Arc Flash Fundamentals

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Introduction

- What is arc flash?
- OSHA Requirements and Terminology
- Identifying Arc Flash Potential
- Intensity Factors & Categories
- Labeling
- PPE
- Mitigation Techniques
- Case Study – Ameren's Tyson Substation

Arc Flash Demonstration Video
Category 1

What is Arc Flash?

- Rapid release of energy due to an arcing fault
- Caused by insulation breakdown, equipment failure, tool insertion, or accidental contact with live parts
- Results in extremely high temperatures, vaporizes metals, and explosive volumetric expansion
- Workers can be exposed to burns, percussive force, shock, high sound pressure levels, and shrapnel
- Hazard is expressed in categories 1-4

Dangers of Arc Flash

- Electrical arc can cause shock
- Temperatures of an arc flash can reach 35,000°F
- Impulse sound pressure Levels can reach 160 dB
- Shrapnel can be propelled up to 700 mph
- Percussive force can knock down and injure workers

OSHA Requirements

- Performance Standard NFPA 70E referenced
- Applies to any business with employees, excluding utilities
- Requires labeling or documentation of circuits with arc flash potential
  - Operation
  - Maintenance
  - Inspection

Arc Flash Factors

- Available fault current
- Feeder or conductor length and gauge
- Fault duration & clearing time
- Working distance
- Energy is expressed in cal/cm^2

Circuits with Arc Flash Potential

- 250 volts circuits typically do not have enough potential to sustain an arc
  - *4 cal/cm^2 PPE is required (category 1)*
- All circuits over 250 volts must be evaluated for Arc Flash hazard
  - Arcs do not self-extinguish

Arc Flash Demonstration Video
Category 1 – Not Sustained Arc

Terminology

- **Working Distance** – Distance between arc source and workers face or chest
- **Incident Energy** – Amount of energy in a sphere to the working distance, expressed in cal/cm^2
- **Qualified Person** – Demonstrated skills and knowledge to perform task, received safety training
- **Restricted Approach Boundary** – Distance from arc incident that requires PPE, qualified person only
- **Limits of Approach Boundary** – Requires PPE, unqualified person if supervised by qualified
- **Arc Flash Boundary** – Distance from arc incident that will result in second degree burns, unqualified person

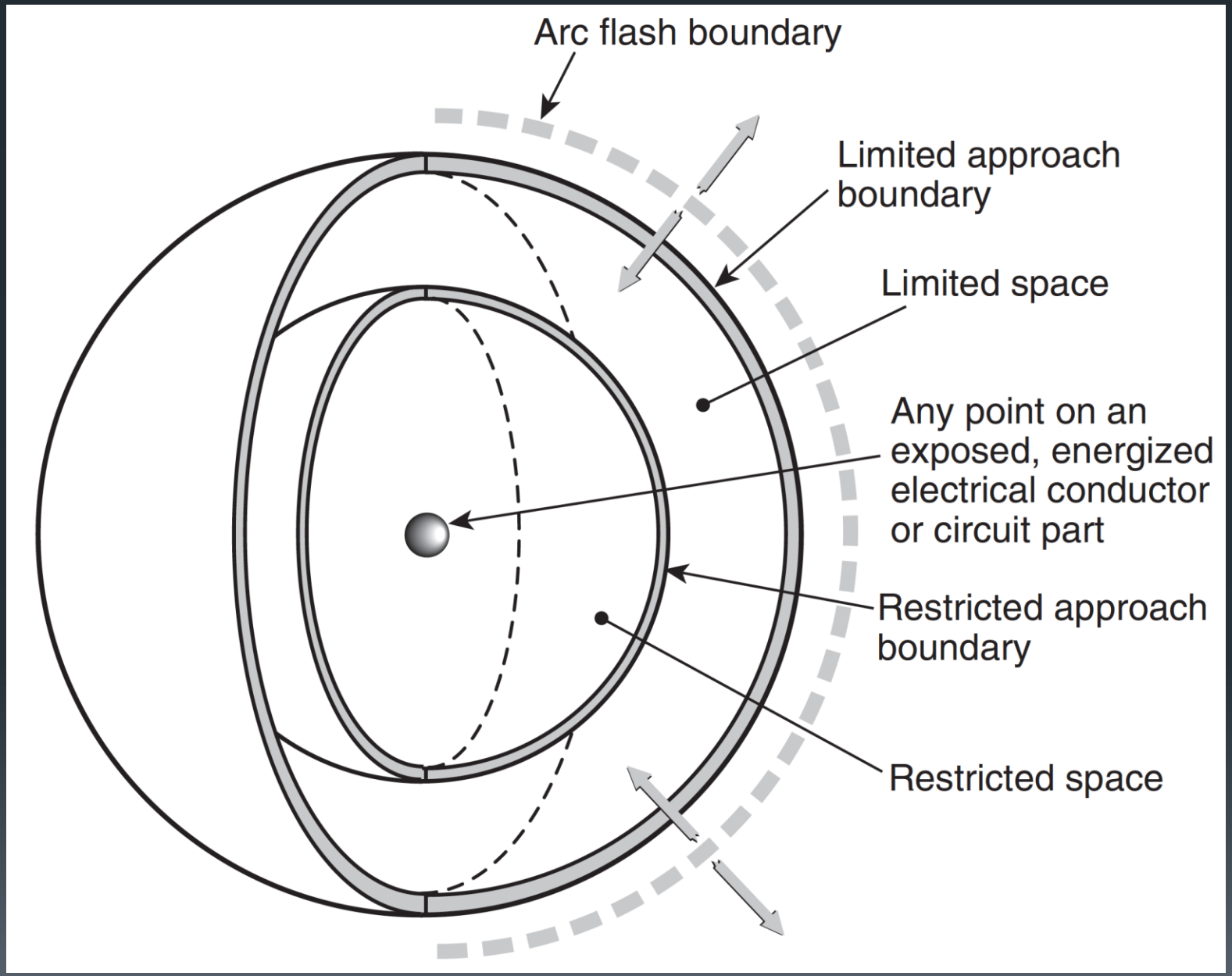


Image: NFPA-70E

Category 1 PPE

Up to 4 cal/cm^2

- Leather shoes or rubber safety footwear
- Long sleeved FR shirt
- FR Pants
- Leather gloves (minimum)
- Face Shield or Goggles rated for at least 4 cal/cm^2
- Balaclava rated for at least 4 cal/cm^2
- Hearing protection (ear canal inserts or ear muffs)

Image: National Safety Apparel, www.thinknsa.com

Category 2 PPE

Up to 8 cal/cm^2

- Rubber gloves with leather protectors
- Long sleeved FR shirt or flash suited rated for 8 cal/cm^2
- FR Pants or flash suit rated for 8 cal/cm^2
- Face Shield or Goggles rated for 8 Cal/cm$_2$
- Balaclava rated for at least 8 Cal/cm$_2$

Image: National Safety Apparel, www.thinknsa.com

Category 3 PPE

Up to 25 cal/cm^2

- Arc Flash suit rated for 25 cal/cm^2
- Arc flash hood or balaclava with Goggles rated for at least 25 cal/cm^2

Image: National Safety Apparel, www.thinknsa.com

Category 4 PPE

Up to 40 cal/cm^2

- Arc Flash suit rated for 40 cal/cm^2
- Arc flash hood or balaclava with Goggles rated for at least 40 cal/cm^2

Image: National Safety Apparel, www.thinknsa.com

Unsafe Category

- Greater than 40 cal/cm^2 - No Energized Work

Image: www.rogenstudio.com

Arc Flash Demonstration Video
Category Unsafe

Arc Flash Demonstration Video
Category Unsafe with Mannequin

Arc Flash Labeling

- Labeling standard should reflect and reinforce the companies arc flash program
- Minimum Requirements:
  - Nominal Voltage
  - Limits of approach boundary
  - Incident Energy OR PPE Requirements
- Other information
  - Equipment name
  - Current
  - Arc boundaries
  - Category Number
  - Working Distance

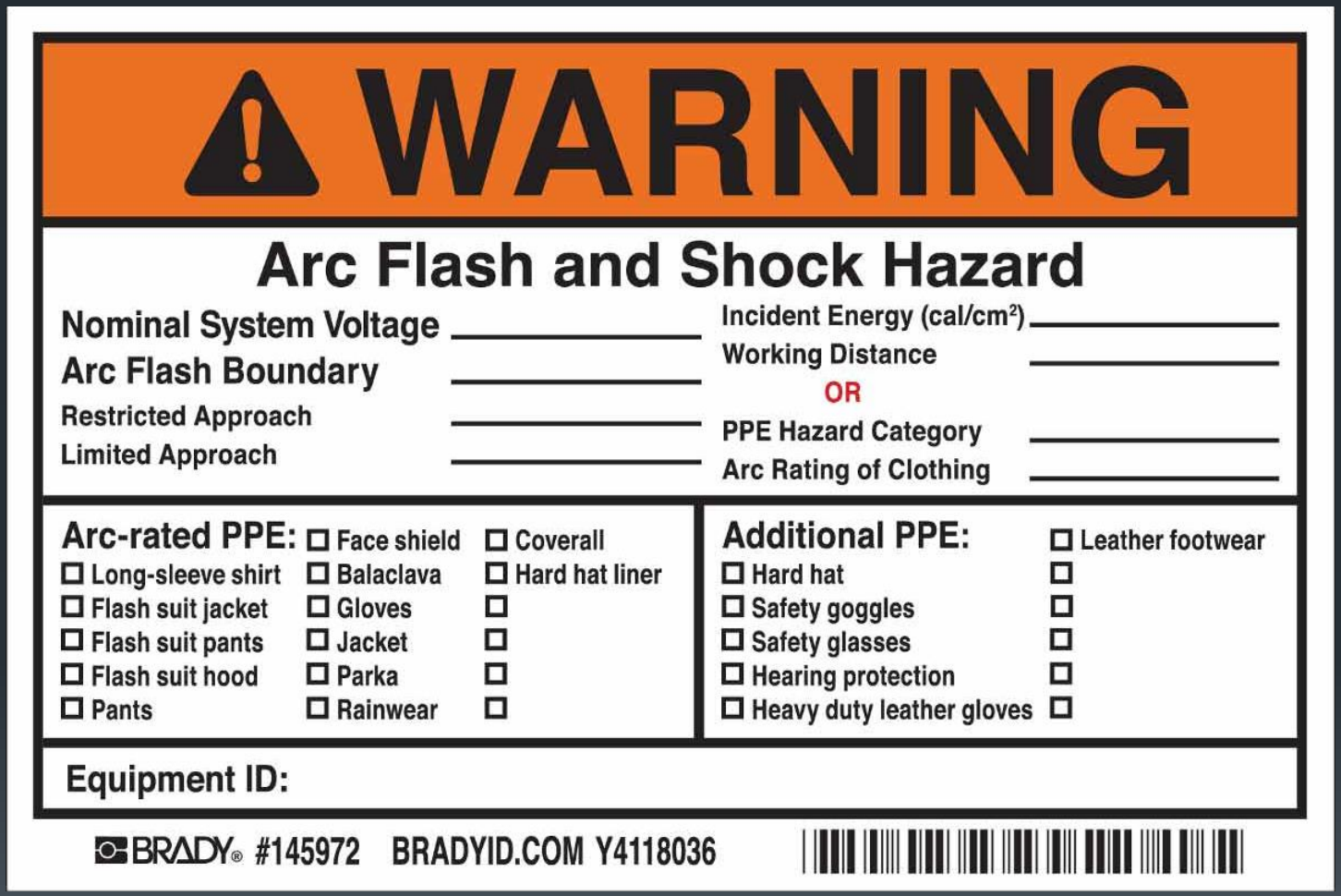


Image: Brady, www.bradyid.com

Calculation Methods

- NFPA 70E Tables
- NFPA 70E & IEEE 1584 Formulas
- IEEE 1584 Calculation Spreadsheet
- Software

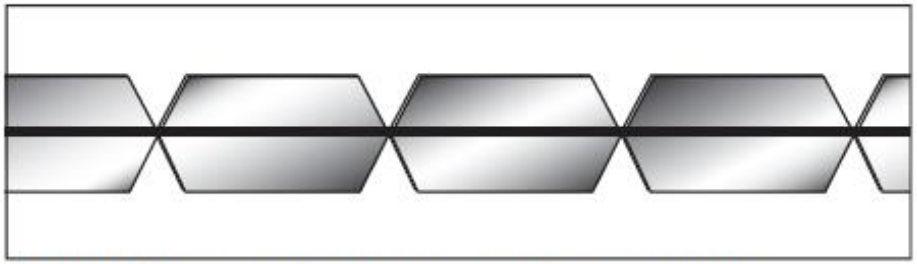
Reducing Arc Flash Hazards

- Design to accommodate de-energized work where possible
- Use lowest voltage possible
- Use arc flash limiting fuses on service entrances
  - Fast-acting fuse that limits fault current
  - Protects downstream circuits
  - Inrush must be considered for motor loads
- Protective Relay Settings Changes
- Arc Flash Breakers (AFBI)

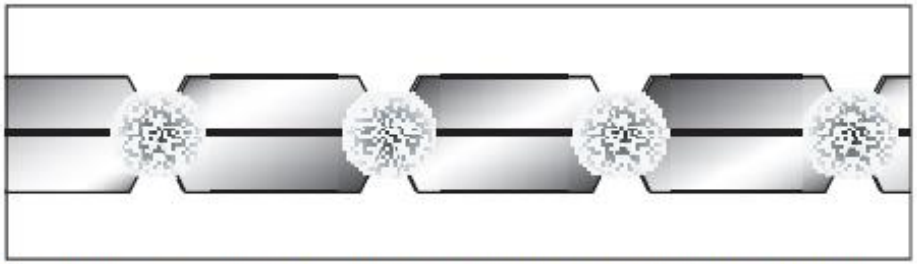
Class J Fast-Acting Fuses

- Overload Mode
  - Operates as a normal fuse
  - The fuse element will melt, opening the circuit
- Short-Circuit Mode
  - Fuse element melts nearly instantaneously
  - The resulting arcs inside the fuse will melt the surrounding silica, turning it to glass. This transition rapidly increases the resistance in the fuse and reduces the current.

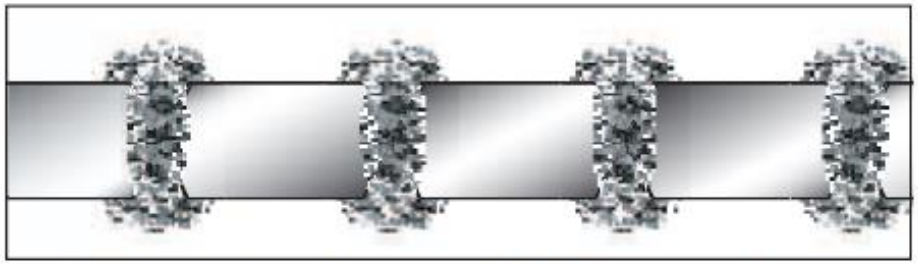
Image: Littlefuse POWR-GARD JLS Series 600 VAC Datasheet



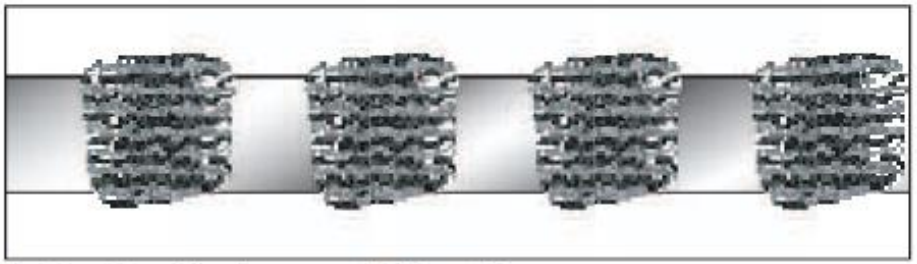
Element melts forming multiple series arcs at element necks



Heat from arcing melts the sand into a glass-like structure referred to as "fulgurite"



Fulgurite absorbs the heat from the arcs but also encloses them, depressing current peak value



Arc is extinguished as current is forced to zero

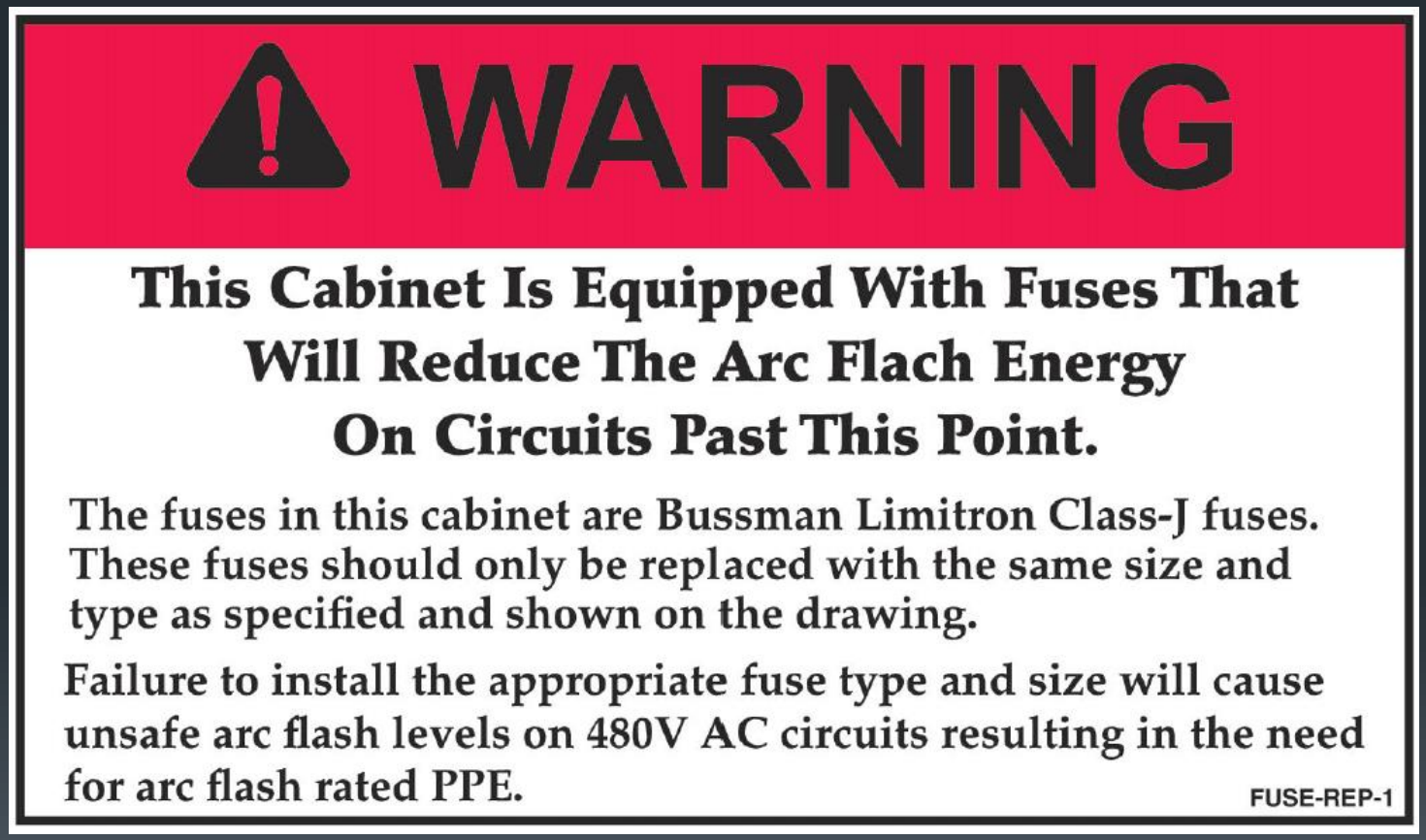


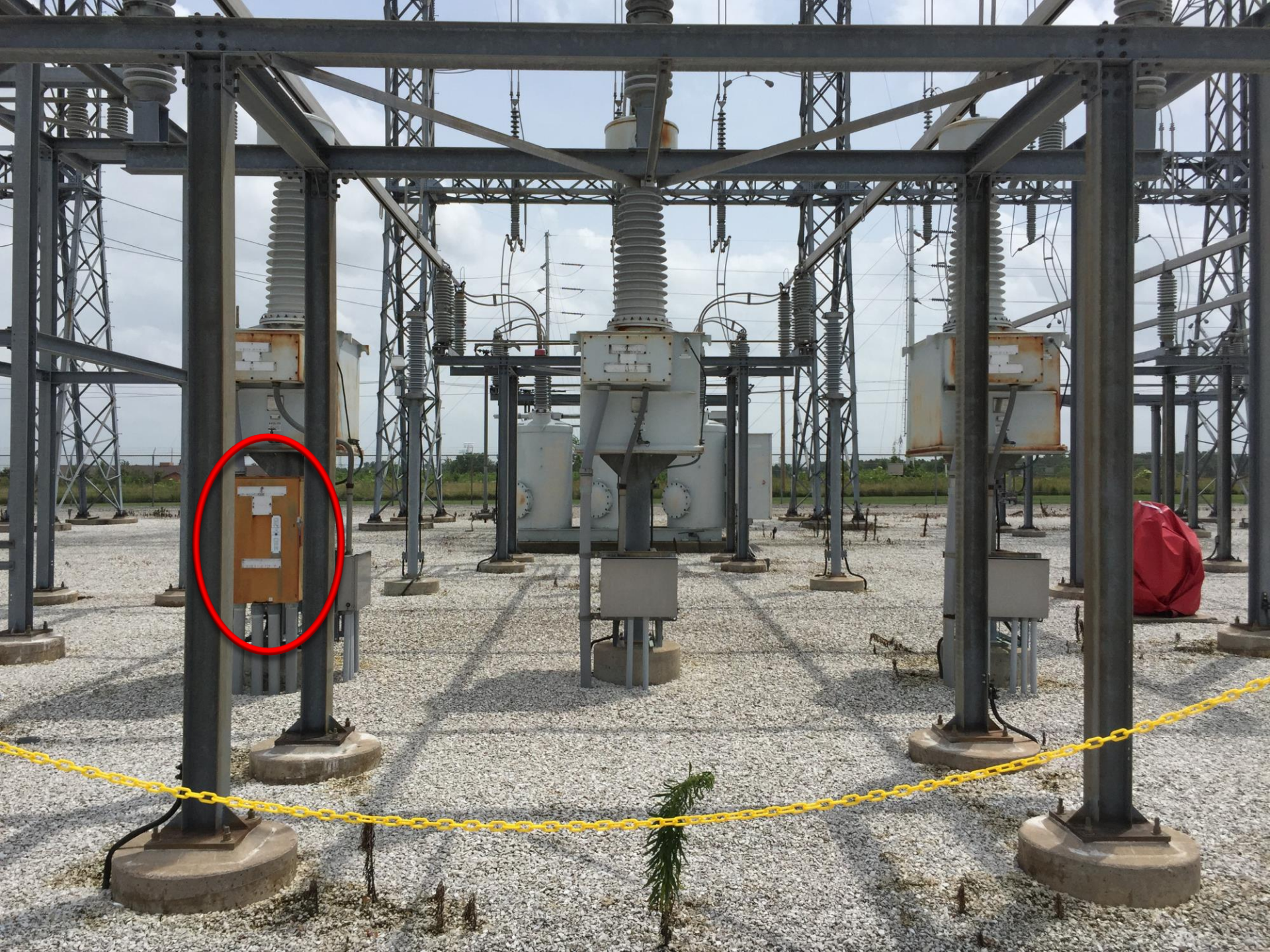
Image: Ameren Transmission

Tyson Substation Case Study

480 Volt Arc Flash Reduction

Project Goals

- Reduce the arc flash hazard at a 480 volt, three-phase, breaker cabinet
- Apply labels to the breaker cabinet
- Apply labels to the fused disconnect service entrance




52-2
DANGER!
ARC FLASH HAZARD
FLASH PROTECTION
Wear Appropriate PPE for the Hazard
Flash Hazard Category: 3
Required Min. Arc Rating (cal/cm²): 25
3
FEDERAL PACIFIC
MANUAL CLOSE DISABLED
TRIP
CLOSE
OPEN
SPRINGS CHARGED
IN
OUT

Arc Flash Analysis Objectives

- Determine the existing arc flash hazards, comparing and contrasting three different methods
  1. NFPA 70E Table Method
  2. IEEE 1584 Calculation Method
  3. Software Method
- Apply fast-acting fuses on the service entrance, re-evaluate the arc flash hazard
- Evaluate arc flash hazard reduction
- Determine labeling for fused disconnect service entrance

Likelihood of Occurrence

Maintenance and testing on individual battery cells or individual multi-cell units in an open rack	Abnormal	Yes
Insertion or removal of individual cells or multi-cell units of a battery system in an open rack.		
Arc-resistant switchgear Type 1 or 2 (for clearing times of less than 0.5 sec with a prospective fault current not to exceed the arc-resistant rating of the equipment) and metal enclosed interrupter switchgear, fused or unfused of arc resistant type construction, 1 kV through 15 kV.		
Insertion or removal (racking) of CBs from cubicles;		
Insertion or removal (racking) of ground and test device; or		
Insertion or removal (racking) of voltage transformers on or off the bus.		

NFPA 70E Table 130.5(C) Estimate of the Likelihood of Occurrence of an Arc Flash Incident for ac and dc Systems

Method 1: NFPA 70E Table

- Category 4, 20ft Arc Flash Boundary

600-volt class switchgear (with power circuit breakers or fused switches) and 600-volt class switchboards	4	6 m
Parameters: Maximum of 35 kA available fault current; maximum of up to 0.5 sec (30 cycles) fault clearing time; minimum working distance 455 mm (18 in.)		(20 ft)

NFPA 70E Table 130.7(C)(15)(a) Arc-Flash PPE Categories for Alternating Current (ac) Systems

Method 2:
IEEE 1584 Calculation

- More accurate method than NFPA 70E Tables
- Required Information
  - Transformer Ratings
  - Conductor Length and Type
  - Bolted Fault Current
  - Clearing Time
  - Equipment Class

Transformer Nameplate	
Voltage	480 V
Power Rating	300 kVA
Impedance	9%

$$R_{PT} = \frac{V^2}{kVA} * \%Z = \frac{480^2}{300{,}000} * 0.09 = 0.06912\ \Omega$$

$$R_{cable} = \frac{0.0382}{2} * \frac{150}{1000} = 0.0029\ \Omega$$

$$I_{SC} = \frac{480}{(0.06912 + 0.0029) * \sqrt{3}} = 3.849\ kA$$

IEEE 1584 Constants	
Working Distance	18 inches
Equipment Class	Switchgear
Grounding Type	Solid Grounded

IEEE 1584 Calculation Method

- Inputs

Name of bus	kV of bus	Bolted fault current of bus in kA (from study)	Trip Time	Opening Time	Working Distance in mm	Equipment Class	Grounding Type
Tyson Breaker	0.48	3.849	2	0	457	3	1

- Results

Name of Location	Incident Energy cal/cm^2	Arc Flash Boundary ft	PPE per NFPA 70E Category
Tyson Breaker	16.5	8.9	3

Method 3: Software Analysis

- Considered the most accurate method
- An Ameren System Protection Engineer modeled the electrical system in the Aspen analysis software, he reported the following results:

2 Sec. Max	cal/ cm^2	PPE Cat.
Tyson Breaker	18.09	3

Method Comparisons

Method	Energy (Cal/cm$^{2)}$	Category	Arc Boundary (ft)
NFPA 70E Table	-	4	20 ft
IEEE 1584 Calculation	16.5	3	8.9 ft
Software	18.1	3	-

Reducing the Arc Flash Hazard

- Install fast-acting fuses at the service entrance
- Will reduce the clearing time, decreasing the arc flash hazard at the breaker
- From the fuse datasheet, the fuse will clear the fault in 0.06 seconds at 3,849 amps

IEEE 1584 Calculation Method - Fast Acting Fuse

- Inputs

Name of bus	kV of bus	Bolted fault current of bus in kA (from study)	Trip Time	Opening Time	Working Distance in mm	Equipment Class	Grounding Type
Tyson Breaker	0.48	3.849	**0.06**	0	457	3	1

- Results

Name of Location	Incident Energy cal/cm^2	Arc Flash Boundary ft	PPE per NFPA 70E Category
Tyson Breaker	**0.5**	**1.5**	**1**

- Reduction to from Category 3 to Category 1

Fused Disconnect Service Entrance

- Fuses do not reduce the arc flash level at the service entrance terminals
- Determine the bolted fault current at the fused disconnect service entrance

$$I_{FL} = \frac{kVA * 1000}{V_{LL} * \sqrt{3}} = \frac{300 * 1000}{480 * \sqrt{3}} = 361\ A$$

$$I_{BF} = \frac{I_{FL}}{\%Z} = \frac{361}{.09} = 4011\ A$$

Likelihood of Occurrence

For ac systems, work on energized electrical conductors and circuit parts, including voltage testing.	Any	Yes
For dc systems, working on energized electrical conductors and circuit parts of series-connected battery cells, including voltage testing.		
Removal or installation of CBs or switches.		
Opening hinged door(s) or cover(s) or removal of bolted covers (to expose bare, energized electrical conductors and circuit parts). For dc systems, this includes		

NFPA 70E Table 130.5(C) Estimate of the Likelihood of Occurrence of an Arc Flash Incident for ac and dc Systems

IEEE 1584 Calculation Method - Fused Disc. Service Entrance

- Inputs

Name of bus	kV of bus	Bolted fault current of bus in kA (from study)	Trip Time	Opening Time	Working Distance in mm	Equipment Class	Grounding Type
Fused Disconnect Service Entrance	0.48	**4011**	**2**	0	457	3	1

- Results

Name of Location	Incident Energy cal/cm^2	Arc Flash Boundary ft	PPE per NFPA 70E Category
Fused Disconnect Service Entrance	17.2	9.2	3

- Fused Disconnect Service Entrance is labeled Category 3 with 9.2 ft Arc Flash Boundary

Bonus Video

- https://www.youtube.com/watch?v=2SopsQEfoc4

References

- Westex http://www.westex.com/resource-center/
- Eaton Current Limiting Fuses Vol14
- Littlefuse POWR-GARD JLS Series 600 VAC Datasheet
- Bussmann Limitron Class J JKS Series 600 VAC Datasheet
- Bussmann Fusetron Class RK5 600 VAC Datasheet
- Ameren Illinois Arc Flash Protection Program, Revision 1
- “What is Arc Flash” www.mikeholt.com
- IEEE Standard 1584-2002 Guide for Performing Arc Flash Hazard Calculations.
- NFPA 70E-2018 National Electric Code
- Cooper Bussmann “Short Circuit Current Calculations”