circuit breakers. The covers are kept in place, while doors (if any) that only expose dead-front components, such as the operating handle side of circuit breakers, are opened. The temperatures of the enclosure box, cover, and exposed dead-front components may be checked in one of three ways: a non-contact infrared temperature gauge or imager, a contact thermocouple, or fingertip touch, in descending order of preference. Abnormally warm components are noted and reported to generate orders for corrective work.

4.9.3. Mechanical cycling

Basic mechanical cycling consists of mechanically moving a manually operated circuit breaker's handle from the on position to the off position and back again to the on position. The same process is followed for a motor- or solenoid-operated breaker using the electrical controls. This test is considered successful when the operator moves smoothly, and for manually-operated circuit breakers, there is a clear "over the center" action that prevents holding the circuit breaker contacts in an intermediate position.

If a circuit breaker has one or more "push to test" buttons, these buttons also engage the sensor trip mechanism in addition to the switch itself. If one or more of these buttons are present, each button shall be pressed to verify that it will initiate a trip.

4.9.4. Cleaning & Tightening

MCCBs do not themselves require any cleaning, but the interior of the enclosure in which they are mounted should be cleaned of dirt and debris. Solvent sprays should not be used as they can compromise the lubricants inside the MCCBs. Likewise, compressed air or other gases should not be used to avoid the injection of dirt and debris into the MCCB interiors. Dry or sparingly dampened cloths or fiber dusters are recommended.

Power circuit breakers should be serviced, cleaned, and lubricated in accordance with manufacturer instructions, or when instructions are unavailable, in accordance with industry standard practice. Where cleaning finds evidence of water ingress or infestations of insects or small animals, the path of ingress should be determined and the blocked if reasonably possible. Where heat build-up is likely or in outdoor locations, ventilation paths should be cleared of debris and screens or other features to prevent ingress of critters is not compromised. Cleaning shall be coordinated with the thermographic inspection as described in section 4.8.4.

Tight connections between conductors and circuit parts minimize resistive heating which can damage components and cause premature clearing of fuses, circuit breakers, and overload relays. The tightness of bolts and other fasteners holding conductors and circuit parts of power circuits in contact shall be checked using a torque-measuring tool at 90% of the values specified by the manufacturer or as found in UL 486A-B, which are also found in Informative Annex I of the 2017 NEC. Applying torque to a power circuit connection fastener without a torque-measuring tool is no longer permitted.

Tightness checks on older equipment, especially legacy equipment, may have been previously performed without the aid of torque measuring equipment. This has been found to produce over-tightened connections, which can displace conductor strands and damage threaded components. Where torque readings meet or exceed 90% of the values specified by the manufacturer or as found in UL 486A-B, or a torque indicating tool is unavailable, connections shall be checked for physical looseness by attempting to move the cable or connection. Connections that exhibit looseness shall be repaired or replaced.

Where contact between components relies on springs or deflection of contact parts, such as between MCC cubicles and buswork and between light-duty circuit breakers and panelboards, such connections shall be inspected for corrosion, heat discoloration, or other indicators of damage or deterioration. For certain equipment, this may require some disassembly.

Loose connections that carry significant load currents, whether bolted or spring tension, may exhibit indicators of overheating, such as metal discoloration, melting or baking of insulating components, and acrid odors. Even in the absence of demonstrably loose connections, the presence of these indicators should prompt corrective actions.

4.9.5. Thermography

Thermographic inspection is a process that views the exposed portions of circuit breakers to identify any that exhibit anomalously high temperatures. Thermographic inspection is preferably done while energized and under load and with covers removed to expose connections and other energized parts if infrared-transparent viewing ports are unavailable. If viewing ports are unavailable, this does present potential shock and arc-flash hazards to the workers. Management shall determine in advance how best compromise between risks to employees and data quality.

Thermography for a particular facility are preferably scheduled during different seasons to capture different operating modes. A poor connection on an air conditioning circuit is unlikely to be found if the facility receives thermographic inspections only in February.

Thermographic equipment is available in a range of quality and capability. For electrical work, equipment able to provide quantitative temperature readings for specific items in the field of view is preferred. Thermographic cameras that show only relative temperatures make it impossible to tell just from the image if the range between blue and red is 5 degrees or 500 degrees. If only a relative temperature image is available, it is helpful to augment that with a contact thermocouple (rated for the highest exposed voltage) that can quantify the temperature at points of concern.

Equipment with infrared-transparent viewing ports shall receive thermographic inspections at the intervals recommended by the manufacturer or as specified in the table in section 4.2.2. Images or temperature readings of specific components shall be recorded and compared with images or records from prior inspections. Thermography of equipment without viewing ports is at the discretion of the building manager and electrical coordinator, considering the criticality of the equipment, the maintenance history of the equipment and similar equipment, and the risks that opening energized equipment presents to personnel performing the work.

4.9.6. Electrical Testing

Direct-injection testing provides the most complete test of a circuit breaker's ability to detect and interrupt fault currents. It requires a testing machine that produces high amperage AC currents that are placed through each phase of a circuit breaker's main contacts. Typical test currents are 3 times and 10 to 20 times a circuit breaker's rated current. For the purposes of safety-related maintenance, only the fault current (10 to 20 times rated) is of significance, since 3 times the full load current is unlikely to sustain an arc. However, once the equipment is set up it requires little extra time to obtain the 3-times data as well.

Secondary-injection testing provides nearly as thorough testing as direct-injection testing and can be considered as thorough where the relay protection includes ground-fault detection, which will identify CT defects. Test currents values should be selected to verify each relay (or relay function enabled in an electronic multi-function relay) operates as specified.

5.0 REFERENCES & RESOURCES

DOE HDBK-1092-2013, Electrical Safety Handbook

NFPA 70E "Standard for Electrical Safety in the Workplace" 2015 Edition Chapter 2

NFPA 70B "Recommended Practice for Electrical Equipment Maintenance" 2016 Edition

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

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"

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

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