Arc Flash Assessment
Lessons Learned and Common Hazard Environments

November 13, 2024

Keith Mullen, P.E.
Shane Hall

ENERCON
Excellence—Every project. Every day.

Agenda

- Introductions
  - The Why's and What's?
- Inputs
  - Data & Assumptions
  - Standards & Methods
- Lessons Learned
  - Utility
  - Commercial/Private
- Common Hazard Environments

Introduction – The Why’s and What’s?

The Why's:

- NESC 410.A.3 - 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 lines, parts, or equipment.
- NFPA 70E Article 130.5 Requirement - An arc flash assessment must be completed to determine if an arc flash hazard exists, taking into consideration the design of the overcurrent protective device, its opening time, and its condition of maintenance. The assessment must be updated if a **major modification or renovation** takes place, and it must be reviewed periodically, at intervals not to exceed 5 years.

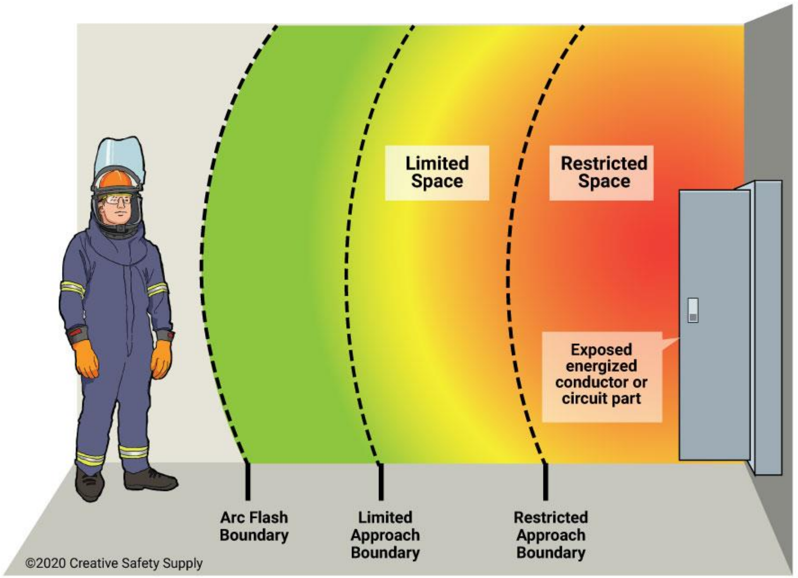
Introduction – The Why’s and What’s?

The What's:

- Numbers/Values we look for:
  - Wide range of voltages (115kV, 13.2kV, 480V, 120V)
  - HV Substation/MV Distribution Switchgear/Transformers/MVS/VFI’s/Relay’s
  - LV Switchgear/LV Panel Bus Amp & kAIC ratings
  - Motor sizes and types
  - Various equipment – “Other” bucket
  - Breaker Frame, Plug, and Trip settings – LSIG, LSI, Thermal Magnetic
    - Long Time, Short Time, Instantaneous, and Ground Fault
  - Arc Flash Incident Energy
    - Measured in calories per square centimeter (cal/cm^2) + working distance (determined by equipment)
    - Four Safety PPE Categories – 1 (4 cal/cm^2) / 2 (8 cal/cm^2) / 3 (25 cal/cm^2) / 4 (40 cal/cm^2)
    - Arc Flash Boundary – minimum “safe” distance from exposed energized equipment with a potential for an arc flash

Arc Flash and Shock Risk
Appropriate PPE Required

FLASH PROTECTION		SHOCK PROTECTION	
PPE Minimum: Arc Rating	**40.0 cal/cm^2@24 in** **8.00 cal/cm^2@66 in**	Shock Risk when cover is removed	**480 VAC**
Arc flash Boundary:	**215 in**	Limited Approach	**42 in**
		Restricted Approach	**12 in**



Inputs – Data & Assumptions

System Definition

- Engineering Model(s)
- Delivery Point Impedances
- One-line(s)
- Protective Devices & Settings
- Normal & Alternate Configurations

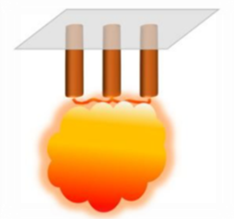
Working Practices & Tools

- PPE Requirements
- Energized vs. De-Energized Work
- Working Distances (Gloved vs. Hot Stick)
- Insulating Sleeves & Blankets
- Alternate Device Settings

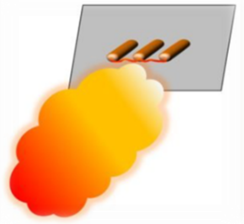
Excellence—Every project. Every day.

Inputs – Standards & Methods (IEEE 1584-2018)

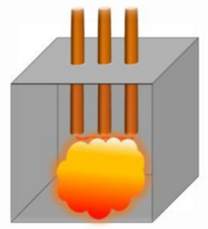
- Voltages in the range of 208 V-15 000 V, three-phase
- Frequencies of 50 Hz or 60 Hz
- Bolted fault current ranges
  - 208 V – 600 V: 500 A – 106,000 A
  - 600V – 15,000 V: 200 A – 65,000 A
- Grounding of all types and ungrounded
- Equipment enclosure size
  - Width, Height, Depth
- Gaps between terminals with variable configurations
  - 208 V – 600 V: 0.25 in – 3 in
  - 600V – 15,000 V: 0.75 in – 10 in
- Working distances of 12 in or higher



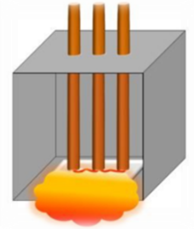
VOA: Vertical electrodes in open air (also in 2012 Edition)



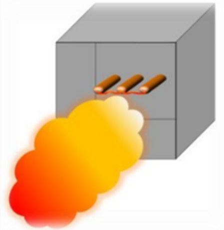
HOA: Horizontal electrodes in open air



VCB: Vertical electrodes in a metal box/enclosure (also in 2002 Edition)



VCBB: Vertical electrodes terminated in an insulating barrier in a metal box



HCB: Horizontal electrodes in a metal box

Inputs – Standards & Methods (NESC 410.A.3)

NESC Table 410-1

Equipment Type	Nominal Voltage Range & Cal/cm^2	
	50 V - 250 V	251 V - 600 V
Self-contained meters/cabinets	4[2]	20[4]
Pad-mounted transformers	4[7]	4[7]
CT meters and control wiring	4[2]	4[5]
CT compartment/customer switchgear	4[2]	[13]
Metal-clad switchgear/motor control centers	8[3]	40[6]
Pedestals/pull boxes/hand holes	4[2]	8[15]
Open air (includes lines)	4[2]	4[15]
Network protectors with transformer energized	4[8]	[9]
Network protectors with transformer de-energized	4[14]	8[14]
Panel boards–single phase (all)/three phase (< 100A)	4[2]	8[10]
Panel boards–three phase (> 100A)	4[2]	[11]

[1-15]: See References Slide

Inputs – Standards & Methods (OSHA 29 CFR 1910.269)

Selecting a Reasonable Incident-Energy Calculation Method

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-2004 Annex D (Lee Equation)[3]	Y-C	Y	N	Y-C	Y-C	N	N[4]	N[4]	N[4]
Doughty, Neal, and Floyd	Y-C	Y	Y	N	N	N	N	N	N
IEEE Std. 1584a-2004[5]	Y	Y	Y	Y	Y	Y	N	N	N
ARCPRO	Y	N	N	Y	N	N	Y	Y[6]	Y[6]

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
[1-15]: See References Slide

Inputs – Standards & Methods (OSHA 29 CFR 1910.269)

Minimum Head and Face Protection

Exposure	Minimum Head and Face Protection		
	None [1]	[1] Arc Rated Faceshield with a Minimum Rating of 8 cal/cm^2	Arc-Rated Hood or Faceshield with Balaclava
Single-phase, open air	2 – 8 cal/cm^2	9 – 12 cal/cm^2	13 cal/cm^2 or higher [2]
Three-phase	2 – 4 cal/cm^2	5 – 8 cal/cm^2	9 cal/cm^2 or higher [3]

1. These ranges assume that employees are wearing hardhats meeting the specifications in §1910.135 or §1926.100(b)(2), as possible.
2. The arc rating must be a minimum of 4 cal/cm^2 less than the estimated incident energy. Note that §1926.960(g)(5)(v) permits this type of head and face protection, with a minimum arc rating of 4 cal/cm^2 less than the estimated incident energy, at any incident energy level.
3. Note that §1926.960(g)(5) permits this type of head and face protection at any incident energy level.

Inputs – Standards & Methods (OSHA 29 CFR 1910.269)

Selecting a Reasonable Distance from the Employee to the Arc

Class of Equipment	Single-Phase Arc mm (inches)	Three-Phase Arc mm (inches)
Cable	NA*	455 (18)
Low voltage MCCs and panel boards	NA	455 (18)
Low voltage switchgear	NA	610 (24)
5 kV switchgear	NA	910 (36)
15 kV switchgear	NA	910 (36)
Single conductors in air (up to 46 kV), work with rubber insulating gloves	380 (15)	NA
Single conductors in air, work with live-line tools and live-line bare hand work	MAD – (2 x kV x 2.54) (MAD – (2 x kV /10)) †	NA

*"NA" = Not applicable
†The terms in this equation are:
MAD = The applicable minimum approach distance
kV = The system voltage in kilovolts

Inputs – Standards & Methods (OSHA 29 CFR 1910.269)

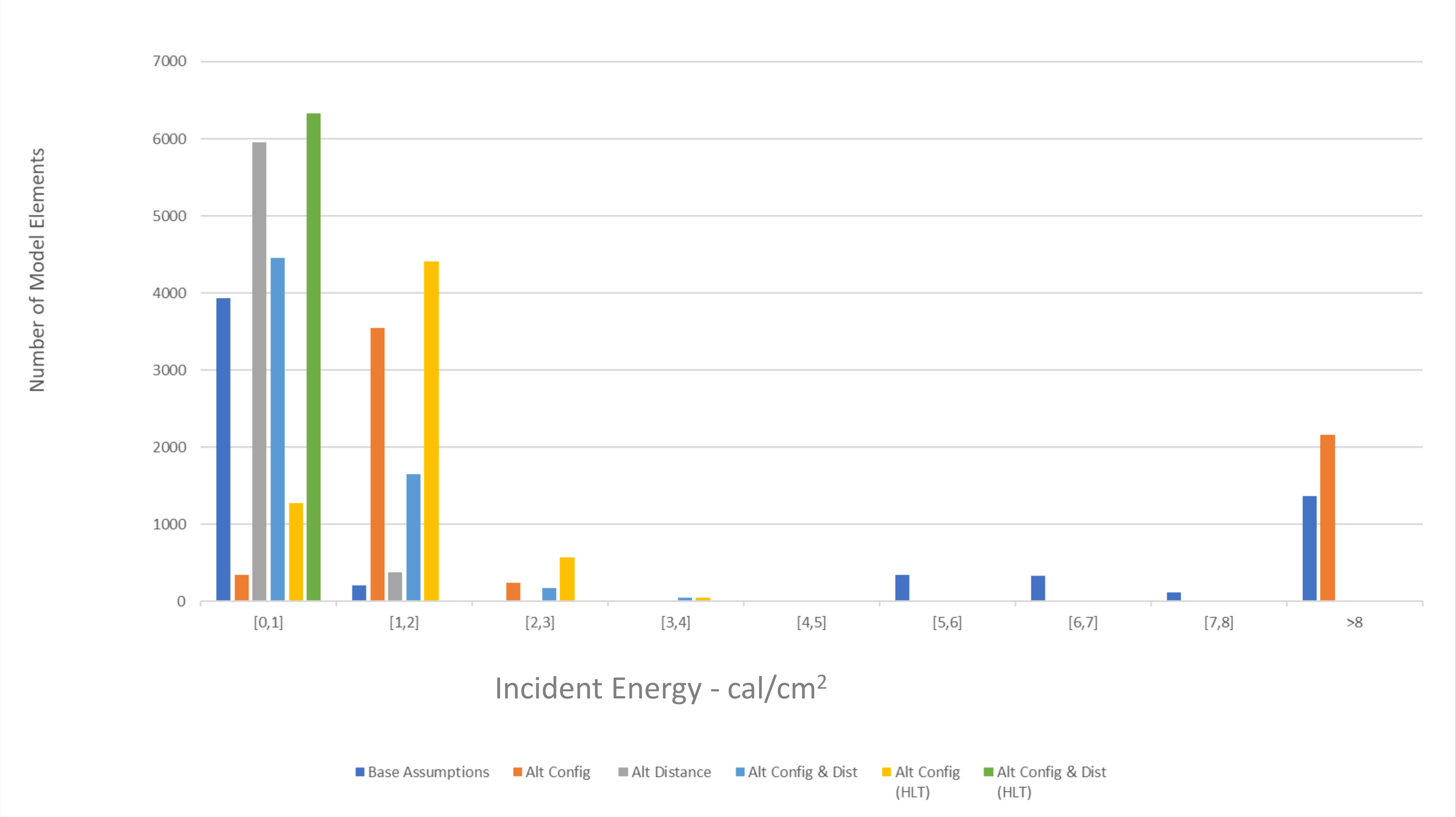
Selecting a Reasonable Arc Gap

Class of Equipment	Single-Phase Arc mm (inches)	Three-Phase Arc mm[1] (inches)
Cable	NA[2]	13 (0.5)
Low voltage MCCs and panel boards	NA[2]	25 (1.0)
Low voltage switchgear	NA[2]	32 (1.25)
5 kV switchgear	NA[2]	104 (4.0)
15 kV switchgear	NA[2]	152 (6.0)
Single conductors in air, 15 kV and less	51[3] (2.0)	Phase conductor spacing
Single conductor in air, more than 15 kV	Voltage in kV times 2.54 (0.1), but no less than 51 mm (2 inches)[3]	Phase conductor spacing

[1] Source: IEEE Std. 1584a-2004
[2] "NA": Not applicable
[3] Table 6 of Appendix E of final Subpart V uses a more conservative arc gap that equals the electrical component of the minimum approach distance rather than a value corresponding to the dielectric strength of air for the system voltage which forms the basis for the values in this table.

Lessons Learned - Utility

- Minimum PPE requirements generally at 8 cal/cm^2 or better
- Majority of distribution system is typically below minimum PPE
- Contributing Factors:
  - Rapid response of protective devices
  - Working practices
  - System maintenance
  - New technologies



ENERCON
Excellence—Every project. Every day.

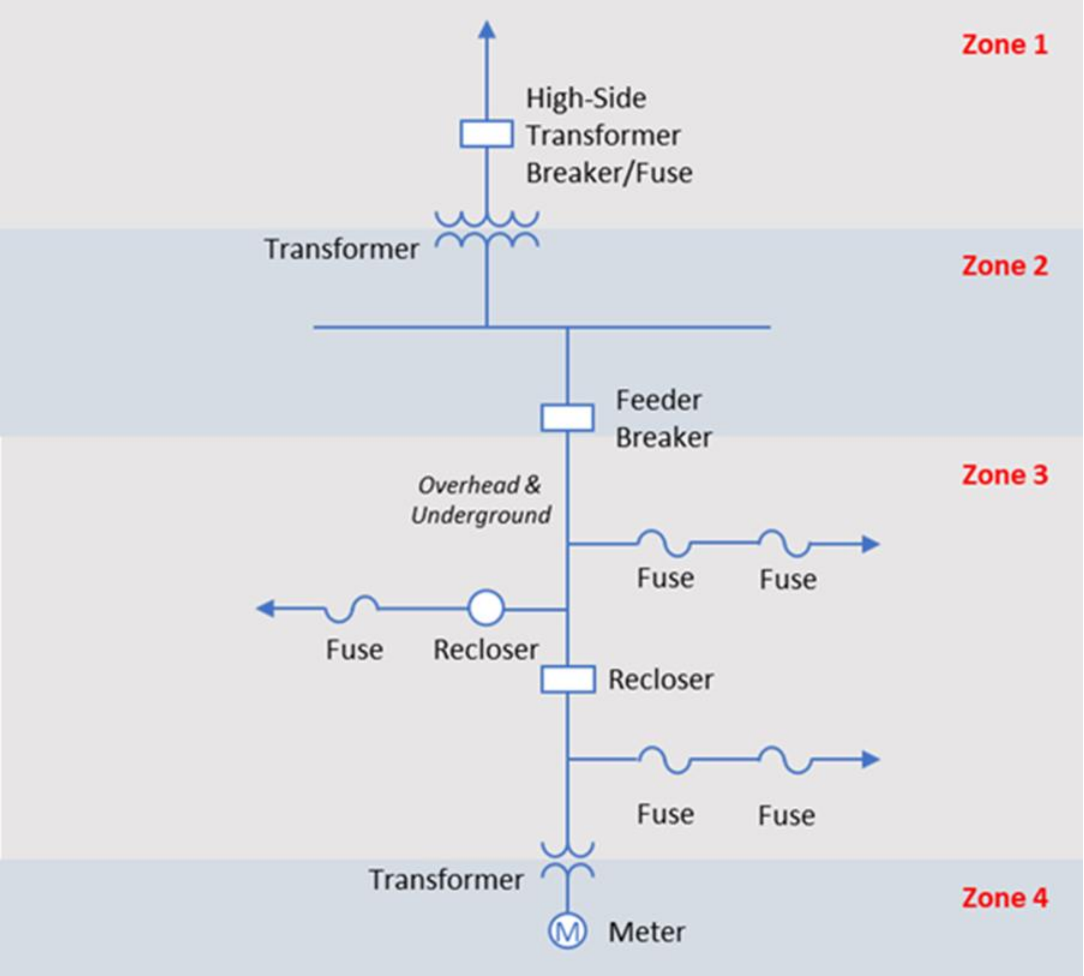
Lessons Learned - Utility

Equipment Type	Analysis Basis	Maximum Incident Energy (cal/cm²)					
		Base	Alt Config	Alt Distance	Alt Config & Dist	Alt Config (HLT)	Alt Config & Dist (HLT)
Overhead Lines	Overhead	13.72	32.49	1.24	2.51	3.28	0.25
Underground Lines	Underground	15.22	33.71	1.73	3.35	7.79	0.78
Protective Device	Overhead	11.28	24.12	1.02	1.86	2.96	0.23
	Underground	15.08	33.34	1.72	3.32	3.41	0.34
Switch	Overhead	13.70	32.43	1.24	2.50	2.93	0.23
	Underground	15.21	33.71	1.73	3.35	7.71	0.77
Capacitor	Overhead	8.52	19.17	0.77	1.48	2.43	0.19
Regulator	Overhead	13.72	32.49	1.24	2.51	3.28	0.25
System Max		15.22	33.71	**1.73**	**3.35**	**7.79**	**0.78**
System Average		**3.29**	**7.10**	**0.33**	**0.62**	**1.38**	**0.12**
System Median		**0.74**	**1.55**	**0.08**	**0.14**	**1.32**	**0.11**

$_1$HLT: Hot Line Tag

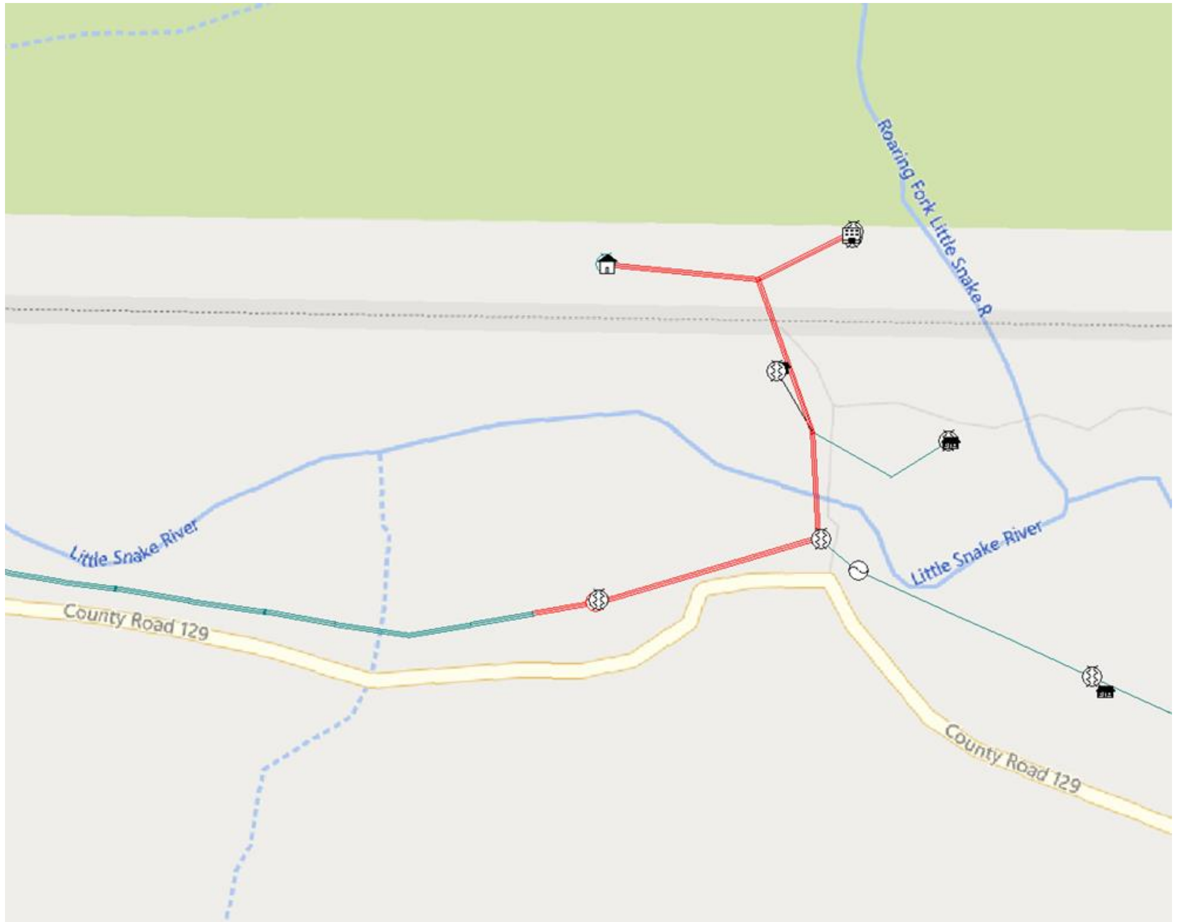
Lessons Learned - Utility

- Description: Incident energy exceeds 8 cal/cm^2 in Zone 2
- Potential Causes:
  - Slow transformer protection response (Example: fuse)
  - Limited or no differential protection
- Mitigations:
  - De-energized if work cannot be performed with hot-stick
  - Alternate device settings
  - Add bus differential protection



Lessons Learned - Utility

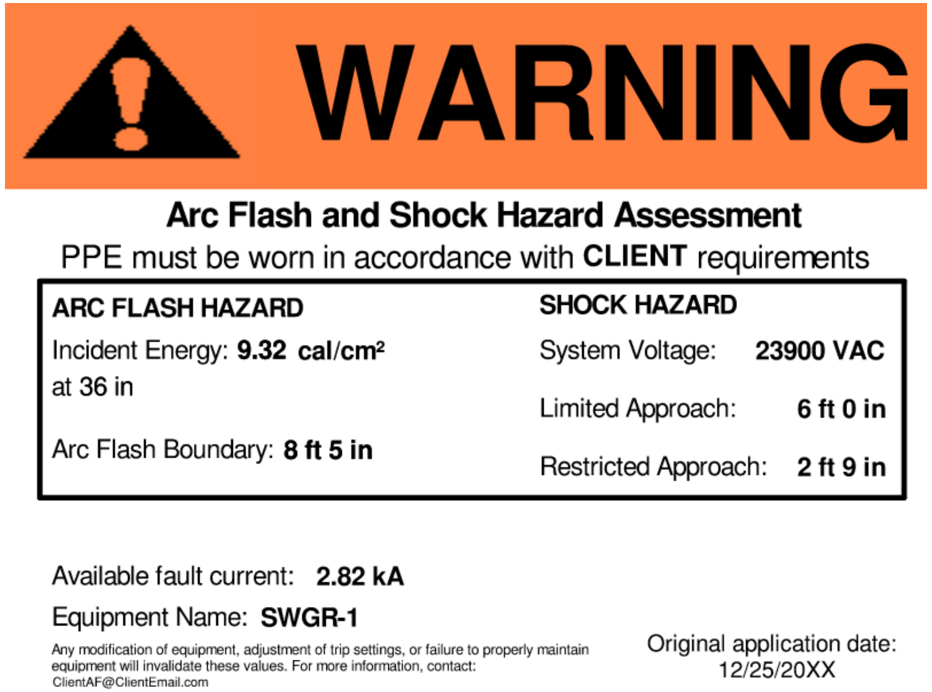
- Description: Incident energy exceeds 8 Cal/cm^2 near end of distribution line
- Cause: Extremely low faults & device clearing time exceeding 3 seconds
- Mitigation: Implement HLT on the first upline device and update standard work practices



Lessons Learned – Commercial/Private

- Description: The arc flash incident energy values at the TX secondary are approx. 65 cal/cm^2. This high incident energy limits any work near the PTX secondary terminals and requires de-energization.
- Cause:
  - Incorrect modeling enclosure dimensions weren't updated
  - Arcing time at TX secondary used is 0.65 seconds and TX has a maximum arcing time to be 5 cycles/0.0833 sec.
- Mitigation: Implemented changes from the cause and re-ran arc flash analysis. Bringing the results to 12.5-13.3 cal/cm^2 allowing crews to work on the transformer without needing to take an outage.

Common Hazards Environments



- Outdated labels and/or studies – Leads to improper PPE and known dangers at equipment.
- Outdated models & relay settings – Not using latest standards (IEEE 2018) or existing conditions and equipment settings don't match the model. – Leads to under rated PPE.
- Assumptions – one piece of electrical equipment is like another, might have similar characteristics. Internal mechanisms are different that react and respond another way.
- Faulty equipment or poor maintenance over time – Leads to failures at critical times like storms/hurricanes and increases the dangers for crews and customers.

References

- 1 - Although OSHA will consider these methods reasonable for enforcement purposes when employers use the methods in accordance with this table, employers should be aware that the listed metho ds do not necessarily result in estimates that will provide full protection from internal faults in transformers and similar equipment or from arcs in underground manholes or vaults.
- 2 - At these voltages, the arc is presumed to be three-phase unless the employer can demonstrate that only one phase is present or that the spacing of the phases is sufficient to prevent a multiphase arc from occurring.
- 3 - The entries for NFPA 70E-2004 Annex D (Lee equation) apply equally to NFPA 70E-2012, and the comparable table in Appendix E refers to NFPA 70E-2012 Annex D (Lee equation).
- 4 - Although OSHA will consider this method acceptable for purposes of assessing whether incident energy exceeds 2.0 cal/cm2, the results at voltages of more than 15 kilovolts are extremely conservative and unrealistic.
- 5 - The entries for IEEE Std 1584a-2004 apply equally to IEEE 1584b-2011, and the comparable table in Appendix E refers to IEEE Std 1584 with this latest amendment.
- 6 - OSHA will deem the results of this method reasonable when the employer adjusts them using the conversion factors for three-phase arcs in open air or in an enclosure, as indicated in the program’s instructions.

Thank you!

Questions?

Contact Info:
Keith Mullen, P.E.
kmullen@enercon.com
Shane Hall
shane.hall@enercon.com