The “Latest” on Arc Flash

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What We Will Cover (Briefly)

- AC Arc Flash
- Latest DC Arc Flash Testing
  - Leading to NFPA 70E-2024 Changes
  - Better Formulas Coming
    - e.g., IEEE IAS Paper This Year on Modifying Max Power Time and “New” Arc-in-a-Box Multipliers for Arc Flash Boundary
- How the Culture Around Electrical Safety Has Changed
- How to Work Safely
  - Batteries Can’t be Made Dead – What to Do?
  - Don’t “Over”-Protect, Especially when System Proven Ungrounded

It's Just Power…

AC Arc Flash Sample Video

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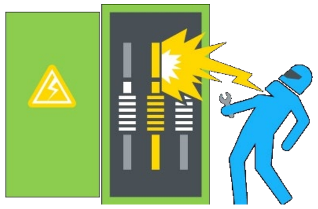
The Power of Electricity



- Shock
  - Current Through Body’s Nervous/Vascular, or Across Surface
  - 50 VAC_{rms} in NFPA 70E or 30 VAC_{rms} in NEC®
  - 70E: 100 VDC < 40 mA (Wet Body?) or 50 VDC (nominal); 60 VDC in NEC®
- Arc-Flash
  - Extremely High Temperature Conductive Gases and Plasma

- Arc-Blast
  - Pressure Wave Caused by Gas Expansion, with Flying Molten Metal
- Thermal Burn (Energy Created by OverHeating

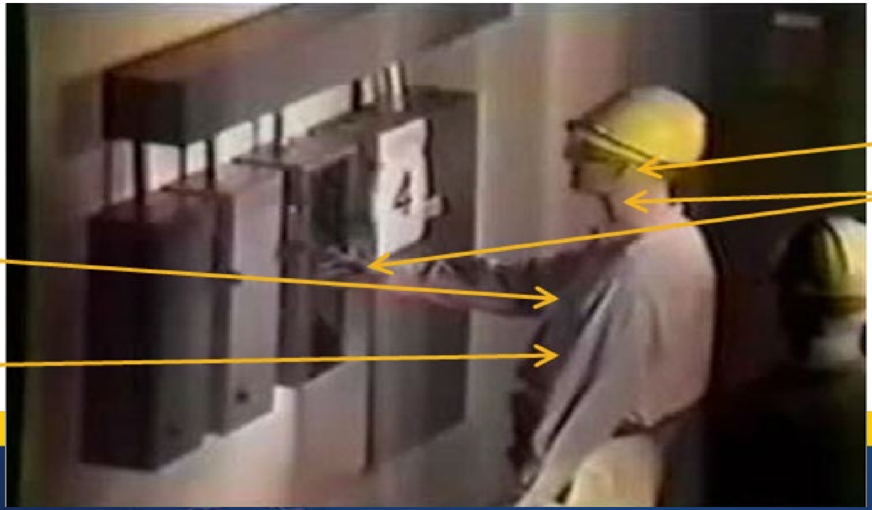
Measurements from an AC Arc-Flash/Blast video

141.5 dBa (instant nerve damage >140)

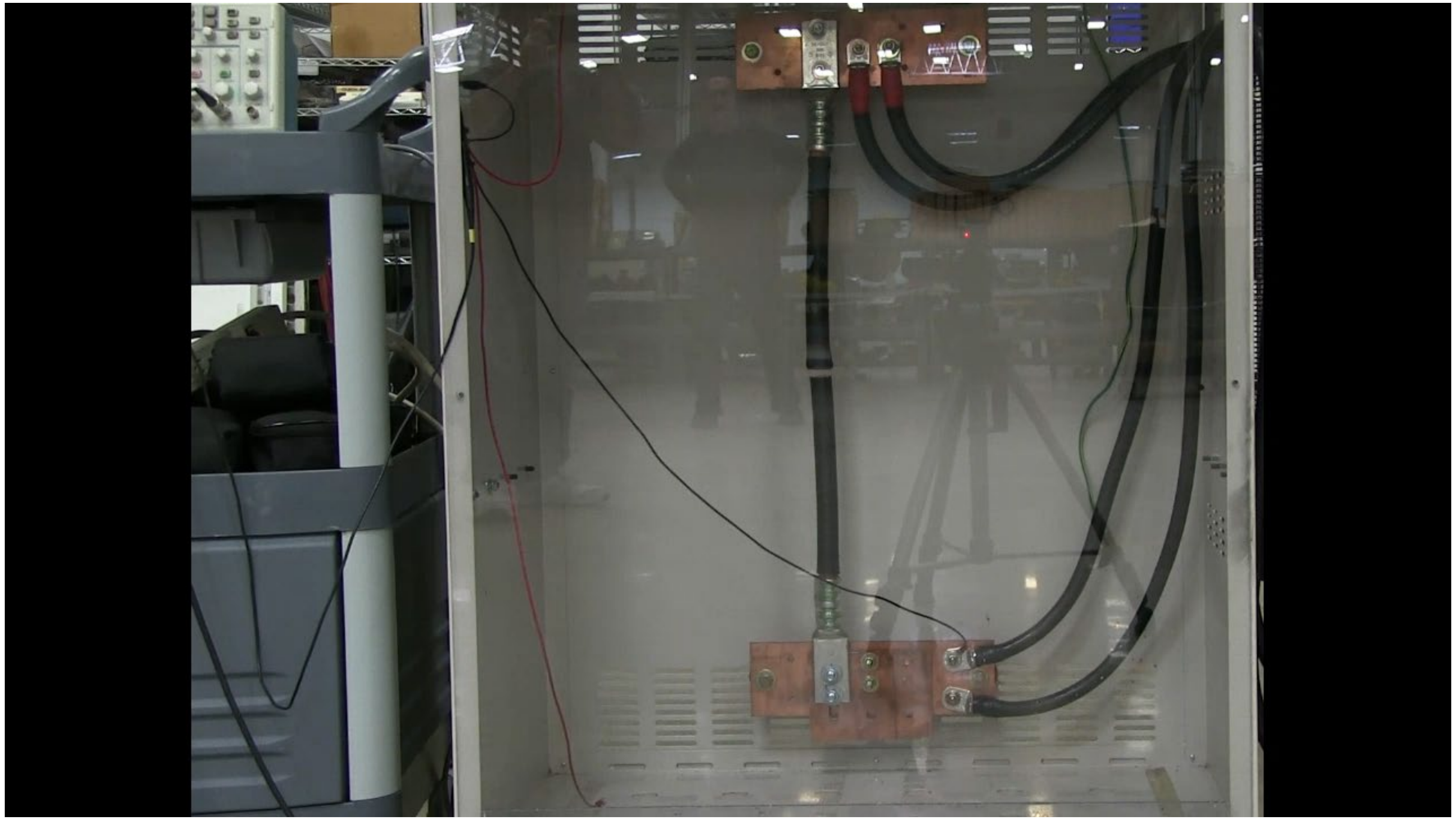
> 437°F

2,160 lbs/ft^2 pressure wave

122°F under shirt



48 VDC Arc Flash Test



240 VDC Arc Flash Test

480 VDC Slo-Mo Arc Flash Test

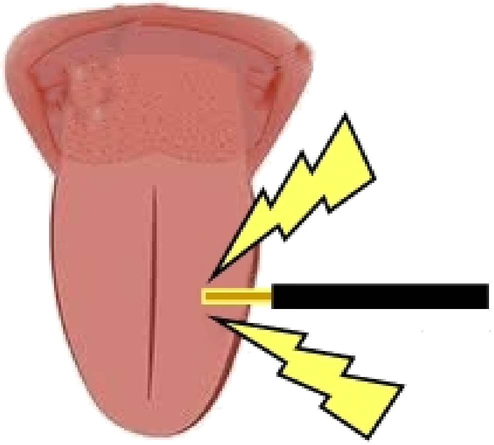
The Steve Lenz Story

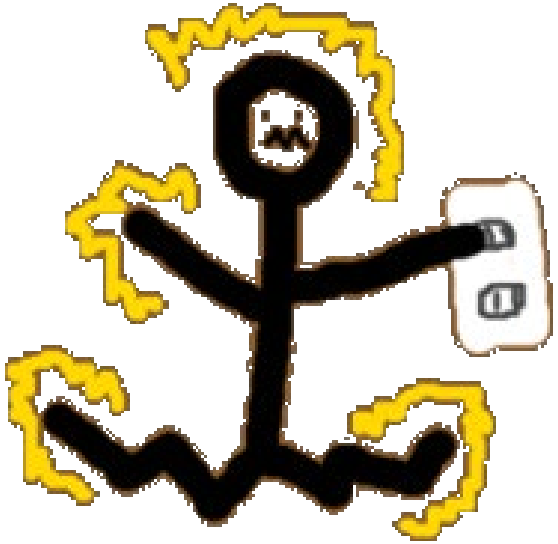
Electrical Injury Statistics

- Average of 1 Person/Day Electrocuted
  – #4 Cause of Workplace Fatalities
- 8,000 Electrical Contact Injuries per Year
  – 97% of Electrical Workers have experienced a Shock
- 2,000 Burn Center Admissions Per Year from Severe Arc-Flash
- Majority of Electrical Injury Hospital Admits are for Arc Flash
- Arc Flashes Can and Do Kill at Distances of 10 Feet
- 67% of Electrical Injuries are Caused by Unsafe Acts

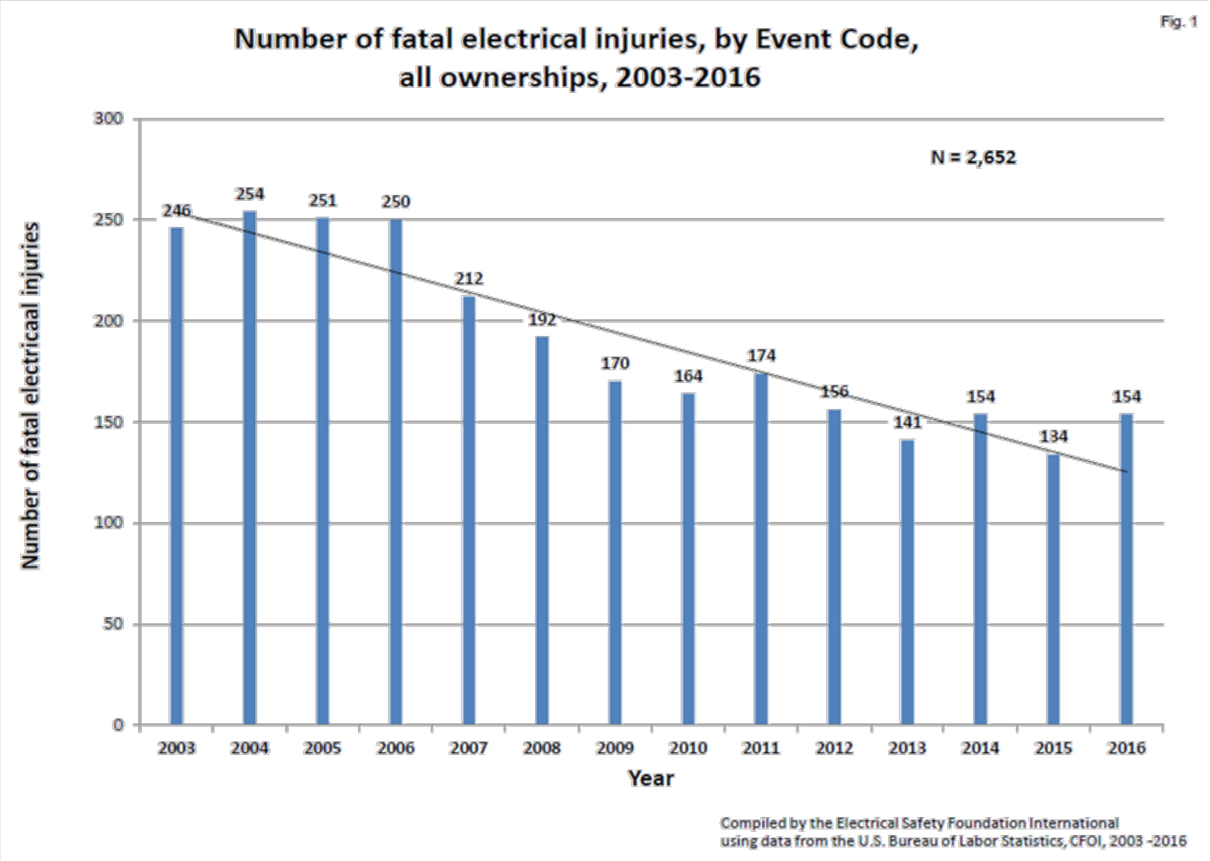
History of Electrical Injuries

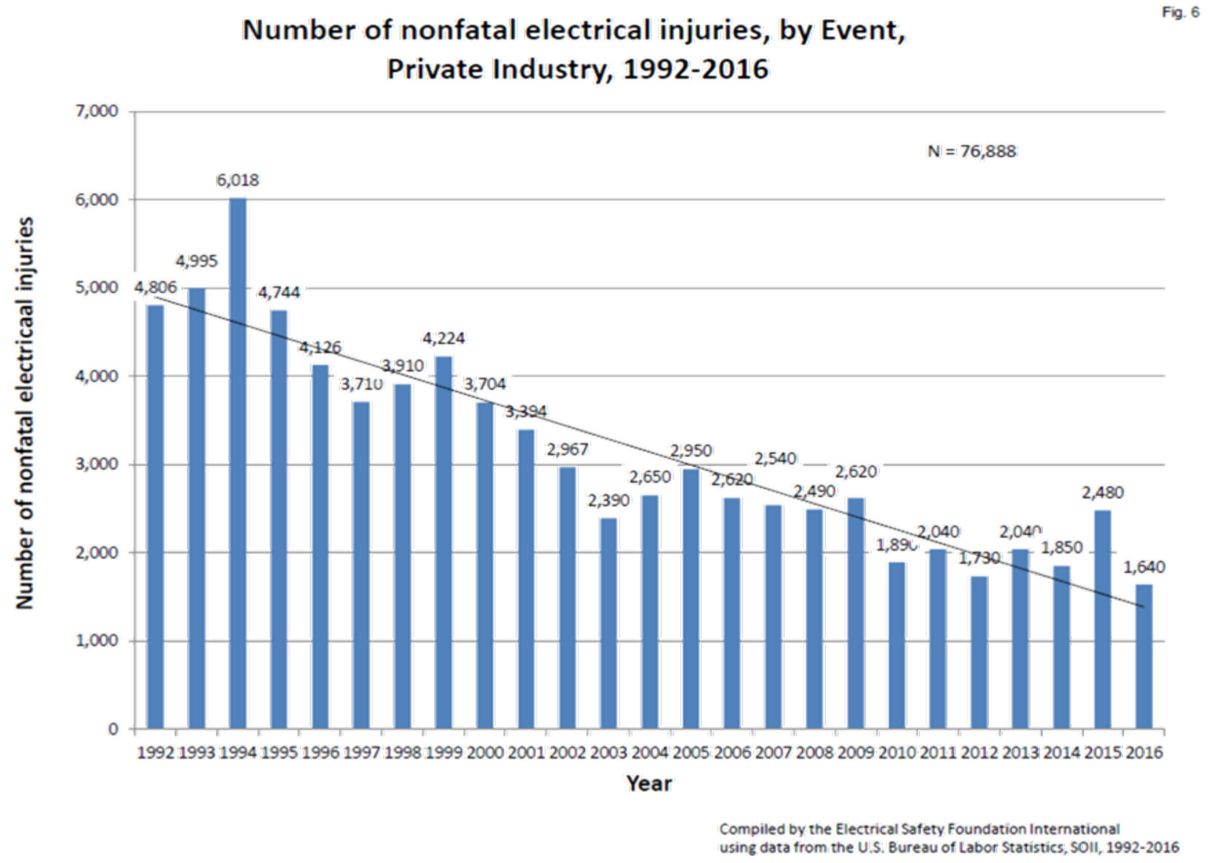
- As Recently as 1953:
  - Presence of Voltage up to 250 V was done by the Finger Test
  - Lower-Voltage Testing was done by Tasting



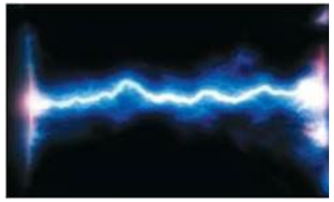


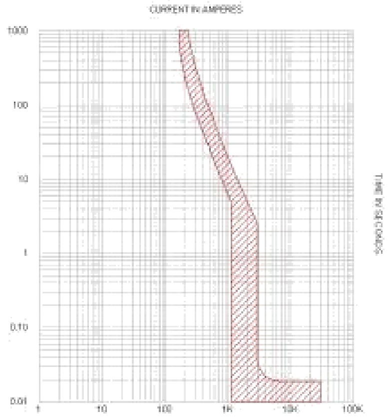
Electrical Fatality and Injury Trends





Definition of Terms



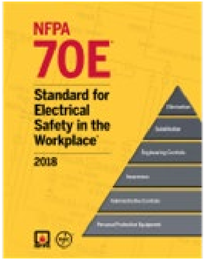


- Arc
  - Continuous Luminous Discharge of Electricity Across (usually Air), usually "Spattering" Metal. *Arc has Impedance, thus Arc Current < Bolted Fault Current*
- OverCurrent Protective Device (OCPD – e.g., Fuse or Circuit Breaker)
  - Opens a Circuit at Excessive Temperatures and/or Magnetic Forces to Protect Downstream Components from Excessive Heating or Burning.

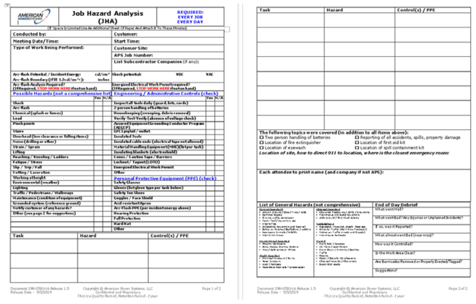
- Clearing Time
  - Time from Beginning of OverCurrent Condition to Final Circuit Interruption. *OCPDs determined by I-t curve (hi fault current usually settable for large breakers.*
  - Arc Flash Limiting Devices Available from Various Vendors to Shorten Time to Open

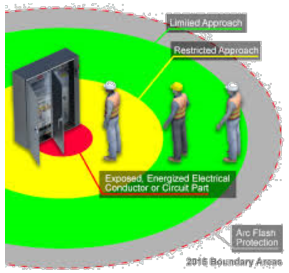
The National Electrical Code®, OSHA, and 70E

- OSHA is the Law
  - – All States (and most of the Americas) have adopted the NEC® (NFPA® 70)
    - Mostly an Electrical Install/Engineering Standard – is what **Must/Shall** be Done
      - – Not much on DC, and Telecoms / Electric Utilities mostly “Not Covered”
- OSHA Electrical Safety Rules that are Law: 29CFR Parts 1910S, 1926K
  - – Most Rules based on 1988 Version of NFPA 70E (3rd, but first “complete”)
    - NFPA 70E “Endorsed” by OSHA (OSHA “requested” NFPA to write 70E, but Not Law
      - – Much Learned since ‘88 about Arc-Flash/Blast
      - – NFPA 70E is **How** Electrical work **Should** be Safely Done

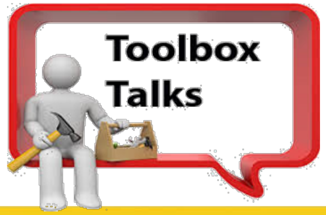


Safe Electrical Work Practices





- Electrical Safety Program –Safety Policy and…
- Training
- Determination of Qualified Personnel
- Shut Off Power Whenever Possible
  - – Work it "Cold" for the most Electrically Safe work condition
- Risk Assessment (Job Hazard Analysis – JHA, Tailgate Meeting)
- PPE



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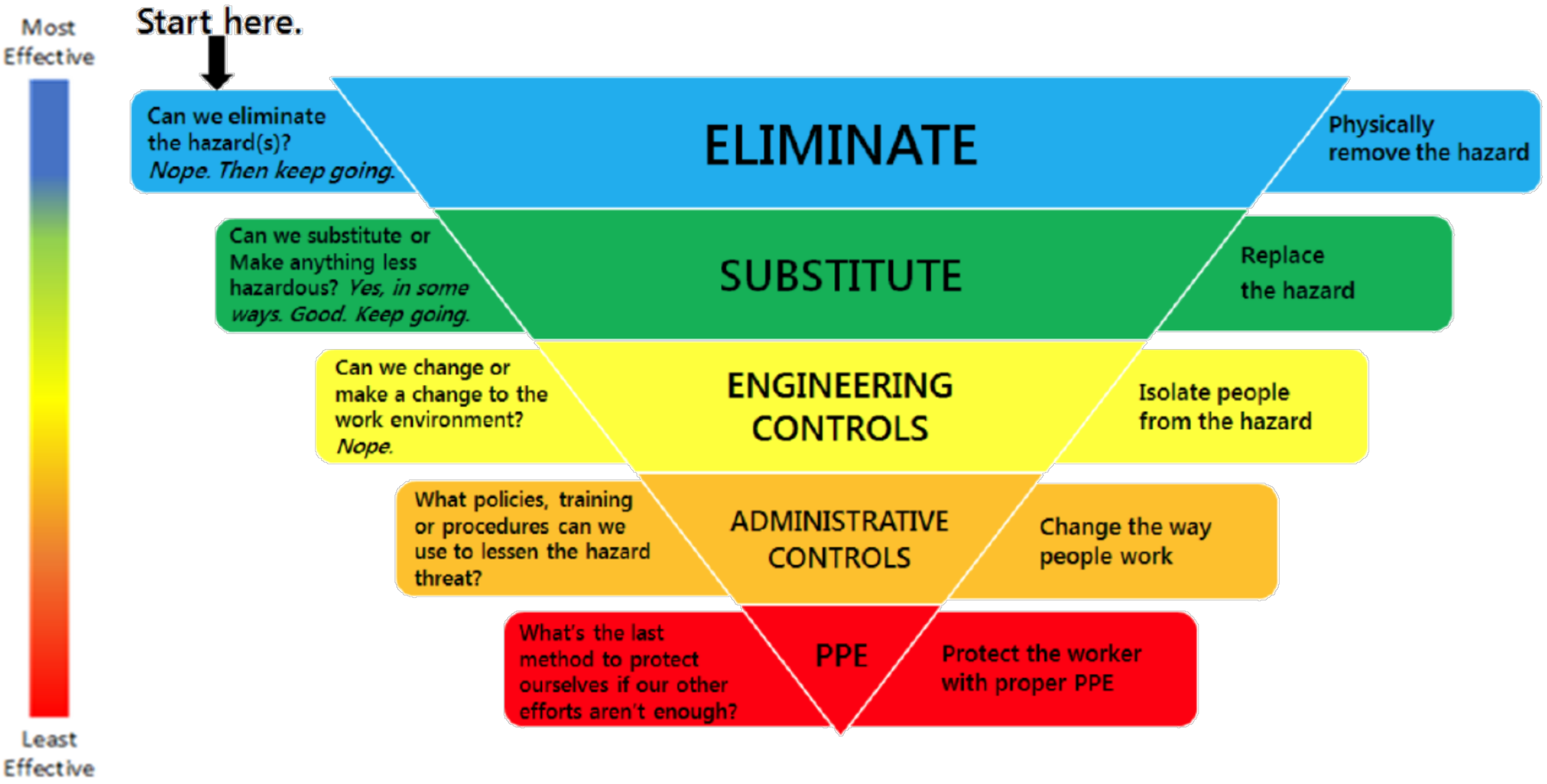
Hierarchy of Safety (Inverse Pyramid)



Electrically Safe Work Condition

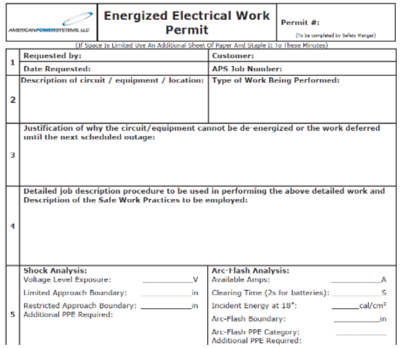
- Conductor/Part Disconnected from Energized Parts, Locked/Tagged (<u>Minimum Tag</u>), Test to Ensure No/Low Voltage, Ground as Needed
- Four Steps
    1. Documentation
    2. Disconnect Power Source
    3. Lockout/Tagout (LOTO)
    4. Verification

- Necessary PPE <u>**must**</u> be Worn Until Proven Electrically Safe

3-Step "Absence of Voltage" Test Method

1. Verify the Functionality of the Meter by Testing a known Live Voltage
2. Test for the Absence of Voltage on the Conductors or Circuit Part that was supposedly Isolated
3. Re-Verify the Functionality of the Meter by Testing a known Live Voltage

Battery Work Almost Always Energized



AMERICANPOWERSYSTEMS, LLC	Energized Electrical Work Permit	Permit #: (To be completed by Safety Manger)

(If Space Is Limited Use An Additional Sheet Of Paper And Staple It To These Minutes)

1	Requested by:	Customer:
	Date Requested:	APS Job Number:
2	Description of circuit / equipment / location:	Type of Work Being Performed:
3	Justification of why the circuit/equipment cannot be de-energized or the work deferred until the next scheduled outage:	
4	Detailed job description procedure to be used in performing the above detailed work and Description of the Safe Work Practices to be employed:	
5	Shock Analysis: Voltage Level Exposure: ________V Limited Approach Boundary: ________in Restricted Approach Boundary: ________in Additional PPE Required:	Arc-Flash Analysis: Available Amps: ________A Clearing Time (2s for batteries): ________S Incident Energy at 18": ______cal/cm² Arc-Flash Boundary: ________in Arc-Flash PPE Category: ________ Additional PPE Required:

- No Way to Fully Discharge Most Batteries to Eliminate All Voltage – Almost All Work on Most Batteries must be Performed as if Energized Unless “Proven” Not So
  - Some (Definitely Not All) Modern Li-ion Batteries Can Have a Breaker Turned Off so There is no Available “External” Energy; + Damaged Li-ion May Be Completely Drained in Saltwater Bath

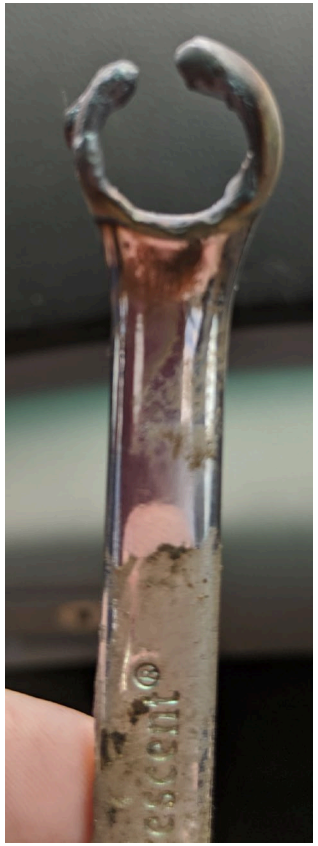
- Ensure Employees are Trained in the Safe and Proper Work Practices for Work performed on Energized Systems
- Energized Electrical Work Permit Possibly Needed

Insulated Tools

- Insulated Tools are **<u>Required</u>** Inside the Restricted Boundary
  - They are also Required Inside the Limited Boundary if Accidental Contact with Live Parts is Possible
  - Look for Double Triangle, ASTM F 1505 (or IEC 60900)
    - Voltage Rating is Typically 1000 V
  - Accessories must also be Non-Conductive in Areas Where Insulated Tools are Required

Improperly Insulated Tools

Danger of Uninsulated Tools on Even SELV -48 VDC



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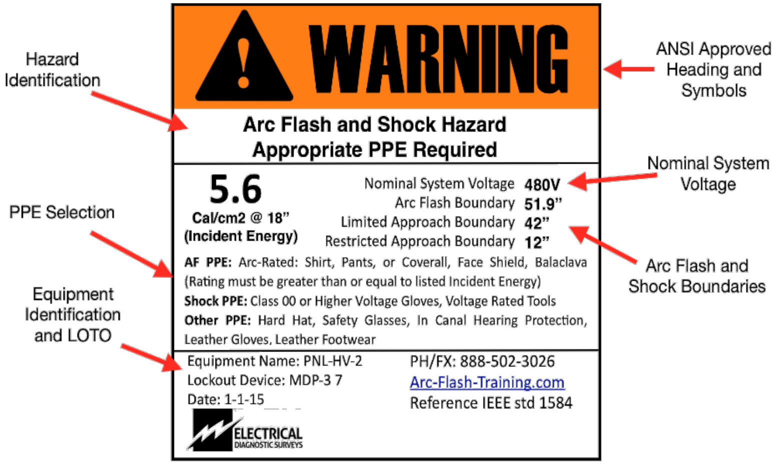
Arc-Flash PPE Categories

- Arc Flash Boundary: ≤1.2 cal/cm^2, 2nd degree burn threshold
  - Minimum Suggested to work on Live Voltages (Even SELV):
    - Natural Fiber (cotton, wool, rayon, flax, silk) Clothing
    - Long sleeves to reach into battery/electrical cabinets
- Arc Flash PPE Category (was HRC) 1:
  - 4 cal/cm^2, ATPV (Arc Thermal Performance Value)
- Arc Flash PPE Category 2: 8 cal/cm^2
  - "Informal" PPE Category "2+": 12 cal/cm^2
- Arc Flash PPE Category 3: 25 cal/cm^2
- Arc Flash PPE Category 4: 40 cal/cm^2

AC Arc-Flash Risk Analysis

- Determine Boundaries from NFPA 70E, 130 Tables if No Label
  - Calculated Label is First Choice
    - See Next Slide for Methods of Calculation
  - Table Below Incomplete (Assumes Lower Power Feed Transformers)

nominal Ph-Ph Voltage	Arcing Current	Arc-Flash Boundary	PPE Category
0 – 240 VAC (120, 208, 240)	<25 kA and 0-0.03 sec (2 cycles) fault clearing time	19”	1
241 – 600V (480 VAC)		36”	2



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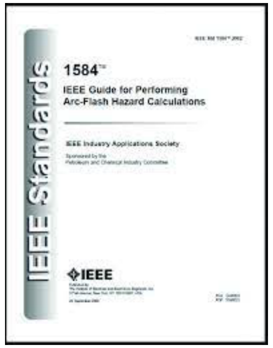
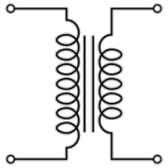
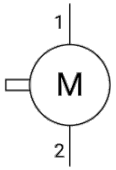
How to Calculate AC Arc Flash



- NFPA 70E Provides “Guidance” and Minimal Calculations
- IEEE 1584 Provides Far More Calculations
- AC Calculations (Max Short Circuit Current) More Difficult - Need:
  - Transformer Characteristics (X/R, Impedance)
  - All Motors Connected to Feed Transformer Secondary for SpinDown Short Ckt Currents
  - All Breaker Models Must be Known as well
  - Wire Sizes and Distances More Important if Long Runs
  - Use a Specialized Computer Program (If Inputs Not Right, Answer is Wrong!)
    - SKM, ETAP, Arc Advisor, Kinectrics, ArcWear, Easy Power, Eaton, etc.
      - ArcAD Arc Flash Analytic, ArcPro™, ArcFlash™, CYME, etc.
- No Calculations for 120 or 240 V Single or Split Single-Phase
  - Can Guesstimate From 3-Phase 208 or 240 V Calculations





DC Arc-Flash Risk Analysis

- Calculate (see Next Slides) if Possible
  – Or, Determine Boundaries from NFPA 70E Article 130 Tables (see below)

Nominal DC Voltage	Fault Current	Arc-Flash Boundary	Risk Category
0 - 150V	Any	N/A	N/A
150 - 250V	<4 kA	3’	2 - (8 cal/cm^2)
	≥4 kA and <7 kA	4’	2 - (8 cal/cm^2)
	≥7 kA and <15 kA	6’	3 - (25 cal/cm^2)
250 - 600V	<1.5 kA	3’	2 - (8 cal/cm^2)
	≥1.5 kA and <3 kA	4’	2 - (8 cal/cm^2)
	≥3 kA and <7 kA	6’	3 - (25 cal/cm^2)
	≥7 kA and <10 kA	8’	4 - (40 cal/cm^2)

How to Calculate DC Arc Flash

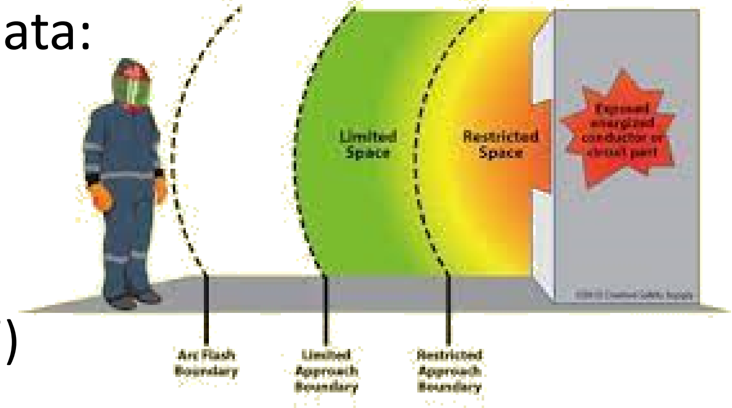
- NFPA 70E Provides “Guidance” and Minimal Calculations
- IEEE 1584 Provides No Calculations (Yet)
- Simpler than AC, but Still Need:
  - Short Circuit Current Capability of Charger(s)/Rectifier(s)
    - Can be Guesstimate-Calculated if Not Available from Manufacturer
  - Short Circuit Current Rating of Batteries (Always Available from Battery Manufacturer)
  - All Breaker Models Must be Known as well
  - Wire Sizes and Distances More Important if Long Runs
  - Use a Specialized Computer Program (Bad Inputs Yield Poor Outputs)
    - Uses Iterative Stokes/Oppenlander, Paukert, or Ammerman Models
    - Mostly Same Vendors as AC Calculation Programs, but Possibly Separate Module
  - Doan Max Power Transfer Theorem is Simplest and can be Done by Hand
    - Less Accurate than Iterative Models, but Can be Made More Accurate by Adjusting Time (see next slides)

How DC Arc-Flash cal/cm² Calculated per NFPA 70E Max Power, & BPA/HydroQuebec (& Other) Studies/Tests

- Formula from NFPA 70E: $E_i = 0.01 \times V_{nom} \times \frac{I_{sc}}{2} \times \frac{t_{arc}}{d^2}$
  - *d* is usually defined as 18”, but in cm (45.72)
  - Based on NFPA 70E, + BPA & Hydro Quebec (and “other”) studies/tests, max t_{arc} =
    - 0.025 s for most breakers (unless known otherwise), when applicable
    - 0.0043 x V_{nom}
      - Maximum of 2 seconds
        - » > 465 V
  - Simplifying:
    - $E_i(\leq 465\ \mathrm{V}) = 0.00000001029 \times {V_{nom}}^2 \times I_{sc}$
    - $E_i(> 465\ \mathrm{V}) = 0.000004784 \times V_{nom} \times I_{sc}$

How DC Arc-Flash Boundary Calculated w/NFPA 70E Max Power, and BPA/HydroQuebec Studies

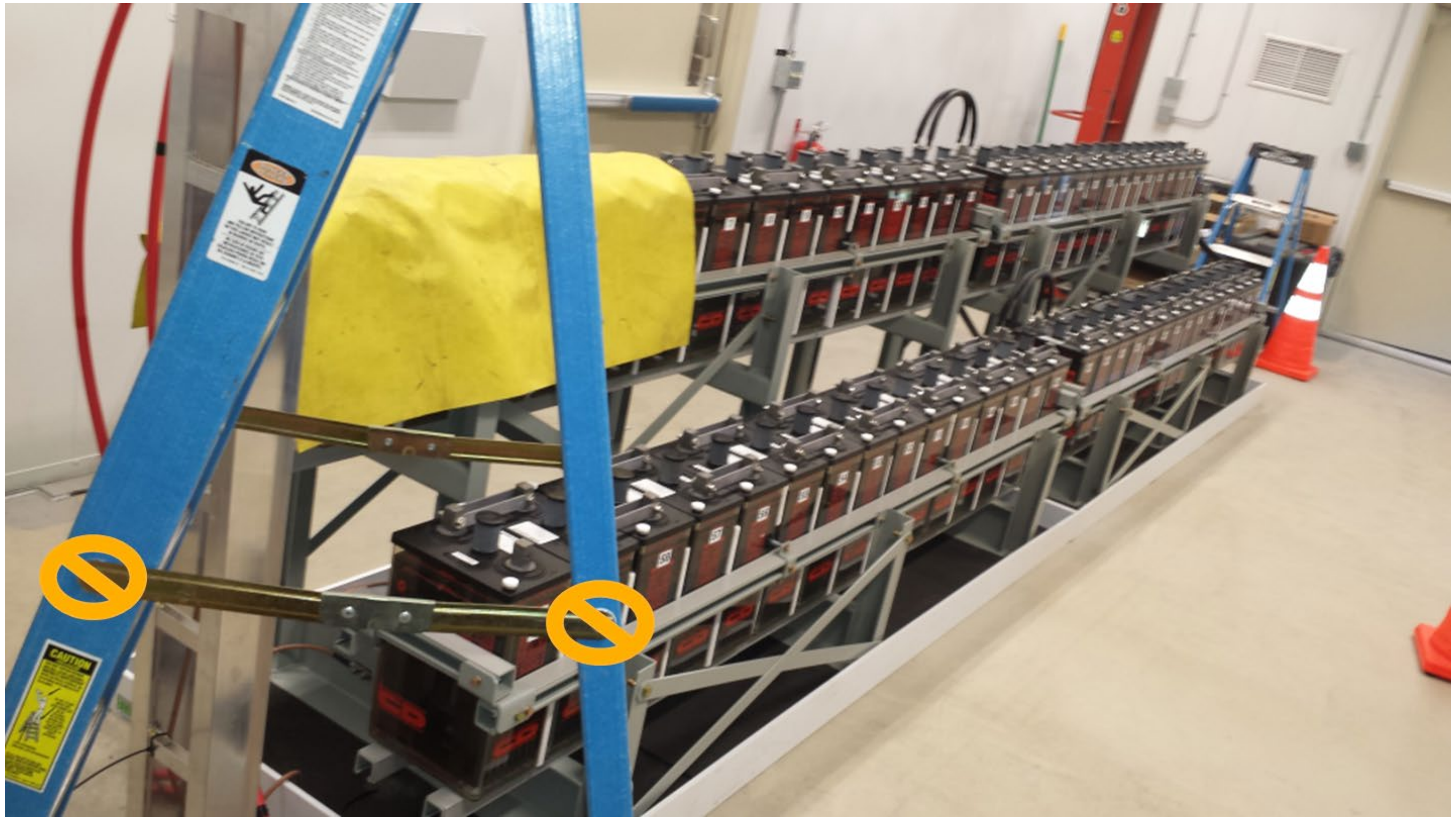
- Algebraically Rework Formula: $d(\text{cm}) = \sqrt{\frac{0.01 \times V_{nom} \times I_{sc} \times t_{arc}}{2 \times E_{i-m}}}$
  - The incident Energy ($E_{i\text{-}m}$) to set the arc-flash boundary is 1.2 cal/cm^2
  - Based on NFPA 70E, + BPA & Hydro Quebec studies, max t_{arc} =
    - 0.025 s for most breakers (unless known otherwise), when applicable
    - 0.0043 x V_{nom} (Maximum of 2 seconds > 465 V)
  - Arc in a Box Multiplier per NFPA 70E and Associated Studies Data:
    - 1.6 for Panelboards (> 18")
    - Cabinets (e.g., UPS Battery Cabinet): $0.55 \times \ln d$ $(> 18 \text{ in})$
  - Simplifying:
    - $d\ (\text{in})[\leq 465\ \text{V}] = 0.00167\ \times \sqrt{{V_{nom}}^2 \times I_{sc}}$ (maximum = 120")
    - $d\ (\text{in})[> 465\ \text{V}] = 0.036\ \times \sqrt{V_{nom} \times I_{sc}}$ (maximum = 120")



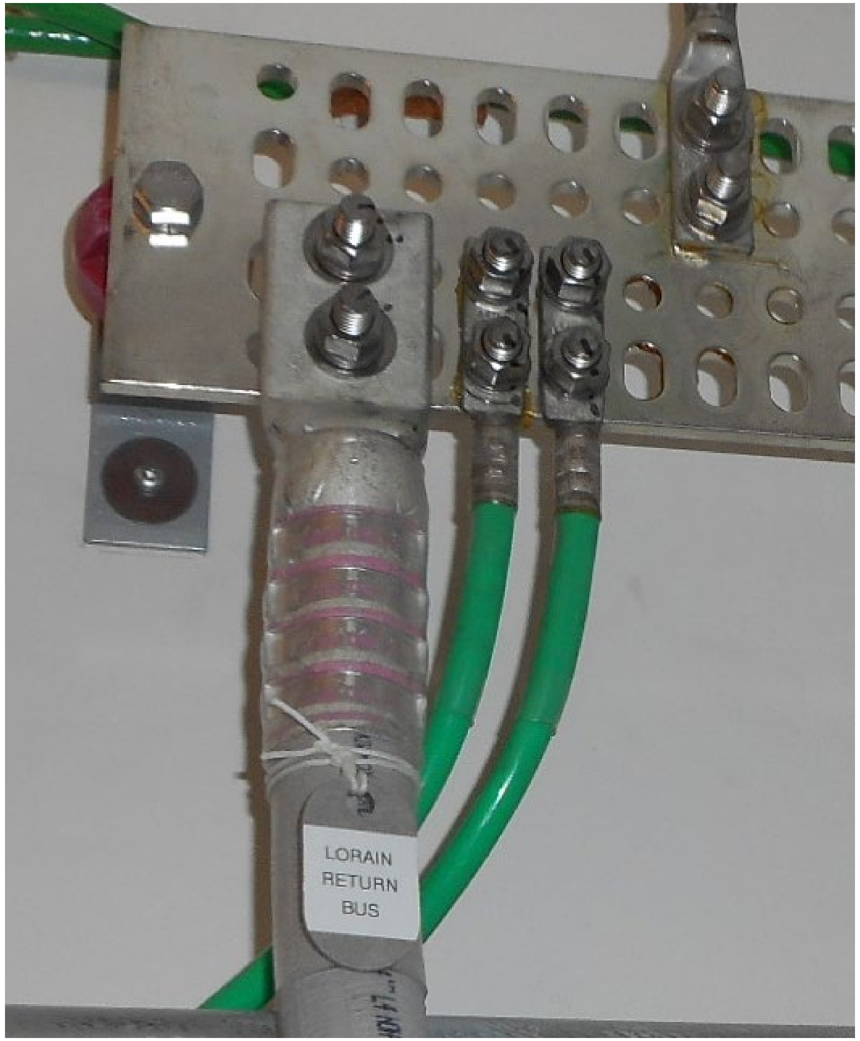
Samples From Max Power NFPA 70E Modified for Time Based on Recent Testing

Battery Model	VDC	PPE Cat	Open Rack Arc-Flash Boundary	Arc-in-a-Box Arc-Flash Boundary	Short Circuit Amps	cal/cm^2 @ 18"
MCTII-4000	2	N/A	1	N/A	26,653	0.001
	48		13			0.6
KCR-15	2		1		7,407	0.0003
	120		17			1.1
	236	2	34			4.2
HR7500ET	12	N/A	1		4,801	0.01
	120		14			0.7
	240	1	34	66		2.8
	480	2+	87	120		11.0
AVR125-33	2	N/A	1	N/A	11,131	0.004
	120		21			1.6
	240	2	42			6.6
	480	4	83			25.6

Eliminate the Hazard and Don't OverSuit

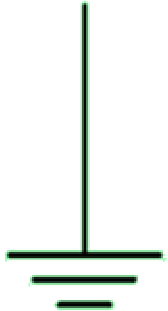


Grounded System/Conductor



Determining if your System is Grounded or Ungrounded

- Telecom 24 and 48 V systems should be grounded
- Electric Utility / Industrial 125/250 VDC and UPS DC Typically Ungrounded
  - Might be a center-tap high resistance ground as part of ground fault detection circuit
    - Battery Monitoring Circuits May Introduce Unintentional Low Resistance Grounds
  - How to Test to Ensure You are “Ungrounded” or “Grounded” for Safety PPE Purposes
    - Measure DC Voltage Between Both Polarities & a Grounded Point (e.g., Rack)
      - For Grounded system, Voltage from one polarity to ground typically close to nominal system voltage, and voltage of opposite polarity to ground near 0
      - For Ungrounded, Voltage of either pole to ground shouldn’t be near 0, but DMM might “drain” towards 0 as surface charge drains via meter impedance
        - » Might See Half Voltage Due to Ground Fault Detection Circuit?



Arc-Flash Ratings of Gloves

- Rubber Insulating Gloves with Leather Protectors Satisfy the Majority of Arc-Flash Protection Requirements, and Separate Arc-Rated Gloves are Not Required
  - Most Leather Protectors (and almost all heavy-duty dry leather gloves) are Rated at 10-12 cal/cm^2
    - Most of Our Arc-Flash Suits are Rated at 12 cal/cm^2
  - Voltage-Rated Rubber Gloves are Arc-Flash Rated/Tested to at least 17 cal/cm^2

"Testing"/Replace Electrical Insulating PPE

Electrical Insulating "Tool"	Manufacturing Standard	Testing/Replacement Intervals
Blankets/ Electro-Shield	 ASTM F479	12 months for natural rubber 18 months for synthetic rubber (Type II) replace (smaller pieces), or send out for testing
 Rubber Gloves	ASTM F476	6 months (15 months for telecom Type II [synthetic rubber]) send out for electrical testing {air test before each trip/use} 

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