Understanding and Reducing Arc Flash Hazards

J. Weigel, J. Clough, and B. Leuschner (Square D/Schneider Electric)

Introduction
Recent changes in workplace safety regulations have heightened the awareness of hazards associated with electrical arcs. The hazard level must be quantified and workers properly protected before entering proximity of exposed energized conductors. The evolution of safe work practice standards has spawned significant research into the characteristics of and energy within an electrical arc. As a result, new models have been developed for calculating incident energy, which overcome many of the limitations associated with earlier methods. Furthermore, the need to protect the worker against arc flash without introducing additional hazards is driving a greater emphasis on engineering controls and product development.

As employees work on or near energized conductors or circuits, contact with or failure of the equipment may cause a phase-to-phase or phase-to-ground fault. An arc flash occurs when insulation or isolation between electrified conductors is breached or can no longer withstand the applied voltage. The arc reaches temperatures well over 5,000 degrees Fahrenheit and produces a pressure wave capable of exerting thousands of pounds of force on the chest of a worker within the flash protection boundary.

Regulatory Changes
OSHA has enacted new rules in a concerted effort to reduce electrical-related work fatalities. Part 1910 of 29 CFR contains several rules that prescribe requirements for clothing, training, and hazard assessment when employees are exposed to electrical hazards.

NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplaces, was created to provide OSHA a standard establishing safe work practices for electrical workers. Among other things, this document requires hazard analysis and aids in the selection of personal protective equipment (PPE). Minimum approach boundaries are also established.

Recognizing the limitations of existing methods of arc flash hazard analysis, the Institute of Electrical and Electronics Engineers (IEEE) embarked on a test program in order to develop an accurate model for incident energy under all real conditions. The result, IEEE 1584-2002, IEEE Guide for Performing Arc-Flash Hazard Calculations, provides new empirically derived models for calculating incident energy and arc flash boundaries.

Origins of an Electrical Arc
An electrical fault may be classified as arcing or bolted. In an arcing fault, current flows through air. The impedance of the air results in power dissipation and the
release of energy proportional to the duration of the arc. Arcing faults occur when electrical clearances are reduced or compromised by deteriorating insulation or human error, causing a conductive path between opposite phases or between a phase and ground. Bolted faults are typically caused by mistakes made during installation or maintenance, when different phases or a phase and ground come in direct contact.

Until recently, bolted fault current was the standard by which the effectiveness of electrical protection equipment was measured. Now extensive testing by the IEEE has quantified arc flash hazards in different types of equipment, leading to a better understanding of the difference between arc fault current and bolted fault current. Because a voltage drop occurs when current flows through air, the arc fault current is always lower than the bolted fault current.

This difference is important, because circuit breakers and fuses have traditionally been designed to disconnect current very rapidly when a specific bolted fault current level is reached, while allowing a time delay when the current magnitude is somewhat lower. Since arc flash incident energy is proportional to the fault duration, the hazard is often greater when evaluated at arcing fault current levels rather than the bolted fault current level typically calculated in a short-circuit study. This realization is leading electrical equipment manufacturers to develop new designs which result in faster clearing times of lower magnitude faults and reduce exposure to hazardous conditions. By limiting incident energy, electrical workers can safely perform tasks on energized equipment while wearing less PPE, thus reducing the chance of heat exhaustion and improving dexterity and visibility.

**Solutions to the Arc Flash Problem**

System design, protective settings, and equipment selection can all impact the hazard level. Switchgear with a main breaker yields greater protection than main lug only equipment. Overcurrent device trip settings can be chosen to reduce incident energy without compromising coordination. Zone selective interlocking, differential protection, current-limiting devices, and fast fault making devices all act to reduce the energy released during an arc flash event. Features such as remote racking systems and infrared windows add a measure of protection by isolating workers from the hazard. Both functions are equally valuable in protecting workers and the workplace from arc flash hazards and can be employed in new equipment or by upgrading existing equipment.

**The benefits and limitations of fuses**

Fused switches and fused circuit breakers utilizing current-limiting fuses have long been recognized as a way to reduce the energy released during a fault. When used with a circuit breaker, the fuse protects the breaker at fault current levels above the breaker’s interrupting rating. By interrupting high fault current prior to the first half cycle peak, arc flash incident energy is substantially reduced. At fault levels below the current-limiting region, fuses operate slower.
For continuous current ratings of 400 amperes and lower, both fuses and circuit breakers provide very effective limitation of arc flash incident energy. Calculations for both fuses and circuit breakers, using formulas published in IEEE 1584-2002, indicate that the incident energy values are within Hazard Category 0 or 1 over the applicable fault current range.

For ratings above 400 amps, circuit breakers may provide better arc flash protection than fuses. The reason is that fuses have relatively high thresholds of current limitation compared with the lower instantaneous tripping levels of circuit breakers. Therefore, breakers will clear many arcing faults more rapidly than will a current-limiting fuse. The performance of both is compared in Figures 1 and 2 for 1200A and 2000A ratings, respectively.

![Figure 1](image1.png)  
**Figure 1** Comparison of 1200A devices

![Figure 2](image2.png)  
**Figure 2** Comparison of 2000A devices
**New breaker design limits arcing current**

Traditionally, low voltage power circuit breakers have used current path geometry to withstand the circuit forces for a short time. Magnetic forces within the circuit breaker keep the contacts closed, allowing downstream overcurrent devices time to open to clear a fault. As the current flow increases, this “blow closed” design increases the force keeping the contact assembly closed.

A new current-limiting design acts in reverse, blowing open the terminal to interrupt the circuit. This unique design approach allows the circuit breaker to go into an accelerated opening mode at about 30,000A, comparable to current-limiting fuses. At a slightly higher current the circuit breaker goes into a fully current limiting mode. Even below that level, the circuit breaker will open in 50 milliseconds at current values down to its instantaneous setting.

The blow-open terminal in these circuit breakers is shaped so that there is a reverse current loop in the moving arm as illustrated in Figure 3. This reverse current flow creates a magnetic force proportional to the amount of current. When the current is high enough, the force quickly pushes open the contacts, without waiting for the mechanism to unlatch and the springs to pull the moving arm open. This results in a faster opening time – 9 milliseconds at 200kA – compared to traditional circuit breakers, limiting incident energy to levels comparable or better than fuses as shown in Figure 4.

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**Figure 3  Current-limiting circuit breaker current path geometry**
Retrofit options for older equipment

Aging equipment and inconsistent maintenance increase the likelihood of an arc flash incident. While most power circuit breakers will last 20 years or more, older installations deserve closer maintenance attention to make sure that they remain functional. As maintenance becomes more frequent on aging equipment, the opportunities for incidents or equipment failures that would cause an arc flash also increase. Replacing existing circuit breakers with new current limiting circuit breakers will allow for longer maintenance intervals and reduce the arc flash hazard. A number of options exist for replacing a circuit breaker, but power system analysis should be performed first to determine the best upgrade solution for each facility.

The direct replacement option for low voltage power circuit breakers provides an upgrade in technology with minimal downtime. The modern circuit breaker makes it relatively easy to replace an aging device because of its smaller size relative to the one it replaces. In a direct replacement, the new circuit breaker’s cradle is custom engineered to fit directly into the existing cell without any modifications to the cell. This ability to upgrade equipment with minimal disruption to operations is particularly important in process industries and other critical power applications where any type of equipment shutdown is to be avoided. It is also a solution that can be used in any manufacturer’s equipment.

A retrofill is another upgrade option, where the existing switchgear cell is modified to accept the new low voltage power circuit breaker. Each circuit breaker cell is modified to allow installation of a current limiting circuit breaker, cradle, racking mechanism and new cell door. A retrofill usually requires a main bus outage of some limited duration, although circuits supporting critical loads can be sectionalized and temporarily rerouted during the process.
Removing workers from the danger zone
Keeping workers out of the arc flash danger zone when equipment is energized is another way to improve workplace safety. Two solutions following this approach are infrared windows and remote racking systems.

An infrared window, available from many manufacturers as a kit, can be installed in both low voltage and medium voltage distribution equipment to allow infrared inspections without removing panels, which would necessitate wearing PPE. Thermography is a valuable tool for preventive maintenance, allowing workers to determine load, connection, component fatigue, over-heating or phase problems. An infrared window allows thermographic electrical inspections to be performed at any time without removing equipment covers or panels.

Remote racking systems for medium voltage circuit breakers can avert arc flash incidents and injuries by moving the worker out of the flash boundary during breaker racking operations – an activity during which a significant percentage of arcing faults involving medium voltage circuit breakers occur. The system allows racking and testing operations to be automatically controlled and monitored without direct human contact. A motorized racking mechanism is retrofitted into each medium voltage circuit breaker cell. The racking operation is initiated and monitored via a remotely located operator interface. Remote racking systems maintain the equipment’s original interlocks and can be retrofitted into existing medium voltage cubicles.

Conclusion
The process of complying with the safe work practices dictated by the 2000 edition of NFPA 70E presents an opportunity to re-examine your electrical system and procedures and gain a better understanding of potential weaknesses. Employee safety can be improved, thereby reducing financial risk to your company, by implementing new engineering philosophies and designs.