Protective Devices Maintenance as it Applies to the Arc/Flash Hazard

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One of the key components of the Flash Hazard Analysis, which is required by NFPA 70E-2000, Part II, paragraph 2-1.3.3, is the clearing time of the protective devices, primarily circuit breakers and protective relays. Fuses, although they are protective devices, do not have operating mechanisms that would require periodic maintenance; therefore, this article will not address them. The primary focus of this article will be the maintenance issues for circuit breakers and protective relays.

Molded case and low-voltage power circuit breakers (600-volts or less) will generally clear a fault condition in 3 to 8 cycles. To be conservative a clearing time of 8 cycles should be used. The majority of older medium-voltage circuit breakers (2300-volts or greater) will clear a fault in around 8 cycles with the newer ones clearing in 3 to 5 cycles. Protective relays will generally add approximately 3 to 4 cycles to the clearing time of the medium circuit breaker. Where proper maintenance and testing are not performed, extended clearing times could occur creating an unintentional time delay that will effect the results of flash hazard analysis.

All maintenance and testing of the electrical protective devices addressed in this article must be accomplished in accordance with the manufacturer's instructions. The NETA *"Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems"* 2001 Edition is an excellent source of information for performing the required maintenance and testing of these devices. Visit the NETA website for more information at http://www.netaworld.org.

This article 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.

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. Visit the PEARL website for more information at http://www.pearl1.org. 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, as well as NFPA 70B, 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 article.

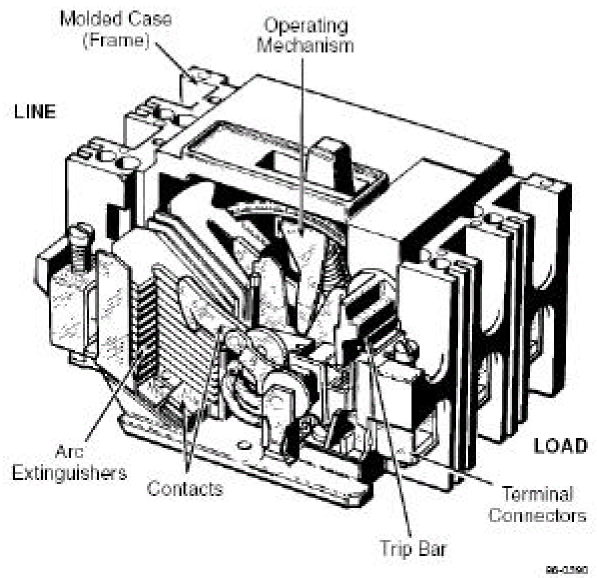

Figure 1
Principle Components of a
Molded-Case Circuit Breaker

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."*

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 a 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: (Vince A. Baclawski, Technical Director, Power Distribution Products, NEMA; published in EC&M magazine, pp. 10, January 1995)

"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."

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.

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, including IEEE, have shown that low-voltage power circuit breakers, which were not maintained within a 5-year period, have 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.

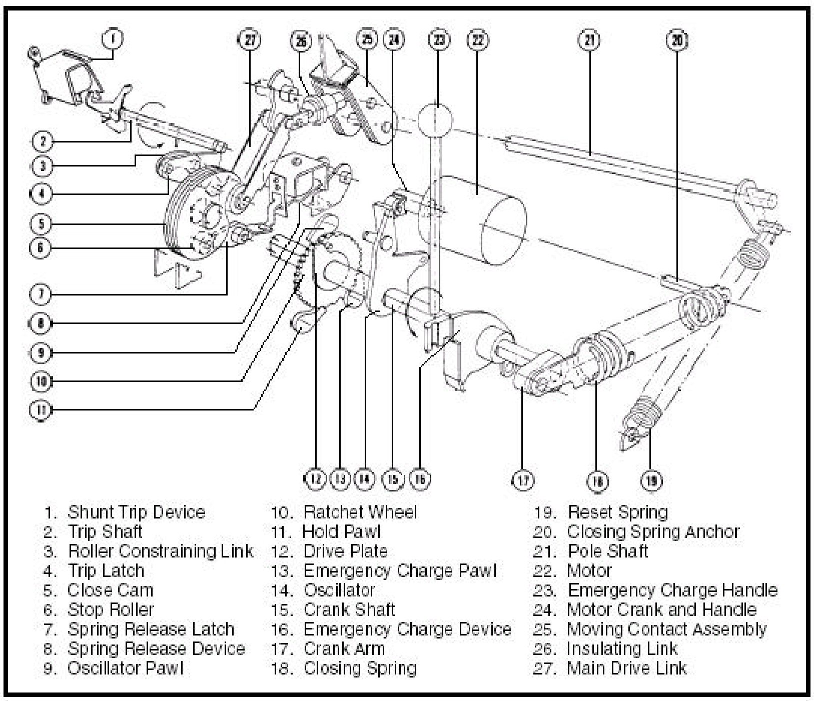

Figure 2
Power-Operated Mechanism of a
Cutler/Hammer "DS" Circuit Breaker

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.

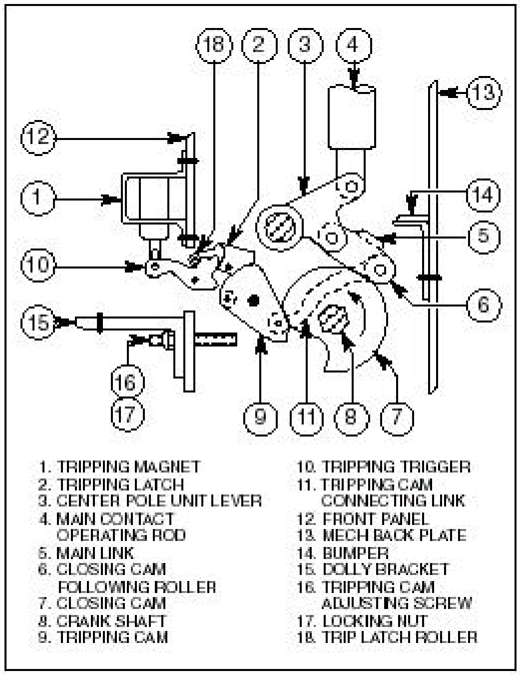

Figure 3
Operating Mechanism
Air Circuit Breaker

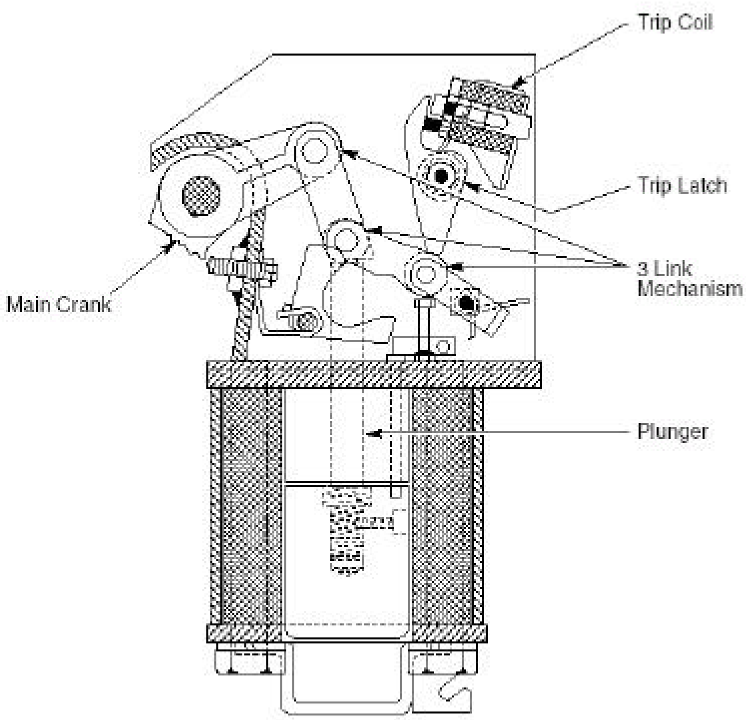

Figure 4
Solenoid-Operated
Mechanism

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:

- Current or voltage supplies to the relays are incorrect.
- DC tripping voltage supply is low or absent.
- Protective relay malfunctions.
- 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 number 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.

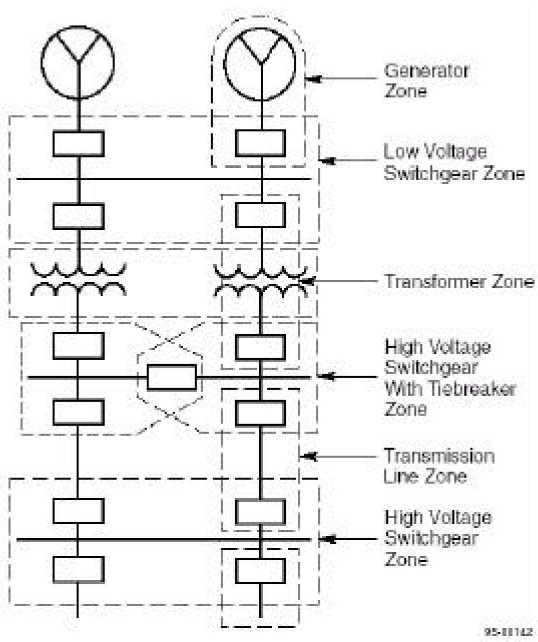

FIGURE 5
Primary Relaying for an Electric Power System

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.

The secondary side of a current transformer must **NEVER** be open circuited. When the secondary side of the CT is open circuited, a high voltage appears at the secondary terminals (usually at the relay case terminals). Because this voltage is limited by saturation of the core, the RMS value, as measured by a voltmeter, may not appear to be dangerous, but as the current passes through zero, the flux field is not limited, thus extremely high peaks or pulses of voltage are induced. These high peaks of voltage may not be measurable on conventional voltmeters, but they can break down insulation and are dangerous to personnel. The actual open-circuit voltage peak is difficult to measure accurately, because it exists only as very short peaks. Even a high impedance measuring circuit tends to reduce the voltage, and because it is not easy to maintain a sine wave of primary current when the secondary circuit is opened (except in an actual power circuit), the voltage generated by an open circuit on a 69 kV CT could be in the thousands of volts. Remember that the connecting studs at the relay are only an inch apart, and high voltage appearing at those studs undoubtedly arcs.

The voltage transformer (VT) is designed to deliver a secondary voltage, which is an integral fraction of the primary voltage, with as little phase-angle difference as possible between primary and secondary voltages. In the voltage transformer, the only reason the output voltage per turn is less than the input voltage per turn is because of losses through resistance and reactance (impedance).

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.

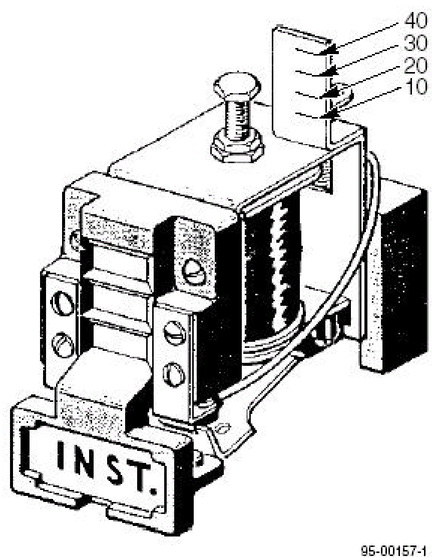

FIGURE 6
Instantaneous Trip Unit

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 ICS unit, 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.

Flash Hazard Analysis

As noted at the beginning of this article, NFPA 70E-2000, Part II, paragraph 2-1.3.3 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, Paragraph 2-1.3.3.2 requires a flash protection boundary to 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.

Maintenance is a very critical part of the flash hazard issue. The information provided in this article clearly indicates the need for a preventive maintenance program on these circuit protective devices. Evidence has proven that inadequate maintenance can cause unintentional time delays in the clearing of a short circuit condition. 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 is a specific example:

If a Flash Hazard Analysis is performed based on what the system is suppose to do, let's say 5 cycle clearing time, and there is an unintentional time delay, due to a sticky mechanism, and the breaker clears in 30 cycles, the worker could be seriously injured or killed because he/she was under protected.

If the calculation is performed for a 20,000-amp fault, 480 volts, 3-inch arc gap, the worker is 18 inches from the arc, with a 5 cycle clearing time for a 3-phase arc in a box (enclosure), the results would be approximately 6.5 cal/cm^2 which would require an Arc/Flash Category 2 protection based on NFPA 70E-2000, Part II, Table 3-3.9.3.

The following example (Figure 7) uses the Heat Flux Calculator (developed by Alan Privette) and the values above for a 5 cycle clearing time:

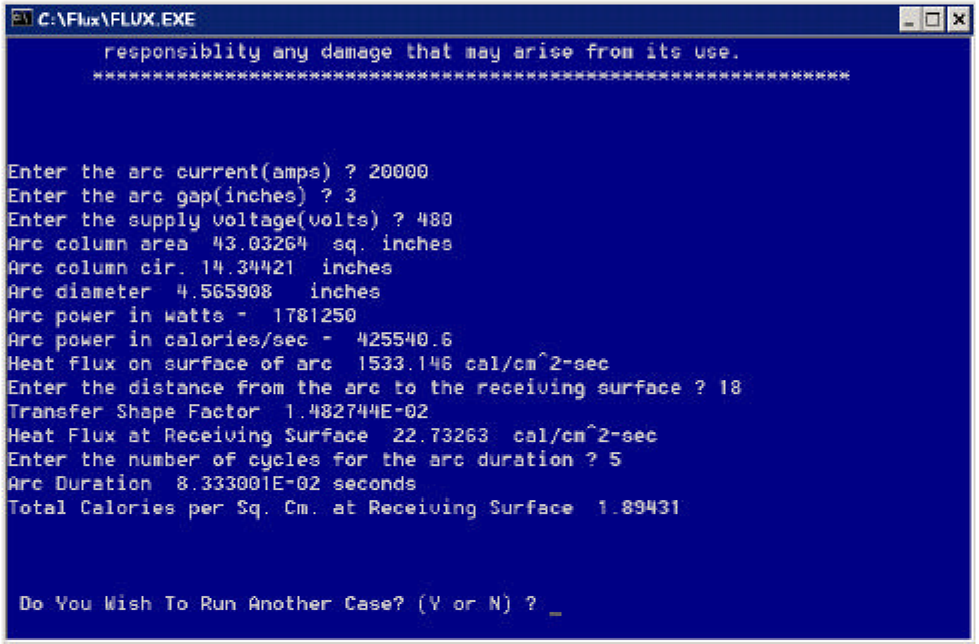

FIGURE 7

Calculation with a 5 Cycle Clearing Time

This value of 1.89431 cal/cm^2 is based on a single-phase arc in open-air. As a general rule of thumb, the value of 1.89431 would be multiplied by a factor of 2 for a single-phase arc in a box (2 x 1.89431 = 3.78862 cal/cm^2 – Category 1) and by a factor of 3.4 for a multi-phase arc in a box (3.4 x 1.89431 = 6.440654 cal/cm^2 – Category 2).

If the clearing time is increased to 30 cycles (Figure 8) then the results are approximately 38.7 cal/cm^2, which requires an Arc/Flash Category 4 protection.

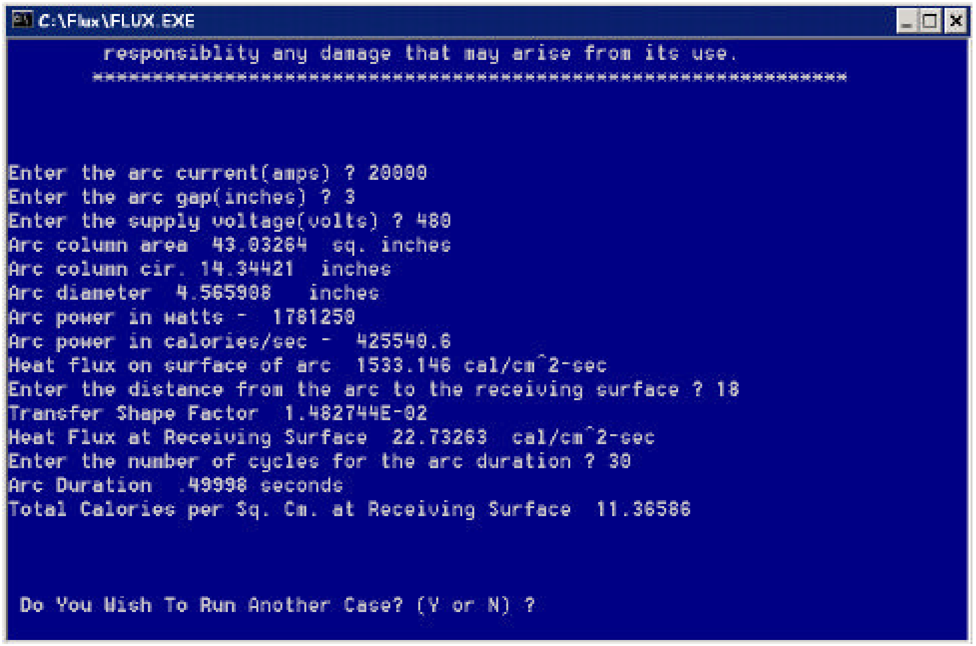

FIGURE 8

Calculation with a 30 Cycle Clearing Time

The value of 11.36586 cal/cm^2 is based on a single-phase arc in open-air. Again, as a general rule of thumb, the value of 11.36586 would be multiplied by a factor of 2 for a single-phase arc in a box (2 x 11.36586 = 22.73172 cal/cm^2 – Category 3) and by a factor of 3.4 for a multi-phase arc in a box (3.4 x 11.36586 = 38.643924 cal/cm^2 – Category 4).

Therefore, 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.

Summary

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.

For further information, concerning electrical protective devices maintenance, testing and electrical safety please contact Dennis K. Neitzel, CPE, Director of AVO Training Institute, 1-800-723-2861, ext. 7315, or e-mail to dennis.neitzel@avointl.com.