Arc Flash Considerations for Low-Voltage Applications

Abstract
This white paper discusses the increasing importance to industry of arc flash hazards and methods for exposure reduction. Calculation methods are reviewed which relate the severity of arc flash with the characteristics of the overcurrent protective devices; namely clearing time and fault current reduction. This leads to the selection of personal protective equipment. It is noted that the calculation method for circuit breakers needs to be refined, in particular relative to current limiting. The paper includes a discussion of the technologies for reducing arc flash hazards and identifies the possibilities for plant-wide arc flash calculations. The conclusions summarize the status and review the significant safety features associated with circuit breakers.

Status of Literature:
There have been several recent codes and standards regulations that relate to the fundamental dangers of arc flash energy. The following provides a brief overview of them.

During the revision cycle, which created the 2002 National Electrical Code (NEC), NFPA 70, there were proposals that would have required the marking of many of our products to “indicate the incident energy in calories per square centimeter for a worker at a distance of 18 in.” Although equipment manufacturers were successful in removing the quantitative portion of this proposal due to enforcement problems, a generic Warning Label requirement was accepted into Article 110.16. It is anticipated that proposals for the 2005 NEC will again attempt to add the quantitative marking requirement. The wording added to the 2002 NEC is as follows:

“Flash Protection. Switchboards, panelboards, industrial control panels, and motor control centers in other than dwelling occupancies, that 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-2000, Electrical Safety Requirements for Employee Workplaces, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.
FPN No. 2: ANSI Z535.4-1998, Product Safety Signs and Labels, provides guidelines for the design of safety signs and labels for application to products.”

To help the installing contractors, since January 2002 Eaton’s Cutler-Hammer business has been supplying loose labels (see below) which are intended for field application on the equipment identified above.
**NFPA 70E, Standard for Electrical Safety Requirements for Employee Workplace** contains some Arc Flash Energy information and calculations in the 2000 edition. This information is very confusing and was relegated to an Informative Appendix. The intent of NFPA 70E is to calculate an energy value that would correspond with choosing the appropriate Personal Protective Equipment (PPE) necessary around electrical equipment. The 2003 edition of NFPA 70E will expand & clarify these requirements and possibly move them from the “informative” Appendix. Additional and modified calculation equations are also proposed for the Flash Hazard Energy Analysis.

The IEEE has just published its [**1584 Standard, Guide for Arc Flash Calculations**](https://ieeexplore.ieee.org/document/3514421), which includes an Excel Spreadsheet that performs the actual calculations. This Standard outlines two methods for quantifying the arc-flash energy available when using molded case circuit breakers. The first is a simple method that only requires input of the available bolted fault current and the breaker type as specified by the continuous current rating. However, this method calculates conservatively high values of arc energy that may mandate more protection than is necessary. This could actually create additional hazards such as heat stress, poor visibility, and limited body movements that are introduced by the overly conservative garments. The second calculation method requires additional input of specific circuit breaker total clearing times. This approach also causes concern because commonly published time/current curves in the instantaneous region have not been a focus of circuit breaker manufacturers, and are very conservative. IEEE 1584 and its associated calculations are intended to be applied to medium-voltage as well as low-voltage applications, but this Cutler-Hammer document will focus primarily on LV, which is the area where the most research has been conducted.

**Status of Low-Voltage Overcurrent Protective Device Calculations:**

Arc flash incident energies can be calculated based upon the spreadsheets in IEEE Std 1584, *Guide for Performing Arc Flash Hazard Calculations*. It is first necessary to input the circuit parameters in order to calculate free-air short-circuit arcing currents. Here it is noted that these arcing currents are significantly less than the available bolted-fault short circuit currents because the arc provides significant circuit impedance. A particular value of the spreadsheet is the ability to input the characteristics of the over current protective device in order to determine the actual energy content of the free-air arc. In the case of certain specific fuses and within a specific range of bolted fault currents, it is possible to input the fuse-type, and the calculation then automatically takes into account both the current-limiting effect of the fuse and the actual time of interruption. Thus both of the important parameters for arc flash, the arc current magnitude and the arc current duration, are taken into account. This program capability is based upon extensive arc-flash experimental data for fuses. For fuses not specifically included, or outside the bolted fault current range specified, input of the fuse’s time/current curve information (opening times) is required. In the case of circuit breakers, there are two possible calculation methods. The first method is for certain circuit breakers within specific continuous current ranges and within specific ranges of bolted fault currents. Although this method only requires input of bolted fault current, the calculation is based upon circuit breaker interruption times for generic breaker-ratings. These are typically worst-case; maximum-duration interruption times based upon the published time-current curves of many manufacturers. This method is conservative and calculates high values of arc energy that may mandate more protection than is necessary. As an alternative second method, the spreadsheet does permit the inclusion of specific circuit breaker interruption times taken from the time current curves at the bolted fault level. Regardless of the method selected for arc time duration, the present 1584 calculation does not take into account the current limiting characteristics of circuit breakers.

Eaton's Cutler-Hammer has made a first attempt to take the reduction in peak current associated with current limiting circuit breakers into consideration. In this approach, the experimental data obtained for current-limiting breakers subjected to given bolted fault currents is used. The data provide observed clearing times and observed peak let-through currents. An rms value associated with the let-through current is entered into the spreadsheet rather than the available bolted fault current. The clearing time associated with the available bolted fault current is also inputted. The resulting arc energies are significantly lower. This methodology needs to be refined. Methodologies for including current-limiting effects of circuit breakers are being worked on by C-H, Sq. D, and NEMA and will ultimately need to be justified to IEEE.
The present 1548 calculations are associated with high current faults with consequent rapid operation of the overcurrent device: either rapid fuse operation or instantaneous tripping of the circuit breaker. It is probable, however, that when using these calculations the highest values of incident energy will actually occur under low-fault-current scenarios. Here the lower arc currents will be more than offset by the longer arc durations. This low-fault-current area needs to be explored.

**Protective Clothing:**

Personal Protective Equipment, or PPE, is designed to protect workers from serious burns resulting from electrical arc flash hazards. Injuries occur during an electric arc because of flash burns from the heat generated by the electric arc and by flame burns from the ignition of clothing or other combustible materials. Clothing that is not flame retardant (FR) can increase the severity of the burns, except in cases of very low energy intensity. Even FR fabric can ignite. FR fabric will self-extinguish after the external ignition source (flame or arc) has finished burning, however, non-FR fabrics that ignite (start to burn) will continue to burn. To totally avoid an electrical arc flash hazard, personnel should only work on equipment that is de-energized. When it is impossible to work on de-energized equipment, personnel should use the proper Personal Protective Equipment (PPE) to prevent serious burn injuries.

1. To determine the proper PPE, it is necessary to know the caloric level of the hazard to which personnel are exposed. An arc flash hazard assessment must be conducted to determine the level (intensity) of energy from the electric arc in units of calories per centimeter squared (cal/cm²). The proper PPE can then be determined. With this PPE the burn should be limited to second-degree. Here it is noted that second-degree burns will occur at 1.2 cal/cm². Choosing inadequate PPE can lead to even more severe burns.

2. Look for the arc energy rating on the label in the garment. The Arc Energy Rating of the garment (Arc Thermal Performance Exposure Value, ATPV) will identify the energy above which a 2nd degree or greater burn could result. Burns are a matter of life and death for the worker. By properly analyzing the hazard, the injury can be avoided. To specify the right protection, the rating of the garment must be matched to the value of the assessed electrical flash hazard. ASTM F1506-00 calls for every garment to be labeled with the electric arc energy rating.

3. Do not use synthetic fabric made from Acetate, Nylon, Polyester or non-FR rayon unless the clothing meets ASTM F1506. These fabrics can melt and drip. The melted fabric can stick to the skin and increase the severity of the injury.

In addition to normally used hard hat, safety shoes, safety glasses, and hearing protection, required PPE includes:

- Flame-resistant clothing
- Flash suits (for high-energy arc exposure)
- Flash suit hoods
- Insulating gloves
- Insulated tools
Industry Tendencies
Pertaining to arc flash, the following have been identified as directions that the electrical industry is taking:

- **Suit-up**
  Operation / Maintenance: NFPA 70E requirements state that personnel wear Hazard Risk Category 3 PPE (3 FR layers including coveralls) during racking procedures with doors open on an energized system if an arc flash analysis has not been performed. Suited operators remain vulnerable to intense heat, percussive forces and airborne debris from a fault explosion.

- **Lines on the floor.** Users to identify "safe" personnel clearances from various pieces of electrical equipment. When the conservative calculation approach is taken for circuit breakers, customers will be falsely forced into believing they must utilize larger equipment rooms than necessary to accommodate the greater distances. Below is an illustration, which demonstrates the boundary distances.

- **Future Code Proposals:** As previously mentioned, it is anticipated that proposals for the 2005 NEC will again attempt to add quantitative marking requirements. An example of a label that includes this type of information is shown below.

- **Remote Racking/Operating Systems:** Remote racking or operation systems allows operators to perform these procedures from a distance instead of in front of the cell and within a breaker’s flash boundary.

- At least one known customer has begun calculating “zones of protection” around their electrical equipment, and are actually marking the floor areas to indicate the “safe” area, depending upon whether the equipment covers are in place or not. This could make it extremely difficult to even view energized equipment with the door open, let alone perform routine trouble-shooting, such as taking power quality measurements, etc.
Technologies for Reducing Arc Flash

When arc flash considerations are a significant factor in the selection of electrical distribution equipment, the following existing technologies should be considered:

- **Zone Selective Interlocking (ZSI):** ZSI deactivates the preset delay on the circuit breaker closest to the fault, which then trips with no intentional delay. Faster tripping reduces the amount of time that current flows during a fault condition. Thus, zone-selective interlocking reduces the amount of arc flash and stress ($I^2t$ energy) that the system encounters during fault conditions, resulting in improved personal protection and prolonged equipment life.

- **Ground Fault Detection:** trips the circuit breaker during the early stages of fault development and prior to "bolted fault" conditions.

  The National Electric Code (NEC®) requires the installation of ground fault protection per Article 230.95, Ground-Fault Protection of Equipment: Ground fault protection of equipment shall be provided for solidly grounded wye electrical services of more than 150V to ground, but not exceeding 600V phase-to-phase for each service disconnect rated 1000A’s or more.

  (a) Setting - 1200A’s max pick-up with max time delay @ 1sec for $I_{GF} \geq 3000$A’s
  (b) Fuses - If a switch and fuse combination is used, the fuse shall be capable of interrupting any current greater than the interrupting capacity of the switch, during the time that the ground fault protective system will not cause the switch to open.
  (c) Performance Testing - System shall be tested when first installed on-site

- **Arc eliminating “Crowbar” approach for LV Assemblies (Switchgear & MCC):** The concept of the “Crowbar” system is a viable option for arc protection in switchgear equipment. This concept not only offers increased personnel protection, but it can also protect the associated faulted equipment. These were developed to reduce the damage done by internal arcs and thereby limit the outage time on critical loads. They work by quickly putting a solid "bolted" fault across the busbars of a board when an arc is optically detected anywhere within the board. One-advantage is that they work even when equipment doors are open and devices are being removed or inserted. In the long run these devices may offer the best protection against arc faults, but the technology is new and the total operational hours are low. Considerable work is being done to eliminate spurious tripping due to other light sources, including arcs produced by LV air break devices during normal interruption. As these are critical safety devices, for the time being they are being considered as added protection for critical loads rather than as an alternative to arc containment.

- **Use of finger-safe electrical components** as much as possible. This can reduce the chance that an arcing fault will occur.

- **Use of insulated bus** for equipment such as motor control centers, switchboards, switchgear, etc. This will reduce the chance that an arc fault may occur. In addition, it increases the probability that an arc fault will self-extinguish.

- **Use of current-limiting overcurrent protective devices.** Obtain verifiable engineering data on the current-limiting ability of the overcurrent protective devices. Current Limiting MCCBs limit the faulted circuit before that current reaches potential maximum value. The current-limiting action limits thermal and mechanical stress created by the fault currents.

  Peak let-through current (Ip) and $I^2T$ are two measures of the degree of current limitation.

- **Sizing the current-limiting branch circuit overcurrent protective devices as low as possible.** Typically, the lower the ampere rating, the greater degree of current-limitation.

- **Limiting the ampere rating size of main and feeders where possible.** For example by splitting large feeders into two feeders.
CONCLUSIONS

Industry, in particular the Petro-Chemical industry, is placing increased attention on arc flash exposure. At present, more data are available for fuses than for circuit breakers. Additional data are now being obtained for circuit breakers, with due consideration of both low and high current faults. As the industry moves forward to address the issues of arc-flash hazards, a few recommendations are appropriate:

- Improved workplace training programs are needed to increase awareness of the hazards associated with arc-flash energy.
- Although it sounds simple, no electrical accident can occur when equipment is not energized. Users should look for new ways to reduce or eliminate the necessity for personnel to work on energized equipment. Most industrial and commercial applications are capable of maintaining reliable production without working on energized equipment. Improving safe work practices is a priority.
- When there is no alternative to working on energized equipment, always do a hazard assessment. When this assessment indicates the possibility of severe burns, the use of Personal Protective Equipment (PPE) is typically required. The user should look for the Arc Rating label in the clothing/equipment, and match it to the specific arc hazard determined. The latest NFPA70E Standard is an excellent guide in identifying the level of protective clothing required based on specific electrical conditions.
- Test and safety standards for all power distribution assemblies, regardless of the interrupting device, should be based on successful fault interruption with the enclosure door closed and secured.
- Short-time delay settings should be carefully considered when applying LV power circuit breakers in systems where employees will be exposed to live parts. Although better selective coordination can be achieved with the use of a short-time setting, permitting fault current to flow longer during an arcing condition will result in higher levels of incident energy. Use the shortest delay setting possible to minimize arc duration, and employ zone selective interlocking wherever possible to further reduce this interval.

Today’s circuit breaker technologies provide significant features for safety and performance:

- Simultaneous operation of all poles with resulting avoidance of single-phase conditions
- Ability to provide ground fault (earth leakage) protection
- Ability to provide zone selective interlocking
- Remote open/close capability
- Reset without exposure to energized parts
- System-information transmission-capability via electronic trip units
- Sophisticated protective curve shaping for the ultimate flexibility in coordination with minimization of delays between protective devices
- Total enclosure of current carrying parts
- Inherent external visual trip indication
- Current limiting designs.

At present, most arc flash test data available is based on fault currents near the prospective fault current. Most faults, however, are at lower levels, or are significantly reduced due to the impedance of the resulting arc. Better understanding of low level fault conditions is needed.