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Arc Flash Studies

An Introduction on How to Not End Up Like a Scout Camp Hot Dog



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Why me?

- University of Wyoming: BSEE 1999
- Idaho National Laboratory – 2000-2012
 - » Electrical Design Engineer – Test Reactor Area
 - » Electrical System Engineer – Test Reactor Area/Advanced Test Reactor
 - » Electrical Safety Committee Chair – 2008-2012
- POWER Engineers, Inc. – 2012-present
 - » Electrical Systems Studies

I've been doing arc flash calculations since 2001.

Overview

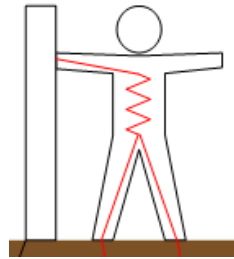
- Electrical Hazards
- Standards
- Do you Need to Comply?
- How to Comply

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Electrical Hazards and Arc Flash

Electric shock

- Occurs when a person completes an electric circuit.
- Currents as low as 6mA can be fatal due to heart fibrillation and respiratory paralysis.
- Tissues burn at higher current levels (~5A).
- Most understood and addressed hazard



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Arc Flash

- Sudden release of energy due to uncontrolled electric arc.
- Product of short circuit current and arc duration.
- Plasma cloud created when metals vaporize.
- Gas temperatures can reach 35,000°F.
- Temperatures and Incident Energy (IE) levels required to ignite normal clothing and cause tissue burns are fairly low.
- Severity based upon
 - » Proximity, temperature, and time to clear



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Arc Blast

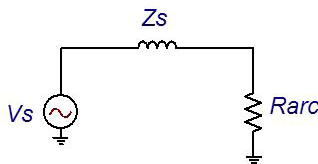
- Rapid expansion of gases due to an electric arc flash.
- Possible shrapnel, molten metal expulsion
- Copper expansion of 67,000 times (similar to TNT).
- If the arc flash intensity is high enough, blast hazards can be more dangerous than flash hazards.
- Pressure wave due to expanding metal and air.
- Pressure waves can cause injury or death even if the AR PPE prevents burns.
- Shrapnel speeds can exceed 700 mph.



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Arc Flash Theory

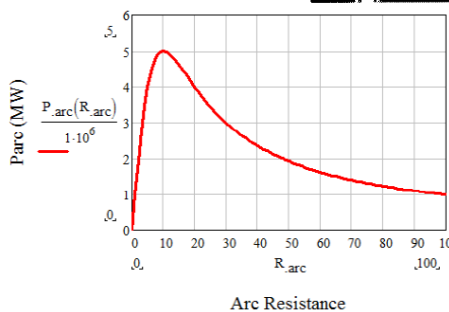
- Thermal aspects of arc flash were first described mathematically by Ralph Lee in a 1982
 - "The Other Electrical Hazard: Electric Arc Blast Burns". Based upon maximum power transfer theorem



For a bolted Three Phase Fault:

$$P_{app_max_fault} := \frac{V_s^2}{|Z_s|} = 10 \text{ MVAR}$$

$$I_s(R_{arc}) := \frac{V_s}{Z_s + R_{arc}} \quad P_{arc}(R_{arc}) := (|I_s(R_{arc})|)^2 \cdot R_{arc}$$



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Arc Flash Theory

- Incident Energy (IE) is reported in Joules/cm² or Calories/cm²
- Energy on a surface at a distance (d) from the source is inversely proportional to the distance squared
$$\text{Energy} \propto \frac{\text{Volts*Current*Time}}{d^2}$$

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**Why Do You Need to Know About
Electrical Hazards and Arc Flash?**

Arc Flash Causes

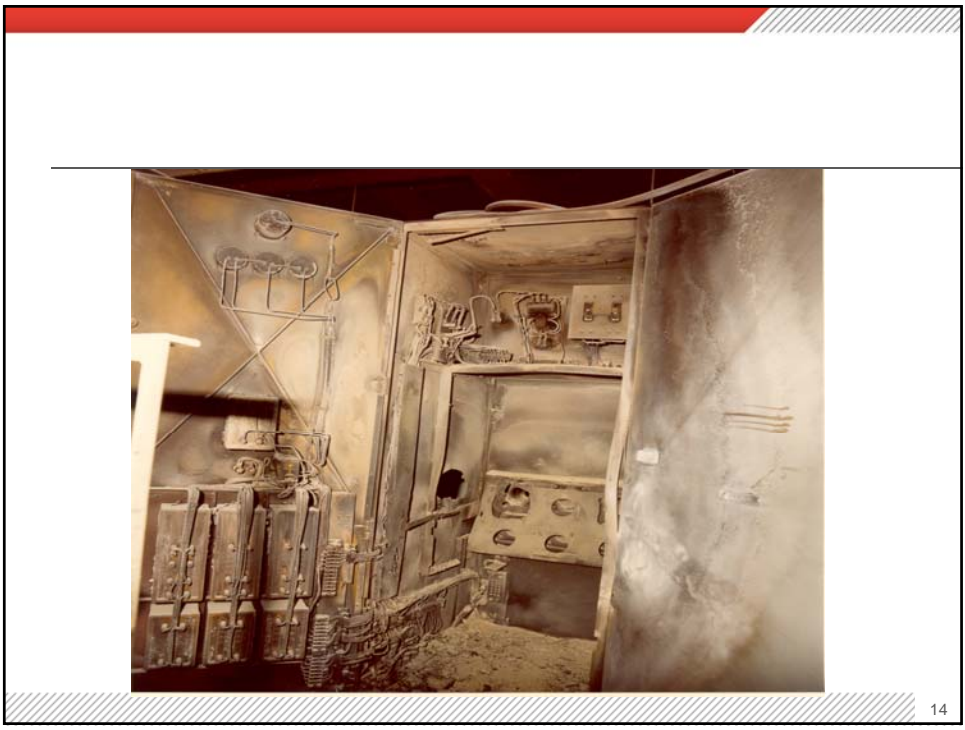
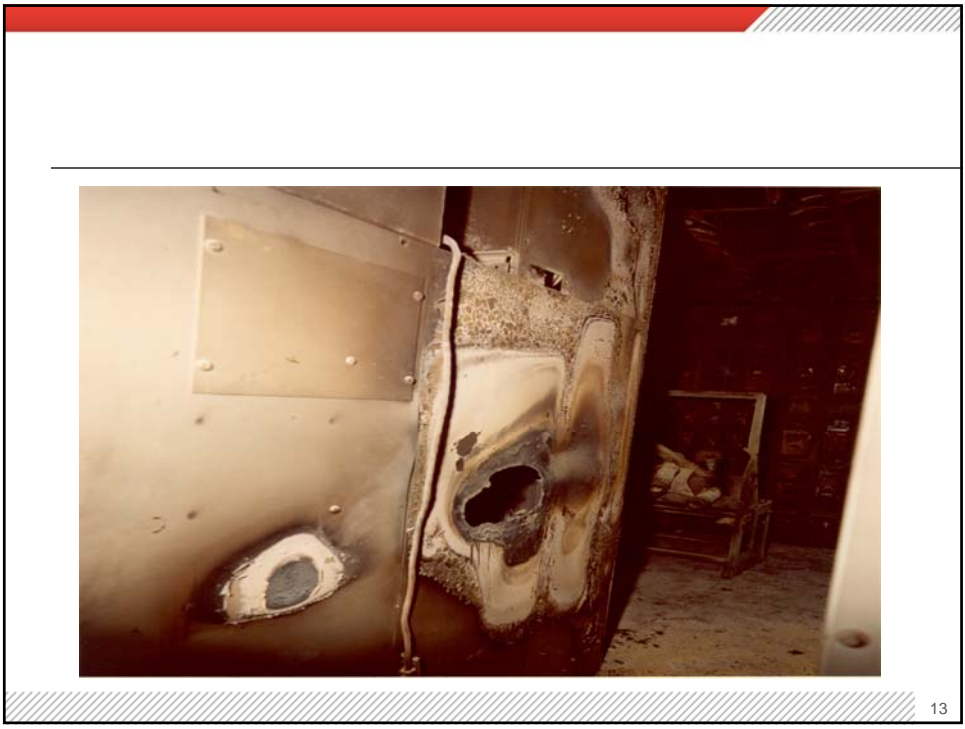
- Human error (the #1 cause)
 - » Accidental contact by person or tool (engineers are not exempt)
 - » Incorrect assembly/repair
 - » Incorrect tool use
- Mechanical failure
 - » Lack of maintenance
 - » Material defect
- Foreign object intrusion
 - » Dust/debris
 - » Water
 - » Animals
- Faults or Current overload
 - » Stressed/weakened components

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What do these pictures have in common (besides blown up gear)?



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- Engineers were involved in the initiation of the arc flash events pictured.
- Engineers were injured in those arc flash events.

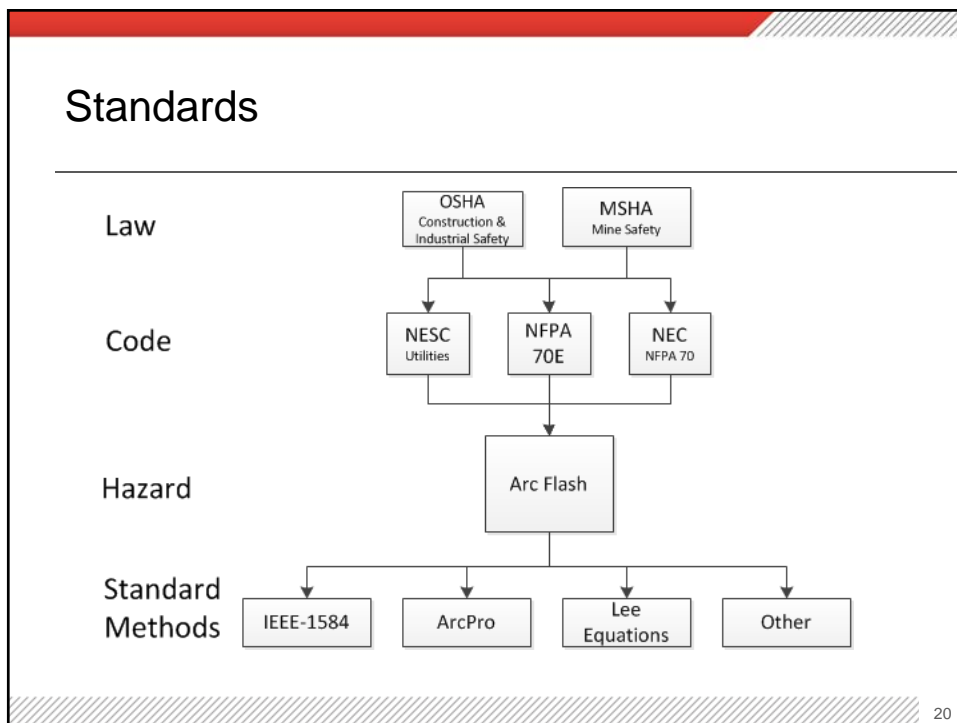
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Electrical Engineer Responsibilities

- You may be asked to perform arc flash studies.
- You may be asked to interpret arc flash studies.
- You may be asked to scope or contract out arc flash studies.
- You most likely will need to abide by the results of an arc flash study.
- #!@&! this up could result in the loss of life and/or property.

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Standards



Standards

- OSHA 29 CFR 1910 (revised 2014)
 - » Effective April 1, 2015
- NEC - NFPA 70-2017 (revised every 3 years)
- NFPA 70E-2018 (revised every 3 years)
- IEEE 1584-2002
 - » Update presently in approval process with IEEE
 - » Expected adoption late 2018
 - » Complete overhaul of 2002 standard.

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OSHA 29 CFR

- 1910 Sub part S
 - » General electrical safety standards
 - Training, analysis, PPE, proper tools
- 1910.269
 - » Electric Power Generation, Transmission, and Distribution
 - Applicable to electric utilities as well as equivalent installations of industrial establishments.

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OSHA 29 CFR

- 1910.269
 - » New update
 - Requirement for employer to determine the maximum anticipated per-unit transient overvoltage through engineering analysis or assume maximum anticipated per-unit transient overvoltage's (up to 3.5) this must be used on all minimum approach distances
 - » No later than April 1, 2015, for voltages over 72.5 kilovolts
 - » Based upon 2007 NESC and IEEE 516-2009
 - » (l)8
 - (i)The employer shall assess the work place to identify employees exposed to hazards from flames or from electrical arcs
 - (ii)for each exposed hazard the employee shall make a reasonable estimate of the incident heat energy to which the employee will be exposed.
 - » Appendix E provides guidance via tables or calculation methods

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NEC – NFPA 70

- Article 110.16
 - » Requires electrical equipment that that are in other than dwelling units and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazard
 - » Points to NFPA 70E and ANSI Z535.4 for labels
- Electrical equipment
 - » Switch boards, panel boards, MCCs, meter enclosures, industrial control panels, etc...

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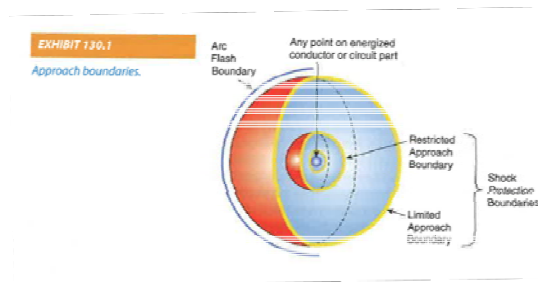
NFPA 70E

- Details method to identify, analyze, and document electrical safety-related work practices when safe work conditions must be established
- Article 130
 - » 130.1 states “ All requirements of this article shall apply whether an incident energy analysis is completed or if tables are used in lieu of incident energy analysis in accordance with 130.5”
- AC circuits operating over 50V and DC operating over 100V
- Hazard/Risk Categories are no longer defined
 - » Article 130.7 defines arc flash hazard identification
- Approach boundaries
- Tables for common conditions
- Label minimum requirements
- Points to several methods for arc flash calculations
 - » IEEE-1584 is industry preferred standard for calculations for 3-phase analysis up to 15 kV
- No method for single phase analysis is included in the standards.
 - » Several approaches have been developed.

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Boundaries

- Arc Flash (not a fixed distance)
 - 1.2 cal/cm²
- Limited Approach
 - Qualified personnel only
- Restricted Approach
 - Shock protection (>50V)



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IEEE

- **IEEE 1584**
 - » Guide for performing Arc Flash analysis(revised 2002, next update late 2018)
 - » Does not cover DC
 - » Will still only cover 3-ph AC from 208V to 15kV.
 - » Used for most software analysis
- **Non IEEE 1584 methods:**
 - » Duke Heat Flux
 - » ArcPro (by Kinectrics)
 - » Others (EPRI, IEEE published studies, NESC studies)

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Do you Need to Comply?

Who Needs to Comply?

- **OSHA general rules require a work place free from known hazards**
 - » OSHA 29 CFR 1910.296 provides clear direction and defines arc flash as a known hazard.
- **Employer**
 - » Provide electrical safety program
 - » Safety polices
 - » Safety training
 - » Documentation/labels
 - » Proper PPE
 - » Proper Tools
- **Employee**
 - » Implementing and following the procedures
- **Property owner**
 - » Responsible for all employees and contractors onsite

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How to Comply

Arc Flash Risk Assessment Process

- Identify requirements
- Data collection
- Determination of calculation method
- System modeling and initial analysis
- Mitigation
- Document and implement

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Identify Requirements

- Multiple branches/ departments may require different procedures and documentation
- May require development of:
 - » Safety training procedure
 - » Procedure to transfer knowledge
 - » Label standards
 - » Change of tools and PPE currently used
- Identify all electrical equipment at sites that have an arc flash hazard
 - » Equipment greater than 50V that are likely to require examination, adjustment, servicing, or maintenance while energized.
 - » This can be maintenance operations center, substations, generation facility, industry facility, etc....

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Identify Requirements

- Select one method for selecting PPE, but not both (NFPA 70E).
 - Incident Energy Analysis Method
 - Preferred method
 - Arc Flash PPE Table Method
 - Will require evidence that the allowed short circuit and clearing time values are not exceeded.

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Data Collection

- Conductor/Cable lengths
- Protection elements,
 - » Size, model information, and settings
- Sources with short circuit MVAs
- All major equipment name plate
 - » Motors, generators, transformers,
- Enclosure sizes/ type
 - » open air, tank, NEMA arc-resistant....
- Description of the area surrounding the work area

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Determination of Calculation Method

- What are the voltage levels?
- How many calculations?
- Software
 - What software do you already use?
 - Many software packages have the ability to perform arc flash calculations. Some require additional modules to be purchased.
- Spreadsheets or hand calculations.
 - Not recommended for large systems or multiple scenarios.
 - New IEEE-1584 equations will be much more complex than previous equations so this may not be an option.

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OSHA Guidelines for IE Calculations

Table 3—Selecting a Reasonable Incident-Energy Calculation Method¹

Incident-Energy Calculation Method	600 V and Less ²			601 V to 15 kV ²			More than 15 kV		
	1Φ	3Φa	3Φb	1Φ	3Φa	3Φb	1Φ	3Φa	3Φb
NFPA 70E-2012 Annex D (Lee equation)	Y-C	Y	N	Y-C	Y-C	N	N ³	N ³	N ³
Doughty, Neal, and Floyd	Y-C	Y	Y	N	N	N	N	N	N
IEEE Std 1584b-2011	Y	Y	Y	Y	Y	Y	N	N	N
ARCPRO	Y	N	N	Y	N	N	Y	Y ⁴	Y ⁴

Key:

- 1Φ: Single-phase arc in open air
- 3Φa: Three-phase arc in open air
- 3Φb: Three-phase arc in an enclosure (box)
- Y: Acceptable; produces a reasonable estimate of incident heat energy from this type of electric arc
- N: Not acceptable; does not produce a reasonable estimate of incident heat energy from this type of electric arc
- Y-C: Acceptable; produces a reasonable, but conservative, estimate of incident heat energy from this type of electric arc.

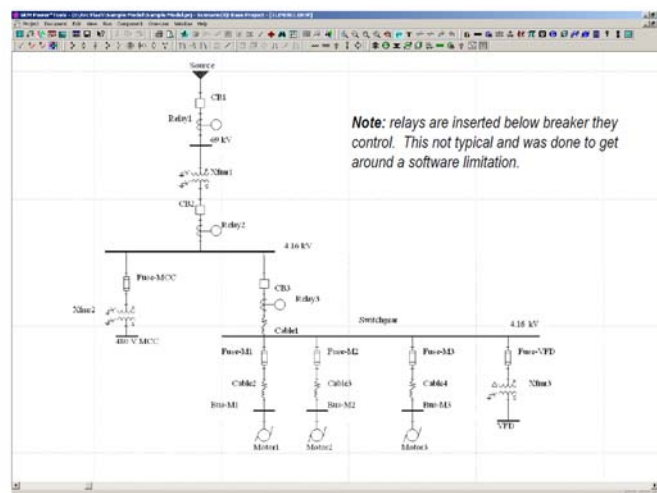
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System modeling and Initial Analysis

- Develop a system model in a program capable of determining fault currents as well as arcing currents
 - » Some typical software packages include:
 - ETAP, SKM Power Tools, EASY POWER, and ARCPRO.
- Determine all modes of operation
 - » Worst case may not be highest fault current
 - » Develop TCCs to analyze coordination/operation
- Determine select working distances
 - » This will be modified based upon enclosure
- Determine duration of faults
- Calculate incident energies
- Calculate protection boundaries

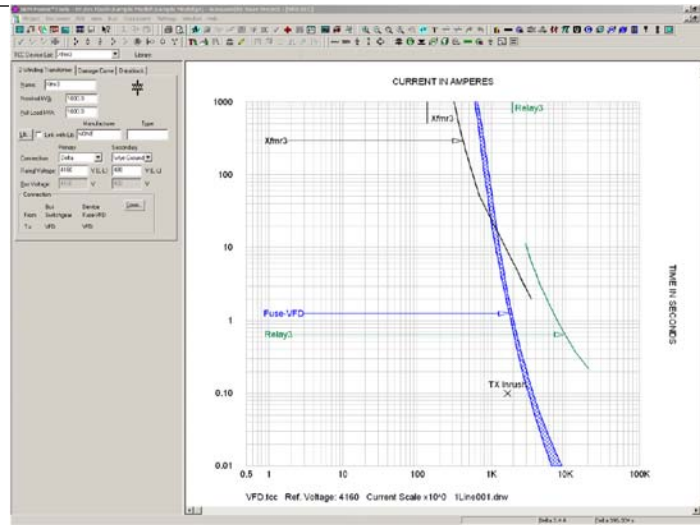
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System modeling and Initial Analysis



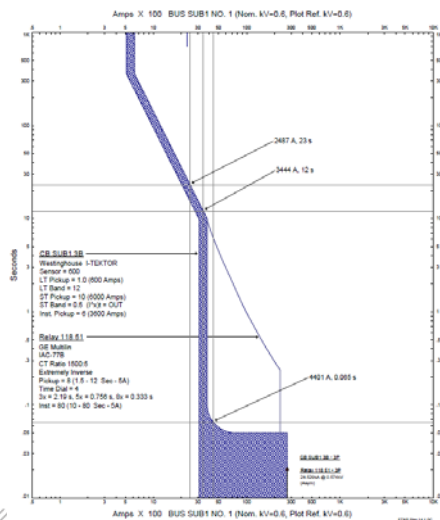
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System modeling and Initial Analysis



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System modeling and Initial Analysis



What happens to the Incident Energy levels as the curve is moved to improve coordination?

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System modeling and Initial Analysis

Bus Name	Voltage	Power	...
1	13.8 kV
2	13.8 kV
3	13.8 kV	...	...
4	13.8 kV	...	...
5	13.8 kV	...	...
6	13.8 kV	...	...
7	13.8 kV	...	...
8	13.8 kV	...	...
9	13.8 kV	...	...
10	13.8 kV	...	...
11	13.8 kV	...	...
12	13.8 kV	...	...
13	13.8 kV	...	...
14	13.8 kV	...	...
15	13.8 kV	...	...
16	13.8 kV	...	...
17	13.8 kV	...	...
18	13.8 kV	...	...
19	13.8 kV	...	...
20	13.8 kV	...	...
21	13.8 kV	...	...
22	13.8 kV	...	...
23	13.8 kV	...	...
24	13.8 kV	...	...
25	13.8 kV	...	...
26	13.8 kV	...	...
27	13.8 kV	...	...
28	13.8 kV	...	...
29	13.8 kV	...	...
30	13.8 kV	...	...
31	13.8 kV	...	...
32	13.8 kV	...	...
33	13.8 kV	...	...
34	13.8 kV	...	...
35	13.8 kV	...	...
36	13.8 kV	...	...
37	13.8 kV	...	...
38	13.8 kV	...	...
39	13.8 kV	...	...
40	13.8 kV	...	...
41	13.8 kV	...	...
42	13.8 kV
43	13.8 kV
44	13.8 kV
45	13.8 kV
46	13.8 kV
47	13.8 kV
48	13.8 kV
49	13.8 kV
50	13.8 kV

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System modeling and Initial Analysis

Considerations:

- Be aware of available evacuation space or lack thereof.
- Make sure to take into account type of enclosure and main PD isolation.
- Higher fault currents and longer clearing times compete for worst case arc flash conditions.
- Be aware of interrupting device ratings.
 - » Device may not operate in all conditions.
- Remember to include the time required for the breaker operation (typical 3-5 cycles).
 - » This is included in the Time Current Curves for low voltage breakers and trip units.

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Mitigation


- Arc Rated (AR) clothing
 - » Flame-Resistant (FR) clothing without an arc rating has not been tested for exposure to an electric arc.
- Additional PPE
- Prohibit energized work
- Faster clearing time
 - » Resize equipment
 - » Added additional equipment
 - » Reduce pickup/ time dial (may require maintenance mode settings)
 - » Cubicle flash detecting instantaneous elements (arc flash/ optical relays)
- Remote operation
- Reduce available fault current
- Arc Rated electrical equipment
 - » Vents arc energy and debris in a direction away from the worker

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Document

Develop labels per NFPA 70E

- Labels must included:
 - » Nominal System Voltage
 - » Arc Flash Boundary
 - » At least one of the following:
 - Available incident energy and corresponding work distance, or the arc flash PPE category per table 130.7(C)(15) but not both
 - Minimum arc rating of clothing
 - Site specific level of PPE
- Labels applied prior to September 30, 2011 are acceptable if they have available incident energy or PPE level required 2011

 WARNING	
ARC FLASH AND SHOCK HAZARD WEAR REQUIRED PPE	
Arc Flash Boundary	1 ft.
ATPV @ 18 In.	8 Cal/cm ²
Shock Hazard when cover is removed	480 V
Glove Class	00
Limited Approach (Fixed Circuit)	3.5 feet
Restricted Approach	1.0 feet
Equipment: Transformer AT1	<small>Review Date: 1/30/14 - Rev 0 Study Date by Power Engineers, Inc.</small>

Labels are not an OSHA requirement and may not be required by 70E in some cases.

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Document

- Develop report detailing all required mitigation
- Develop a final detailed report with all incident energies and appropriate labels.
- Update safety/training documents
- Update operational/ maintenance procedures
- Update procurement and asset management
- Ensure labels and training are implemented and documented

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Follow-Up

- Labels and studies must be kept up to date
 - » Update whenever major modification or renovation takes place
 - » Reviewed at least every 5 years
- Maintenance
 - » Failure to maintain equipment may result in
 - Slower clearing times that may cause an increase in the arc flash hazard
 - Increased probability of an arc flash event

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Arc Flash Studies

Questions?

