Arc Flash Mitigation – An Overview

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Agenda

- Origin of Modern Arc Flash studies
- Why Now more than before
- NFPA 70E Standards
- Protection Zone
- IEEE 1584 – 2002
- IEEE 1584 Vs NFPA 70E
- Arc Flash Assessment & Mitigation
- Minimizing Energy
- Unit Presence of Personnel Near Arc Flash
- Options Available Arc Flash Resistant switchgear, Chicken switch, Time delay switches and Relays
- Questions

What is Arc Flash?

- “An Arc Flash is an electric current that passes through air when insulation or isolation between electrical conductors is no longer sufficient to withstand the applied voltage.” [NFPA 70E]
- “Arc flash results from an arcing fault, where the electric arcs and resulting radiation and shrapnel cause severe skin burns, hearing damage, and eye injuries. “(OSHA Training Grant SH-16614-07)
- Arc flash causes damage from energy flux, not electric current and is distinct from electrocution.

Origin of Modern Arc Flash Study

- *The Other Electrical Hazard: Electric Arc Blast Burns* (Ralph Lee, 1985)

- Wakeup call
- Start of Modern Arc Flash Safety Studies, based on industrial experience
- Put arc flash hazards on a par with those of electrocution

Origin of Modern Arc Flash Study

- Key Results from Lee 1985:
  - *Arcs are extremely hot: 4 x Temperature of the Sun*
  - *Importance of incident energy and threshold for very serious burns of 1.2 cal/cm^2 - still in use.*
  - *Calculation of effects of arc current, distance from arc, voltage, and other variables. More on this later.*
  - *"All that is necessary to incur serious or fatal injuries is to be within five feet or so from a severe power arc with bare skin or flammable clothing."*

Other Key Early Work

- *Pressures Developed by Arcs,* Ralph Lee 1987.
  Up to 2,000 psf
- *Testing Update on Protective Clothing and Equipment for Electric Arc Exposure,* Bingham, Doughty, and Neal 1997
  Besides data on personnel protective equipment and clothing (PPE) also discussed the amplifying effect of enclosures.
- *Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600-V Power Distribution Systems,* Doughty, Floyd, and Neal 2000

Why now?

- More attention to worker safety
- More medium and high voltage feeds in industrial applications
- Better data (and more is on the way)
- Large increase in electricity usage
- Higher Efficiency Equipment (Lower Impedance)

NFPA 70E

- Provides guidelines to limit injuries to second degree burns.
- Defines zones depending on risks of electrocution and arc flash burns.

NFPA 70E

- Shock/electrocution boundaries depend on voltage.
  - Limited Approach Area: no untrained personnel may approach live conductors within this distance.
  - Restricted Approach Area: trained personnel with PPE and a written plan
  - Prohibited Approach Area: trained personnel, PPE, written plan and risk assessment. Assumption is that work within this zone is the same as touching the live conductor. Training, tools and documentation must be appropriate.

Flash protection Boundary and Limits of Approach

WARNING

Arc Flash and Shock Hazard
Appropriate PPE Required

24 inch	Flash Hazard Boundary
3	cal/cm² Flash Hazard at 18 inches
1DF	PPE Level, 1 Layer 6 oz Nomex®, Leather Gloves, Faceshield
480 VAC	Shock Hazard when Cover is removed
36 inch	Limited Approach
12 inch	Restricted Approach - 500 V Class 00 Gloves
1 inch	Prohibited Approach - 500 V Class 00 Gloves

Equipment Name: Slurry Pump Starter

NFPA 70E

NFPA 70E, Section 130.3 (B) states:

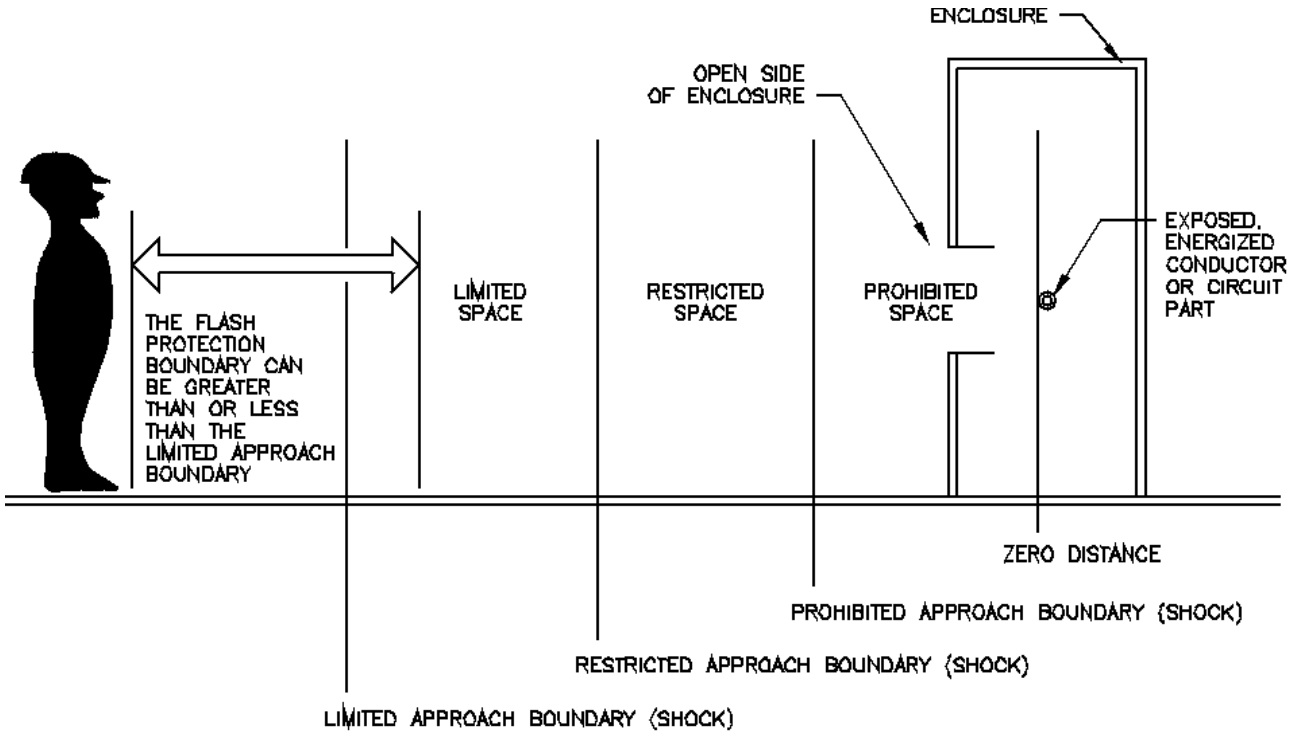
> The incident energy exposure level shall be based on the working distance of the worker's face and chest areas from a prospective arc source for the specific task to be performed

NFPA 70E

- Flash Protection Boundary
  - Depends on available energy: arc voltage * fault current * duration
  - Can easily be a larger or smaller area than the limits from system voltage
  - NFPA calculations are easy to do and are often conservative. More on this later.
  - There are three methods in NFPA 70E, with different applicability and computational effort required.
  - Online calculators and other tools are available.

Typical NEC Warning Label

Protection Zones



- From an excellent training presentation prepared by West Virginia University for OSHA under grant SH-16614-07. Available on the web in English and Spanish.

NFPA 70E Boundries

Good safety practices minimize risk:

- Switch remotely if possible.
- Standing aside and away as much as possible during switching.
- Avoid leaning on or touching switchgear and metallic surfaces.
- Use proper tools and PPE.

IEEE 1584-2002

- *Guide for Performing Arc Flash Hazard Calculations*
- Based on statistical analysis of lab data
- Well defined, but somewhat lengthy procedure for calculating energy, flash boundary and required PPE.
- 49 case studies of incidents

IEEE 1584

- In the process of being revised, hopefully for this year.
- Extensive, well funded effort to get new data
- Should cover a variety of situations (new voltages) with new experimental data
- More accurate equations

Using IEEE 1584 to Calculate Incident Energy and Flash Boundary

- Step 1: Calculate the Arcing Current
  - Inputs: Bolted Fault Current, System Voltage, Gap, Enclosed/Not Enclosed
  - Output: Arcing Current

$$\begin{aligned}\text{Log}(I_a) = {} & K + 0.662*\log(I_{bf}) + 0.0966*V \\ & + 0.000526*G + 0.5588*V*\log(I_{bf}) \\ & - 0.00304*G*\log(I_{bf})\end{aligned}$$

$$I_a = 10^{\log(Ia)}$$

Using IEEE 1584 to Calculate Incident Energy and Flash Boundary

- Step 2: Determine Incident Energy
  - Inputs Open/Boxed, High/Low Impedance Ground, Gap, Voltage, Time and Distance from Arc
  - Incident Energy is proportional to Time and inversely proportional to $1/D^2$ or $1/D^{1.437}$ or in between.

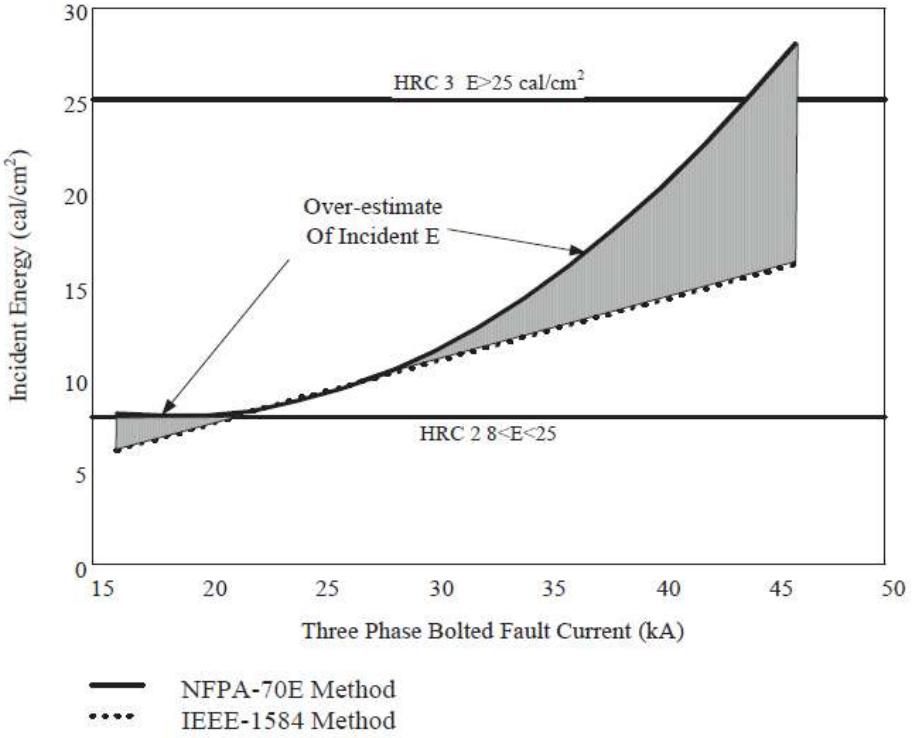
- $\log(E_n) = K_1 + K_2 + 1.081 * \log(I_a) + 0.0011 * G$
- $E = C_f * E_n * (t/0.2) * (610^x / D^x)$

Using IEEE 1584 to Calculate Incident Energy and Flash Boundary

- Step 3: Calculate Flash Boundary
  - Distance where incident energy falls to 1.2 cal/cm^2
- $D_B = 610 * [C_f * * (t/0.2) * (E_n / E_B)]^{1/x}$

IEEE 1584 v. NFPA 70E

70E is often very conservative.



From *A Survey of Arc Flash Computation Methods and Mitigation* Strategies, Carl Spezia 2010

Arc Flash Assessment

- Determination of degree of risk and precautions required.
- Arc flash incidents are "high cost/low probability events" (Spezia 2010)
  - Injury, litigation, regulatory requirements
  - NIOSH DVD *Arc Flash Awareness* gives accounts from electrical workers
- Assessing risk and benefits can be difficult
- See, for example: http://www.nsc.org/safetyhealth/Pages/411resourcesImportanceofArcFlashSalisbury.aspx

Arc Flash Mitigation

- [Incident Energy] = K * time * F(fault current)/ $D^{1.497}$
  - NFPA 70E for enclosures
- Problem is caused by the intersection of factors
  - Energy in the arc
    - Fault current
    - Clearing Time (Time is more important than fault current)
  - Presence of personnel near the arc
  - Proximity to the arc, ie. Working at close quarters
    - Incident Energy α $1/D^2$ (Open area)
      or $1/D^{1.5}$ (Enclosure)
  - Susceptibility of personnel to incident energy (PPE)
- All of these factors can be addressed!

Minimizing Energy

- Decrease fault current
  - Series reactance can lower fault current – but…
    - Lower current can slow clearing devices
    - Often not practical or cost effective

Minimizing Energy

- Current Limiting Fuses
  - Must clear a short circuit fault in less than a half cycle
  - Because of fast melting and increased fuse impedance in the first quarter cycle both time and peak current are greatly reduced.
  - Can greatly reduce incident energy (by more than a factor of ten)
  - Only work within limited ranges. Great when you have one that fits the application. IEEE 1584 and vendor web sites have detailed ratings

Minimizing Energy

- Fiber Optic Flash Sensors
  - Provide very fast arc detection - ~2 msec
  - Work in closed spaces such as switchgear
  - Readily available
  - Some newer digital relays have inputs for up to four optical arc sensors
  - See Inshaw, C., & Wilson, R. A. , Western Protective Relay Conference, 2004.

Minimizing Energy

- Change Relay Settings During Maintenance or Other Operations
  - Uses existing equipment
  - Requires coordination study
  - May increase system vulnerability during maintenance
  - Depends greatly on particular circumstances.

Limit Presence of Personnel Near Arcs

- If you aren't there you won't get hurt.
- Only work on energized equipment when absolutely necessary
  - Look hard for any alternative.
  - Observe OSHA and NFPA guidelines and rules
  - Lockout/tagout!
  - Check that voltage is really not present.
- Remote racking of breakers, Mimic panels, etc.
- Arc resistant switchgear (any potential arc is shunted away from personnel)

Limit Presence of Personnel Near Arcs

- Use Time Delay Trip and Close Control Switches in Metalclad Switchgear
- Provide 10 to 30 second delay from instigation of operation to actual switching.
- Discrete switch solution from Electroswitch
- Also available in some newer digital protective relays

Limit Presence of Personnel Near Arcs

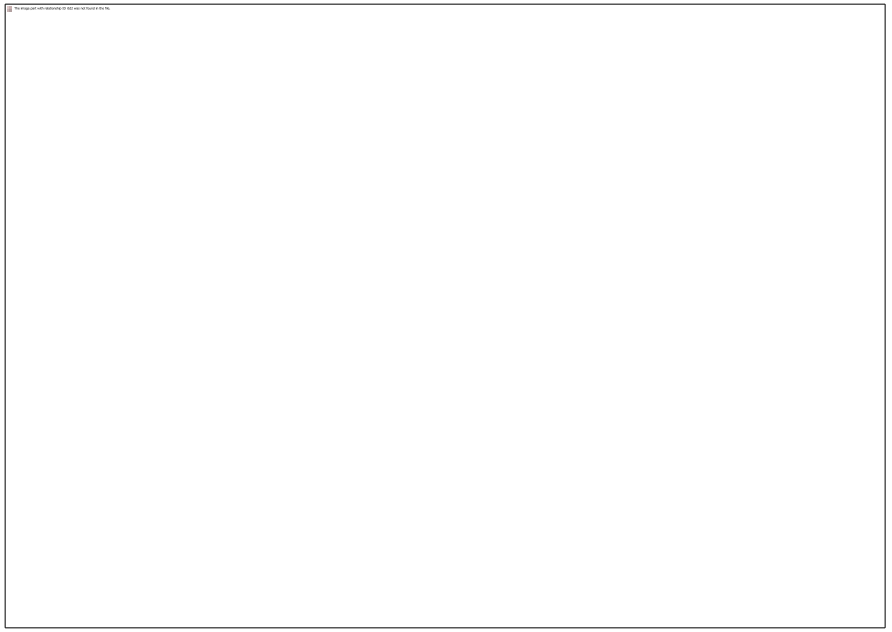
- Electroswitch Time Delay Control Switch
- Simple, intuitive operation
- Trip and close operations started and cancelled via pushbuttons
- Remote operation also built in.

Increase Distance of Personnel to Arc

- For metalclad this often means operating a control switch remotely.
- Homegrown solutions
  - Hot sticks
  - Rope
  - Other

Increase Distance of Personnel to Arc

- The Chicken Switch
- Clamps on to existing switch handle.
- Disadvantages:
  - Has to be found each time you need to operate the switch
  - Needs careful installation to avoid breaking the switch handle



Protect Personnel Subject to Arc Flash

- This is the last line of defense! It is there to protect against life threatening injury.
- It is important to specify the PPE reasonably accurately.
  - Too little protection can result in disaster
  - Overprotection reduces worker mobility and vision, causing other problems.

Protect Personnel Subject to Arc Flash

- Ranges from:
- class 0 (Untreated cotton)
- Class 4 (Cotton underwear plus FR shirt, pants, coveralls and multilayer flash suit) for up to 40 cal/cm^2
- Beyond 40 cal/cm^2 equipment must be deenergized.

Arc Flash Mitigation

- Solvable problem
- Better standards and information (IEEE 1584 revision are on the way.
- Information is readily available.
- Questions?