ARCING FLASH/BLAST REVIEW WITH SAFETY SUGGESTIONS FOR DESIGN AND MAINTENANCE

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***Abstract* - Significant engineering and test efforts have been undertaken in the last few years into the area of arc flash/blast hazards in electrical equipment. The result has been a better understanding of arcing faults and how to prevent and/or minimize the hazards to personnel and equipment. This paper highlights some of the findings that may help in safety management and equipment selection. This paper concludes with some design considerations that will help reduce the hazards of arcing faults.**

Index terms - current-limiting fuses, arc flash, arc burn, arcing faults, incident energy, arc burn prevention, electrical safety, circuit breakers

I. Introduction

In recent years, significant progress has been made in understanding the hazards of arcing faults to maintenance personnel working on electrical equipment. The National Electrical Code® (NEC®) requires that equipment be installed the way it is listed and labeled. However, the NEC® and product standards do not address the hazards associated when the equipment doors are open and a maintenance worker accidentally creates an arcing fault.

Numerous workers are injured and killed each year while working on energized equipment. To address this, the IEEE/Petroleum and Chemical Industry Committee formed an ad-hoc working group within their safety committee with the intent to raise awareness of electrical workers to the hazards associated with arcing faults. The ad-hoc group consisted of ten members, of which one was a medical doctor with electrical burn expertise, two were consulting engineers, four were engineers for petro-chemical companies, and three were from an electrical manufacturer. Tests were run at a high power test lab and analytical information was gathered to quantify the hazards associated with arc faults. Subsequently, other IEEE papers by various authors have resulted in providing even more knowledge. Arcing faults have many variables and the predictability is not certain. However, the work by many on this subject provides some good engineering analytical tools. These efforts have also resulted in industry awareness, safety training program materials[1], and design guidelines for electrical systems designs.

II. Arc Fault Hazards

Arc faults can cause serious injury or death to workers. At the initiation of an arc fault, tremendous energy can be released in a very brief time. Metal conductor parts can vaporize resulting in hot vapors and hot metal being violently spewed. The thermal energy can result in severe burns to workers caused by direct exposure or by igniting clothing. The rapid thermal escalation of the air and vaporization of metal can create a very loud explosion and tremendous pressures. This can result in ruptured eardrums, collapsed lungs, and forces that violently knock workers back.

An arcing fault is the passage of substantial electric currents through air and typically the vaporized arc terminal material such as copper. Arcing involves high temperatures of up to or beyond 35,000°F at the arc terminals [2]. This is approximately four times the surface temperature of the sun. The pressures created by an arc fault are extremely explosive. Pressure is generated by expansion due to metal vaporization and the rapid heating of the air by the arc passing though it. Copper vapor expands to 67,000 times the volume of solid copper. For example, 16.39 cm^3 (1 $inch^3$) of copper vaporizes into 1.098m^3 (1.44 yd^3) of vapor [3]. The air in the arc stream expands in heating up from ambient to that of the arc at about 35,000°F [3]. The vaporization of metal and heating of the surrounding air results in a very rapid blast due to the high pressure. In incidents, workers have been knocked off ladders and thrown across rooms. One positive consequence of high blast pressure of arcing faults is that it can reduce the time a worker is exposed to the arc flash temperatures. A serious hazard is that this explosion of metal and air results in propelling molten metal and equipment parts from the incident point.

Many IEEE members have contributed by conducting extensive tests under various conditions. For instance, it has been demonstrated through arc fault tests where the temperature and pressure were measured, that current-limiting overcurrent protective devices not only limit the damage to circuit components but can also measurably reduce personnel exposure to serious injury. "Staged Tests Increase Awareness of Arc-Flash Hazards in Electrical Equipment"[1] presented experimental results of tests simulating workers being exposed to various arcing flash/ blast hazards in the test cell. These tests initiated arc faults under controlled conditions with various circuit components. Mannequins were used to simulate personnel working on the equipment. Measuring devices were placed on the mannequins at various locations as well as other points in the test cell to determine temperatures, the sound decibels and pressures (reference figure 1).

Fig. 1 Mannequins set up in test cell [1]

These test measurements can be compared to certain injury thresholds for each parameter to determine what the effect would have been to a human worker. In "The Other Electrical Hazard: Electric Arc Blast Burns"[2], authored by Ralph Lee, it is determined that skin subjected to temperatures above 96° C/205° F for .1 second resulted in total destruction of the tissue (incurable burn) and skin subjected to temperatures below 80° C/176° F for .1 second allowed for skin that can be cured [2].

Damage to ear drums, lungs, brain, and central nervous system can result from the blast pressure of arcing faults. In "Correlation Between Electrical Accident Parameters and Sustained Injury" [4], the authors cover these aspects. In this referenced paper [4], values are provided for fast-rising 400msec duration overpressures as 720 lbs/ft^2 threshold for eardrum rupture and 1728 to 2160 lbs/ft^2 threshold for lung damage.

The total force exerted on a worker's body due to an arcing fault blast is dependent on the body surface exposed to the blast wave. For instance, if the upper body is exposed at approximately 3 sq. ft. and the blast pressure is 500 lbs./sq.ft., then the total force the worker experiences would be 1500 lbs. The potential health risks to a worker due to the total forces exerted on his/her body depends on the worker's situation. A worker standing on the floor would most likely be able to safely withstand more pressure than a person on a ladder. A worker on a ladder or working from a scaffold or bucket increases their health risks due to injury from falling.

In "Staged Tests Increase Awareness of Arc-Flash Hazards in Electrical Equipment"[1], 23 tests were sited under various circumstances. Three tests are highlighted in this paper to illustrate the serious hazards of arcing faults and some means to reduce these hazards. The following Test No. 4, Test No. 3, and Test No. 1 referenced in this paper are the same test numbers documented in "Staged Tests Increase Awareness of Arc-Flash Hazards in Electrical Equipment"[1]. These three tests illustrate the potential consequences of arcing faults to workers in terms of temperature, pressures, and sound levels. In addition, the results show that the size and type overcurrent protective device can effect the outcome when an incident occurs.

Figure 2 is the one-line for test No. 4 simulating a 600 ampere feeder to a combination motor starter. The available fault current is 22,000 rms symmetrical amperes. The circuit breaker used has a 640 ampere setting and this circuit breaker is equipped with a short-time delay of twelve cycles. However, the test lab interrupts the circuit at six cycles which simulates the circuit breaker having a short-time delay of six cycles. The fault is initiated on the line-side of the 30 ampere UL Class RK1 fuses that are protecting the motor branch circuit. This simulates a worker causing a fault in the combination starter on the line-side of the branch-circuit device; consequently the feeder overcurrent protective device is the device that is required to react. Figures 3 and 4 are photos of the test cell for Test No.4 during the fault condition. The mannequin simulating "working on the equipment" is totally engulfed in the arc flash/blast. The mannequin at the lower right simulates a coworker several feet from the equipment. The results are shown in figure 5: the pressure of greater than 2160 lbs./ sq. ft. (pressure measuring instrument pegged) would exert potentially over 6,000 pounds of force against a workers chest, violently flinging him backwards and damaging his lungs. There is a high likelihood that a worker's eardrums would have incurred damage. The temperature on the hand at point of fault (T1) and neck (T2) areas pegged the measuring instruments at greater than 225° C/437° F, which would probably have resulted in serious burns to the hand and neck. The temperature of the chest under the shirt was 50° C/122°F, which should not cause any skin damage on the chest (tests and results from [1]).

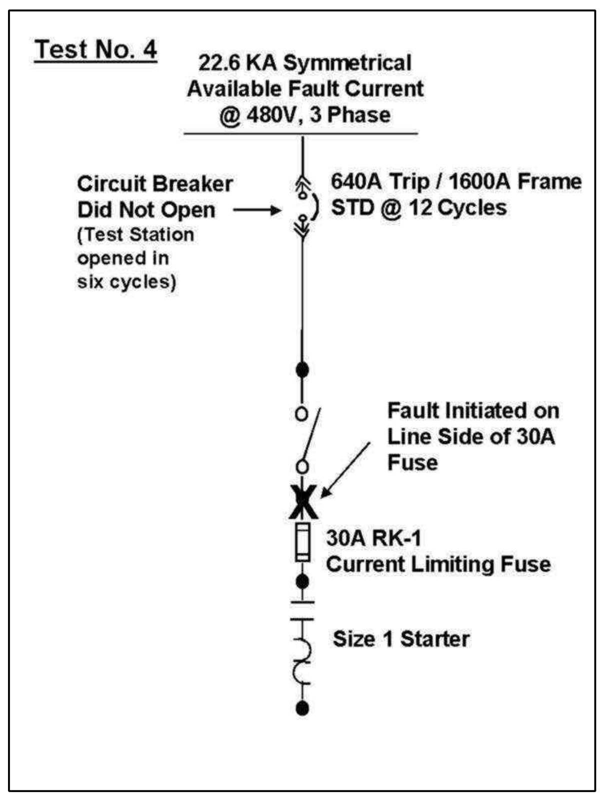

Fig. 2 - Test No. 4 One-line

Fig. 3 - Photo of Test No. 4 during test

Fig. 4 - Another photo of test No. 4 during test

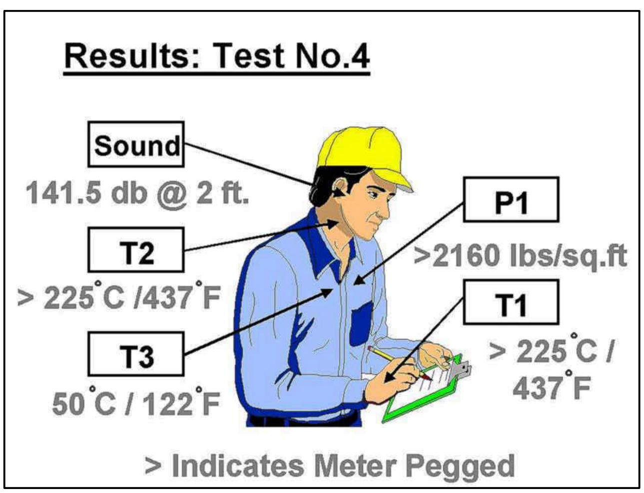

Fig. 5 - Results of Test No. 4

Figure 6 is the one-line for test No. 3 which is similar to the test set up for the previous test No. 4 except 601 ampere, Class L, current-limiting fuses are used to protect the feeder circuit. The fault is again initiated on the line side of the 30 ampere branch circuit fuses. In test No. 3, the 601 ampere Class L fuses cleared the arcing fault in less than 1/4 cycle and limited the current. Figure 7 is a photo of the test cell for Test No. 3 during the fault condition. The results of test No. 3 to the "personnel working on the equipment" are shown in Figure 8: the pressure on the chest was 504 lbs./sq. ft., which would have knocked a person back. The temperature on the hand at point of fault (T1) was greater than 225° C/437°F, which could result in a serious burn. However, the temperature on the neck (T2) is 62° C/143°F, which would not result in a burn. The result is the 601 ampere current-limiting overcurrent protective device greatly limited the hazard when compared to the results of test No. 4, which did not have a current-limiting protective device. Compare results of test No. 4 in Figure 5 to the results of test No. 3 in Figure 8. (Tests and results are from [1]).

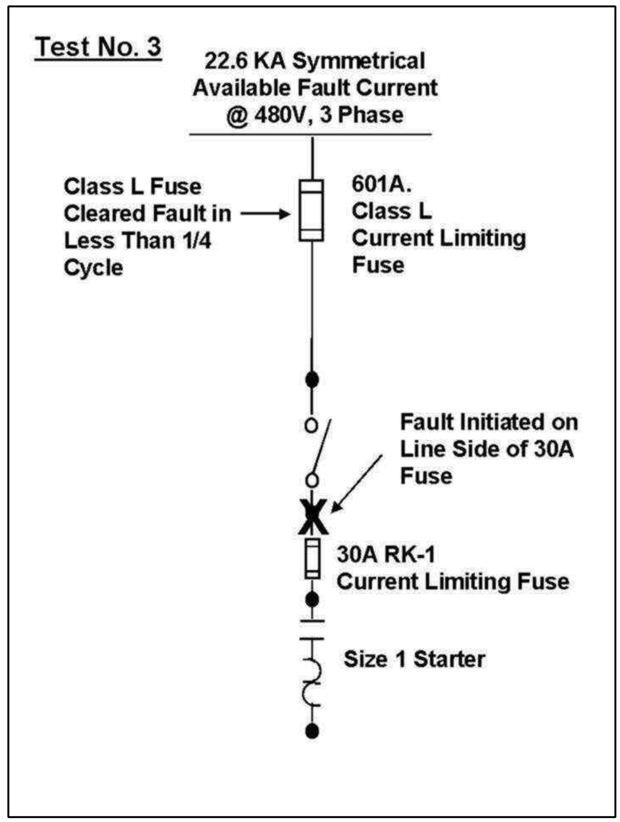

Fig. 6 - Test No. 3 One- line

Fig. 7 - Photo of Test No. 3 during test

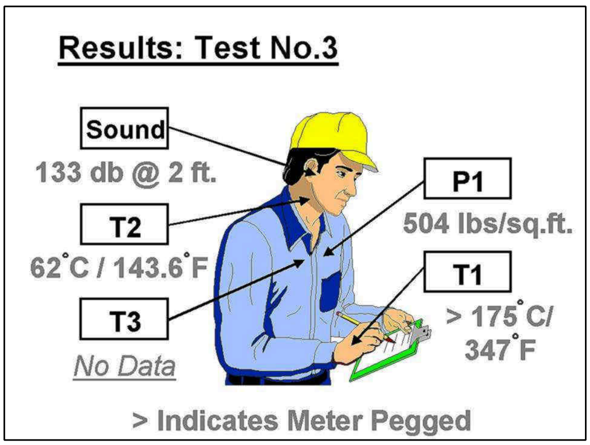

Fig. 8 - Results of Test No. 3 from [1]

Figure 9 is the one-line for test No. 1 simulating a 600 ampere feeder to a combination motor starter branch circuit with a 30 ampere RK1 fuse. Available short circuit current is 22,600 amperes. In this test, the arc fault was initiated on the load side of the starter. The 30 ampere current limiting fuse cleared the fault in less than 1/4 cycle. Figure 10 illustrates the results to the mannequin which simulates a worker with his hand in the equipment enclosure at the point of the fault. The resultant sound at the ear from the arcing fault was too low to measure. The resultant pressure on the chest area did not change from normal ambient pressure. The temperatures at the neck (T2), the hand near the arcing fault initiation (T1), and chest under the shirt (T3) did not change from ambient. The conclusion is that the arc fault was rapidly cleared by the 30A, RK1 fuse, thereby limiting the energy emitted. The 601 ampere, Class L fuses did not open since the 30A fuses and 601 ampere fuses are selectively coordinated. Compare the results of this test in figure 10 to the results for test No. 4 and test No. 3 in Figure 8. (Tests and results are from [1]).

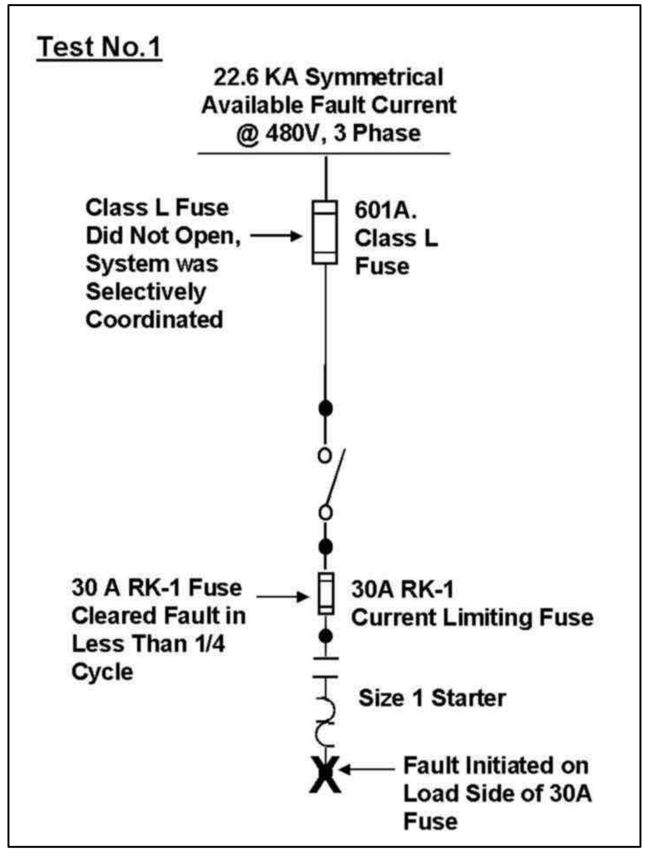

Fig. 9 Test No. 1 One-line

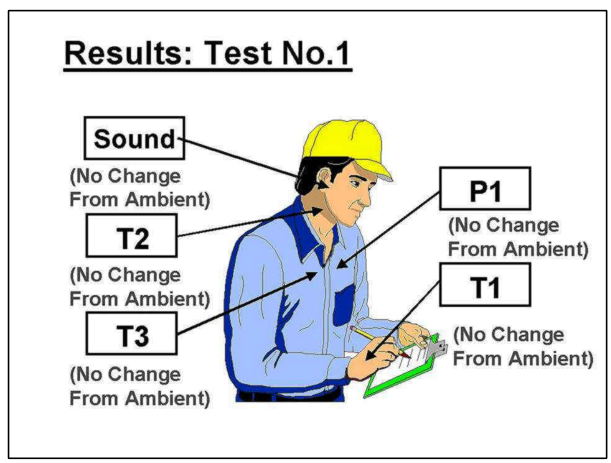

Fig. 10 - Results of Test No. 1 from [1]

These three tests demonstrate that the effects of an arcing fault can be quantified as to the risk to an individual. It also illustrates that the type and ampere rating size of overcurrent protective devices can affect the degree of risk to a worker. In addition, it illustrates the need for adequate personal protective equipment when working on energized parts.

"Staged Tests Increase Awareness of Arc-Flash Hazards in Electrical Equipment"[1] had several informative discussion points learned from the battery of 23 tests. These included:

1) Fatal and survivable electrical accidents suggest that the majority of workplace events are related to work processes and practices. This suggests the need for appropriate work practices and effective training.
2) Personal protective equipment can greatly reduce the chances of receiving flash burns. However, this equipment provides minimal protection from shrapnel expelled and the explosive pressures exerted.
3) Insulated buses in equipment are beneficial. In tests with insulated buses, the arc fault traveled away from the source to the insulated bus area and the arc was extinguished, greatly reducing the arc energies.
4) The tests confirmed that single-phase faults are more difficult to sustain than three phase faults.
5) "The results support the observation that current-limiting devices reduce damage and arc-fault energy. Several identical tests were performed with and without current-limiting devices. In each of the tests, the damage and observed arc-fault energy was tremendously reduced by the current-limiting overcurrent protective device. One particularly impressive test (#23) was on a new vertical section of motor control center (MCC) with the incoming lugs located in the bottom of the section. A wrench was laid on the incoming lugs and the MCC was energized with 601 -amp, class-L, current-limiting fuses in the circuit. The door did not open, and all three fuses cleared the fault. Further inspection revealed minimum pitting on the bus bars that were in contact with the wrench and some carbon was found on the left wall of the incoming section. The MCC section could have been placed in service without any cleanup or repair required."

   "This scenario was repeated in test #24 when the current-limiting fuses in the circuit were removed from the circuit. The protection was provided by an 800-amp frame/640 amp trip air power circuit breaker alone. The wrench was again placed on the incoming lugs and the MCC energized. This time the fault blew the door open and progressed up the vertical bus, completely destroying the vertical section of the MCC."[1]
6) Codes, standards, and procedures do not adequately protect individuals from the hazards of arcing faults. Manufacturers do not recommend open doors while equipment is energized and nationally recognized testing labs typically do not include open door testing. Yet for various reasons, workers do access energized equipment with the door open. The paper's [1] authors felt that the standards should include testing with the equipment doors open. This data would be beneficial for evaluating protection levels.

III. Safe Working Distances

Over the years, analytic tools have been developed to better assess the hazards possible from arcing faults. The knowledge and tools for managing arcing fault hazards is still in the early stages of development, but strides are being made. Because of injuries and deaths, NFPA70E (Electrical Safety Requirements for Employee Workplaces) adopted formulas to define the safe working distance from a potential arc. These formulas are used to determine the type of protective gear a worker needs to wear when working on equipment. The formulas for this calculation are based upon the work and technical paper by Ralph Lee, "The Other Electrical Hazard; Electrical Arc Blast Burns" [2].

As stated previously, Mr. Lee's work showed temperature/time thresholds for incurable and just curable burns. At a distance of 3 feet, the arc energy required to produce these temperatures was determined to be 23 MW and 17 MW, respectively. He also found that the maximum arc energy occurred when it represented 50% of the available three phase bolted fault. Therefore, the arc from a 46 MVA available source for .1 second could cause an "incurable burn" at a distance of 3 feet. And, the arc from a 34 MVA available fault for .1 seconds at 3 feet would result in a "just curable" burn.
Following are the formulas developed by Mr. Lee and incorporated into NFPA70E [5]:

$$D_c = (2.65 x MVA_{bf} x t)^{1/2}$$
$$D_f = (1.96 x MVA_{bf} x t)^{1/2}*$$

Where

D_c - distance in feet for a "just curable" burn

D_f - distance in feet for an "incurable burn"*

MVA_{bf} = bolted three phase MVA at point of short circuit

= 1.73x VOLTAGE $_{L-L}$x AVAILABLE SHORT-CIRCUIT CURRENT x 10^{-6}

t - time of exposure in seconds

Example 1:

Assume an available 40 896 ampere bolted 3 phase fault on a 480 volt system with a clearing time of 6 cycles (.1 second). Find the distance in feet for a just curable burn.

$$D_c = (2.65 x MVA_{bf} x t)^{1/2} ft$$

$$D_c = (2.65 x 1.732 x 480 x 40896 x 10^{-6} x .1)^{1/2} ft$$

$$D_c = (9.00)^{1/2} ft$$

$$D_c = 3 \text{ ft}$$

*Not included in NFPA70E

This means that any exposed skin, closer than 3 feet to this available fault, for .1 seconds or longer, may not be curable, should an arcing fault occur. If the employee must work on this equipment where parts of his/her body would be closer than 3 feet from the possible arc, suitable protective equipment must be utilized so that the employee injury is minimized.

Example 2:

Assume that the same criteria exists as for Example 1 except that the equipment is being protected by popular Class J, 200 amp, current-limiting, upstream fuses. The opening time is assumed at 1/4 cycle (.004 seconds) and the equivalent RMS let-through current is read off a chart as 6,000 amperes.

$D_c = (2.65 x MVA_{bf} x t)^{1/2} ft$

$D_c = (2.65 x 1.732 x 480 x 6000 x 10^{-6} x .004)^{1/2} ft$

$D_c = (.0528)^{1/2} ft$

D_c = .229 ft (or 2.75 inches)

Thus, the flash protection boundary was significantly decreased, from 3 feet (Example 1) to 2.75 inches (Example 2), by limiting the short circuit current from 40,896 to 6,000 amperes and by reducing the exposure time from 6 cycles to 1/4 cycle.

Employees must wear, and be trained in the use of, appropriate protective equipment for the possible electrical hazards with which they are faced. Examples of equipment could include head, face, neck, chin, eye, ear, body and extremity protection as required. All protective equipment must meet the requirements shown in Table 3-3.6 of NFPA70E-1995 [5].

Protective equipment, sufficient for protection against an electrical flash, would be required for any part of the body which could be within 3 feet of the fault in Example 1. Such equipment would likely include a hard hat, face shield, flame retardant neck protection, ear protectors, Nomex™ suit, insulated rubber gloves with leather protectors, and insulated footwear.

Significantly less equipment would be required for Example 2 because the flash zone is within 2.75 inches. In this case, the required equipment might be reduced to a hard hat, safety glasses, ear protection, cotton clothing, insulated rubber gloves with leather protectors, and insulated footwear.

In addition, the worker in Example 2 has less required protective equipment getting in his or her way, and therefore may have less of a chance of accidentally creating the fault for which the protective equipment is necessary.

In an actual case where an electrical worker is to work on equipment, the safe working distance must be determined by making calculation over the full range of possible currents and estimation of exposure time. The worker is required to wear protective clothing and gear for the worst case condition. The possible currents would encompass the range of currents up to the maximum available current that could occur if a mishap occurred. The exposure time is dependent upon reasonable reaction time and is situational. For example, a worker standing in front of a piece of switchgear might reasonably be expected to get out of the way of a blast in one second (might be blown away in much less time with a significant blast), but a worker on his or her knees might be exposed for two or three seconds. A worker lying on the ground might be there for three to five seconds. However, a worker in a bucket truck might be exposed for many seconds or minutes. These times can be utilized with the time current curves to determine the maximum amount of current at those times where the overcurrent protective device does not open in that time. With that information the hazard can be calculated for the worst case condition.

IV. Incident Energy Related to Risk

Subsequent works refined practical knowledge for arc fault protection considerations. "Protective Clothing Guideline for Electric Arc Exposure" "enhanced the knowledge about:

(1) potential arc energy as a function of prospective fault current, and

(2) arc protective clothing designs that are suitable for different levels of incident arc energy.

Incident energy levels are correlated with second degree burn criteria for unprotected human skin."[6] "Incident energy level" measured in calories/cm^2 is a common way to evaluate the hazard of burns to bare skin and evaluate levels of protection provided by protective gear. In [6] the value of 1.6 cal/cm^2 is shown to be the level at which a second degree burn would occur for a short time (less than 1/2 second) exposure to bare skin. Additional safety factors would be provided by using .8 and 1.2 cal/cm^2.

Table I is from [6] and provides incident energy levels for specific test conditions at 5KV and 600 volts. Arc characteristics and resultant energies resultant from arcing faults have many variables. The data in Table I provide good information for the specific conditions used in [6].

TABLE I
from [6]

Distances from Phase-to-Phase Arcs at Which the Onset of a Second Degree Burn is Predicted on Exposed Skin

System Voltage	Arc Current	Arc Duration	Arc Electrode Spacing	Distance in Inches From Arc Center Line Phase-To-Phase — Incident Energy Levels		
kV	kA	Cycles (sec)	Inches	0.8 cal/cm^2	1.2 cal/cm^2	1.6 cal/cm^2
5	60	10(0.167)	12	142	116	100
5	30	10(0.167)	12	90	74	64
5	15	10(0.167)	12	60	49	43
5	8	10(0.167)	12	42	34	29
0.6	40	6(0.10)	4	49	40	34
0.6	20	6(0.10)	4	32	26	23
0.6	10	6(0.10)	4	21	17	15
0.6	40	30(0.5)	4	109	89	77
0.6	40	1(0.017)	4	20	16	14

As an example, using the conservative 1.2 cal/cm^2 as the threshold of a second degree burn, for a 600 volt, 40,000 ampere arc current lasting 6 cycles, a workers bare skin should not be closer than 40 inches.

A follow-up paper, "Testing Update on Protective Clothing Equipment For Electric Arc Exposure", provides "updated protective clothing guidelines and detailed testing results on cotton ignitability and para and meta-aramid protective clothing systems."[7] Six hundred volt, 3 phase, arc fault tests are performed and analyzed providing further analytic information on the thermal and pressure effects of arcing faults. The findings from this paper [7] included:

1) Incident energy is directly proportional to the time duration of the arc.
2) A three-phase arc fault in a box has an incident energy 3 times greater than an equivalent three phase arc fault in open air.
3) Traumatic ear damage was possible from the measurements taken in these three phase arc fault tests.

V. Reducing the Risk

With the findings that arcing fault incident energy can be reduced by reducing the time duration of the arcing and by limiting the current, "The Use of Low Voltage Current-Limiting Fuses to Reduce Arc Flash Energy" produced test results that quantified that current-limiting fuses can reduce arc-flash energy.[8]" Under specific test conditions, the incident energy was measured 18 inches from the arc. The conditions were various arcing faults in a 20 inch cubic box on a 600 volt, 3 phase circuit with the arc gap at 1.25 inch. The available 3 phase bolted currents were varied from 5KA to 106KA. The incident energy at 18" from the fault was recorded as shown in Table II [8]. A value of 1.2 cal/cm^2 was used as the level at which a second degree burn would occur for a short-time (less than 1/2 second) exposure to bare skin.[6]

The 3-phase circuits were calibrated with an available bolted fault shown in column 1 of Table II. Then, with no overcurrent protection in the circuit, an arcing fault was created which provided the rms current flow - arc fault with no fuse shown in column 2. Then fuses of various ampere ratings and classes were put in the circuit and an arcing fault created. The incident energy at 18" was measured for each test with no fuse and with specific fuses at various fault levels- shown in column 3. As an example, this illustrates (under these specific controlled conditions) that with a bolted 3 phase, 44,000 symmetrical rms available, the arcing fault (approximately 26,000 rms amps) would be cleared by the Class L 800 fuse with an incident energy of 0.09 cal/cm^2 at 18" from the fault. This value is well below the second-degree burn threshold of 1.2 cal/cm^2, so bare skin at 18" from the arcing fault would not incur a burn. The incident energy at 18" from the fault for this test without the 800 ampere, Class L fuse was 12.23 cal/cm^3, which could result in a severe burn to bare skin.

TABLE II
from [8]

Three Phase Fuse Arc Test Results
600V, 1.25 Inch Arc Gap

(1) Three Phase Bolted Fault Avail. kA rms	(2) Arc Fault with No Fuse kA rms	**(3) Average Incident Energy at 18" cal/cm^2**					
			Fuse amp & UL Class				
		No Fuse	600A RK1	800A L	1200A L	1600A L	2000A L
22	15.8	5.93	0.10	0.63	4.65	7.01	23.12
44	25.97	12.23	0.05	0.09	0.24	0.73	9.90
66	36.77	16.21	0.05	0.14	0.18	0.99	6.48
106	45.98	22.42	0.03	0.18	0.14	0.29	1.94

Characteristic curves were generated for each size fuse tested to develop quantifiable data to assess the hazard of skin burns for these test conditions. Figures 11 and Figures 12 are the curves developed for the Class RK1 600 amp and Class L 800 amp respectively [8].

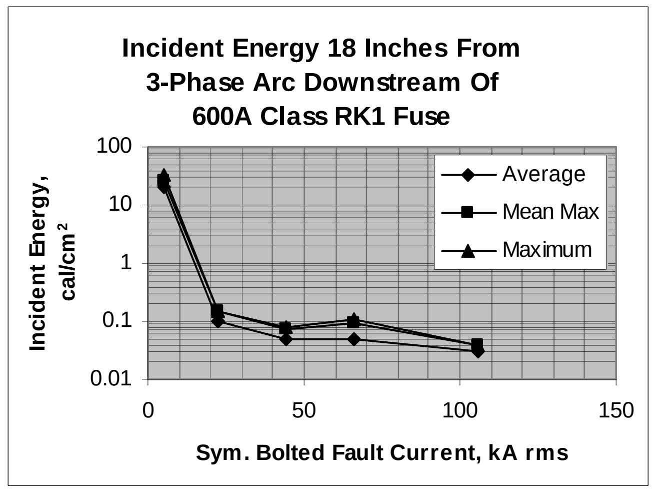

Fig. 11 - Incident Energy - 600A Class RK1 Fuse

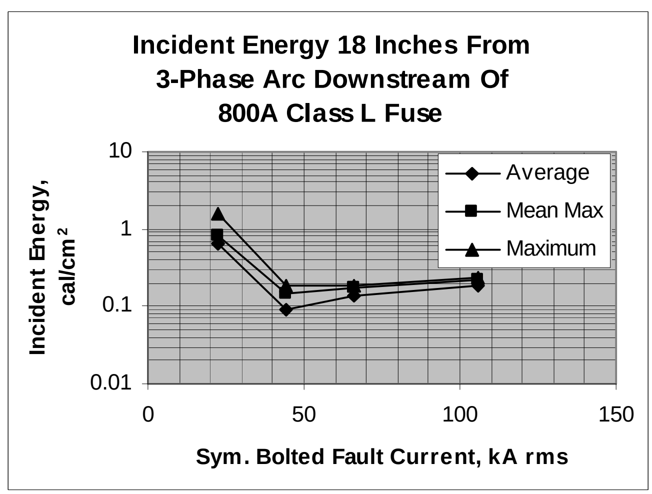

Fig. 12 - Incident Energy - 800A Class L Fuse

The data shown in Figure 11 and Figure 12 is based only upon measured incident energy under specified test conditions and it does not address potential hazardous effects of projectiles and pressures that can occur. However, it does illustrate the benefit of current-limiting overcurrent protective devices in reducing the potential hazards of arcing faults.

A correlation between the available three-phase bolted short-circuit current and the actual three-phase arcing fault current that occurred is evident in both [8] and [9]. Both papers did testing with a 600 volt, 3-phase system with 1.25 inch arc gap. Data in Table III [8] results from the 3-phase arc in a box. Data in Table IV [9] results from both the arc in a box and the arc in open air.

TABLE III
Arc in a Box from [8]

Available 3-Phase Bolted Short- Circuit Current kA rms	Actual 3-Phase Arc Fault Mean Maximum Current kA rms
22.6	15.8
44.1	25.97
65.9	36.77
106.0	45.98

TABLE IV
from [8]

Test Set-up Description	Available Bolted Fault Current kA	Average Arc. Ph. Current kA
Open Arc	16.30	11.58
Open Arc	19.08	13.27
Open Arc	23.41	16.44
Open Arc	27.66	18.74
Open Arc	31.16	20.99
Open Arc	35.29	22.30
Open Arc	40.92	24.08
Open Arc	40.92	25.47
Open Arc	40.92	25.44
Open Arc	45.36	30.15
Open Arc	50.39	34.88
Arc in Box	16.30	13.24
Arc in Box	19.08	15.57
Arc in Box	23.65	19.01
Arc in Box	27.66	21.90
Arc in Box	31.20	24.92
Arc in Box	36.25	27.31
Arc in Box	41.99	31.59
Arc in Box	41.99	31.36
Arc in Box	41.99	32.12
Arc in Box	41.99	32.15
Arc in Box	41.99	31.79
Arc in Box	41.99	32.16
Arc in Box	46.05	36.33
Arc in Box	51.19	41.15

Table III and Table IV results clearly shows that the higher the available 3-phase bolted short-circuit current, the higher the 3-phase arcing current. This has different ramifications depending on the type overcurrent protective devices that are used. With non-current limiting protective devices, it means the resultant arc energy will likely be greater as the 3-phase available short-circuit is increased. So a designer would want to use high impedance components to lower the available short-circuit current. However, this can have negative effects on the voltage regulation and increase costs. With current-limiting protective devices it is possible to have a higher available short-circuit current. Once the current-limiting overcurrent protective device is in it's current limiting range, it greatly reduces the resultant arc energy. So, with current-limiting overcurrent protective devices it is a good design practice to have low impedance circuit components (increase short-circuit current) and utilize current-limiting protective devices with the greatest degree of current-limitation such as Classes RK1, J, T, and L fuses.

VI. Conclusion: Suggestions for Safety

After reviewing the many papers researching the hazards of arcing faults to workers and equipment, the authors developed some design considerations for electrical distribution systems. It must be cautioned that arcing faults are subject to many variables. Consequently, the effects of arcing faults is variable. The intent is to reduce the probability that workers will be subjected to conditions where an arcing fault will be hazardous to electrical workers. Also, it is important that companies have good work practices, that the workers are well trained on these practices, and that the appropriate protective gear is used by workers.

1) Use finger safe electrical components as much as possible. This can reduce the chance that an arc fault will occur.
2) Use insulated bus for equipment such as motor control centers, switchboards, panelboards, etc. This will reduce the chance that an arc fault may occur. In addition, it has been found that it increases the probability that an arc fault will self-extinguish.[1]
3) Use current-limiting overcurrent protective devices such as fuses and current-limiting circuit breakers. Obtain verifiable engineering data on the current-limiting ability of the overcurrent protective devices. Be sure to specify the most current-limiting devices available where possible; the greater the degree of current-limitation the less will be the arc fault energy released (when the fault current is in the current-limiting range of the overcurrent protective device). For instance, for fuses, it is suggested to use UL Class RK1 or Class J rather than RK5 since RK1 and Class J fuses are more current-limiting than RK5.
4) Size current-limiting, branch circuit overcurrent protective devices as low as possible. Typically the lower the ampere rating, the greater degree of current-limitation.
    a) Limit the ampere rating size of main and feeders where possible. Split large feeders into two feeders. For instance, rather than a 1200 ampere motor control center, have two 600 ampere motor control centers.
    b) Size current-limiting branch circuit overcurrent protective devices as low as possible. For instance, for a 100hp, 460 volt, three phase motor, the NEC® maximum for dual-element, Class RK1 fuses would be

a 225 amperes. However, it is possible to use a 175 ampere dual-element, Class RK1 fuse for this application. Under fault conditions the 175 ampere fuse will let-thru less energy than the 225 ampere fuse.

5) Motor starter protection: use starter/overcurrent protective device combinations that have been tested and witnessed for Type 2 protection. For all practical purposes, the regular UL 508 and Type 1 starter/overcurrent protective device combinations permit extensive damage to the starter. As long as a fire is not started outside the enclosure, as long as the enclosure does not become energized and as long as the door does not blow open, a UL 508 and Type 1 starter passes. If a worker has the door open and a fault is initiated on a UL 508 or Type 1 starter, the hazard is much greater to the electrical worker. Type 2 protection for starters typically is provided by current-limiting overcurrent protective devices such as Class J or Class RK1 fuses and the starter sustains "no damage" under short-circuit conditions[10].

6) Several papers referenced documented lab tests that demonstrated the value of current-limiting overcurrent protectives in reducing the energy associated with some types of arcing faults. If current-limiting protective devices are utilized, then arc-fault hazards can be reduced even more by utilizing low impedance circuit components such as low impedance transformers. It has been shown that all other variables constant, if the 3-phase available bolted short-circuit current is higher, the 3-phase arc fault current is higher. With the low impedance circuit approach, an arcing fault current will tend to be higher magnitude, increasing the probability the overcurrent protective device will react quickly. This increases the probability a current-limiting overcurrent protective devices will be in their current-limiting range; which results in the current let-thru being reduced and the fault time reduced. Hence, lower incident energy. Lower impedance circuit components also enhance the distribution system voltage regulation.

7) If non-current-limiting overcurrent protective devices are used:

   a) then utilize high impedance circuit components to at least try to limit the arc-fault current potentially available. This approach may result in voltage regulation issues, but with non-current-limiting protective devices the incident energy of a fault can attain significantly high levels.

   b) do not use circuit breakers with short-time delays. It has been well documented that arc-fault incident energy is directly proportional to the time the fault is permitted to persist. Permitting an arcing fault to intentionally flow for 6, 12, or 30 cycles dramatically increases the hazards to electrical workers. If selective coordination of overcurrent protective is the objective, then use current-limiting fuses which can be selectively coordinated simply by adhering to minimum ampere rating ratios between main and feeder fuses or feeder and branch circuit fuses.

VII. References

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