Protective Devices Maintenance as it Applies to the Arc Flash Hazard

By Dennis K. Neitzel, CPE

1. Introduction

Electrical preventive maintenance and testing is not only important for the reliability and integrity of electrical distribution systems, but it is also important for the safety and protection of people. However, preventive maintenance, specifically with regard to overcurrent protective devices, is often overlooked, performed infrequently, or is performed improperly. This chapter will focus on:

1. Guides for electrical equipment and overcurrent protective device maintenance and testing.
    a. Molded-Case Circuit Breakers
    b. Low-Voltage Power Circuit Breakers
    c. Medium-Voltage Circuit Breakers
    d. Protective Relays
2. Analysis of various electrical equipment installations and the maintenance program for overcurrent protective devices.
3. Failure statistics for overcurrent protective devices.
4. The reliability and integrity of overcurrent protective devices.
5. Arc-flash hazards with respect to preventive maintenance of overcurrent protective devices.

2. Maintenance and Testing

The *National Electrical Code* (NEC) states "Overcurrent protection for conductors and equipment is provided to open the circuit if the current reaches a value that will cause an excessive or dangerous temperature in conductors or conductor insulation." With regard to circuit breakers, the only way to accomplish this is through proper maintenance and testing of these devices. There are several steps that must be taken in order to establish an effective maintenance program.

The first step in properly maintaining electrical equipment and overcurrent protective devices is to understand the requirements and recommendations for electrical equipment maintenance from various sources. Examples of sources include, but are not limited to, the Manufacturer's instructions, NFPA 70B, IEEE Standard 902 (Yellow Book), NEMA AB-4, NETA Specs, and NFPA 70E.

The second step in performing maintenance and testing is to provide adequate training and qualification for employees. NFPA 70E, Section 205.1 states: "Employees who perform maintenance on electrical equipment and installations shall be qualified persons…and shall be trained in and familiar with the specific maintenance procedures and tests required."

The National Electrical Code (NEC) defines a qualified person as "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved." It is vitally important that employees be properly trained and qualified to maintain electrical equipment in order to increase the equipment and system reliability, as well as the employee's safety.

The third step is to have a written, effective Electrical Preventive Maintenance (EPM) program. NFPA 70B makes several very clear statements about an effective EPM program. These statements include [2]:

1. Deterioration of electrical equipment is a normal process, but that does not mean that equipment failure is eminent. If unchecked, deterioration will eventually cause equipment malfunction or complete failure. There are several factors that can accelerate the deterioration process, such as the environment, overload conditions, or severe duty cycles. An effective EPM program will help to identify and correct any or all of these conditions.

2. In addition to the deterioration problem, there are several other potential causes of equipment failure. These causes include, but are not limited to, load changes, circuit alterations, improper or misadjusted settings of protective devices, improperly selected protective devices, and changing voltage conditions.

3. With the absence of an effective EPM program, management assumes a greater responsibility for and an increased risk of a serious electrical failure, as well as the consequences.

4. An effective EPM program, that is administered properly, will reduce costly shutdowns and outages, reduce accidents, and save lives. These programs will identify impending troubles and apply solutions to correct them, before they become major problems that require time consuming and more expensive solutions.

IEEE Standard 902 states: "In planning an electrical preventive maintenance (EPM) program, consideration must be given to the costs of safety, the costs associated with direct losses due to equipment damage, and the indirect costs associated with downtime or lost or inefficient production." [4]

The forth step is that all maintenance and testing of electrical protective devices must be accomplished in accordance with the manufacturer's instructions. NFPA 70E adds to this by stating: "Protective devices shall be maintained to adequately withstand or interrupt available fault current." It goes on to state, "Circuit breakers that interrupt faults approaching their ratings shall be inspected and tested in accordance with the manufacturers' instructions." In the absence of the manufacturer's instructions, the NETA *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems* is an excellent source of information for performing the required maintenance and testing of these devices. However, the manufacturer's time-current curves would also be required in order to properly test each protective device. [3]

The fifth and final step that will be addressed in this chapter is the arc-flash hazard considerations. One of the key components of the Flash Hazard Analysis, which is required by NFPA 70E, is the clearing time of the protective devices, primarily circuit breakers, fuses, and protective relays. Fuses, although they are protective devices, do not have operating mechanisms that would require periodic maintenance; therefore, this chapter will not address them. The primary focus of this chapter will be the maintenance issues for circuit breakers and protective relays as noted previously.

This chapter will address some of the issues concerning proper maintenance and testing of these protective devices, according to the manufacturer's instructions. It will also address how protective device maintenance relates to the electrical arc/flash hazard.

2.1 Molded-Case Circuit Breakers

Generally, maintenance on molded-case circuit breakers is limited to proper mechanical mounting, electrical connections, and periodic manual operation. Most lighting, appliance, and power panel circuit breakers have riveted frames and are not designed to be opened for internal inspection or maintenance. All other molded-case circuit breakers that are UL approved are factory-sealed to prevent access to the calibrated elements. An unbroken seal indicates that the mechanism has not been tampered with and that it should function as specified by UL. A broken seal voids the UL listing and the manufacturers' warranty of the device. In this case, the integrity of the device would be questionable. The only exception to this would be a seal being broken by a manufacturer's authorized facility.

Molded-case circuit breakers receive extensive testing and calibration at the manufacturers' plants. These tests are performed in accordance with UL 489, *Standard for Safety, Molded-Case Circuit Breakers, Molded-Case Switches and Circuit Breaker Enclosures*. Molded-case circuit breakers, other than the riveted frame types, are permitted to be reconditioned and returned to the manufacturer's original condition. In order to conform to the manufacturer's original design, circuit breakers must be reconditioned according to recognized standards. The Professional Electrical Apparatus Recyclers League (PEARL) companies follow rigid standards to recondition low-voltage industrial and commercial molded-case circuit breakers. It is highly recommended that only authorized professionals recondition molded-case circuit breakers.

Circuit breakers installed in a system are often forgotten. Even though the breakers have been sitting in place supplying power to a circuit for years, there are several things that can go wrong. The circuit breaker can fail to open due to a burned out trip coil or because the mechanism is frozen due to dirt, dried lubricant, or corrosion. The overcurrent device can fail due to inactivity or a burned out electronic component. Many problems can occur when proper maintenance is not performed and the breaker fails to open under fault conditions. This combination of events can result in fires, damage to equipment or injuries to personnel.

All too often, a circuit breaker fails because the minimum maintenance (as specified by the manufacturer) was not performed or was performed improperly. Small things, like failing to properly clean and/or lubricate a circuit breaker, can lead to operational failure or complete destruction due to overheating of the internal components. Common sense, as well as manufacturers' literature, must be used when maintaining circuit breakers. Most manufacturers [1], as well as NFPA 70B [2], recommend that if a molded-case circuit breaker has not been operated, opened or closed, either manually or by automatic means, within as little as six months time, it should be removed from service and manually exercised several times. This manual exercise helps to keep the contacts clean due to their wiping action and ensures that the operating mechanism moves freely. This exercise however does not operate the mechanical linkages in the tripping mechanism (Figure 1). The only way to properly exercise the entire breaker operating and tripping mechanisms is to remove the breaker from service and test the overcurrent and short-circuit tripping capabilities. A stiff or sticky mechanism can cause an unintentional time delay in its operation under fault conditions. This could dramatically increase the arc/flash incident energy level to a value in excess of the rating of personal protective equipment. There will be more on incident energy later in this chapter.

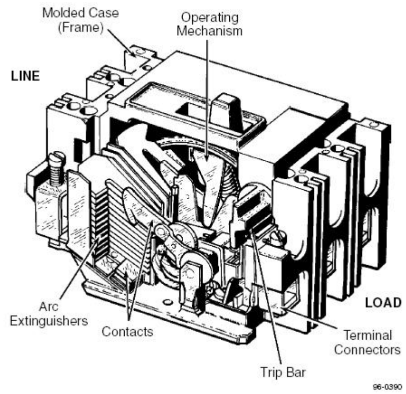

Figure 1
Principle Components of a
Molded-Case Circuit Breaker

Another consideration is addressed by OSHA in 29 CFR 1910.334(b)(2) which states:

*"**Reclosing circuits after protective device operation**. After a circuit is deenergized by a circuit protective device, the circuit may NOT be manually reenergized until it has been determined that the equipment and circuit can be safely reenergized. The repetitive manual reclosing of circuit breakers or reenergizing circuits through replaced fuses is prohibited.*

***NOTE:** When it can be determined from the design of the circuit and the overcurrent devices involved that the automatic operation of a device was caused by an overload rather than a fault condition, no examination of the circuit or connected equipment is needed before the circuit is reenergized."* [9]

The safety of the employee, manually operating the circuit breaker, is at risk if the short circuit condition still exists when reclosing the breaker. OSHA no longer allows the past practice of resetting circuit breaker one, two, or three times before investigating the cause of the trip. This previous practice has caused numerous burn injuries that resulted from the explosion of electrical equipment. **BEFORE** resetting a circuit breaker, it, along with the circuit and equipment, must be tested and inspected, by a qualified person, to ensure a short circuit condition does not exist and that it is safe to reset.

Any time a circuit breaker has operated and the reason is unknown, the breaker must be inspected. Melted arc chutes will not interrupt fault currents. If the breaker cannot interrupt a second fault, it will fail and may destroy its enclosure and create a hazard for anyone working near the equipment.

To further emphasize this point the following quote from the National Equipment Manufacturer's Association (NEMA) is provided:

"After a high level fault has occurred in equipment that is properly rated and installed, it is not always clear to investigating electricians what damage has occurred inside

encased equipment. The circuit breaker may well appear virtually clean while its internal condition is unknown. For such situations, the NEMA AB4 'Guidelines for Inspection and Preventive Maintenance of MCCBs Used in Commercial and Industrial Applications' may be of help. Circuit breakers unsuitable for continued service may be identified by simple inspection under these guidelines. Testing outlined in the document is another and more definite step that will help to identify circuit breakers that are not suitable for continued service.

After the occurrence of a short circuit, it is important that the cause be investigated and repaired and that the condition of the installed equipment be investigated. A circuit breaker may require replacement just as any other switching device, wiring or electrical equipment in the circuit that has been exposed to a short circuit. Questionable circuit breakers must be replaced for continued, dependable circuit protection." [10]

The condition of the circuit breaker must be known to ensure that it functions properly and safely before it is put it back into service.

2.2 Low-Voltage Power Circuit Breakers

Low-voltage power circuit breakers are manufactured under a high degree of quality control, of the best materials available, and with a high degree of tooling for operational accuracy. Manufacturer's tests show these circuit breakers to have durability beyond the minimum standards requirements. All of these factors give these circuit breakers a very high reliability rating. However, because of the varying application conditions and the dependence placed upon them for protection of electrical systems and equipment as well as the assurance of service continuity, inspections and maintenance checks must be made on a regular basis. Several studies have shown that low-voltage power circuit breakers, which were not maintained within a 5-year period, have an average of a 50% failure rate.

Maintenance of these breakers will generally consist of keeping them clean and properly lubricated. The frequency of maintenance will depend to some extent on the cleanliness of the surrounding area. If there were very much dust, lint, moisture, or other foreign matter present then obviously more frequent maintenance would be required.

Industry standards for, as well as manufacturers of, low-voltage power circuit breakers recommend a general inspection and lubrication after a specified number of operations or at least once per year, whichever comes first. Some manufacturers also recommend this same inspection and maintenance be performed after the first six months of service regardless of the number of operations. If the breaker remains open or closed for a long period of time, it is recommended that arrangements be made to open and close the breaker several times in succession, preferably under load conditions. Environmental conditions play a major role in the scheduling of inspections and maintenance. If the initial inspection indicates that maintenance is not required at that time, the period may be extended to a more economical point. However, more frequent inspections and maintenance may be required if severe load conditions exist or if an inspection reveals heavy accumulations of dirt, moisture, or other foreign matter that might cause mechanical, insulation, or electrical failure. Mechanical failure would include an unintentional time delay in the circuit breakers tripping operation due to dry, dirty or corroded pivot points or by hardened or sticky lubricant in the moving parts of the operating mechanism. The manufacturer's instructions must be followed in order to minimize the risk of any unintentional time delay.

Figure 2 provides an illustration of the numerous points where lubrication would be required and where dirt, moisture, corrosion or other foreign matter could accumulate causing a time delay in, or complete failure of, the circuit breaker operation.

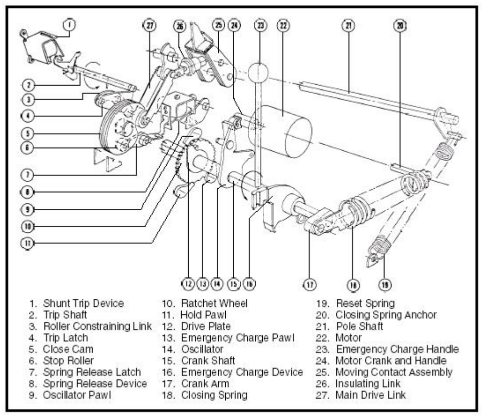

Figure 2
Power-Operated Mechanism of a Cutler/Hammer "DS" Circuit Breaker

2.3 Medium-Voltage Power Circuit Breakers

Most of the inspection and maintenance requirements for low-voltage power circuit breakers also apply to medium-voltage power circuit breakers. Manufacturers recommend that these breakers be removed from service and inspected at least once per year. They also state that the number and severity of interruptions may indicate the need for more frequent maintenance checks. Always follow the manufacturer's instructions because every breaker is different. Figures 3 and 4 illustrate two types of operating mechanisms for medium-voltage power circuit breakers. These mechanisms are typical of the types used for air, vacuum, oil and SF_6 circuit breakers. As can be seen in these figures, there are many points that would require cleaning and lubrication in order to function properly.

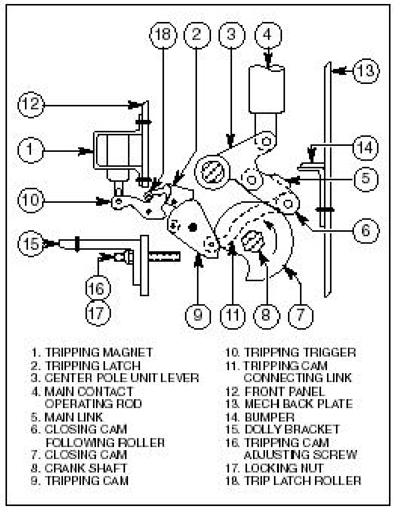

Figure 3
Operating Mechanism
Air Circuit Breaker

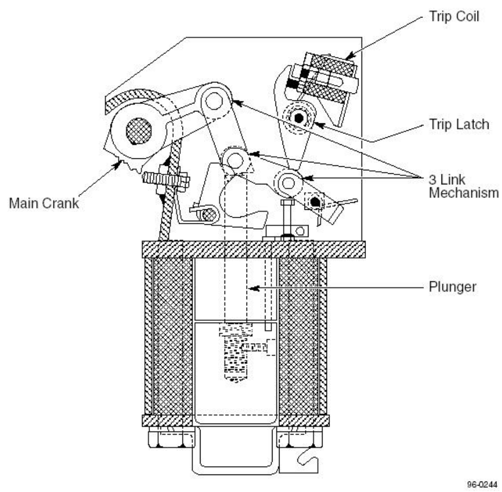

Figure 4
Solenoid-Operated
Mechanism

2.4 Protective Relays

Relays must continuously monitor complex power circuit conditions, such as current and voltage magnitudes, phase angle relationships, direction of power flow, and frequency. When an intolerable circuit condition, such as a short circuit (or fault) is detected, the relay responds and closes its contacts, and the abnormal portion of the circuit is deenergized via the circuit breaker. The ultimate goal of protective relaying is to disconnect a faulty system element as quickly as possible. Sensitivity and selectivity are essential to ensure that the proper circuit breakers are tripped at the proper speed to clear the fault, minimize damage to equipment, and to reduce the hazards to personnel.

A clear understanding of the possible causes of primary relaying failure is necessary for a better appreciation of the practices involved in backup relaying. One of several things may happen to prevent primary relaying from disconnecting a power system fault:

1. Current or voltage supplies to the relays are incorrect.
2. DC tripping voltage supply is low or absent.
3. Protective relay malfunctions.
4. Tripping circuit or breaker mechanism hangs up.

There are two groups of protective relays: *primary* and *backup*. Primary relaying is the so-called first line of defense, and backup relaying is sometimes considered to be a subordinate type of protection. Many companies, however, prefer to supply two “lines” of relaying and do not think of them as primary and backup. Figure 5 illustrates primary relaying. Circuit breakers are found in the connections to each power system element. This provision makes it possible to disconnect only the faulty part of the system. Each element of the system has *zones of protection* surrounding the element. A fault within the given zone should cause the tripping of all circuit breakers within that zone and no tripping of breakers outside that zone. Adjacent zones of protection can overlap, and in fact, this practice is preferred, because for failures anywhere in the zone, except in the overlap region, the minimum numbers of circuit breakers are tripped.

In addition, if faults occur in the overlap region, several breakers respond and isolate the sections from the power system. Backup relaying is generally used only for protection against short circuits. Since most power system failures are caused by short circuits, short circuit primary relaying is called on more often than most other types. Therefore, short circuit primary relaying is more likely to fail.

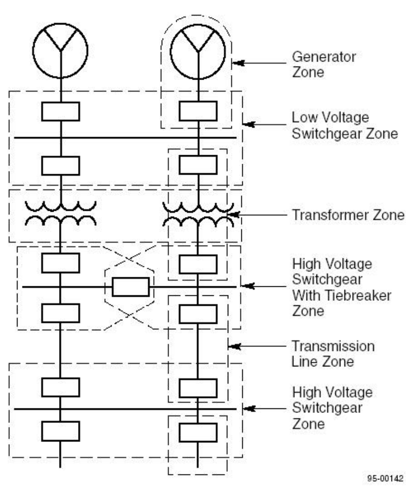

FIGURE 5
Primary Relaying for an Electric Power System

Voltage and current transformers play a vital role in the power protection scheme. These transformers are used to isolate and protect both people and devices from high voltage, and to allow current carrying devices such as relays, meters, and other instruments to have a reasonable amount of insulation. It should be clearly understood that the performance of a relay is only as good as the voltage and current transformers connected to it. A basic understanding of the operating characteristics, application, and function of instrument transformers is essential to the certified relay technician. [5][6][7]

Some overcurrent relays are equipped with an instantaneous overcurrent unit, which operates when the current reaches its minimum pickup point (see Figure 6). An instantaneous unit is a relay having no intentional time delay. Should an overcurrent of sufficient magnitude be applied to the relay, both the induction disc and the instantaneous unit will operate. However, the instantaneous unit will trip the circuit breaker, since it has no intentional time delay. In Figure 6, the operating coil is in the AC portion of the relay in series with the induction coil. The contacts are directly across the trip circuit and the spiral spring is never involved in the tripping action.

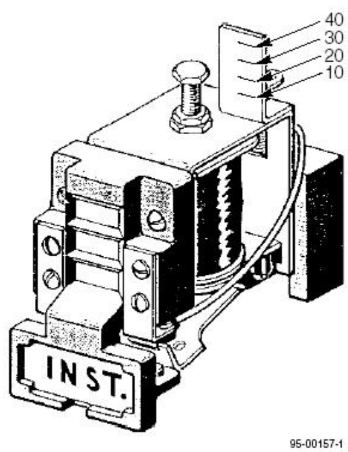

FIGURE 6
Instantaneous Trip Unit

The instantaneous trip unit is a small, AC-operated clapper device. A magnetic armature, to which leaf-spring-mounted contacts are attached, is attracted to the magnetic core upon energization. When the instantaneous unit closes, the moving contacts bridge two stationary contacts and complete the trip circuit. The core screw, accessible from the top of the unit, provides the adjustable pickup range. Newer designs also feature tapped coils to allow even greater ranges of adjustment.

The instantaneous unit, like the one shown in Figure 6, is equipped with an indicator target. This indication shows that the relay has operated. It is important to know which relay has operated, and no relay target should be reset without the supervisor's knowledge and permission.

As can be seen, several things can go wrong that would prevent the instantaneous unit from operating properly. These things include an open or shunted current transformer, open coil, or dirty contacts. Protective relays, like circuit breakers, require periodic inspection, maintenance, and testing to function properly. Most manufacturers recommend that periodic inspections and maintenance be performed at intervals of one to two years. The intervals between periodic inspection and maintenance will vary depending upon environment, type of relay, and the user's experience with periodic testing.

The periodic inspections, maintenance, and testing are intended to ensure that the protective relays are functioning properly and have not deviated from the design settings. If deviations are found, the relay must be retested and serviced as described in the manufacturer's instructions.

3. Failure Statistics

Several studies on electrical equipment failures have been completed over the years by IEEE. These studies have generated failure statistics on electrical distribution system equipment and components. IEEE Std. 493 (Gold Book) "IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems" contains the information and statistics from these studies and can be used to provide failure data of electrical equipment and components such as circuit breakers. One key study that was completed and yields reliability data on circuit breakers was completed in 1974. The results of this study were based upon low- and medium-voltage power circuit breakers (drawout and fixed) as well as fixed mounted molded-case circuit breakers. The results of the study indicated [8]:

- 32% of all circuit breakers failed while in service.
- 9% of all circuit breakers failed while opening.
- 7% of all circuit breakers failed due to damage while successfully opening.
- 42% of all circuit breakers failed by opening when it should not have opened.
- 77% of fixed mounted circuit breakers (0-600V including molded case) failed while in service.
- 18% of all circuit breakers had a mechanical failure
- 28% of all circuit breakers had an electric-protective device failure.
- 23% of all circuit breakers failures were suspected to be caused by manufacturer defective component.
- 23% of all circuit breaker failures were suspected to be caused by inadequate maintenance.
- 73% of all circuit breaker failures required round-the-clock all-out efforts.

A 1996 IEEE survey was conducted on low-voltage power circuit breakers and the results concluded [8]:

- 19.4% of low-voltage power circuit breakers with electromechanical trip units had unacceptable operation.
- 10.7% of low-voltage power circuit breakers with solid-state trip units had unacceptable operation.

4. Reliability and Integrity

Reviewing the data from the IEEE studies, it can be seen that nearly 1/3 of all circuit breakers failed while in service and thus would not have been identified unless proper maintenance was performed. In addition, 16% of all circuit breakers failed or were damaged while opening. The fact that 42% of all circuit breakers failed, by opening when they should not have opened, suggests improper circuit breaker settings or a lack of selective coordination to be the problem. This type of circuit breaker failure can significantly affect plant processes and could result in a total plant shutdown.

Also of significance is that a very large percentage of fixed mounted circuit breakers, including molded-case had a very high failure rate of 77.8%. This is most likely due to the fact that maintenance of this style of device is often overlooked, but certainly is just as important.

The fact that 18% of all circuit breakers had a mechanical failure and 28% had an electrical protective device failure suggests that both the mechanical linkages, as well as the trip units, need to be maintained. Furthermore, although mechanical maintenance is important, proper testing of the trip unit is much more critical.

Also of importance, is the realization that maintenance and testing is needed because nearly ¼ of all circuit breaker failures were caused by a manufacturer's defective component and nearly another ¼ of all circuit breaker failures were due to inadequate maintenance. Thus, if proper maintenance and testing is performed, potentially 50% of the failures could be eliminated or identified before a problem occurs. But perhaps the most important issue for an end user is downtime. With regard to this concern, the study indicated 73% of all circuit breaker failures required round-the-clock all-out efforts. This could most likely be greatly reduced if preventive maintenance was performed on a regular basis.

The results from the 1996 IEEE study show that technology has improved the failure rate of low-voltage power circuit breakers and could potentially be cut by almost half, but maintenance and testing would still be needed. [8]

5. Flash Hazard Analysis

Maintenance and testing is also essential to ensure proper protection of equipment and personnel. With regard to personnel protection, NFPA 70E requires a flash hazard analysis be performed before anyone approaches exposed electrical conductors or circuit parts that have not been placed in an electrically safe work condition. In addition it requires a flash protection boundary be established. All calculations for determining the incident energy of an arc, and for establishing a flash protection boundary, require the arc clearing time. This clearing time is derived from the engineering coordination study which is based on what the protective devices are supposed to do.

If, for example, a low-voltage power circuit breaker had not been operated or maintained for several years and the lubrication had become sticky or hardened, the circuit breaker could take several additional cycles, seconds, minutes, or longer to clear a fault condition. The following are specific examples:

Two Flash Hazard Analyses will be performed using a 20,000-amp short-circuit with the worker 18 inches from the arc:

1. Based on what the system is supposed to do:
   - 0.083 second (5 cycles)
2. Due to a sticky mechanism the breaker now has an unintentional time delay:
   - 0.5 second (30 cycles)

Example #1:

E_{MB} = maximum 20 in. cubic box incident energy, cal/cm^2
D_B = distance from arc electrodes, inches (for distances 18 in. and greater)
t_A = arc duration, seconds
F = short circuit current, kA (for the range of 16 kA to 50 kA)

(1) D_A = 18 in.
(2) t_A = 0.083 second (5 cycles)
(3) F = 20kA

$$E_{MB} = 1038.7 D_B^{-1.4738}\, t_A [0.0093F^2 - 0.3453F + 5.9675]$$
$$= 1038 \times 0.0141 \times 0.083[0.0093 \times 400 - 0.3453 \times 20 + 5.9675]$$
$$= 1.4636 \times [2.7815]$$
$$= 3.5 \text{ cal/cm}^2$$

NFPA 70E-2009 130.3(B)(1) requires arc-rated FR clothing and other PPE are to be selected based on this incident energy level exposure. Therefore the FR clothing and PPE must have an arc rating of at least 3.5 cal/cm^2.

Example #2:

E_{MB} = maximum 20 in. cubic box incident energy, cal/cm^2
D_B = distance from arc electrodes, inches (for distances 18 in. and greater)
t_A = arc duration, seconds
F = short circuit current, kA (for the range of 16 kA to 50 kA)

(1) D_A = 18 in.
(2) t_A = 0.5 second (30 cycles)
(3) F = 20kA

$$E_{MB} = 1038.7D_B^{-1.4738}\, t_A\, [0.0093F^2 - 0.3453F + 5.9675]$$
$$= 1038 \times 0.0141 \times 0.5[0.0093 \times 400 - 0.3453 \times 20 + 5.9675]$$
$$= 7.3179 \times [2.7815]$$
$$= 20.\ 4\ \text{cal/cm}^2$$

NFPA 70E-2009 130.3(B)(1) requires arc-rated FR clothing and other PPE are to be selected based on this incident energy level exposure. Therefore the FR clothing and PPE must have an arc rating of at least 20.4 cal/cm^2.

If the worker is protected based on what the system is supposed to do (0.083 second or 5 cycles) and an unintentional time delay occurs (0.5 second or 30 cycles), the worker could be seriously injured or killed because he/she was under protected.

As can be seen, maintenance is extremely important to an electrical safety program. Maintenance must be performed according to the manufacturer's instructions in order to minimize the risk of having an unintentional time delay in the operation of the circuit protective devices.

Additionally, Section 110.16 of the NEC titled "Flash Protection" states: "Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment."

"FPN No. 1: NFPA 70E, *Standard for Electrical Safety in the Workplace*, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment."

Figure 7 is an illustration of the minimum label that NEC 110.16 requires.

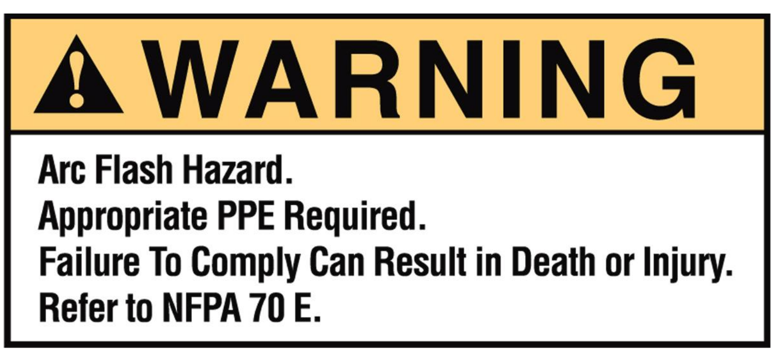

Figure 7
NEC 110.16 Required Label

Figure 8 is an illustration of a typical recommended label.

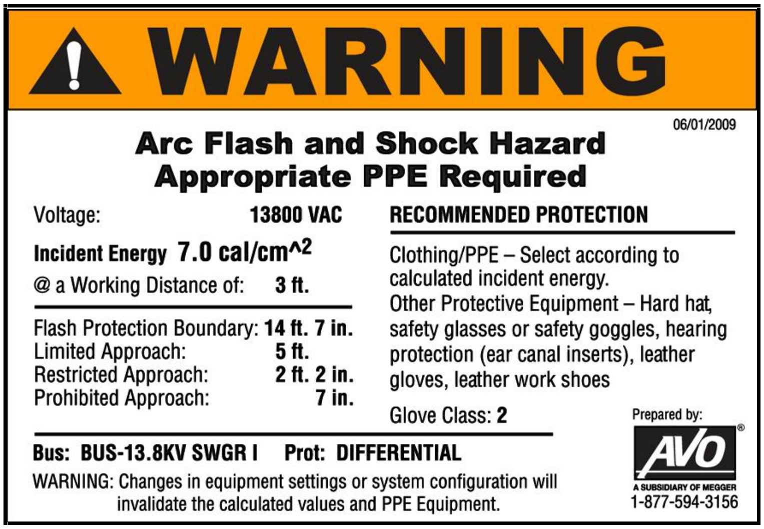

Figure 8
Recommended Label

6. Setting up a Preventive Maintenance Program

It is extremely important to properly maintain electrical protective devices as noted above. An electrical preventive maintenance program should be set up in order to reduce hazards to employees, as well as to reduce the risk of failure or malfunction of electrical systems and equipment. The information in this section is derived from NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance.* [2]

There are four basic steps that should be taken in planning and development a maintenance program. In their simplest form, they are as follows:

(1) Compile a list of all equipment and systems.
(2) Determine which equipment and systems are most critical and most important.
(3) Develop a system for tracking maintenance.
(4) Train people for the work that is required or contract for the special services.

There are several items that are necessary before starting a maintenance program, which include, but are not limited, to the following:

(1) Inspection and testing procedures for all electrical equipment
(2) Copies of previous reports
(3) Single-line diagrams
(4) Schematic diagrams
(5) Records of complete nameplate data
(6) Vendors' catalogs (Manufacturer's Instructions)

(7) Equipment maintenance forms or reports

The manufacturer's instructions will generally provide a list of the tools and other items required to adequately perform maintenance. The following is provided as a general guide:

(1) Assorted tools and equipment
(2) Lubrication greases
(3) Various types and sizes of wrenches
(4) Nonmetallic hammers and blocks to protect against injury to machined surfaces
(5) Wheel pullers
(6) Feeler gauges to function as inside- and outside diameter measuring gauges
(7) Instruments for measuring torque, tension, compression, vibration, and speed
(8) Standard and special mirrors with light sources for visual inspection
(9) Industrial-type portable blowers and vacuums having insulated nozzles for removal of dust and foreign matter
(10) Nontoxic, nonflammable cleaning solvents
(11) Clean, lint-free wiping cloths
(12) Electrical test equipment appropriate for the device

The use of safety equipment is essential and is mandatory when working on or near live electrical equipment. Some of the more important articles that should be provided are as follows:

(1) Heavy leather gloves
(2) Insulating rubber gloves, mats, blankets, and boots as required
(3) Flame Resistant (FR) shirts, pants, and jackets as required
(4) Arc-flash suits and/or face shields as required
(5) Insulated hand tools as required
(6) Electrically rated non-metallic hard hat
(7) Insulated hot-line tools with hooks to safely open isolating switches

Table 1 illustrates typical maintenance intervals for the types of circuit protective devices mentioned above, along with the approximate time to perform the recommended maintenance. More detailed information can be found in NFPA 70B, *Electrical Equipment Maintenance*, Annex H.

Table 1
Recommended Maintenance Schedule

Protective Device	Recommended Maintenance Interval	Approximate Minutes Required
Molded-Case Circuit Breaker (MCCB)	depending on application and usage	30-90 min.
Low-Voltage Circuit Breaker (LVCB)	Annual	60-90 min.
Medium-Voltage Circuit Breaker (MVCB)	Annual	60-90 min.
Simple Protective Relays	Annual	30 min.
Complex Protective Relays	Annual	90 min.

The "approximate minutes required" is based on the equipment sitting on the work bench. Additional time would be required for removing and re-installing the device.

7. Conclusion

With the proper mixture of common sense, training, manufacturers' literature and spare parts, proper maintenance can be performed and power systems kept in a safe, reliable condition. Circuit breakers, if installed within their ratings and properly maintained, should operate trouble-free for many years. However, if operated outside of their ratings or without proper maintenance, catastrophic failure of the power system, circuit breaker, or switchgear can occur causing not only the destruction of the equipment but serious injury or even death of employees working in the area.

In order to protect electrical equipment and people, proper electrical equipment preventive maintenance must be performed. In addition to the manufacture's literature, several standards and guides exist to assist users with electrical equipment maintenance. When the overcurrent protective devices are properly maintained and tested for proper calibration and operation, equipment damage and arc-flash hazards can be minimized as expected.

8. References

[1] Manufacturer's Instructions,
[2] NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*,
[3] NETA *Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems*,
[4] IEEE Std. 902, *Maintenance, Operation, and Safety of Industrial and Commercial Power Systems*
[5] Various IEEE Standards, including, but not limited to:
(a) IEEE Std. C57.13, *IEEE Standard Requirements for Instrument Transformer*s

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

[6] IEEE Std. C57.13, *IEEE Standard Requirements for Instrument Transformer*s and IEEE Std. 242 (Buff Book), *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.*

[7] IEEE Std. 242 (Buff Book), *IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.*

[8] IEEE Std. 493 (Gold Book), *IEEE Recommended Practices for the Design of Reliable Industrial and Commercial Power Systems.*

[9] OSHA 29 CFR 1910.331-.335, *Electrical Safety-Related Work Practices*, Final Rule August 6, 1990

[10] Vince A. Baclawski, Technical Director, Power Distribution Products, NEMA; published in EC&M magazine, pp. 10, January 1995

9. Author's Biography

Dennis K. Neitzel, *CPE (SM, IEEE) is the Director of AVO Training Institute, Inc. (a Subsidiary of Megger); Dallas, Texas. He is an active member of IEEE, ASSE, NFPA, AFE, and IAEI. Mr. Neitzel serves as a Principal Committee Member for the NFPA 70E, "Standard for Electrical Safety in the Workplace", is co-author of the Electrical Safety Handbook, McGraw-Hill Publishers, and is the Working Group Chairman for revising IEEE Std. 902 (the Yellow Book), "IEEE Guide for Maintenance, Operation, and Safety of Industrial and Commercial Power Systems". He received the Engineering Practice Specialty "Safety Professional of the Year" award for 2003-2004 from the American Society of Safety Engineers. Mr. Neitzel earned his Bachelor's degree in Electrical Engineering Management and his Master's degree in Electrical Engineering Applied Sciences.*

Dan Neeser *(M. IEEE) Dan Neeser is employed by Cooper Bussmann and holds the title of Manager, Technical Sales. He participates in IEEE, NEMA, NFPA, NJATC, IBEW, NECA, and IAEI activities. He specializes in training on the design and application of overcurrent protective devices in electrical distribution systems in accordance with the National Electrical Code. Prior to his position with Cooper Bussmann, he was a Sales Engineer for Cutler-Hammer focusing on construction project sales of electrical distribution products. He has a BSME from the University of North Dakota.*

Mike Callanan, *Mike is the President of the National Joint Apprenticeship & Training Committee (NJATC) in Washington D.C. The NJATC is the training arm of the International Brotherhood of Electrical Workers (IBEW) and the National Electrical Contractors Association (NECA). Mike also serves as the Director of Codes & Standards for the IBEW. In this capacity he represents the IBEW on the Technical Correlating Committee (TCC) of NFPA 70, The National Electrical Code. He is a Principal Member of NFPA 70E, The Standard for Electrical Safety Requirements for Employee Workplaces and NFPA 70B, Electrical Equipment Maintenance. Mr. Callanan also serves as the Chairman of NFPA 79, Electrical Standard for Industrial Machinery. In addition to his Codes & Standards responsibilities, Mike is an OSHA Master Instructor and conducts OSHA training seminars on OSHA 1926 Construction and 1910 General Industry Standards.*