Arc Flash

Do You Understand The Dangers?

What is Arc Flash?

An Arc Flash is a rapid release of energy due to an arcing fault between a phase conductor and another phase conductor, a neutral conductor or a ground.

The Result:

?? Rapid release of energy – a fire ball exploding outward
?? Rapid release of heat – can cause incurable burns
?? Blinding light - flash
?? Shock/Pressure wave – Deadly, like a hammer hitting you in the chest
?? Sound wave – Damage the ears – acoustic wave trauma
?? Sudden spray of molten metal droplets
?? Hot shrapnel flying in all directions

This type of fault is an accidental connection of energized electrical conductors and/or the earth. They are created by mechanical failures, failures of insulation, or accidentally while a person is working on an energized electrical system.

The Causes:

?? Spark Discharge
    ## Accidental touching
    ## Accidental dropping of tools
    ## Mechanical failure – part falling
?? Dust & Impurities buildup
?? Corrosion
?? Condensation
?? Insulation Failure
?? Over-voltage Stress- narrow gap

This type of short circuit is the result of a brief contact of energized conductors, such as a metal part falling onto an energized circuit. The initial short is of relatively high impedance but the impedance begins to drop as the arc is produced and the air basically becomes the conductor. These arc faults are generally limited to systems where the voltage is in excess of 120 volts. At 120 volts and below, the fault normally will not sustain an arc. An arc fault is similar to the arc produced during electric welding and the fault has to be manually started by something creating the path of conduction or by a failure, such as a breakdown in insulation.

The cause of the short normally burns away during the initial flash and the establishment of highly conductive plasma that sustains the arc fault. The plasma will conduct as much energy as is available and is only limited by the impedance of the arc and the overall electrical system impedance. This massive energy discharge burns the bus bars or wiring, vaporizing the copper or aluminum and thus causing an explosive volumetric increase. The arc flash is a blast and is conservatively estimated as an expansion in volume of 40,000 to 1. This fiery explosion devastates everything in its path, creating deadly shrapnel and droplets of molten metal flying in many directions.

- When water boils there is a volume increase of 1,670 to 1
- When copper vaporizes (boils) there is a volume increase of 67,000 to 1
- An arc-flash results in a volume increase from a conservative 40,000 to 1 to as high as 67,000 to 1

The terminal of the arc is extremely hot having a temperature estimated to be in excess of 35,000 ^{o}F. This is in addition to plasma of vaporizing metal having a temperature of 23,000 ^{o}F. In comparison with the sun's surface that is only 9,940 ^{o}F and an atomic bomb, after 0.3 seconds, reaches only 12,632 ^{o}F, this arc is unbelievably hot.

- The sun's surface temperature is 9,940 ^{o}F
- 0.3 seconds after an atomic bomb explodes, its core is at 12, 632 ^{o}F
- The arc flash conductive plasma is at temperature of >23,000 ^{o}F
- The terminal points of an arc are >35,000 ^{o}F

The high heat and volume expansion produces a pressure wave that can literally knock a person over, producing sound at a level that can damage hearing. It's a fireball with shrapnel exploding outward. Injury and fires resulting from such an event is primarily the result of the radiant heat produced and by the molten metal (1,832 ^{o}F) rather than by the arc itself.

The arc fault current that is produced during an arc flash is usually much lower than the available bolted fault current that occurs during a direct short circuit. Thus, it is often below the rating/setting of the protecting circuit breaker or fuse. Unless these protective devices have been selected to handle the arc fault condition, they normally will not trip or trip fast enough to minimize the full force of an arc flash. The amount of energy produced at the point of the arc is a function of the voltage and current present as well as the time that the arc is sustained; this time is the most important part of the energy equation, every second matters greatly. The transition from the arc fault to the arc flash takes a finite time, increasing in intensity as a pressure wave develops. The challenge to protect against an arc flash is to sense the arc fault current and shut off the current in a timely manner before it develops into a serious arc flash condition.

Why the focus on Arc Flash?

On a daily basis the number of arc flash incidents in the United States is greater than most electricians or engineers believe. The Chicago-based Capelli-Schellpfeffer, Inc. reports that five to 10 arc flash injuries occur a day requiring hospitalization[1]. Severe arc-flash burns can cause a slow painful death. The hot gasses produced can injure lungs and impair breathing. The very loud sound can destroy the eardrums and the blast can propel the person some distance away, often causing injury. If the person is lucky enough to be far enough away from the direct effects of the arc-flash, there can be psychological effects lasting many years. These effects can result in depression, job apprehension, and family tension.

Louisville Courier-Journal:

Electrical blast burns 3 working at XXXXXXXX hospital

By JIM ADAMS
The Courier-Journal

Two men were critically injured and a third suffered burns on his hands in an electrical explosion yesterday in the basement of

The men, employees of Electric Co., were doing routine maintenance work in a small room where the building's electrical panels are housed when the explosion occurred about 7:30 a.m., said Daniel Shaw, public-relations manager for Health System.

No patients were affected, Shaw said.

Two of the men were in critical condition yesterday afternoon at University of Louisville Hospital. The hospital would not release their names, at the request of their families, but the Louisville Fire Department identified them as and

Lt. Col. Keith Milliner of the fire department said seven workers were in the basement when touched something carrying a current with a metal-tipped ruler, causing an arc and an electrical flash.

suffered second-degree burns over 40 percent of his body and third-degree burns over another 20 percent, Milliner said. suffered second-degree burns over 20 percent of his body and third-degree burns over another 20 percent.

Shaw said the third injured worker was treated at and released. Milliner identified him as and said he suffered first- and second-degree hand burns.

The ages and addresses of the workers were not available.

The explosion knocked out power to the building, but emergency generators immediately kicked on. An alarm sounded, but Shaw said no patients were moved in the hospital, formerly

He said patients probably didn't notice anything was amiss unless they happened to see firefighters arrive.

Fire crews found a haze of smoke but no fire in the basement, Milliner said. They spent about two hours trying to clear the basement of smoke.

Telephone calls yesterday to ., were not returned.

What were they doing?

They were installing a tap to a bus bar system at a hospital. The work had to be performed hot. Electricians were using insulating blankets and insulated tools. Supervisor was closely supervising every action taken. They were following all the safety rules, so what went wrong?

The supervisor used a wooden ruler to point as he directed the work. Unbeknownst to him and unfortunately for the entire crew, the ruler had a ***metal*** tip. No one knows exactly what happened but.

Electrician 1

- 2nd Degree Burns – 40% of his body
- 3rd Degree Burns – 20% of his body
- End result – death after 11 days in intensive care

Electrician 2

- 2nd Degree Burns – 20% of his body
- 3rd Degree Burns – 20% of his body
- End result – Critical Condition, Lengthy hospital stay

Supervisor – Treated and released, off work an extended time due to the trauma of the accident

Electrical safety is the most over-looked employee work hazard:

- 432 work related deaths last year (Source: Department of Labor)
- Electrocution is fourth in work related fatalities with a majority of these incidents occurring at 600 volts or less.
- 7,600 disabling and non-disabling electrical injuries occur in the US each year
- OSHA published top 10 most violated standards. Electrical is now #4 on the list

The prevailing mind-set of the electrical industry and electricians is, ***"It won't happen to me,"*** – famous last words.

In the early 1980's a paper titled "The Other Electrical Hazard: Electric Arc Blast Burns" by Ralph Lee was published in the IEEE Transactions on Industrial Applications. The effect of this paper was to realize the need to protect people from the hazards of arc flash. Now four separate industry standards concern the prevention of arc flash incidents:

- OSHA 29 Code of Federal Regulations (CFR) Part 1910 Subpart S.
- NFPA 70-2002 National Electrical Code.
- NFPA 70E-2004 Standard for Electrical Safety Requirements for Employee Workplaces.
- IEEE Standard 1584-2002 Guide for Performing Arc Flash Hazard Calculations.

OSHA's General Duty Clause:

Section 5(a)(1) of the Occupational Safety and Health Act requires an employer to furnish to its employees:

“(A) Each employer.

(1) Shall furnish to each of his employees employment and a place of employment which is free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;”

OSHA 29 CFR 1910.303(b)(1) Electrical General Requirements

“**Examination**. Electrical equipment shall be free from recognized hazards that are likely to cause death or serious physical harm to employees. Safety of equipment shall be determined using the following considerations:”

OSHA 29 CFR 1910.132(d)(1):

“the employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall: Select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified in the hazard assessment; ….”

NFPA 70E-2004:

“A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the Flash Protection Boundary and the personal protective equipment that people within the flash Protection Boundary shall use.”

NEC-2008:

“**110.16 Flash Protection.** Equipment such as switchboards, panel boards, 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.”

Compliance with OSHA involves adherence to a six-point plan:

1. A facility must provide, and be able to demonstrate, a safety program with defined responsibilities.
2. Calculations for the degree of arc flash hazard.
3. Provide correct personal protective equipment (PPE) for workers.
4. Training for workers on the hazards of arc flash.
5. Appropriate tools for safe working.
6. Warning labels on equipment.

Note that the labels are provided by the equipment owners, not the manufacturers. It is expected that the next revision of the National Electric Code will require that the labels contain the equipment's flash protection boundary, its incident energy level, and the required personal protective equipment (PPE).

Companies will be cited and fined for not complying with these standards.

Personal Protective Equipment (PPE)

The types of personal protective equipment/clothing required for working on energized electrical equipment has been defined in NFPA 70E and is described in the following categories. Each category is further defined by other NFPA standards with respect to the functionality of each type of PPE.

Category	Cal/cm^2	Clothing
0	1.2	Untreated Cotton
1	4	Flame retardant (FR) shirt and FR pants
2	8	Cotton underwear FR shirt and FR pants
3	25	Cotton underwear FR shirt, FR pants and FR coveralls
4	40	Cotton underwear FR shirt, FR pants and double layer switching coat and pants

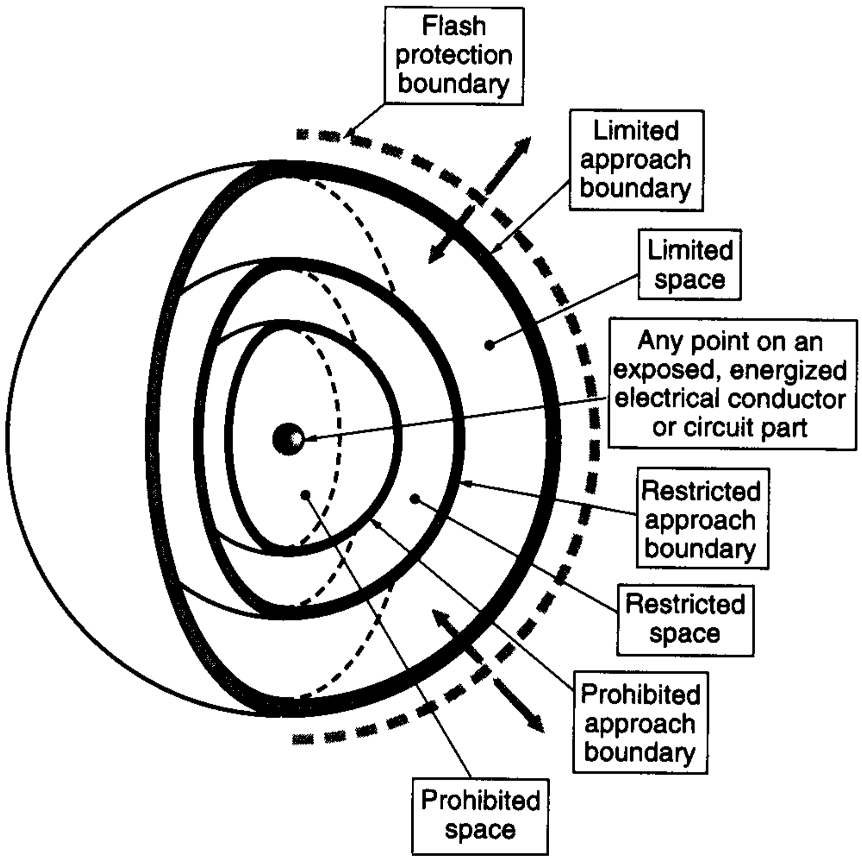
Cal/cm^2 are the units of incident energy that the PPE can withstand. Note that a hard hat with full-face shield and the appropriate gloves are also required.

The Category 4 PPE is not intended to protect under all conditions but rather only up to a limit of 40 Cal/cm^2. Many arc flashes produce energy far in excess of 40 Cal/cm^2 with energy values in the hundreds of Cal/cm^2.

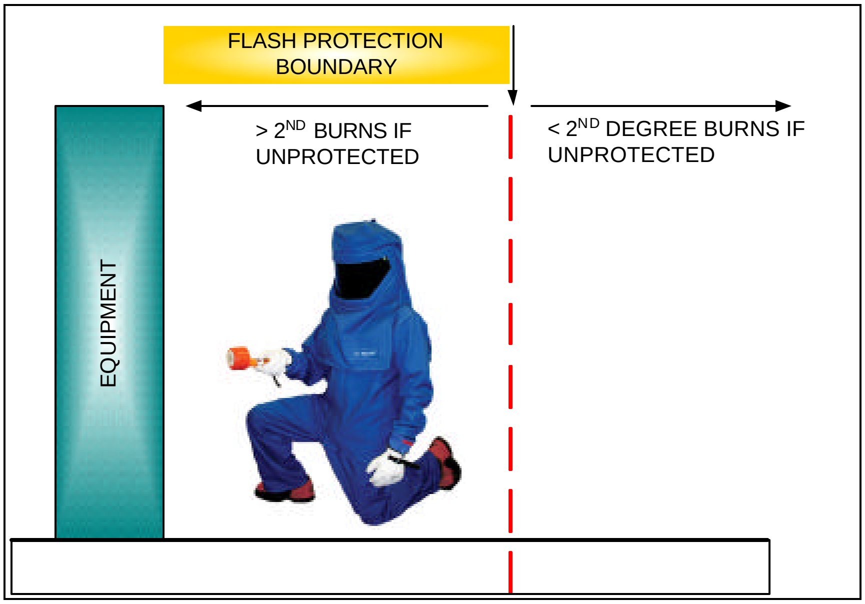
The PPE categories only provide protection for the effects of he heat. They do not provide protection for the flying shrapnel, molten metal, pressure wave or from electric shock.

Limits of Approach

NFPA 70E defines boundaries that correlate PPE with the type of work being preformed. The following diagram[2] illustrates these boundaries in all directions from any point where there are exposed energized electrical conductors.



Flash protection boundary: An approach limit at a distance from exposed live parts within which a person could receive a second-degree burn if an electric arc flash were to occur.

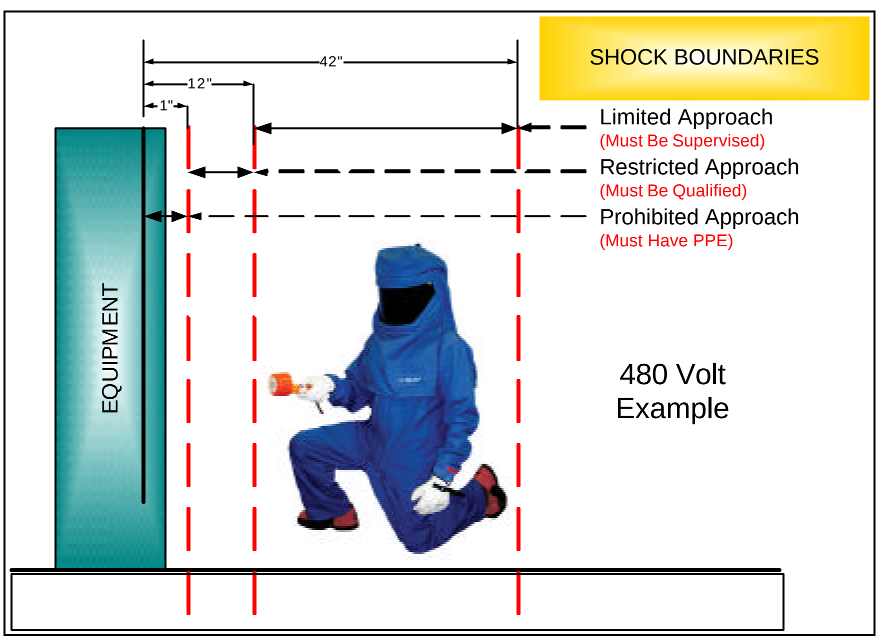


It is generally accepted that a second-degree burn results from exposure of incident energy of 1.2 Cal/cm²

Limited Approach Boundary: An approach limit at a distance from an exposed live part within which a shock hazard exists.

Restricted Approach Boundary: An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part.

Prohibited Approach Boundary: An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part.



Arc Flash Equations

The following equations form the basis of the arc flash calculations. Manual calculations are very time consuming and can only be easily applied on small case studies. The only practical approach is to use arc flash analysis software.

STEP 1

Arc Fault Current:[3]

For V < 1 kV, D.8.2(a)[4]

$\text{Log } I_A = K + 0.662 \text{ Log } I_{BF} + 0.0966\, V + 0.000526\, Gap + 0.5588 (\text{Log } I_{BF})\, V - 0.00304 (\text{Log } I_{BF})\, Gap$

For V > 1 kV, D.8.2(b)

$\text{Log } I_A = 0.00402 + 0.983 \text{ Log } I_{BF}$

- I_A = Arc Fault Current (.7kA to 106kA)
- I_{BF} = Bolted Short circuit current (3 phase symmetrical RMS kA)
- GAP = Gap between conductors (13mm to 152mm)
- K = -0.153 for open air
- K = -0.097 for "In Box"
- V = System voltage (.208 kV to 15kV)

STEP 2

Use the protective device coordination curve to determine the time to clear the fault.

STEP 3

Incident Energy (Jouls/cm^2)

$E_n = 10^{\{k1 + k2 + 1.0811 * \log(IA) + 0.0011G\}}$ Normalized to 0.2 seconds and 610 mm working distance D.8.3(a)

$E = 4.184 C_f\, E_n (t/0.2) (619/D)^x$ Adjustable to other values of t and working distance D.8.3(c)

Jouls/cm^2 = 0.2388 Cal/cm^2

- E_n = Normalized Incident Energy (Jouls/cm^2)
- E = Incident Energy (Jouls/cm^2)
- K_1 = -0.729 for Open Air,
- K_1 = -0.555 for In-A-Box
- K_2 = 0 for ungrounded and high resistance grounded
- K_2 = -0.113 for grounded systems
- C_f =Calculation factor (1.5 for V < 1kV & 1.0 for V > 1kV)
- G = Gap (mm)
- D = Working Distance (610mm, 24 in. normal)
- t = Time to clear arc (seconds)
- x = Distance exponent (from table)

System Voltage (kV)	Type of Equipment	Typical Gap (mm)	Distance X-Factor
0.208 to 1	Open-air	10 – 40	2.000
	Switchgear	32	1.473
	MCCs & Panels	25	1.641
	Cables	13	2.000
>1 to 5	Open-air	102	2.000
	Switchgear	13-102	.0973
	Cables	13	2.000

> 5 to 15	Open-air	13-153	2.000
	Switchgear	153	0.973
	Cables	13	2.000

Or

Incident Energy - For system voltages > 15kV

$E = 2.124 \times 10^6\ V\ I_{bf}\ (1/D^2)$ D.8.4

- E = Incident Energy (Jouls/cm^2)
- V = System Volts (kV)
- I_{BF} = Bolted Short circuit current (3 phase symmetrical RMS kA)
- D = Working Distance (610mm)
- t = Time to clear arc (seconds)
- x = Distance exponent (from table)

$E = 793\ D^{-2}\ V\ I_{bf}\ t$

- E = Incident Energy (Cal/cm^2)
- D = Working Distance (24 in.)

OR

Incident Energy (Cal/cm2) – In The Box:[5] (=< 600v)

$E_{MB} = (1038.7\ D_B^{\ -1.4738}\ T_A)\ \ (.0093\ F^2 - .3453\ F + 5.9675)$ D6.2(a)

- E_{MB} = Maximum 20 in. cube box incident energy, Cal/cm^2
- D_b = Distance from arc in inches
- T_A = arc duration in seconds
- F = Short circuit current, kA (for the range of 16 kA to 50kA)

Incident Energy (Cal/cm^2) – Open Air:[6] (=< 600v)

$E_{MA} = (5271\ D_A^{\ -1.9593}\ T_A)\ \ (.0016\ F^2 - .0076\ F + 0.8938)$ D.6.1(a)

- E_{ma} = Maximum open arc incident energy, Cal/cm^2
- D_A = Distance from arc in inches (for distances 18in. and greater)
- T_A = Arc duration in seconds
- F = Short circuit current, kA (for the range of 16 kA to 50kA)

STEP 4

Flash Protection Boundary

D_B = Distance from the Arc (mm)

$D_B = [4.184\ C_f\ E_n\ (t/0.2)\ (610^x/E_b)]^{1/x}$ Empirically derived D.8.5(a)

$D_B = [2.142 \times 10^6\ V\ I_{bf}\ \ (t/E_b)]^{1/2}$ Theoretically derived D.8.5(b)

E_b = Incident Energy at the boundary distance (J/cm^2) for desired incident energy level, i.e. 5 J/cm^2 or 1.2 Cal/cm^2

OR

D_B = Distance from the Arc (in)

$D_B = [(t/ E_{MB}) (9.66 F^2 – 358.7 F + 6198)]^{0.6785}$ (distance in inches from the arc terminal for a known E_{MB})[7]

D_B = Distance from the Arc (in)

$D_A = [(t/ E_{MA}) (8.434 F^2 – 40.06 F + 4711)]^{0.5104}$ (distance in inches from the arc terminal for a known E_{MA})[8]

Incident Force:[9]

$Lbs/ft^2 = (11.5 \times I_a/1000) / (\text{Distance in Ft})^{0.9}$

Flash Protection Boundary distance:[10] [11]

$D_C = (2.65\ MVA_{BF}\ T_A)^{1/2}$ Based on bolted fault MVA at point of arc (D.3d)

$D_C = (53\ MVA\ T_A)^{1/2}$ Based on supplying transformer, multiply by 1.25 for MVA <0.75 (D.3e)

Incurable Boundary distance:[12]

$D_F = (1.96\ MVA_{BF}\ T_A)^{1/2}$ Based on bolted fault MVA at point of arc

$D_F = (39\ MVA\ T_A)^{1/2}$ Based on supplying transformer, multiply by 1.25 for MVA <0.75

Steps Required For A Flash Hazard Analysis

To perform an arc flash hazard analysis, data is collected about the facility's power distribution system. The data includes the arrangement of components on a one-line drawing with nameplate specifications of every device. Also required are details of the lengths and cross sectional area of most cables. The utility should be contacted for information including the minimum and maximum fault currents that can be expected at the entrance to the facility. Once the data has been collected, a short circuit analysis is performed followed by a coordination study. The resultant data is then fed into the equations described by either NFPA 70E-2004 or IEEE Standard 1584-2004 as outlined above. These equations produce the necessary flash protection boundary distances and incident energy needed to set the minimum PPE requirements.

1. Collect data
2. Perform a Short Circuit Analysis
3. Perform a Coordination study
4. Perform a Arc Flash study
5. Perform a Sensitivity Study
6. Select PPE
7. Label Equipment
8. Provi de training

Short-Circuit Study

The short-circuit study is based on a review of a facility's one-line drawings. The drawings must be created if they do not exist, and field-verified if they do exist. Maximum available fault current is calculated at each significant point in the system. Each overcurrent protective device is analyzed to determine whether it is appropriately designed and sized to interrupt the circuit in the event of a bolted type of short circuit. Next, the associated equipment is reviewed to insure that the bus bar is adequately braced to handle the available fault current.

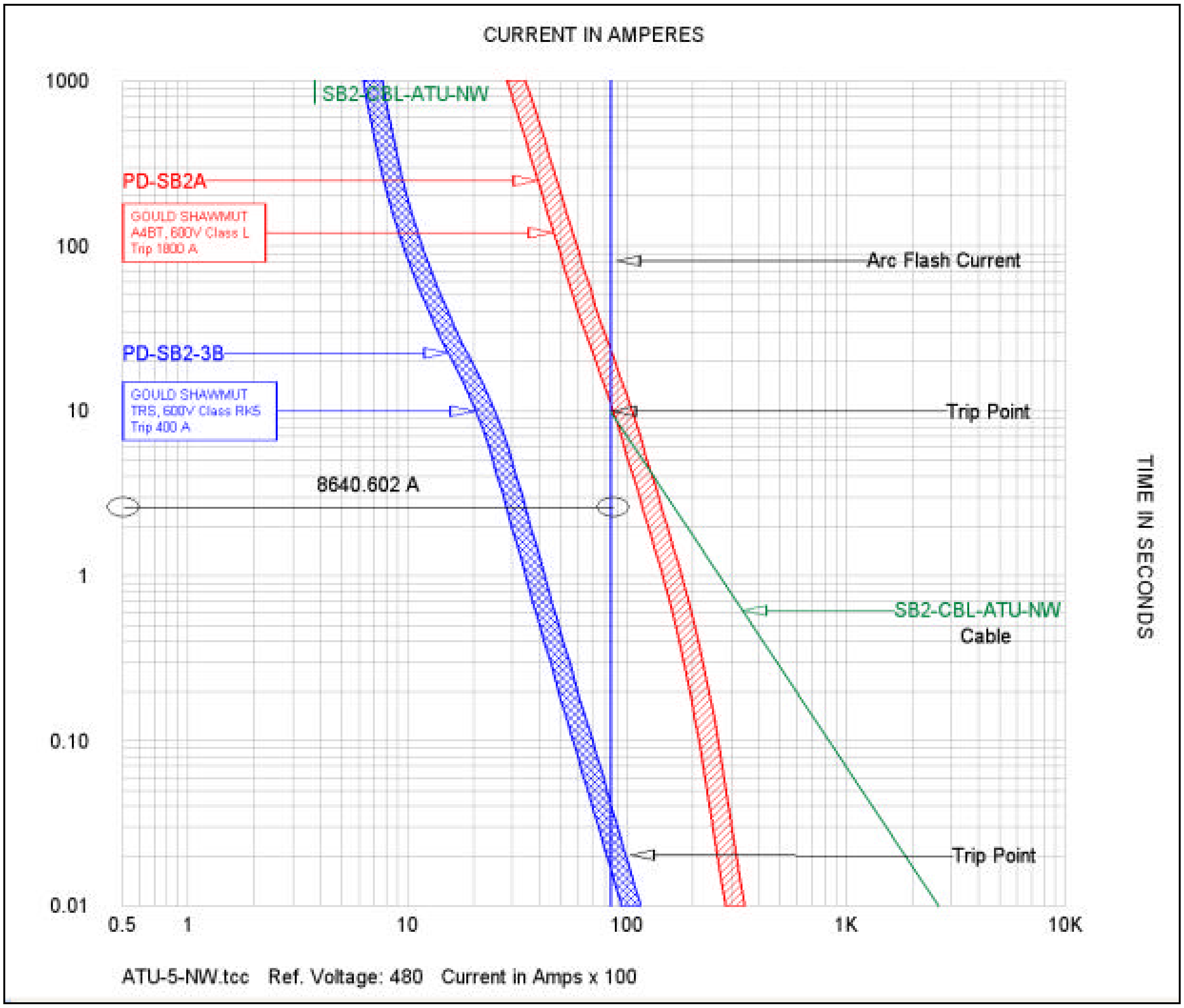
The normal short circuit study is concerned with fault interruption and the protection of equipment from the faults. Thus, the maximum available short circuit current from the utility is needed. Also, many cable lengths (impedances) are assumed to be very short or even zero. This provides a worse case analysis.

In the above the engineer always strives to produce results that are on the safe (more conservative) side. Since, the calculated short circuit current is the basis of calculating the arc fault current, it has been found that this conservative approach is inappropriate when the intent is to produce an arc flash hazards analysis.

In the study for the arc flash hazards analysis the engineer needs to be more detailed. First, the engineer needs to obtain both the maximum and minimum available short circuit current from the utility. This is often very difficult to obtain. Often all that is available is the expected short circuit current. Next, cable impedance data needs to be entered into the study using actual measured cable lengths for major cables such as the primary feeders and main branch circuits. Estimated lengths can be used for smaller feeders and branch circuits. This approach will result in a more realistic short circuit current to base the arc flash hazards analysis on.

Coordination Study

A coordination study is the examination of the electrical system and available documentation with the goal of ensuring that over-current protection devices are properly designed and coordinated. Over-current protective devices are rated, selected and adjusted so only the fault current carrying device nearest the fault opens to isolate a faulted circuit from the system. This permits the rest of the system to remain in operation, providing maximum service continuity. The study consists of time-current coordination curves that illustrate coordination among the devices shown on the one-line diagram. Note that protective devices are set or adjusted so that pickup currents and operating times are short but sufficient to override system transient overloads such as inrush currents experienced when energizing transformers or starting motors.



For an arc flash hazards analysis the overcurrent protective device data is used to determine fault-clearing times based upon the arc fault current rather than a short circuit. The length of time the arc exists along with the amount of arc fault current is used to calculate the incident energy level.

Arc Flash Hazard Analysis and Sensitivity Study

The arc flash analysis uses the arc fault current calculated from the bolted fault current determined in the short circuit analysis. This arc fault current is used along with the over-current protective device fault clearing time based upon the arc flash current. Together these two values, time and current, determine the incident energy level and arc fault boundary distances.

Once the data is prepared and a flash hazard analysis has been performed, most likely it will be discovered that category 4 PPE will be required in many places. This is most unfortunate as this type of PPE is very unwieldy to ware, hot in the summer, could be costly in terms of time taken to perform work and could potentially results in mistakes.

Prior to the new arc flash regulations, coordination studies were targeted at reliability with all settings adjusted towards the high side, i.e. minimize nuisance trips. Compliance with the new arc flash regulations means that not only does the coordination study need to be more accurate but it also needs to take into account the fact that the arc fault current is less than the bolted fault current. And that the clearing times of over-current circuit protection devices need to be fast under arc fault conditions in order to minimize energy releases.

The data can be used to perform a sensitivity study, to adjust breaker/fuse characteristics, and to lower the PPE requirement. To achieve this goal, the existing breakers may need to be replaced, generally by their more modern counterparts. Old breakers have relatively slow reaction times and will trip at too high a current. To limit the arc flash hazard the breakers are adjusted to trip earlier than before. It is expected that the outcome of this sensitivity study, when implemented, may result in most category 4 PPE requirements being decreased to category 1 or 2. The catch: can you reduce the PPE requirements enough without resulting in more nuisance trips?

The Problems

Now that the hazards associated with arc flash have been brought to our attention, we face the problem of trying to eliminate or at least reduce those hazards. The following discusses some of these problems and the subtleties in implementing corrective actions.

There are several problems in dealing with Arc Flash Analysis:

1. Being overly conservative in your short circuit analysis may result in the required PPE protection category being set at a level higher than necessary.

Category 4 PPE

The above figure is of a person in a full Category 4 suit. This suit will provide the necessary protection, but it is cumbersome to work in, it is hot, and it provides poor visibility.

The suits will make many tasks very difficult, if not impossible, to perform. Because of their restrictions to vision and movement, they may even make some tasks more dangerous. There are definitely times when this type of protection is both necessary and required, but being overly conservative will result in excessive stress to workers and unacceptable time to make repairs or adjustments.

2. Relying upon quick analysis methods can expose you to unexpected liabilities. There are a number of shortcuts being offered by individuals and companies that can have disastrous results. Be sure that your methods will stand up to analysis and peer review.

   Cure-all solutions are being promoted, such as the installation of current-limiting fuses. Pfeiffer Engineering is a firm believer in the use of fuses, particularly current-limiting types, but as will be shown below, they are not always the answer. They are definitely not a quick fix solution.

3. Being overly conservative when performing a short circuit analysis results in the misapplication of circuit protection equipment, which in turn has the consequence of calculated Arc Flash levels being higher than they actually are.

4. The calculated bolted fault or short circuit current is a worst-case calculation that assumes very low short circuit impedance. It is a short circuit connection based upon two conductors being bolted together to form the short. In reality, most short circuits are less than ideal resulting in fault currents that are less than the calculated bolted short circuit condition.

5. On the other hand, the Arc Fault should be a more predictable occurrence. The arc fault calculations assume that there is a physical gap between conductors that was bridged by something resulting in the formation of an arc. Once the arc is formed and plasma is produced, the arc current should closely approximate the calculated fault levels. The Arc Fault calculations are an approximation based upon research and testing similar to the short circuit analysis methods. They are not exact and therefore one needs to be careful when using the results.

Solution

The solution is to first perform, as accurately as practical, a short circuit analysis. The goal for most people performing a short circuit analysis has always been to error toward the conservative. For example, when a cable length was needed, it is the practice to always use the shortest practical value, which would result in higher calculated short circuit current values. When the public utility is contacted, it is the practice to only ask for the worse case short circuit value.

The overall result is that the short circuit values are always calculated on the high side. When doing a short circuit analysis for sizing the interrupting capability of protection equipment, this is the best practice. **But**, it is not the best practice when evaluating equipment for Arc Faults and establishing PPE requirements. This is an extremely significant, and quite non-intuitive, situation.

Arc Fault current ($\mathbf{I_{fc}}$) is derived from the available bolted short circuit or fault current ($\mathbf{I_{sc}}$) and is always substantially less than its corresponding short circuit current. The IEEE has established formula for calculating (estimating) the $\mathbf{I_{fc}}$ and they provide a spreadsheet. The following are example results from using their formula:

Bolted Fault Current @ 480 V	**Arc Fault Current**
10 kA	= 6.56 kA
20 kA	= 11.85 kA
30 kA	= 16.76 kA
40 kA	= 21.43 kA

What is now important is to obtain:

1. The expected maximum (worst case) bolted short circuit current.

2. The minimum and maximum voltage to the facility.

3. The minimum expected short circuit current.

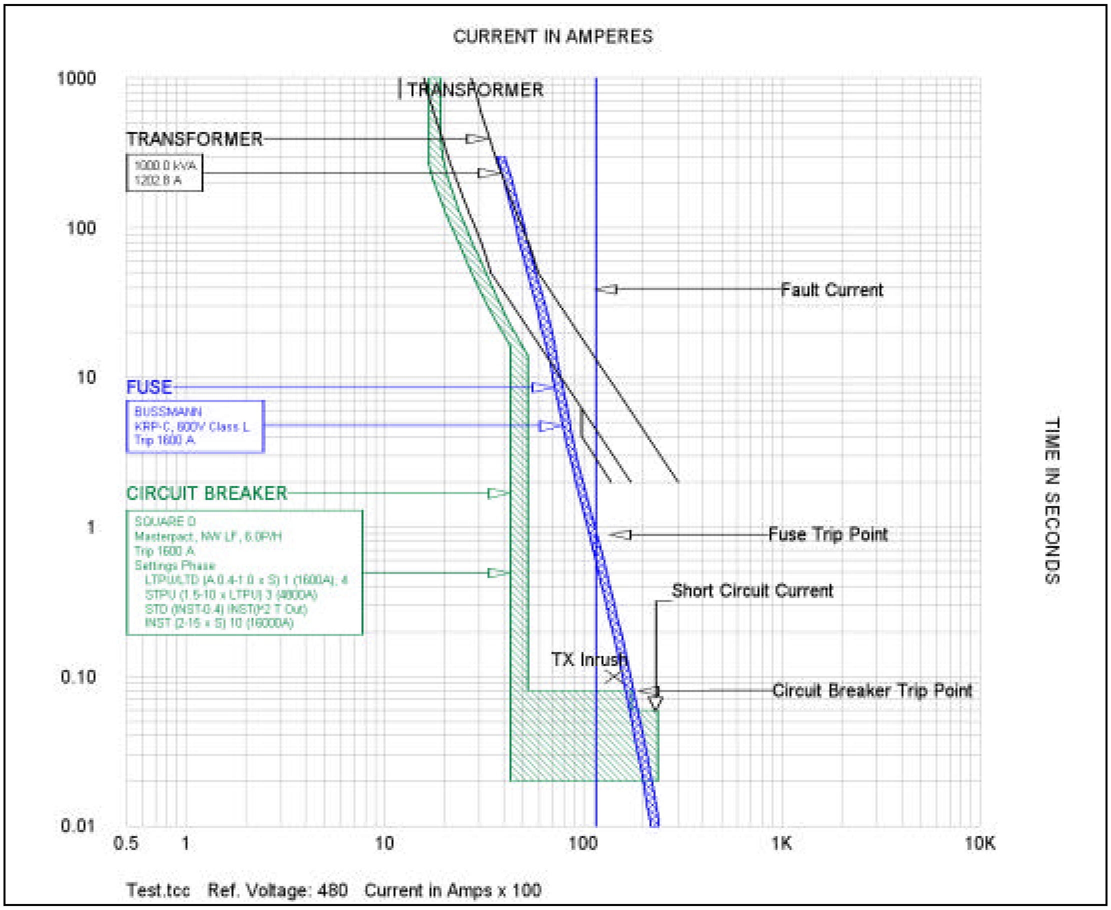
Also needed are definitions of the operating modes of the facility such as:

1. What are the minimum and maximum motor loads expected during normal operation and off-hour operation.

2. Variation in the sources of supply to the plant, such as alternate feeders or co-generation.

The data from the public utility and the determination of the facility's modes of operation should be converted into the maximum and minimum Arc Fault current at various locations in the plant. These results are applied to protective device coordination studies, where the protective devices are evaluated, and adjusted, if necessary, allowing the proper PPE categories to be determined.

The following coordination curve illustrates the point:



The figure above shows the coordination curve for the secondary of a 1000 kVA 480 V transformer. The curve shows two types of secondary protection, a fuse and a circuit breaker, each selected based upon the National Electrical Code requirements. The fuse is a KRP-C 1600A and the circuit breaker, "CB", is one with an electronic trip, such as the Square D Masterpack circuit breaker.

All transformers limit the amount of fault current that can pass through the transformer, a function of the transformer's impedance. The coordination curve shows a line for the $\mathbf{I_{sc}}$, the maximum short circuit current that can pass through this transformer (24,056 amps). The $\mathbf{I_{sc}}$ value used assumes that there actually is sufficient current available at the primary to provide 24,056 amps on the secondary.

Based upon the IEEE formula, the calculated Arc Fault current $\mathbf{I_{fc}}$ is 11,701 amps. Using these two currents and the coordination curve one can estimate the time the circuit breaker and the fuse will take to clear the fault.

Bolted Fault Condition:		
	Fuse clears in	0.02 seconds
	Circuit Breaker clears in	0.08 seconds
Arc Fault Condition		
	Fuse clears in	0.90 seconds
	Circuit Breaker clears in	0.08 seconds

From these current levels and clearing times the PPE category can be determined.

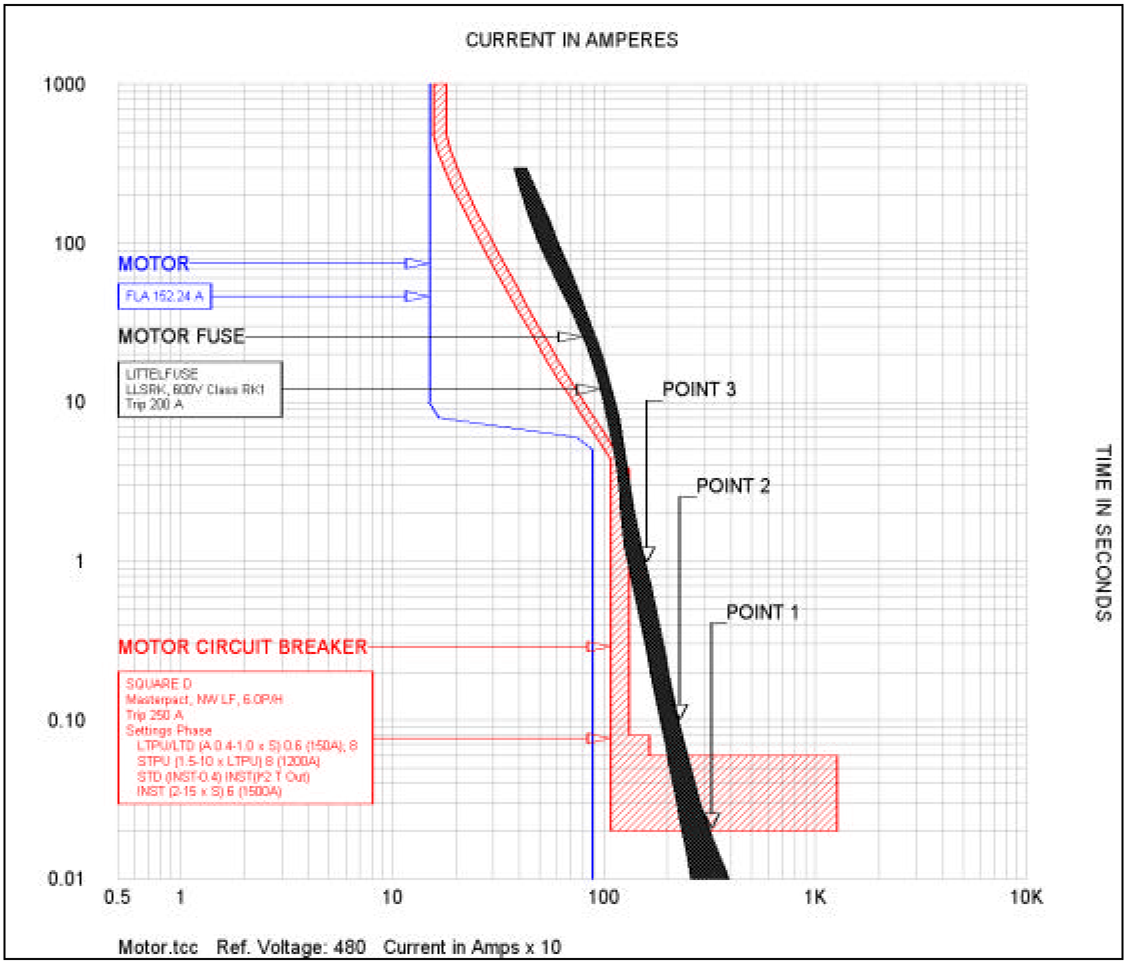
E_{mb} (Maximum in cubic box incident energy)			
	Fuse	36 Cal/cm^2	Category 4 PPE
	Circuit Breaker	2.5 Cal/cm^2	Category 1 PPE

Clearly, in this example the circuit breaker outperforms the current-limiting fuse resulting in a much lower "worker friendly" PPE requirement.

In the above example both the Arc Fault current and the Bolted Fault current are less than the current-limiting point for the fuse, which is approximately 28,000 amps. Thus, there is no current-limiting effect from using the fuse. Current-limiting fuses often do provide additional protection and they are very good devices but they must be applied properly. In this example, the circuit breaker provides the best protection.

Studying this example further, let us assume that the fuse and the circuit breaker are at the main disconnect of a facility and the facility is served by a much larger transformer where the worst-case bolted short circuit current as reported by the utility is 60,000 amps. Under this condition the arc fault current would be 30,300 amps. In this case, the fuse would open in 1/4 cycle and would limit the fault current.

The E_{mb} would equal 1.15 Cal/cm^2, which falls under a category 0 PPE.



In the next example we have a fuse and a circuit breaker protecting a 125 Hp motor. The fuse is a LLS-RK 200 A and the circuit breaker, “CB”, is one with an electronic trip, such as the Square D Masterpack circuit breaker.

There are three Arc Fault currents analyzed.

Point 1

Arc Fault Current	1600 Amps
Bolted Fault Current	3200 Amps

Point 2

Arc Fault Current	1400 Amps
Bolted Fault Current	2400 Amps

Point 3

Arc Fault Current	1100 Amps
Bolted Fault Current	1600 Amps

Results:

Point 1

Circuit Breaker clears in	.06 seconds	4.57 Cal/cm^2	PPE Cat. 2
Fuse clears in	.02 seconds	1.45 Cal/cm^2	PPE Cat. 1

Point 2

Circuit Breaker clears in	.06 seconds	4.57 Cal/cm^2	PPE Cat. 2
Fuse clears in	.1 seconds	7.62 Cal/cm^2	PPE Cat. 2

Point 3

Circuit Breaker clears in	.06 seconds	4.78 Cal/cm^2	PPE Cat. 2
Fuse clears in	1.0seconds	79.8 Cal/cm^2	PPE Cat. > 4

At an Arc Fault current of 4000 amps the fuse will begin to current-limit and will open the circuit in ¼ cycle reducing the PPE category to 0.

The three points analyzed show that a relatively small change in calculated bolted fault current has a major effect on the calculated arc fault current. This situation could easily lead to the misapplication of circuit protection equipment or inappropriate adjustment of it. It should also be noted that as the calculated arc fault current is reduced, the clearing time increases, resulting in the incident energy level increasing and thus, the PPE requirement increases.

In reality, the arc current is primarily effected by facility operating conditions, i.e. motor contribution and changes in the fault current coming from the utility. The examples illustrate that the accuracy required when calculating short currents has to be improved over traditional methods. Both reliability and arc fault conditions must now be considered when performing coordination studies.

The Risk

In a study of 33 plants with 4892 busses or switch points under 600 volts, the median incident energy was only 2.1 Cal/cm^2, however many busses had quite high incident energy levels[13]:

?? 24% of busses over 8 Cal/cm^2	PPE 2
?? 12% of busses over 40 Cal/cm^2	PPE 4
?? 5% of busses over 85 Cal/cm^2	Deadly – no protection
?? 1% of busses over 205 Cal/cm^2	Deadly – no protection

Risks to personnel include[14]:

- ?? Burns[15]
  - ## Just Curable Burn Threshold: 80°C/175°F (0.1 sec.)
  - ## Incurable Burn Threshold: 96°C/205°F (0.1 sec.)
- ?? Damaging sound levels[16]
- ?? High pressure
  - ## 720 lbs/ft^2 eardrums rupture
  - ## 1728 to 2160 lbs/ft^2 lung damage

What happens if someone gets injured or worse?

The lawyers have a field day:

- ?? The problem is now well documented
- ?? Its in the standards now
- ?? Complete adherence is not mandatory but the lawyers don't care.

Do we have any outs?

- ?? The facility owner is primarily responsible

What should you do?

For starters you should at least educate your employees about the hazards, and determine the level of arc flash hazard at the worst locations, **but** this is not enough, OSHA and the NEC do have requirements that MUST be met. They set the "standard of care". This hazard is now a *recognized hazard,* which means that you can be *held liable* if you ignore the hazards and don't comply.
You will be found in "Breach of Duty" to protect if an arc flash happens.

OSHA enforces NFPA 70E under the "General Duty Clause". A section of the US Occupational Safety and Health Act of 1970, known as the "General Duty Clause," requires employers to furnish a workplace which is free from ***recognized hazards*** which may cause or are likely to cause death or serious physical harm. OSHA 29 CFR 1910.303

So why should YOU do anything?

Legal and moral obligations and consequences.
OSHA fines:

Individuals	– up to $250,000
Companies	– up to $500,000
Imprisonment	– up to 6 months in jail

The cost in time, stress and dollars to defend a legal action against you, is severe.

We only use contractors, so why worry?

"All of our contracts have Hold Harmless clauses, which makes the contractor responsible to defend us in the event their employees get injured. So we are in the clear."

WRONG!

The facility manager is responsible to Warn of Arc Flash hazards. If a contractor's employee is injured or killed because of your lack of providing the mandated warnings and protection, you can be found liable. And you may have to pay all the costs. You may have "breached your duty" to protect. Remember. This is a recognized hazard.

Conclusions

1. Arc Fault Analysis is actually Risk Management. There are basically three choices:
   - Be very conservative and require PPE 4 in most cases resulting in higher maintenance cost.
   - Do nothing and suffer the consequences (pay later).
   - Perform the necessary analysis and make adjustments to reduce the arc fault conditions resulting in reduced PPE requirements.
2. A reduction in bolted fault current and thus a reduction in arc fault current can actually result in a worse situation. In the motor example above an arc fault current reduction from 4000 amps to 1800 amps resulted in an <u>increase</u> in arc fault energy from 0.6 Cal/cm^2 to 78.8 Cal/cm^2, exactly the opposite one would expect before doing the math. In terms of the above example coordination curves, this occurs because the arc fault current moves from the instantaneous portion at the bottom of the coordination curve to a point higher up, incurring a time delay before the device trips.
3. Overly conservative short circuit analysis will result in bolted short circuit numbers that may well result in the misapplication of circuit protection equipment.
4. It is very important to obtain the minimum available short circuit current as well as the maximum short circuit current from the electric utility. Voltage fluctuations in the plant supply should be considered when developing the short circuit calculations. The arc fault calculations need to be evaluated at more than just the worst case and the minimum case conditions. In the example above, a reduction in the arc fault current actually resulted in worse conditions. This represents a subtle, but extremely significant, change in the methodology of short circuit analysis.
5. Apart from the fines, nominal compliance with the regulations will cause workers to have to wear cumbersome PPE. This will result in little or no high voltage maintenance being performed, eventually compromising safety, equipment operation, and ultimately productivity. Arc flash is a risk management issue.
6. Have a registered professional engineering firm perform the calculations for arc flash hazards for the devices in your facility and have them recommend any necessary plans that, when executed, would result in the lowest category of PPE being required.

Note:

Short circuit analysis is based upon a number of assumptions, any or all may change over time;

1. Available short circuit current from the utility may vary, particularly in areas where there has been a significant expansion of, or change to, the electrical systems.
2. The number of motors running at the time of a fault affects the amount of short circuit current and arc fault current available (motor contribution).
3. The facility voltage often varies as a function of time of day. The utility is often more loaded during the day.

Similarly, the arc fault may also be affected by variations in any of the following:

1. The available short circuit current.
2. Dirt buildup in the equipment that may affect the conductive path.
3. Moisture (humidity).
4. Circuit supply voltage.
5. Amount of motor contribution during a fault

Definitions

Bolted Fault – Short circuit current resulting from conductors at different potentials becoming solidly connected together.

Arc Fault – Short circuit current resulting from conductors at different potentials making a less than solid contact. This results in a relatively high resistant connection with respect to a bolted fault.

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[1] "Putting Arc-Flash Calculations into Perspective" Conrad St. Pierre, EC&M June 2004
[2] NFPA 70E – 2004
[3] NFPA 70E – 2004
[4] NFPA 70E – 2004 equation reference number
[5] "Predicting Incident energy to Better Manage the Electric Arc Hazard on 600 v Power Distribution Systems," IEEE Paper, R. L. Doughty, T. E. Neal, & H. L. Floyd, II, 1998
[6] See endnote 4
[7] Derived from D.6.2(a)
[8] Derived from D.6.1(a)
[9] "Pressures Developed by Arcs," IEEE Paper, Ralph Lee, 1987
[10] See Endnote 2
[11] "The Other Electrical Hazard: Electrical Arc Flash Burns" IEEE Paper, Ralph Lee, 1982
[12] See endnote 10
[13] "A Summary of Arc-flash Hazard Calculations" D. R. Doan & R. A. Sweigart
[14] "Arcing Flash/Blast Review with Safety Suggestions for Design and Maintenance" Tim Crnko & Steve Dyrnes
[15] See endnote 10
[16] "Correlation between Electrical Accident Parameters and Sustained Injury" M. Capelli-Schellpfeffer

