ARC FLASH HAZARD ANALYSIS AND MITIGATION

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Presented to:
Western Protective Relay Conference
Spokane, WA
October 20th, 2004

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***Abstract*:** Recently enacted guidelines and regulations regarding arc flash hazards have focused industry attention on quantifying the dangers of arc flash events in energized low and medium voltage electrical equipment. Since incident energy from an arcing fault is directly proportional to the arc clearing time, reducing the arcing time is very beneficial. It results in reducing the PPE level requirements and limiting both direct and collateral damage to equipment. This paper provides an overview of arc flash hazards, arc flash calculations, and suggest a means of reducing the arc flash hazard level through faster detection and clearing of arc flash electrical faults.

I. INTRODUCTION

The last few years has seen a great increase in the awareness of arc flash hazards and the injuries that result from the lack of adequate personnel protective equipment. However, arcing faults and injuries have been around from the beginning uses of electricity. So why is it just recently that actions are being taken to define and protect against this hazard?

One factor is the exposure. Over the last 50 years our annual utilization of electricity in the United States has increased over thirteen times from approximately 255 Billion kWh to 3,450 Billion kWh (See Figure 1 below)[1]. At the same time, our utilization voltages have increased in commercial and industrial facilities to regularly include medium voltage switchgear and loads as well as on-site generation (both standby and parallel operation). With the onset of deregulation, there has also been surge in the number of facilities taking power directly at high voltages to take advantage of the lower rates available, and reduction or elimination of facilities charges. As a result, facilities employees are exposed to higher voltages and fault duties than ever before. Unfortunately, in many locations training has not kept pace with the increased hazards associated with these systems. Without adequate training, employees may not be aware of the proper procedures or have sufficient awareness of the hazards to safely perform their work. Without regular reinforcement, workers can be complacent, and increase the risk of an incident. Up to 80% of electrical incidents are caused by human error (based on review of OHSA incidents).

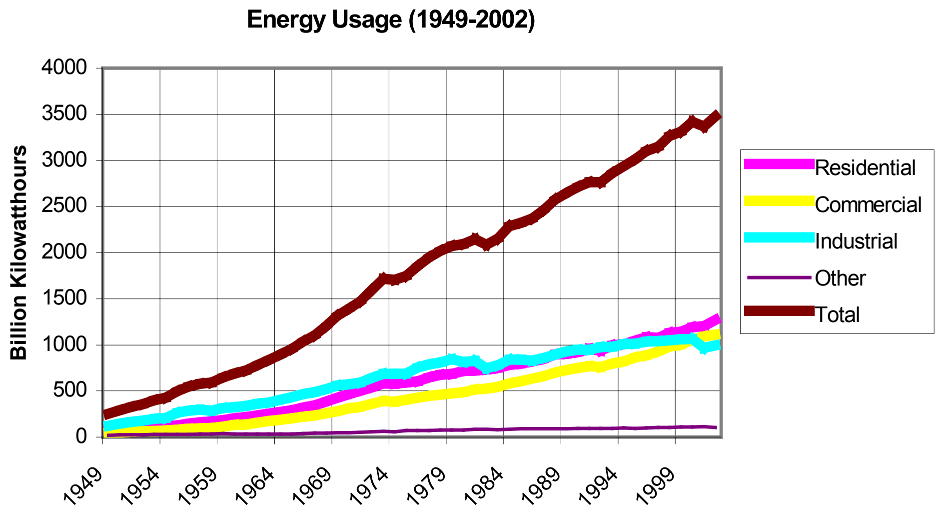

Figure 1: US Energy Utilization (1949-2002)

Another aspect of the exposure is the increased emphasis on system reliability and reducing downtime. Examinations done while energized, such as infrared investigation, power quality and load recording, and partial discharge testing are done to identify potential problems before they result in an unplanned outage. Insurance companies offer discounts if routine infrared investigations are performed.

A third factor is the liability and costs associated with incidents in terms of lawsuits, lost production and repair costs. These costs can add up to millions of dollars . Many companies and jurisdictions are adopting a preemptive approach to arc flash hazards specifically to address the potential liability.

The other major factor has been the testing and research done on quantifying the energies present in arcing faults, and improvements in personnel protective equipment (PPE) that are specifically designed for these energies. The later is important since the original uses for flame-resistant PPE was for use in petrochemical industries which have a maximum temperature near 2,800C (5,000° F). Arcing faults can have temperatures in excess of 20,000C (35,000° F).

II. SHORT HISTORY OF ARC FLASH RESEARCH

It has been almost 20 years since Ralph Lee published what most people consider the first research that could be used to assess the hazards associated with arc flash. In his 1985 paper *The Other Electrical Hazard, Electric Arc Blast Burns*, Mr. Lee was first to describe the thermal event associated with an electric arc and its effects on the human body. He defined the 1.2 cal/cm^2 "curable burn level" (defined as the lower limit for a 3rd degree burn) that is still used today and calculations to determine the curable burn distance for an electric arc in air. In 1987 Ralph Lee published another paper, *Pressures Developed from Arc*s, where he describes the sound and pressure effects of an arc in air. Included in this paper were charts to determine the pressure wave forces at various distances based on the fault duties at the location.

Two more papers were published that further defined the energies in arcing faults. The first was the 1997 paper *Testing Update on Protective Clothing and Equipment for Electric Arc Exposure*, by Bingham, Doughty, and Neal. In that paper the authors used empirical test data to determine the incident energy at various distances from a low voltage arcing fault. They were the first to express the directional effect of an arc within an enclosure. In 2000, Doughty, Floyd, and Neal published *Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600-V Power Distribution Systems*, which defined incident energy based on fault duty, working distance and clearing time for arcs in air or in an enclosure as follows:

$$E_{MA} = 5271 \cdot D_A^{-1.9593} \cdot t_A \left[0.0016F^2 - 0.0076F + 0.8939 \right] \quad (1)$$

$$E_{MB} = 1038.7 \cdot D_B^{-1.4738} \cdot t_A \left[0.0093F^2 - 0.3453F + 5.9675 \right] \quad (2)$$

Where:

E_{MA}	= Incident Energy (cal/cm^2) for an arc in open air
E_{MB}	= Incident Energy (cal/cm^2) for an arc in a box (20 in. maximum)
D_A, D_B	= Distance from the arc in inches
F	= Bolted Fault Current (kA)
t_A	= Time or arc exposure in seconds.

This work was used in the 2000 Edition of NFPA-70E *Standard for Electrical Safety Requirements for Employee Workplaces*, for use in developing safe work practices with regard to arc flash hazards, but was limited to low voltage applications. It also represented the basis for further research that resulted in the publication of IEEE Std. 1584-2002, *IEEE Guide for Performing Arc-Flash Hazard Calculations*.

III. ARC FLASH CALCULATIONS – IEEE STD 1584-2002

IEEE Std 1584-2002 contains calculation methods developed through testing by several sources to determine boundary distances for unprotected personnel and the incident energy at the working distance for qualified personnel working on energized equipment. The incident energy level can be used to determine the proper PPE required for personnel.

The equations developed in the IEEE standard assess the arc flash hazard based on the available (bolted) fault current, voltage, clearing time, equipment type, grounding, and working distance. The working voltage is also used to determine other variables. The equations have other variables that account for grounding, equipment type, and construction. This method can also determine the impact of certain current limiting low voltage fuses as well as certain types of low voltage breakers. It is an improvement over the previous work in that the calculations can be applied over a large range of voltages.

The many variables of this method make it the preferred choice for Arc-Flash evaluations, but at the same time requires either a complex spreadsheet or computer program to be used efficiently. The calculations are summarized as follows:

1. Determine the Arcing Current

For applications under 1000V

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526G + 0.5588V(\lg I_{bf}) - 0.00304G(\lg I_{bf}) \qquad (3)$$

For applications 1000V and higher

$$\lg I_a = 0.00402 + 0.983 \lg I_{bf} \qquad (4)$$

Convert from lg

$$I_a = 10^{\lg I_a} \qquad (5)$$

where:

lg	is the $\log_{10}$
I_a	is the arcing fault current (kA)
K	is –0.153 for open configurations Is –0.097 for box configurations
I_{bf}	is the bolted fault current for three-phase faults (symmetrical RMS)(kA)
V	is the system voltage
G	is the gap between conductors, (mm) (See Table 1)

Calculate a second arc current equal to 85% of I_a, so that a second arc duration can be determined.

2. Determine the Incident Energy

The following equations should be used for both values of I_a determined in the first step.

$$\lg E_n = K_1 + K_2 + 1.081 \lg I_a + 0.0011G \qquad (6)$$

$$E_n = 10^{\lg E_n} \qquad (7)$$

$$E = C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right) \qquad (8)$$

for locations where the voltage is over 15kV the Lee method is used.

$$E = 5.12x10^5 V I_{bf} \left(\frac{t}{D^2}\right) \qquad (9)$$

where:

E_n	is the incident energy (cal/cm^2) normalized for time and distance
K_1	is –0.792 for open configurations Is –0.555 for box configurations
K_2	is 0 for ungrounded or high resistance grounded system is –0.113 for grounded systems
G	is the gap between conductors, (mm) (See Table 1)
E	is the incident energy (cal/cm^2)
C_f	is a calculation factor 1.0 for voltages above 1kV 1.5 for voltages at or below 1kV
t	is the arcing time (seconds)
D	is the distance from the possible arc point to the person (mm)

x	is the distance exponent from Table 1
I_{bf}	is the bolted fault current for three-phase faults (symmetrical RMS)(kA)
V	is the system voltage

The arcing time t is the clearing time for the source-side protecting device that clears the fault first.

Table 1 – Factors for equipment and voltage classes

System Voltage (kV)	Equipment Type	Typical gap between conductors (mm)	Distance x Factor
0.208-1	Open Air	10-40	2.000
	Switchgear	32	1.473
	MCC and panels	25	1.641
	Cable	13	2.000
>1-5	Open Air	102	2.000
	Switchgear	13-102	0.973
	Cable	13	2.000
>5-15	Open Air	13-153	2.000
	Switchgear	153	0.973
	Cable	13	2.000

3. Determine the Flash Boundary

The flash boundary is the distance from an arcing fault where the incident energy is equal to 1.2 cal/cm^2.

For the IEEE Std 1584-2002 empirically derived model

$$D_B = \left[C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{E_B} \right) \right]^{\frac{1}{x}} \tag{10}$$

For the Lee method

$$D_B = \sqrt{5.12x10^5 V I_{bf} \left(\frac{t}{E_B} \right)} \tag{11}$$

where:

D_B	is the distance of the boundary from arcing point (mm)
E_n	is the incident energy (cal/cm^2) normalized for time and distance
C_f	is a calculation factor
	1.0 for voltages above 1kV
	1.5 for voltages at or below 1kV
t	is the arcing time (seconds)
E_B	is the incident energy in cal/cm^2 at the boundary distance
x	is the distance exponent from Table 1
I_{bf}	is the bolted fault current for three-phase faults (symmetrical RMS)(kA)

IV. NPFA-70E-2004 APPLICATION

In April 2004, the NFPA released an update to NFPA-70E that adopted the IEEE Std. 1584-2002 methods for determining the incident energy. The standard was renamed to NFPA 70E *Standard for Employee Safety in the Workplace* 2004 Edition. It is different from IEEE Std. 1584 with regard to arc flash in that it is used to determine the appropriate PPE based on the incident energy calculated. PPE is rated by the Arc Thermal Performance Value (ATPV) with units in cal/cm^2. The required PPE is determined by comparing the calculated incident energy to the ratings for specific combinations of PPE. An example is given in NPFA 70E as follows:

Table 2 – Protective Clothing Characteristics

Hazard/Risk Category	Typical Protective Clothing Systems	Required Minimum Arc Rating of PPE (cal/cm^2)
0	Non-melting, flammable materials (natural or treated materials with at least 4.5 oz/yd^2)	N/A (1.2)
1	FR pants and FR shirt, or FR coverall	4
2	Cotton Underwear, plus FR shirt and FR pants	8
3	Cotton Underwear, plus FR shirt and FR pants and FR coverall	25
4	Cotton Underwear, plus FR shirt and FR pants and multiplayer flash suit	40

This example should NOT be used for final calculations. For actual applications, the calculated incident energy must be compared to specific PPE combinations used at the facility being evaluated. The exception to this is the upper limit of 40 cal/cm^2. While PPE is available in ATPV values of 100 cal/cm^2 or more, values above 40 are considered prohibited due to the sound, pressure and concussive forces present. Above this level these forces are more significant than the thermal values.

V. OTHER STANDARDS

In addition to the IEEE and NFPA standards already discussed, there are other standards that apply to arc flash hazards. The 2002 National Electric Code (NEC) included a section requiring the labeling of panels with an arc flash warning.

> 110-16 **Flash Protection**
>
> Switchboards, panelboards, industrial control panels, and motor control centers in commercial and industrial occupancies that are likely to require examination, adjustment, servicing, or maintenance while energized must be field marked to warn qualified persons of the danger of electric arc flash. The marking must be clearly visible to qualified persons before they examine, adjust, service, or perform maintenance on the equipment.

Proposed wording for the 2005 NEC due out shortly will include meter-socket locations to the list of locations that need to be marked. Fine print notes in the NEC cite NFPA 70E as a guide to quantifying the hazard.

OSHA regulations represent the other major source of standards that apply to arc flash hazards. The primary regulations are in 29CFR 1910 Subparts I, and S. These can be broken down into three general areas, hazard identification and PPE selection, training, and proficiency.

1910.132(d) Hazard assessment and equipment selection.

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; Communicate selection decisions to each affected employee; and, Select PPE that properly fits each affected employee.

The employer shall verify that the required workplace hazard assessment has been performed through a written certification that identifies the workplace evaluated; the person certifying that the evaluation has been performed; the date(s) of the hazard assessment; and, which identifies the document as a certification of hazard assessment.

1910.335(a)(1)(i) Personal Protective Equipment

Employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed.

1910.132(f) Training.

The employer shall provide training to each employee who is required by this section to use PPE. Each such employee shall be trained to know at least the following: When PPE is necessary; What PPE is necessary; How to properly don, doff, adjust, and wear PPE; The limitations of the PPE; and, The proper care, maintenance, useful life and disposal of the PPE.

Each affected employee shall demonstrate an understanding of the training specified in paragraph (f)(1) of this section, and the ability to use PPE properly, before being allowed to perform work requiring the use of PPE.

1910.132(f)(3) Proficiency & Retraining

When the employer has reason to believe that any affected employee who has already been trained does not have the understanding and skill required by paragraph (f)(2) of this section, the employer shall retrain each such employee. Circumstances where retraining is required include, but are not limited to, situations where: Changes in the workplace render previous training obsolete; or Changes in the types of PPE to be used render previous training obsolete; or Inadequacies in an affected employee's knowledge or use of assigned PPE indicate that the employee has not retained the requisite understanding or skill.

The employer shall verify that each affected employee has received and understood the required training through a written certification that contains the name of each employee trained, the date(s) of training, and that identifies the subject of the certification.

Distilling the requirements from the various standards yields the following requirements.

1. The arc flash hazard must be assessed
2. Appropriate PPE must be selected for non-prohibited work
3. The results must be documented
4. Personnel must be trained, understand the hazards, and take appropriate action.
5. Analysis should be revaluated if the standards, PPE types, or system configuration changes.

Documenting the results occurs in two forms. The first is the site safety manual. The Safety manual should include the results of the calculations, and required PPE classifications for each location, complete descriptions of the PPE classifications, and procedures associated with performing energized work. The second is labeling at the locations where energized work is to be performed. In order to meet the requirements of the relevant standards, more than just a warning is necessary. The following are two examples of labels generated using the arc flash module in a power systems analysis software package.

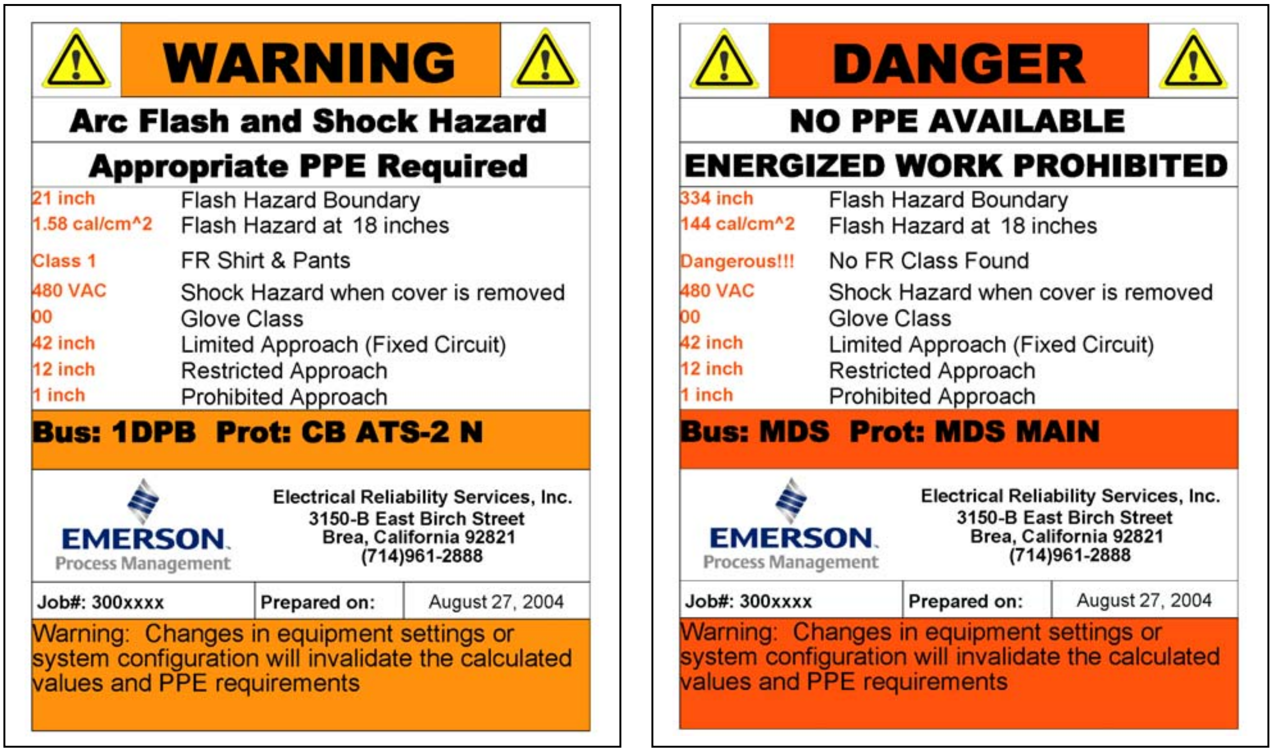

Figure 2: Sample Arc Flash Labels

The left hand label indicates a Class 1 protection (using the NPFA 70E example categories) and the label on the right indicates prohibited work (incident energy is far above the 40 cal/cm^2 limit for energized work). Note that in the right hand label, the text and the color of the label changes to indicate the prohibited status of location. The labels show the calculated flash protection boundary, incident energy and PPE category (with description). In addition to the incident energy information the label also includes required glove classification and the shock protection boundaries required by NFPA 70E. The flash and shock boundaries are broken down as indicated in Figure 3

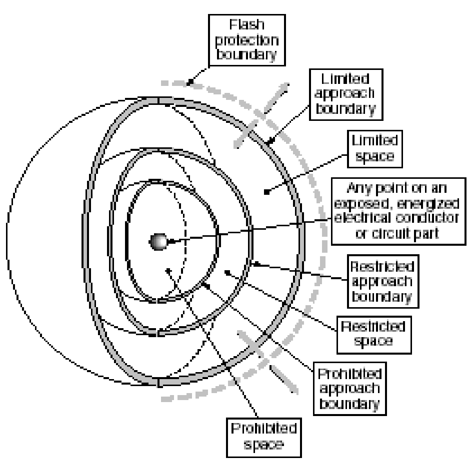

Figure 3: Flash and Shock Approach Limit Regions

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. Appropriate flash-flame protection equipment must be utilized for persons entering the flash protection region.

Limited Approach Boundary. An approach limit at distance from an exposed live part within which a shock hazard exists. A person crossing the limited approach boundary and entering the limited region must be qualified to perform the job/task.

Restricted Approach Boundary. An approach limit at a distance from an exposed live part within which there is an increase risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part. The person crossing the Restricted approach boundary and entering the restricted space must have a documented work plan approved by authorized management, use PPE that is appropriate for the working being performed and is rated for voltage and energy level involved.

Prohibited Approach Boundary. An approach limit at a distance from and exposed live part within which work is considered the same as making contact with the live part. The person entering the prohibited space must have specified training to work on energized conductors or live parts. Any tools used in the prohibited space must be rated for direct contact at the voltage and energy level involved.

VI. ARC FLASH HAZARD ASSESSMENT

In order to complete an arc flash assessment using the IEEE detailed methodology for a specific location there are five items required.

1. Available fault current at the location.
2. Clearing time for the source-side protective device at the calculated arcing fault current.
3. Working distance for energized work.
4. APTV values for PPE combinations use at the site.
5. Site specific issues and limitations (egress, process)

The first two items are generally obtained from short-circuit and protective device coordination studies. In order for the results to be accurate, the study must be complete and up to date. However, unlike most short-circuit and coordination studies, accurate installed source information instead of worst case information is required. Based on IEEE 1584, the limits of the study are defined as all location 240V and higher, and 240V locations served by 125kVA and larger transformers. Locations that fall outside this scope, but covered by NEC 110.16 still require a label, but detailed calculations are not required. For smaller radial systems with just a few locations that need to be assessed, a spreadsheet can be used. Larger more complex systems with multiple sources are best handled with computer software specifically designed to perform arc flash calculations.

The third through fifth items are generally obtained though working with site personnel and investigating the installed equipment configuration. Working distances are generally set at 18 inches for low voltage locations. Medium voltage locations have working distances set based on procedures and equipment configurations. These distances must be documented prior to finalizing the assessment. Site specific PPE descriptions and combinations (and the associated ATPV) are also required to complete the assessment. These PPE descriptions must also be included in the site safety manual.

Site specific installation data is collected to take into account any installed conditions that may increase the hazard/risk. This can include continuous process or chemical installations where an arc fault may increase the risk of other hazards. It also must take into account the physical location with respect to egress. Locations where the flash hazard boundary exceeds the limits of an electrical vault or room, or are elevated, may increase the risk due to limited egress.

When performing the assessment, it may be determined that some locations would require extreme protective equipment (i.e. a flash suit) or be classified a prohibited work area. There are three areas where mitigation can be utilized to reduce the incident energy to workable levels.

VII. TRADITIONAL METHODS FOR REDUCING ARC FLASH HAZARDS

Reducing the Arcing Current

Certain protective devices are current limiting in design. By limiting the current available for a fault there is a corresponding reduction in the incident energy for clearing times that are short in duration (1-3 cycles). Fault duties at these devices must be in the current limiting range for them to be effective (typically at least 10-15 times the device rating).

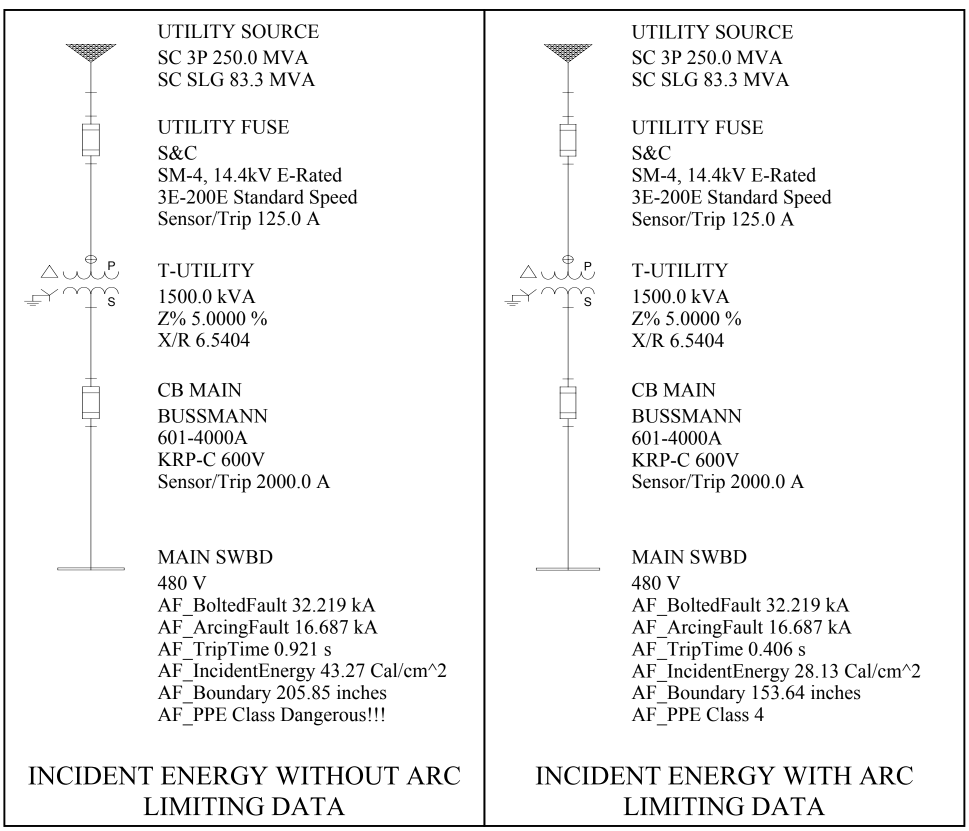

Figure 4: Effect of Arc Limiting Data on Incident Energy

In order to be used for determining the incident energy based on the IEEE 1584 calculation methods, test data is required to provide the coefficients for the simplified equations. Fault currents below the current limiting range are analyzed like non-current limiting devices (based on the time-current characteristics). At present other than the data presented in IEEE 1584 with regard to certain low voltage fuses (Class L and RK1 fuses from one manufacturer), there is practically no test data available. Figure 4 below shows the results of applying the arc limiting data, incident energy was reduced from a prohibited location (43.27 cal/cm^2) to Class 4 (28.13 cal/cm^2).

Increasing the Working Distance

Since the incident energy is proportional to the square of the distance (in open air), increasing the working distance will significantly reduce the incident energy. Working distance can be increased by using remote racking devices, remote operating devices, and extension tools (i.e. hotsticks). Figure 5 below shows the impact of using a remote device to increase the working distance from 18 inches (Class 3, 12.62 cal/cm^2) to 72 inches (Class 1, 3.28 cal cm^2).

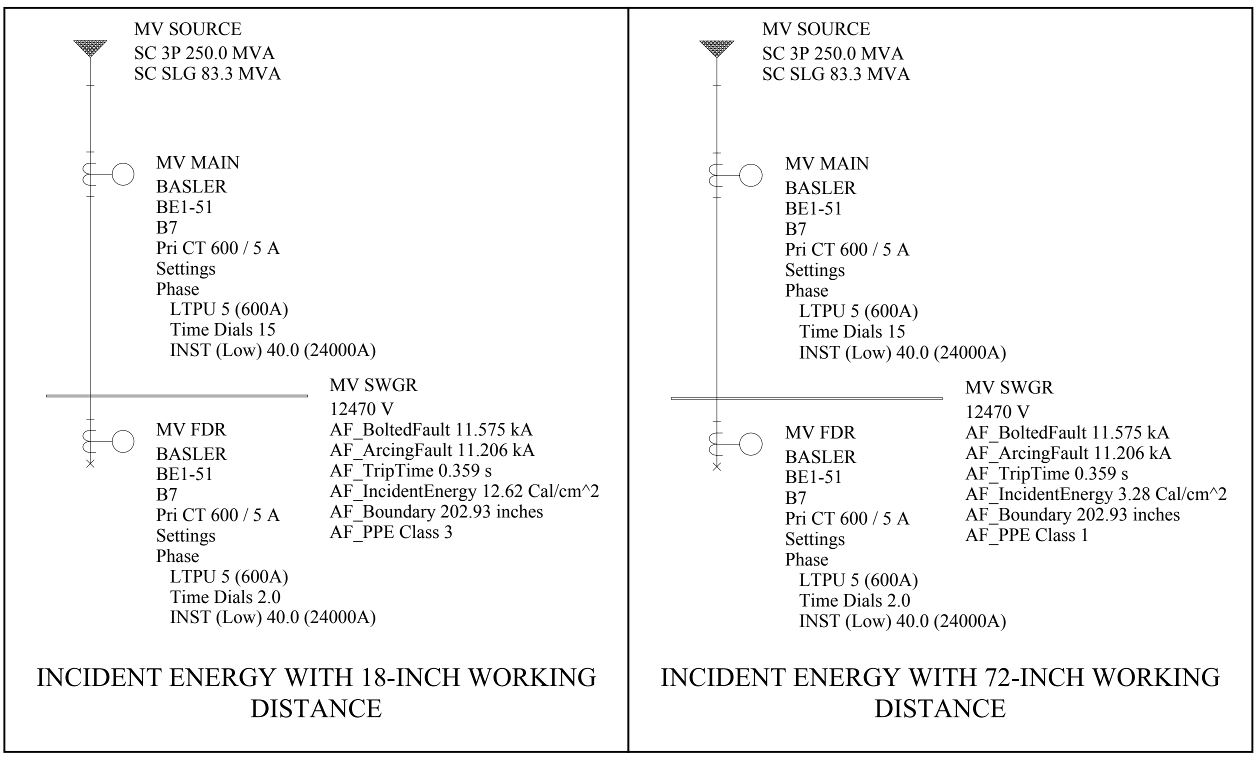

Figure 5: Effect of Working Distance on Incident Energy

Reducing the Clearing Time

Traditional methods to reduce clearing times include: lowered device settings (permanently or temporarily), bus differential protection, and zone selective interlocking (typically low voltage only). It should be noted that the calculations assume that the protective devices are set in accordance with the study, and that the devices operate properly. Figure 6 shows calculations that represent the difference between a low voltage breaker that operates properly and the same configuration where the main protective device fails to operate. Failure of the mains to operate results in a doubling of the incident energy from 38.7 to 78.1 cal/cm^2. Multiple failures of protective devices would result in further increases in the incident energy and the likely complete loss of the equipment.

An alternative to permanently lowering coordinated settings is to temporarily reduce settings for only the time during which on-line work is performed. Locations with microprocessor-based relays can be programmed to implement lower settings (i.e. an instantaneous setting just above the peak demand level) with a contact input, such as a front panel control and/or SCADA control. The disadvantage of this technique is that it results in nonselective operation for downstream faults during the maintenance window.

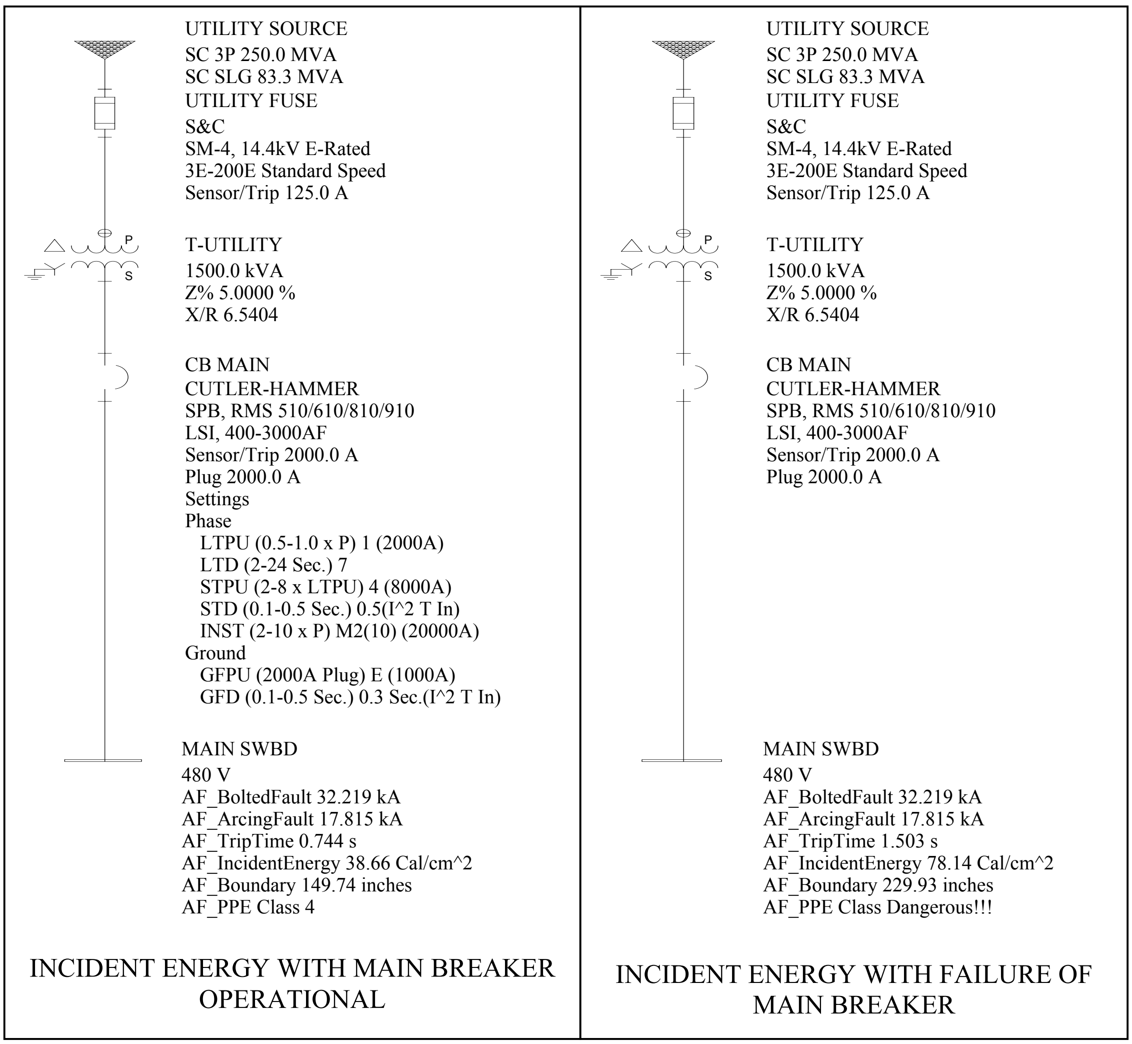

Figure 6: Effect of Mains Failure on Incident Energy

Lowering device settings is the least cost solution to lowering the incident energy, but is limited by the range of available settings that will still achieve selective operation. In medium voltage relaying, this can be achieved by changing the curve shape or lowering the time dial settings. Low voltage protection changes are more limited due the device characteristics. Figure 7 shows one example of changing the settings to improve the incident energy. The incident energy was reduced from a Class 4 (38.7 cal/cm^2) to Class 3 (19.8 cal/cm^2).

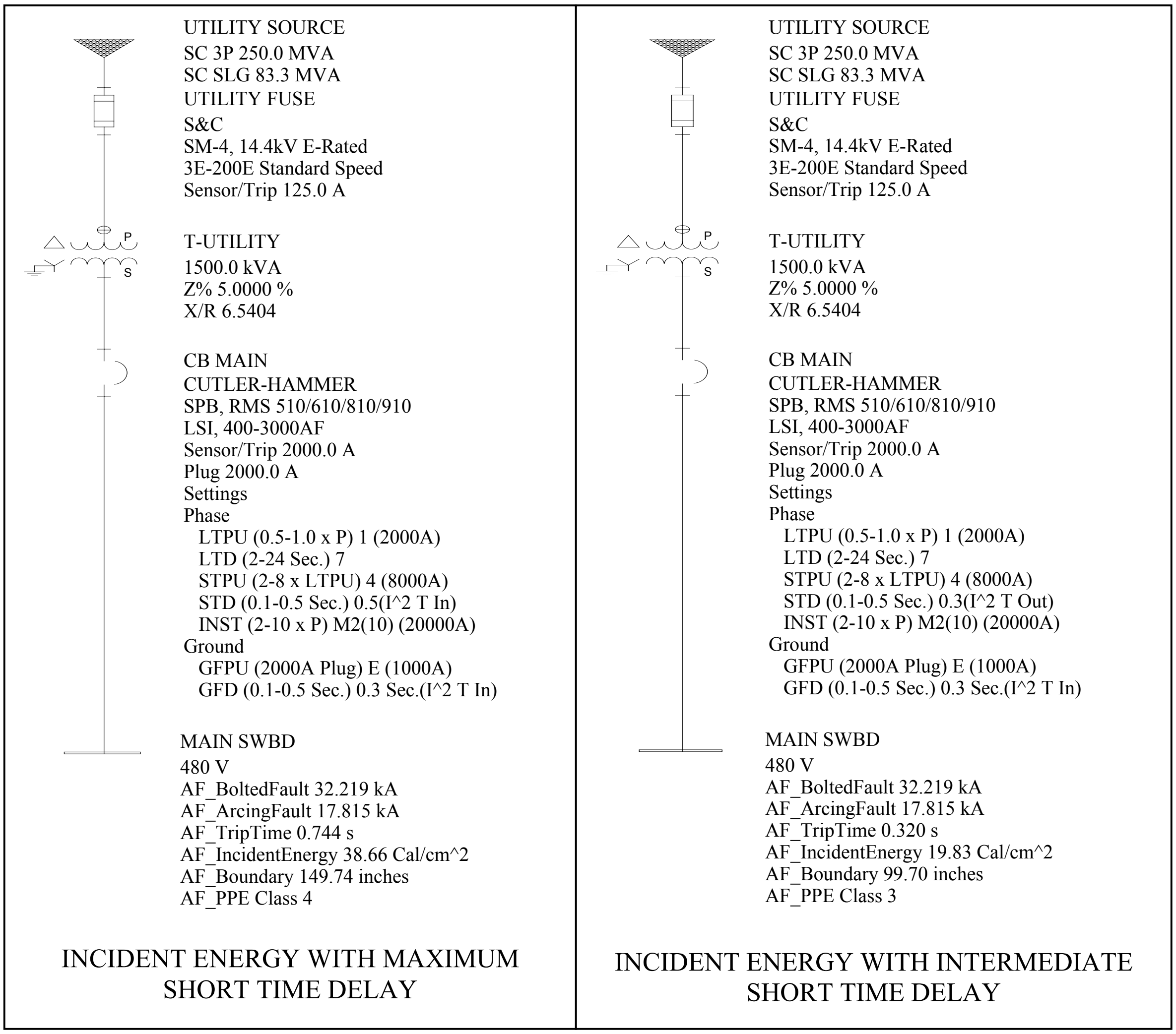

Figure 7: Effect of Reduced Main Breaker Settings on Incident Energy

Zone selective interlocking (ZSI) and bus differential protection are two methods to detect bus faults and quickly clear the fault to minimize damage. The zone selective interlocking (typically low voltage breaker only) uses a communications signal between zones of protection. For a through fault the downstream protection sends a blocking signal to the upper level breaker, allowing normal time selective operation. For an in zone fault, no blocking signal is sent and the time delay (usually for short time and ground fault protection only) is reduced to the minimum setting for the trip unit (typically 100 ms plus the breaker response). ZSI is not generally available as a field modification, and so cannot be used for installed systems.

Buss differential protection is faster than ZSI (2 cycles or less plus breaker response), but can be retrofit to existing systems. It is expensive to install due to the number of current transformers that must be installed.

Using the example in Figure 7 and assuming a clearing time of 150ms for ZSI and 100ms for buss differential protection, the incident energy is reduced from 38.7 cal /cm^2 to 9.3 cal/cm^2 and 5.6 cal /cm^2 respectively.

VIII. NEW STRATEGIES FOR REDUCING ARC FLASH HAZARDS

Arc Flash Detection Principles

An arc flash fault typically results in an enormous and nearly instantaneous increase in light intensity in the vicinity of the fault. Light intensity levels often rise to several thousand times normal ambient lighting levels. For this reason most, if not all, arc flash detecting relays rely on optical sensor(s) to detect this rapid increase in light intensity. For security reasons, the optical sensing logic is typically further supervised by instantaneous overcurrent elements (ANSI device 50) operating as a fault detector. Arc flash detection relays are capable of issuing a trip signal in as little as 2.5 ms after initiation of the arcing fault.

Arc flash relaying compliments existing conventional relaying. The arc flash detection relay requires a rapid increase in light intensity to operate and is designed with the single purpose of detecting very dangerous explosive-like conditions resulting from an arc flash fault. It operates independently and does not need to be coordinated with existing relaying schemes.

Responses to Arc Flash Faults

Once the arc flash fault has been detected, there are at least two design options. One option involves directly tripping the upstream bus breaker(s). Since the arc flash detection time is so short, overall clearing time is essentially reduced to the operating time of the upstream breaker. A second option involves creating an intentional three-phase bus fault by energizing a high-speed grounding switch. This approach shunts the arcing energy through the high-speed grounding switch and both faults are then cleared by conventional upstream bus protection. Because the grounding switch typically closes faster than the upstream breaker opens, this approach will result in lower incident energy levels than the first approach. However, it also introduces a second three-phase bolted fault on the system and it requires that a separate high-speed grounding switch be installed and operational. Assuming there is space available for the addition of the grounding switch, there is a significantly higher cost of implementation involved compared to the first approach, and so may not be a practical alternative, especially for existing switchgear lineups.

The Fiber Optic Solution

A new and novel approach to arc flash detection uses the optical fiber itself as the arc flash sensor. The optical fiber can be up to 60 meters (about 200 ft) long. It uses a plastic fiber with a glass core and is routed throughout all high voltage compartments where an arc could potentially occur. A typical fiber routing in two-high switchgear construction is shown in Figure 8. Single-high construction is handled in a similar manner.

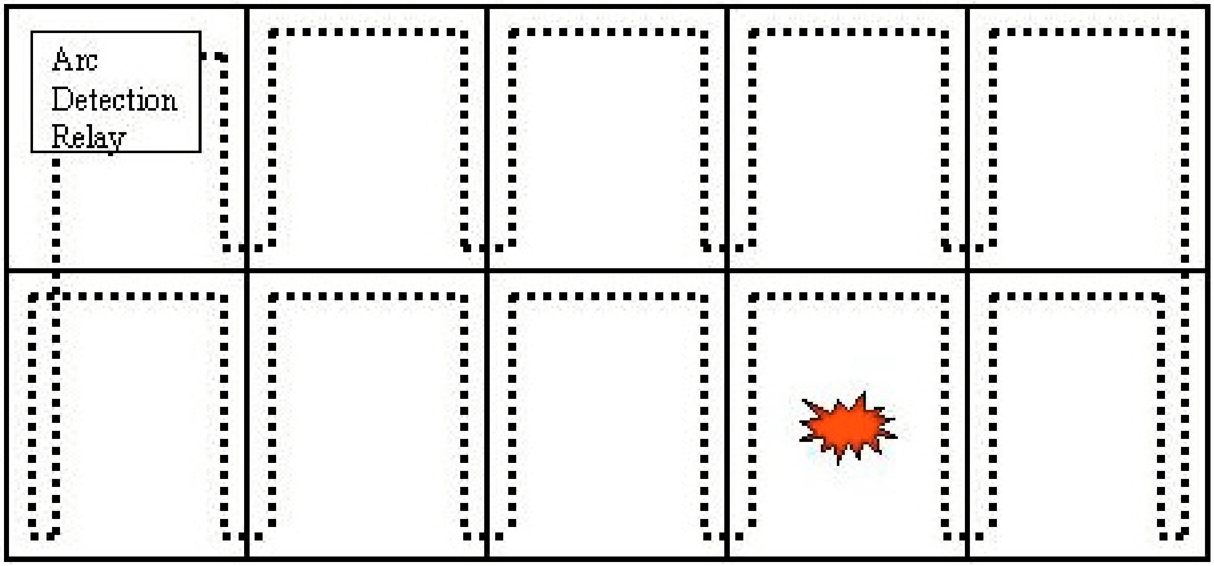

Figure 8: Typical Optical Fiber Routing

Unlike communication fibers, this optical sensor fiber has no cladding to prevent ambient light from entering the fiber. In fact, the system depends on external light to operate. The fiber is a plastic outer sheath with a glass core making it suitable for harsh environments. The minimum bending radius is about 2 inches. Wherever the fiber is exposed to an arc flash, the flash will be captured and the rapid increase in received light intensity will be detected by the relay. No galvanic wires or conventional photocells need to be installed in the high voltage compartments. It is not necessary to loop the fiber as shown in Figure 8 however looping is recommended. If looped, the continuity and integrity of the fiber sensor can be continuously monitored by the system. This is done by periodically sending a test pulse through the fiber loop. If this test pulse is not received at regular intervals, the Internal Relay Failure (IRF) alarm activates.

The relay's sensitivity to light may be adjusted manually or controlled automatically. When set to automatic mode, it continually adjusts its threshold sensitivity to the relatively slow-changing background lighting levels that might result from opening a compartment door. Manual light intensity level settings may be more appropriate where some normal low-level arcing might take place such as in older air-magnetic switchgear.

The optical arc flash system may be supervised by single-phase fault detectors (ANSI device 50). Fault detector supervision is selectable but recommended by the manufacturer for most applications. It provides additional security at a cost of only about 2 ms in operating time. If both optical and electrical systems indicate an arc-flash fault, the relay issues a trip signal. Figure 9 shows a block diagram overview of this arc-flash detection relay.

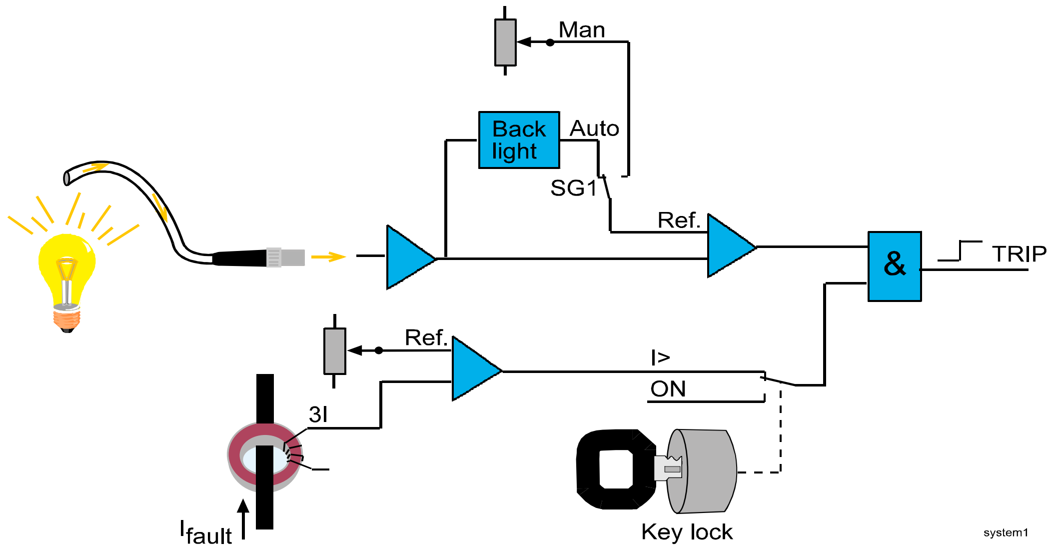

Figure 9: Arc Detection Relay Block Diagram

Two high-speed solid-state output relays and one conventional normally-open dry-type contact are provided for tripping. Overall operating times vary from about 2 ms to about 9 ms depending on the whether fault detector supervision is used and whether the solid-state or dry contact trip contacts are used. Operating times for various combinations are shown in Figure 10.

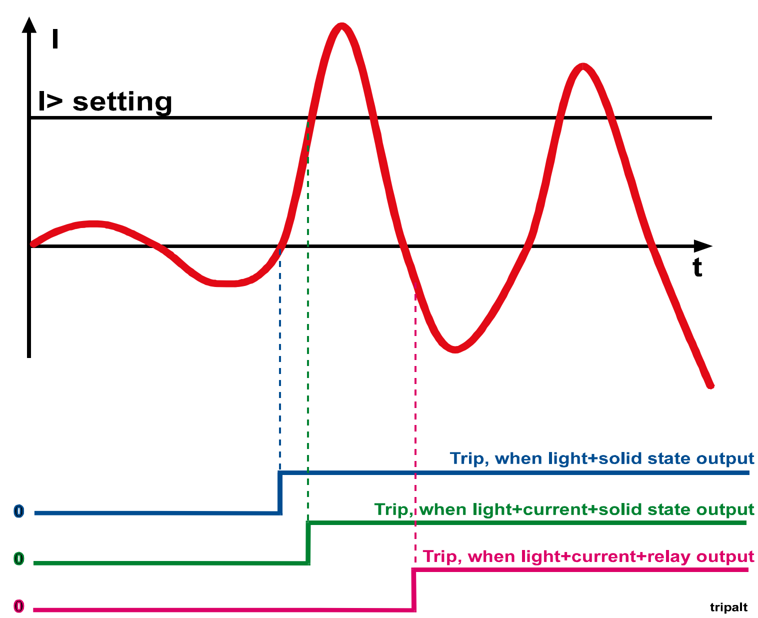

Figure 10: Operating Time Comparisons

IEEE 1584 clearly states that the worst case incident energy level may not occur at the bolted fault current point. Figure 11 is intended to show why that is true. With backup protection consisting of a combination of time overcurrent (ANSI device 51) and instantaneous protection (ANSI device 50), low level fault currents can easily result in higher incident energy levels because the clearing time is so much longer. The additional clearing time more than offsets the lower arcing current to produce a higher incident energy and therefore a more hazardous situation. Once the arcing current exceeds the instantaneous setting, incident energy levels drop dramatically.

The arc flash detection relay provides nearly instantaneous tripping regardless of the magnitude of fault current. Because there is no coordination requirement, clearing time is essentially reduced to the operating time of the backup breaker. This example clearly shows the importance of minimizing clearing time throughout the range of arcing currents.

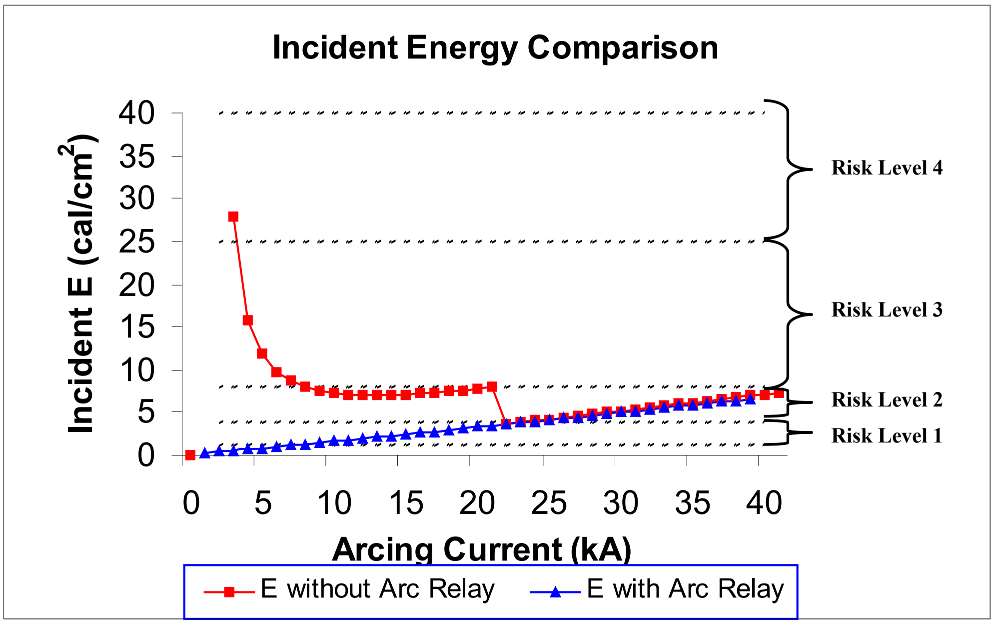

Figure 11: Incident Energy Levels with Backup Instantaneous and Time Overcurrent Protection

Extension Units

Although a 200 foot optical fiber loop is probably adequate to cover most applications, additional coverage may be added with extension units that can be connected in daisy-chain fashion to the central unit. Up to 20 additional fiber loops, each extending up to 200 feet, may be connected for a total effective sensor length of over 4,000 feet. Alternatively, the extension units may be used for more selective or coordinated tripping.

A simple single-loop application is shown in Figure 12 below. This example uses a single optical fiber sensor covering four separate feeders. If an arc flash is detected and the fault detector threshold is exceeded in at least one phase, both high-side and low-side breakers are tripped via the high-speed solid state tripping relays.

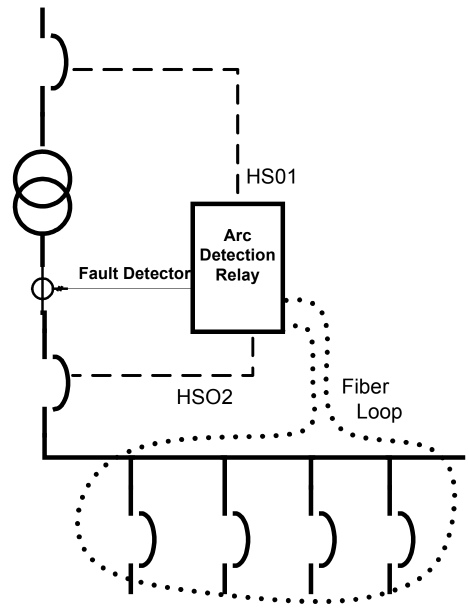

Figure 12: Single Fiber Loop Layout

Figure 13 shows a slightly more complicated layout. In this example, a different version of extension unit is added to provide independent arc flash detection for downstream faults. The extension unit will trip the associated feeder breaker if an arc flash is detected by its loop sensor. At the same time, it will communicate to the central unit that a downstream trip has been issued. If the fault is not cleared within the programmed time (selectable for either 100 ms or 150 ms), the central unit will trip its associated breakers, thereby providing coordinated arc flash backup protection and selective fault clearing.

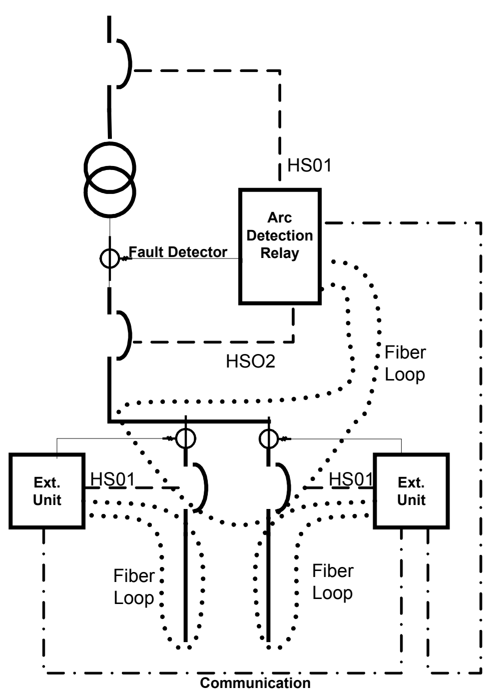

Figure 13: Example of Selective Tripping

Conclusions

This paper has described the process of arc flash hazard analysis, including the calculation of incident energy levels in arc flash faults and selection of appropriate Personal Protective Equipment (PPE) levels.

One of the easiest and most cost effective means of limiting arc flash hazards is accomplished by limiting the arcing time using a dedicated arc-flash detection relay

Arc Flash detecting relays typically reduce the arc-flash incident energy by nearly instantaneous detection of the arc-flash using optical sensors. This provides faster tripping of upstream breakers for arc-flash faults, minimizing the arcing time and thereby reducing the incident energy level in the fault. This also results in a reduced personnel protective equipment (PPE) level required to work near the energized electrical equipment.

A dedicated arc flash detection relay using non-galvanic fiber loop sensor(s) was described. This relay may be easily retrofitted to existing equipment without introducing conductive materials in high voltage compartments. This relay provides a minimally intrusive and relatively inexpensive means of detecting the arc flash and can clear such faults much faster than traditional relaying schemes because coordination time is eliminated.

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