MichiganTech

Arc-Flash Hazard Analysis

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3/20/09

Overview

- Background
- Standards
- Analysis Procedures
- MP Work
- Results
- References

Background

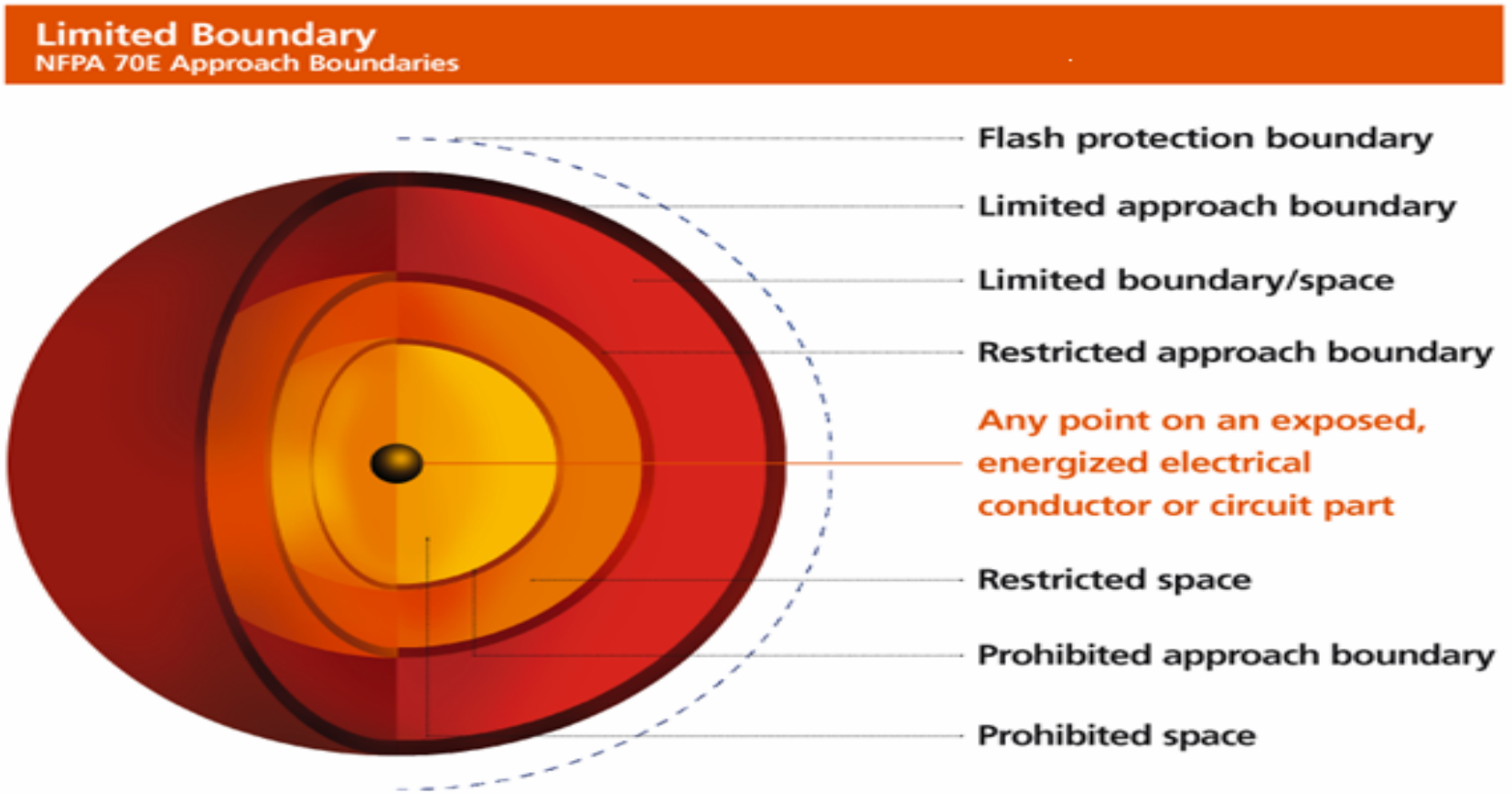
Background

- What is an arc-flash hazard?
  - Definition: A dangerous condition associated with the release of energy caused by an electric arc. [4]
  - Five to ten arc-flashes occur everyday in electrical equipment [7]
  - More than 2000 workers are admitted to burn centers each year [6]
  - Caused by a short circuit
    - Can be human error
    - Normal operations
  - Releases high amount of energy in a short time, pressure blast and shrapnel
  - Can cause severe injuries such as damage to hearing, eyesight, burns and even death

Background

- What is the analysis of arc-flash hazard?
  - Definition: A method to determine the risk of personal injury as a result of exposure to incident energy from an electrical arc flash. [4]
  - Used to determine several parameters
    - Distance to receive second degree burns (Flash Protection Boundary)
    - Correct Personal Protective Equipment (PPE) required
    - Potential incident energy at arc location

Background



The limited boundary is for unqualified personnel. No unqualified person may approach any exposed energized conductor any closer than the limited approach boundary. The limited approach boundary is determined by referring to Table 2-1.3.4 in NFPA 70E – Page 51. (2000 Edition. Note that in the 2000 Edition NFPA has added the concept of movable or fixed conductors. In 2000 edition unqualified workers may approach non-moving conductors (fixed buswork for example) more closely than those which may move (overhead lines for example).

Standards

- **Standards**
  - **OSHA 29 CFR 1910**
    - **1910.335** 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
    - **1910.333** Safety related work practices shall be employed to prevent electric shock or other injuries resulting from direct or indirect electrical contact. Live parts to which an employee may be exposed shall be de-energized before the employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible

Standards

- **Standards Cont.**
  - **National Electric Safety Code (NESC) 2007**
    - **410.A.3** Effective as of January 1, 2009, the employer shall ensure that an assessment is performed to determine potential exposure to an electric arc for employees who work on or near energized parts or equipment. If the assessment determines a potential employee exposure greater than 2 cal/cm^2 exists (see Neal, Bingham, and Doughty [B59]), the employer shall require employees to wear clothing or a clothing system that has an effective arc rating not less than the anticipated level of arc energy.

Standards

- **Standards Cont.**
  - **NESC 2007**
    - *EXCEPTION 1:* If the clothing required by this rule has the potential to create additional and greater hazards than the possible exposure to the heat energy of the electric arc, then clothing with an arc rating or arc thermal performance value (ATPV) less than that required by the rule can be worn.
    - *EXCEPTION 2:* For secondary systems below 1000 V, applicable work rules required by this part and engineering controls shall be utilized to limit exposure. In lieu of performing an arc hazard analysis, clothing or a clothing system with a minimum effective arc rating of 4 cal/cm^2 shall be required to limit the likelihood of ignition.
  - **IEEE 1584,** *IEEE Guide for Performing Arc-Flash Hazard Calculations*
    - *Equations can only be used for 3-phase systems, no DC equations have been developed yet, 3-phase faults*

Analysis Procedures

- How is the analysis conducted?
  - Using IEEE 154 several parameters need to be determined
    - Supply Voltage
    - Short circuit fault currents
    - Overcurrent device data
    - Open or box configuration
    - Air gap between conductors
    - Grounded or ungrounded system
    - Type of equipment being studied
    - Distance the worker is from the flash

Analysis Procedures

- **Arc Current Equation Variables**
  - **I_{arc} = Arcing current**
  - **K = -0.153 for open or -0.097 for box configuration**
  - **V = System voltage**
  - **G = Distance between conductors**
  - **I_{sc} = Short circuit current**

Analysis Procedures

- **Incident Energy Equation Variables**
  - **K_1 = -0.792 for open or -0.555 for box configuration**
  - **K_2 = 0 for ungrounded or -0.113 for grounded system**
  - **G = Distance between conductors**
  - **C_f = Calculation factor - 1.5 for LV and 1.0 for MV**
  - **t = Arcing time**
  - **D = Working distance**
  - **X = Distance factor - 2.0 for LV & MV open air, 0.973 for MV switchgear, 1.473 for LV switchgear, 1.641 for LV MCC and panels**

Analysis Procedures

- **Arc Current Equations (empirically derived from IEEE 1584)**

For system voltages of less than 1 kV (LV)

$$Log(I_{arc}) = K + 0.662 * Log(I_{sc}) + 0.0966 * V + 0.000526 * G + 0.5588 * V * Log(I_{sc}) - 0.00304 * G * Log(I_{sc})$$

For system voltages of 1 – 15 kV (MV)

$$Log(I_{arc}) = 0.00402 + 0.983 * Log(I_{sc})$$

Arc Current

$$I_{arc} = 10^{Log(I_{arc})}$$

All equations from reference [2]

Analysis Procedures

- **Incident Energy Equation**

$$Log(E_a) = K_1 + K_2 + 1.081 * Log(I_{arc}) + 0.0011 * G$$

Normalized Incident Energy

$$E_a = 10^{Log(E_a)}$$

Incident Energy in cal/cm² at a specific working distance

$$E = 4.184 * C_f * E_a * \left(\frac{t}{0.2}\right) * \left(\frac{610^X}{D^X}\right) * 0.24$$

All equations from reference [2]

Analysis Procedures

- **Flash Protection Boundary Equation**

$$D_b = \left[4.184 * C_f * E_a * \left(\frac{t}{0.2} \right) * \left(\frac{610^X}{5^X} \right) \right]^{1/X}$$

All equations from reference [2]

Analysis Procedures

- **Lee Method (15kV >)**
  - **Incident Energy**

$$E = 5.12 * 10^5 * V * I_{sc} * \left(\frac{t}{D^2} \right)$$

  - **Flash Protection Boundary**

$$D_b = \sqrt{5.12 * 10^5 * V * I_{sc} * \left(\frac{t}{25} \right)}$$

All equations from reference [2]

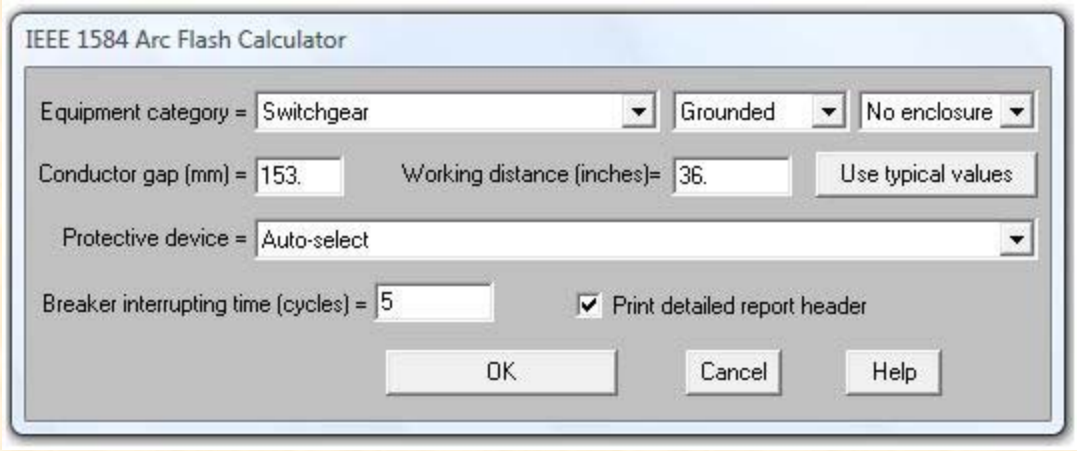
Analysis Procedures

Category	Cal/cm^2	Clothing
0	0 - 1.2	Untreated Cotton
1	1.2 - 4	Flame retardant (FR) shirt and FR pants, Hard Hat, Safety glasses
2	4.1 - 8	Cotton underwear FR shirt and FR pants, Hard Hat, safety visor, gloves
3	8.1 - 25	Cotton underwear FR shirt, FR pants and FR coveralls, Hard Hat, safety visor, gloves
4	25.1 - 40	Cotton underwear FR shirt, FR pants and double layer switching coat and pants, Hard Hat, safety visor, gloves

Anything above 40 cal/cm^2 is considered an unacceptable risk

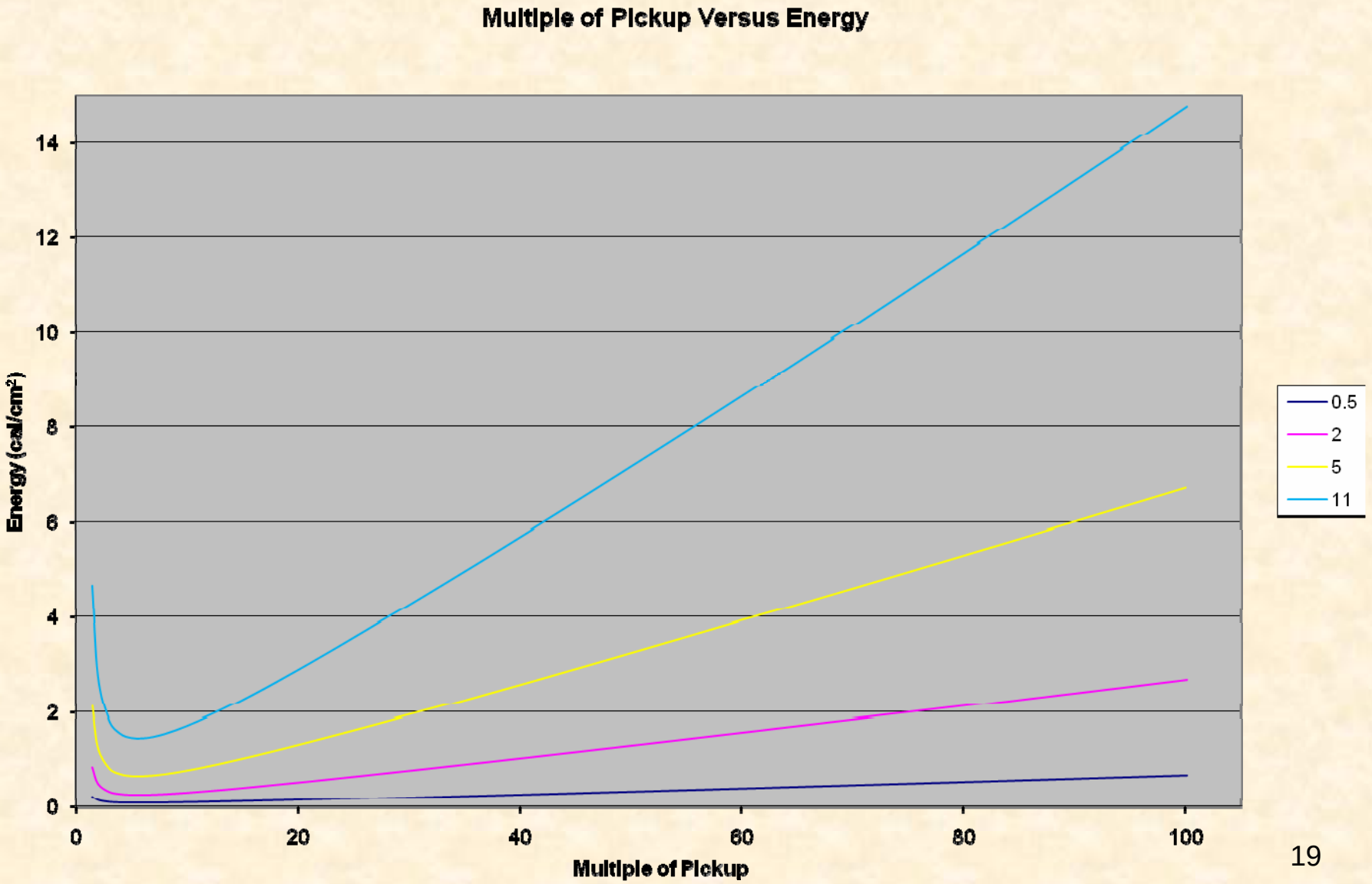
MP Work

- **Tasks that were completed over Summer 2008**
  - **Benchmark Aspen Arc Flash Module**



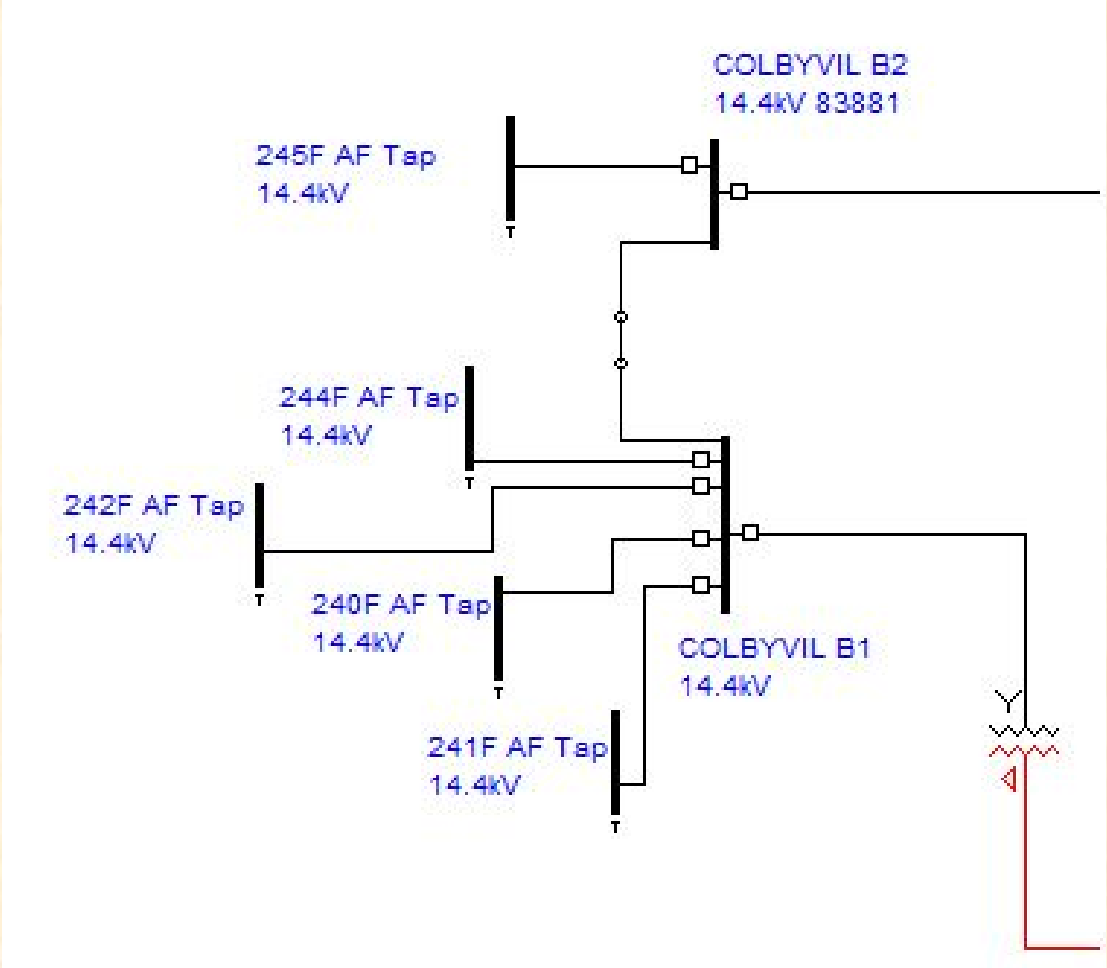
- **Three items were discovered**
  - **Aspen is using the 2004 version of NESC, the level 1 cutoff for PPE is at 5 cal/cm^2**
  - **85% equations for the IE were incorrect**
  - **Module wouldn't recognize reclosers as a protective device**

MP Work


Multiple of Pickup Versus Energy
Energy (cal/cm²)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
Multiple of Pickup
0.5
2
5
11

MP Work

- **Tasks that were completed over Summer 2008, cont.**
  - **Complete full analysis of MP transmission/distribution system**



MP Work

- First run through of analysis
  - Looked through the results to see what levels of IE that were being produced, didn't make sense, they seemed very high for high level voltages
  - Sat down with field personal to see what distances they worked at
  - Went back and looked at NESC again for high level voltages, re-ran analysis

System phase-to-phase voltage (kV)	Distance to employee, working distance, phase-to-phase work (inches)	Conductor gap spacing (mm)
2.4	27	50.8
4.16	27	50.8
13.8	27	50.8
23	34	101.6
34.5	38	152.4
46	39	228.6
69	42	101.1
115	48	168.6
138	53	202.4
161	71	236.1
230	122	337.3
345	172	505.9
500	270	733.2

	Working distances of MP employees based on tables from NESC C2-2007	Gap spacing of MP equipment based NESC C2-2007

MP Work

- **Second run through of analysis**
  - **Went back and looked at NESC again for high level voltages, re-ran analysis based on this table**

Phase to Phase Voltage (kV)	L-G Fault Current (kA)	4-cal system	8-cal system	12-cal system
		Maximum clearing time in cycles (sec)	Maximum clearing time in cycles (sec)	Maximum clearing time in cycles (sec)
1 to 15	5	46.5 (.775)	93 (1.55)	139.5 (2.325)
	10	18 (.3)	36.1 (.6017)	54.1 (.9017)
	15	10 (.1667)	20.1 (.335)	30.1 (.5017)
	20	6.5 (.1083)	13 (.2167)	19.5 (.325)
15.1 to 25	5	27.6 (.46)	55.2 (.92)	82.8 (1.38)
	10	11.4 (.19)	22.7 (.3783)	34.1 (.5683)
	15	6.6 (.11)	13.2 (.22)	19.8 (.33)
	20	4.4 (.0733)	8.8 (.1467)	13.2 (.22)
25.1 to 36	5	20.9 (.3483)	41.7 (.695)	62.6 (1.0433)
	10	8.8 (.1467)	17.6 (.2933)	26.5 (.4417)
	15	5.2 (.0867)	10.4 (.1733)	15.7 (.2617)
	20	3.5 (.0583)	7.1 (.1183)	10.6 (.1766)

MP Work

Arc Flash and Shock Hazard
Appropriate PPE Required

3' - 4"	Flash Hazard Boundary
4.9	cal/cm2 Flash Hazard at 18 Inches
#2	PPE Level
	Cotton underwear plus FR shirt and FR pants
0.48	kV Shock Hazard when cover is removed
3' - 6"	Limited Approach
1' - 0"	Restricted Approach - Class 00 Voltage Gloves
0' - 1"	Prohibited Approach - Class 00 VoltageGloves

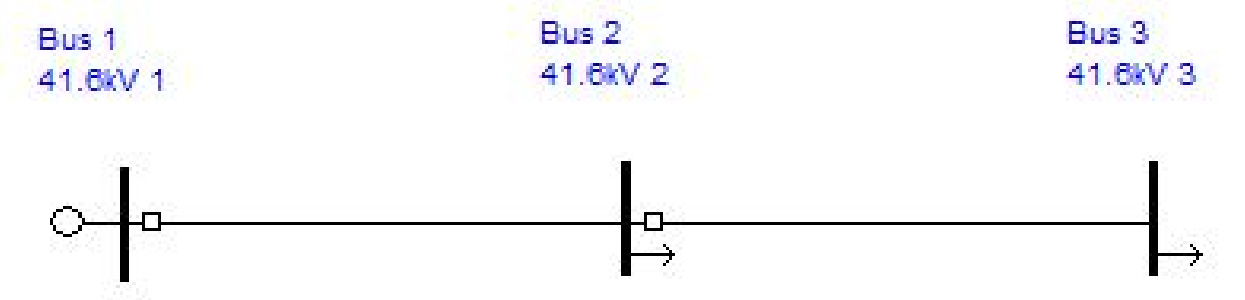
Equipment Name SWG-2A

IEEE 1584 Hazards; Project 1289A -- Safety Procedure #A6D24 --
EasyPower File: "Plant-A6.dez" -- Date: September 9, 2003

Results

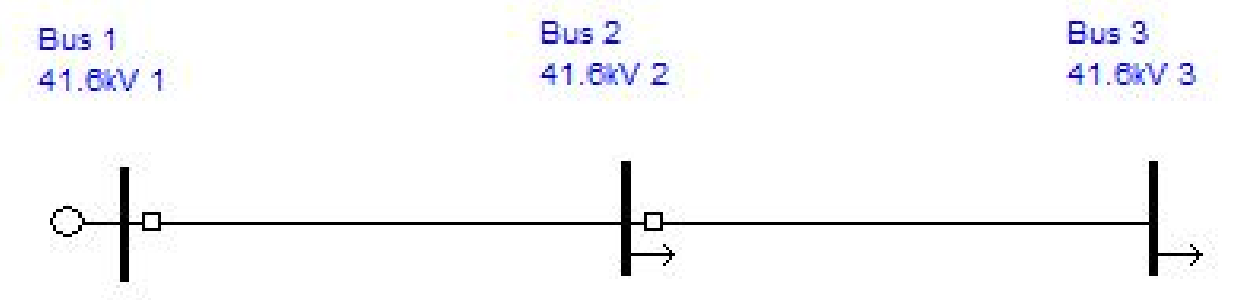
- Three main points were determined
  - Clear time greatly effects IE
  - Working distance greatly effects IE
  - More work needs to be completed on the high level voltage system in regards of developing equations to calculate IE

Example



Relay 2 Operates @ 38 inches		120 inches
Bolted 3PH fault current (kA) = 5.015		Bolted 3PH fault current (kA) = 5.015
Clearing time (seconds) = 0.16		Clearing time (seconds) = 0.16
Incident energy (cal/cm2) = 18.01		Incident energy (cal/cm2) = 1.81
Required PPE cat. per NFPA 70E = 3		Required PPE cat. per NFPA 70E = 1
Relay 1 Operates @ 38 inches		120 inches
Bolted 3PH fault current (kA) = 5.015		Bolted 3PH fault current (kA) = 5.015
Clearing time (seconds) = 0.64		Clearing time (seconds) = 0.64
Incident energy (cal/cm2) = 73.45		Incident energy (cal/cm2) = 7.37
Required PPE cat. per NFPA 70E = N/A		Required PPE cat. per NFPA 70E = 2

Example



Relay 2 Operates	Relay 1 Operates			
Clearing time (seconds) = 0.16	Clearing time (seconds) = 0.65			
Based on NESC table				
		4-cal system	8-cal system	12-cal system
Phase to Phase Voltage (kV)	Fault Current (kA)	Maximum clearing time in cycles (sec)	Maximum clearing time in cycles (sec)	Maximum clearing time in cycles (sec)
36.1 to 46	5	16.2 (.27)	32.4 (.54)	48.6 (.81)
	10	7 (.1167)	13.9 (.2317)	20.9 (.3483)
	15	4.3 (.0717)	8.5 (.1417)	12.8 (.2133)
	20	3 (.05)	6.1 (.1017)	9.1 (.1517)

References

[1] *IEEE Guide for Performing Arc-Flash Hazard Calculations*, IEEE 1584-2002.

[2] *Occupational Safety and Health Hazards*, OSHA 29 CFR 1910 Subpart S, 2000

[3] *Product Safety Signs and Labels*, ANSI Z535.4-2007

[4] *Standard for Electrical Safety Requirements for Employee Workplaces*, NFPA 70E-2004

[5] R. Doughtry, A. Bingham, and T. Neal, "Protective clothing guidelines for electric arc exposure," *IEEE Transactions on Industry Applications*, Volume 33, Issue 4, pp. 1041-1054, July/Aug. 1997

[6] http://us.ferrazshawmut.com/arcflash/arc_background/why_now.cfm

[7] Tom Ernst, MN Power Protection Engineer

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Questions?