IEEE 1584-2018
NFPA 70E
Arc Flash Consortium

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IEEE Electrical Safety Conference

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Agenda – Updates to the NFPA 70E

NFPA 70E - What is it?

New Section Article 360 ‘Safety-Related Requirements for Capacitors’

PPE Personal Protection Equipment

Coordination Curves

Arc Flash labels

IEEE 1584-2018 Incident Energy Calculations

Purpose of the NFPA 70E

- Standard for Electrical Safety in the Workplace
  - Chapter 1: Safety Related Work Practices
  - Chapter 2: Safety Maintenance Requirements’
  - Chapter 3: Safety Requirements for Special Equipment

NFPA® 70E®

Standard for Electrical Safety in the Workplace®

Annexes

- D. Incident Energy and Arc Flash Boundary Calculation Methods
- E. Electrical Safety Program
- F. Risk Assessment
- G. Lock out/Tag Out LOTO
- H. PPE Personal Protective Equipment
- I. Job Briefing and Job Safety Planning Checklist
- J. Energized Work Permit
- O. Safety Required Design Requirements
- Q. Human Performance and Workplace Electrical Safety
- R. Capacitors

Definition

- Electrical Safe Work Condition: A state in which an electrical conductor or circuit part has been disconnected from energized parts, locked/tagged in accordance with established standards, tested to verify the absence of voltage, and, if necessary, temporary grounded for personnel protection.
- NEW Balaclava an arc rated head protective fabric that protects the neck and head expect for a small portion of the facial area.

PPE Personal Protection Equipment

- Table 130.7 (C)(15)(c) Personal Protective Equipment (PPE)
  - Arc-Rated Clothing Minimum Arc Rating of 8 cal/cm^2 (33.5 J/cm^2)

    Arc Rated long-sleeve Shirt and pants or arc-rated coveralls

    Arc Rated flash suit hood or arc-rated face shield and arc-rated balaclava

    Arc Rated jacket, parka, high-visibility apparel, rainwear, or hard hat liner (AN) = As Needed

    Hard Hat

    Safety glasses or safety googles (SR) = Selection required

    Hearing protection (ear canal inserts)

    Heavy duty leather glove, arc-rated gloves, or rubber insulating gloves with leather protectors (SR)

    Leather footwear

Energized work
NFPA 70 sect. 110.16 Arc-Flash Hazard Warning

- Electrical equipment, such as switchboards, switchgear, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that is in other than dwelling units, and is likely to require examination, adjustment, servicing, or maintenance while energized, shall be field or factory marked to warn qualified persons of potential electric arc flash hazards. The marking shall meet the requirements in 110.21(B) and shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

Energized work
NFPA 70 sect. 110.16 Arc-Flash Hazard Warning

(B) Service Equipment.

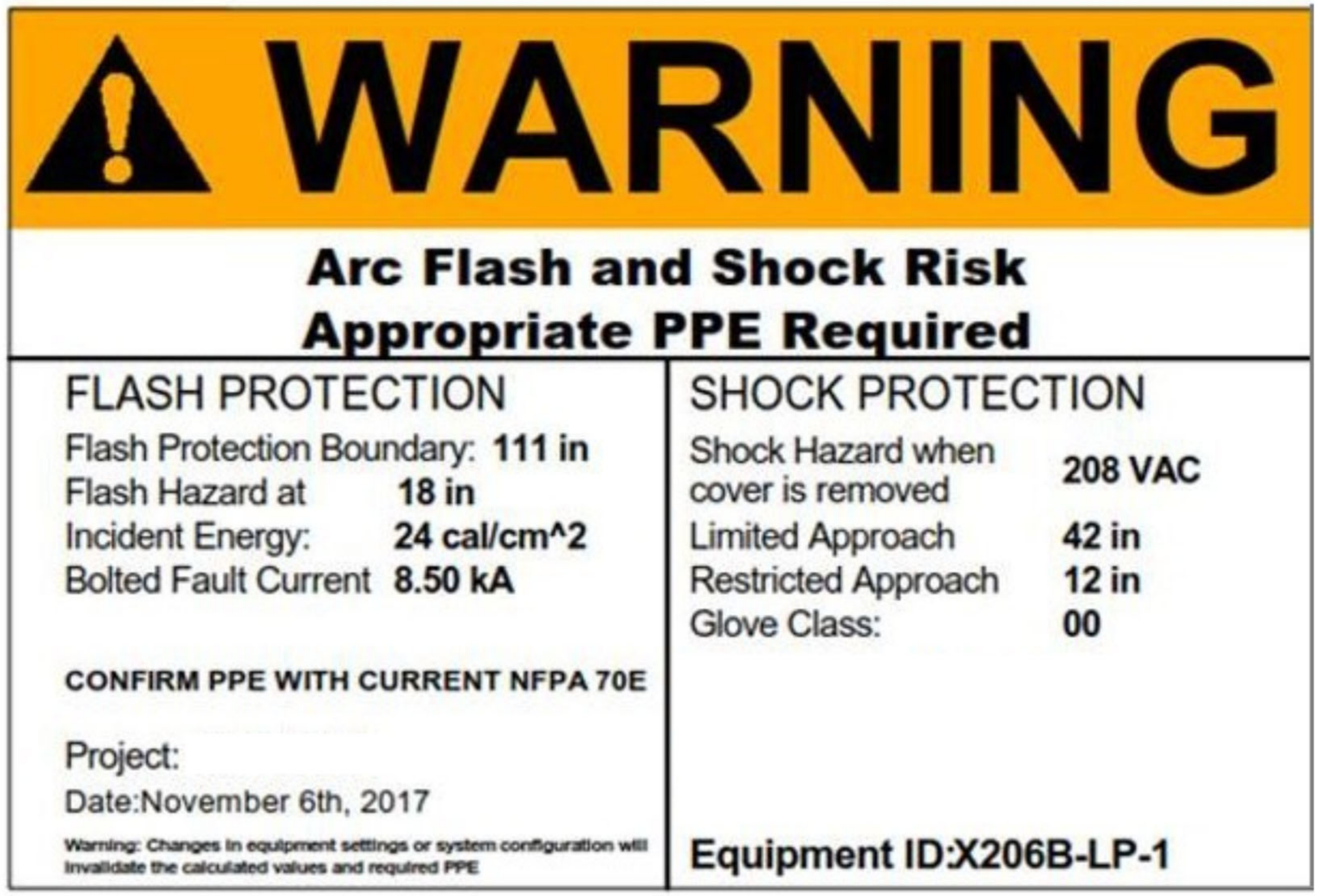
- In other than dwelling units, in addition to the requirements in 110.16(A), a permanent label shall be field or factory applied to service equipment rated 1200 amps or more. The label shall meet the requirements of 110.21(B) and contain the following information:
- (1)Nominal system voltage
- (2)Available fault current at the service overcurrent protective devices
- (3)The clearing time of service overcurrent protective devices based on the available fault current at the service equipment
- (4)The date the label was applied
- Exception: Service equipment labeling shall not be required if an arc flash label is applied in accordance with acceptable industry practice.

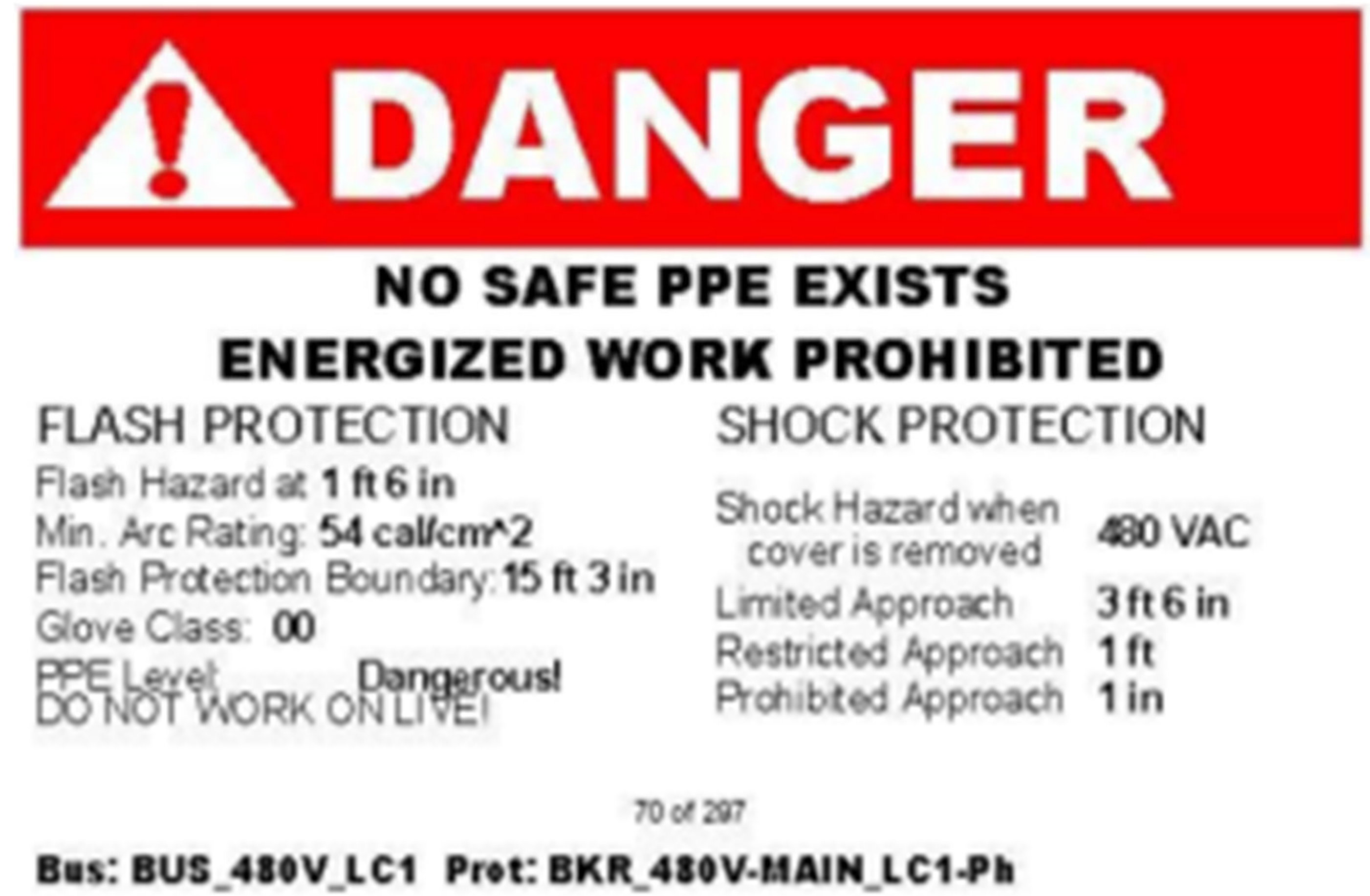
Informational Note No. 1: *NFPA 70E* -2018, *Standard for Electrical Safety in the Workplace*, provides guidance, such as determining severity of potential exposure, planning safe work practices, arc flash labeling, and selecting personal protective equipment.

Informational Note No. 2: ANSI Z535.4-2011, *Product Safety Signs and Labels*, provides guidelines for the design of safety signs and labels for application to products.

Informational Note No. 3: Acceptable industry practices for equipment labeling are described in *NFPA 70E*-2018, *Standard for Electrical Safety in the Workplace*. This standard provides specific criteria for developing arc-flash labels for equipment that provides nominal system voltage, incident energy levels, arc-flash boundaries, minimum required levels of personal protective equipment, and so forth.

Arc Flash Warning/Danger Labels





Warning Labels 0-40 calories/cm2 – Danger +40 cal/cm2 Danger Label:

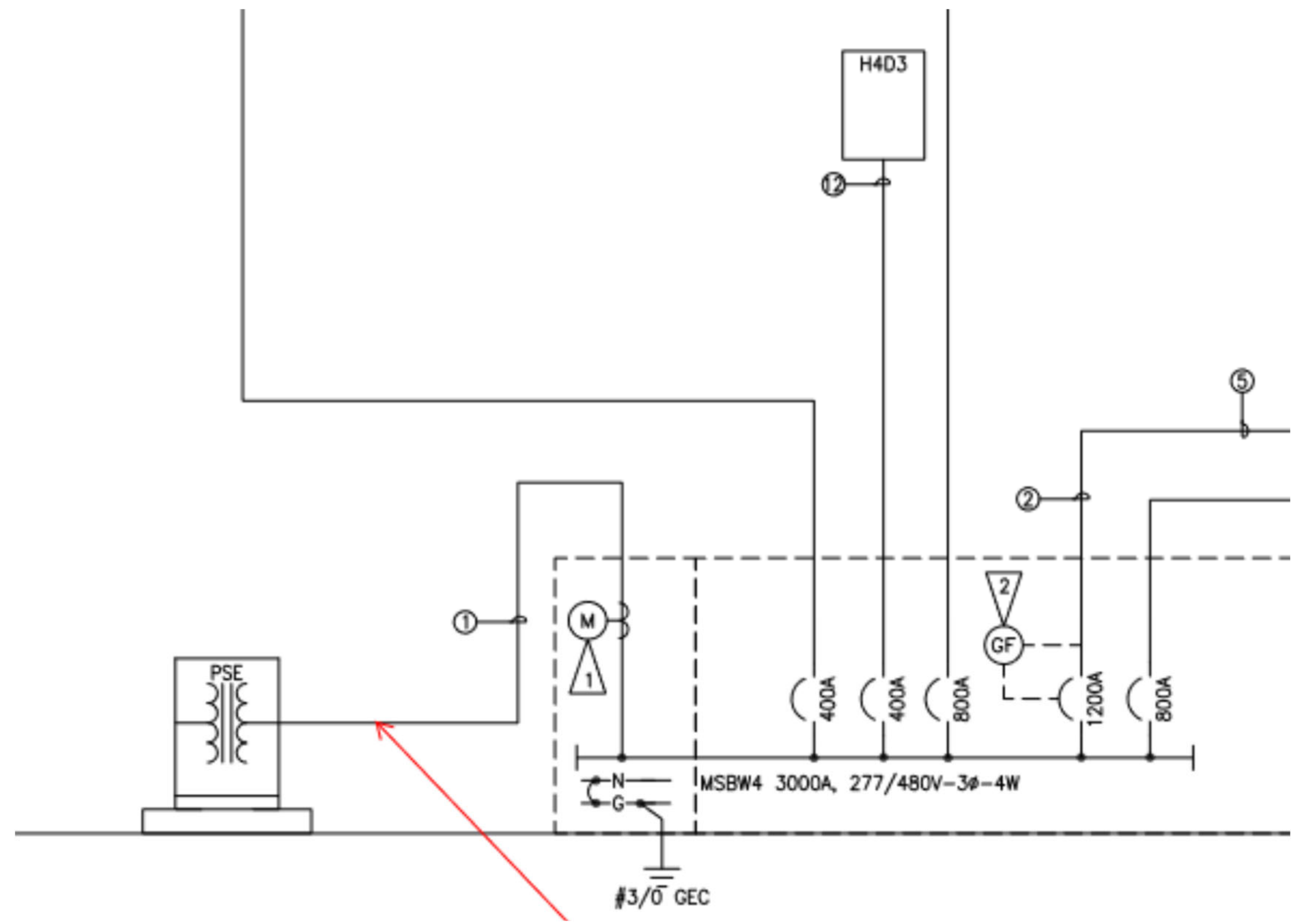
1) Flash Boundary at 9’-2”
2) Working Distance 18”
3) Incident energy at working distance
4) Bolted Fault (Short Circuit worst case) 8500A
5) Note: Warning: Changes in the settings or system configuration will ‘invalidate’ the calculated values and required PPE

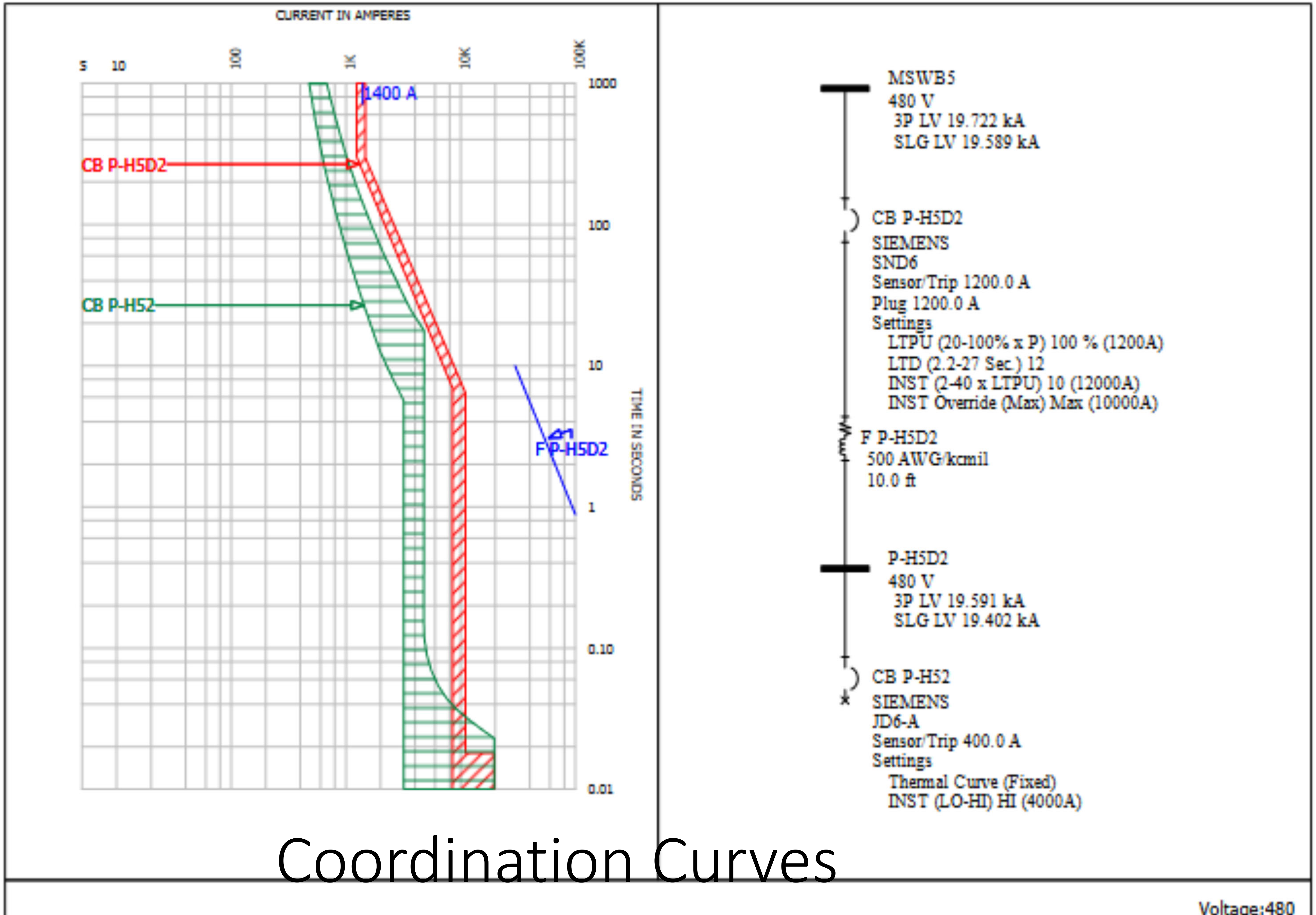
Single Line Diagram

- Field information needed
  - Wire sizes
  - Wire lengths
  - Available Fault Current
  - Motor sizes, HP, voltage, ph
  - Panelboard size, ratings
  - Breaker Sizes, plug sizes

    Mfg., type, settings
  - Transformer size, voltage

    Impedance ZI%, kW





Coordination Curves

Field Data for Power Studies

Cable Name	From Bus To Bus	In/Out Service	Qty /Ph	Length Feet	------ Cable Description ------ Size	Cond. Type	Duct Type	Insul	Per Unit (100 MVA Base)	R pu	jX pu
	P-H54-1								Zero:	2.9835	4.2231
F P-H54-2	P-H54-1	In	1	10	500	Copper	Magnetic		Pos:	0.1276	0.2023
	P-H54-2								Zero:	0.4019	0.4978
F P-H5D1	MSWB5	In	2	10	750	Aluminum	Non-Magnetic		Pos:	0.0671	0.0592
	P-H5D1								Zero:	0.1066	0.1508

IEEE 1584 Calculations vs. Table Method

Arc Flash Evaluation IEEE 1584

	Bus Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Category	Label #
104	P-L13A	0.208	6.60	6.60	2.76	2	0.000	Yes	PNL	25	89	18	17	Category 3 (*N3) (*N9)	# 0098
105	P-L1D	0.208	11.52	11.52	4.80	2	0.000	Yes	PNL	25	128	18	30	Category 4 (*N9)	# 0098

Available Fault Current

Sir/Madam:

We are presently performing the power systems study for the [illegible]. The study includes the arc flash risk assessment, protective device coordination and short circuit analysis. In order to complete the study we need to know the following; including the size, Z% and available fault current for the PSE Utility transformer:

Size __________ kVA 480V sec (voltage primary _____V)

Phase ___3

Impedance Z% min ______ max ______

Available Fault Current _______A (min) 480V sec

Available Fault Current _______A (max) 480V sec

X/R __________ 480V sec

Fuse __________ size

Fuse __________ manufacturer

Fuse __________ type

Sincerely,

Michael Brisbois

Table 6 Maximum short circuit current (in amps) for three-phase transformers, padmounted

Type	Secondary Voltage	KVA	R/X	Minimum %Z	3 Phase &/or L-G Fault Current
3-Phase PM	208Y/120	45	0.8	1.65	7600
		112.5	0.3	1.65	19000
		150	0.3	1.55	26900
		225	0.2	2.15	29100
		300	0.3	2.10	39700
		500	0.2	2.30	60300
		750	0.1	5.30	39300
		1000	0.1	5.30	52400
	480Y/277	45	0.8	1.65	3300
		112.5	0.3	1.65	8200
		150	0.3	1.55	11600
		225	0.2	2.15	12600
		300	0.3	2.10	17200
		500	0.2	2.30	26100
		750	0.1	5.30	17000
		1000	0.1	5.30	22700
		1500	0.1	5.30	34000
		2000	0.1	5.30	45400
		2500	0.1	5.30	56700

NPFA 70E 130.5 (G) Incident Energy Analysis

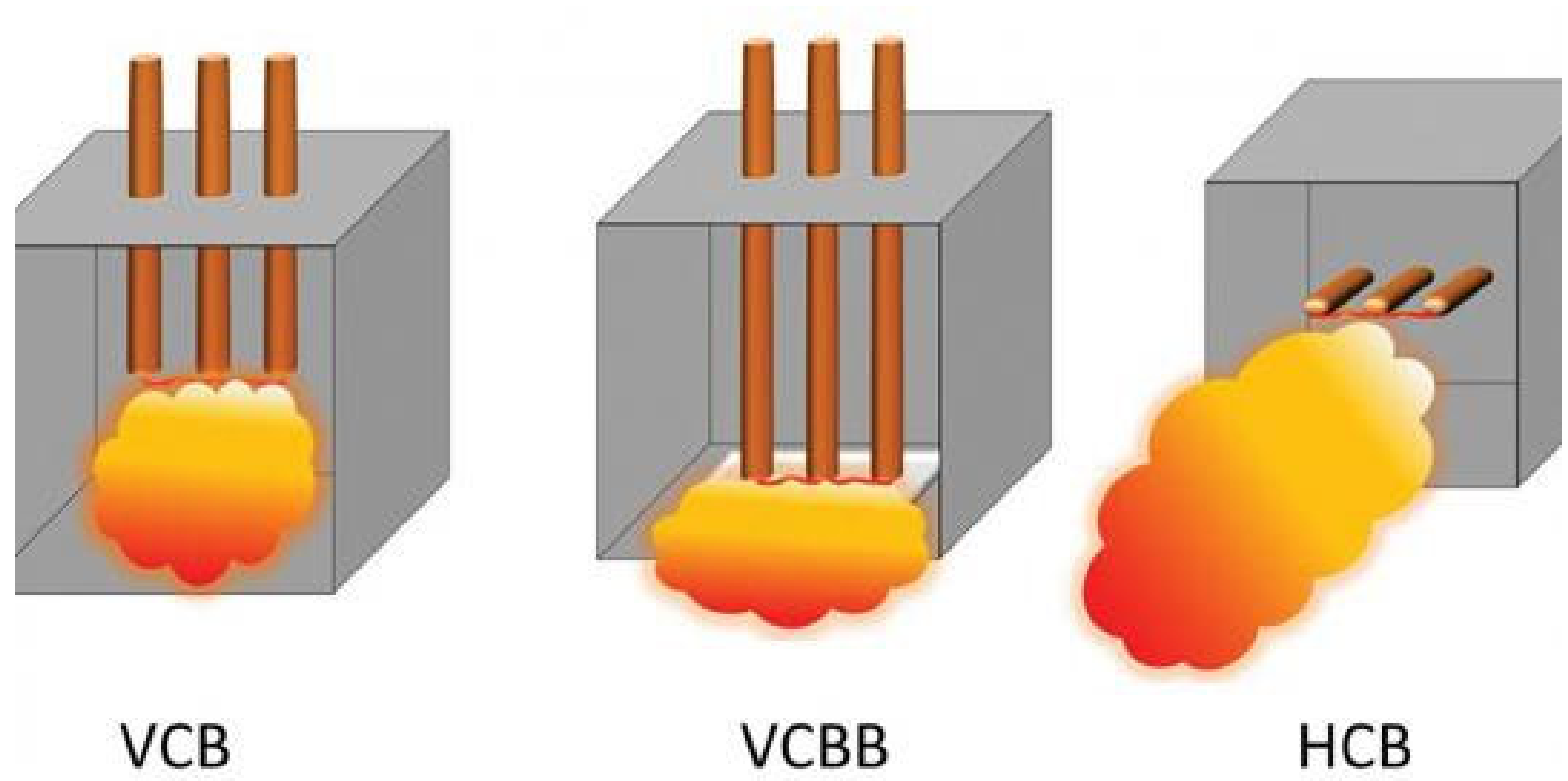
- The incident energy analysis shall be updated when changes occur in the electrical distribution system that could affect the results of the analysis. The incident energy analysis shall also be reviewed for accuracy at intervals not to exceed 5 years.

- 205.2 Single Line Diagram. A Single Line Diagram, where provided for the electrical system, shall be maintained in a legible condition and shall be kept current.

110.4 (D) Normal Operations

- Normal Operation of electrical equipment shall be permitted where a normal operating condition exists. A normal operating condition exists when all of the following conditions are satisfied:
  1) The equipment is properly installed
  2) The equipment is properly maintained
  3) The equipment is used in accordance with instructions included in the listing and labeling and in accordance with manufacturer's instructions
  4) The equipment doors are closed and secured
  5) The equipment covers are in place and secured
  6) There is no evidence of impending failure

D.4.6 Electrical Configuration



VCB = Vertical Conductors/electrodes inside a metal box enclosure
VCBB = Vertical conductors/electrodes terminated in an insulating barrier inside a metal box
HCB = Horizontal conductors/electrodes inside a metal box or enclosure
VOA/HOA = Vertical/Horizontal conductors in open Air

IEEE Std 1584™-2018
(Revision of IEEE Std 1584-2002,
as amended by IEEE Std 1584a™-2004
and IEEE Std 1584b™-2011)

IEEE Guide for Performing Arc-Flash Hazard Calculations

Sponsor

Petroleum and Chemical Industry Committee
of the
IEEE Industry Applications Society

Approved 27 September 2018

IEEE-SA Standards Board

3.1 Definitions

arc: A plasma cloud formed in a gap between two electrodes with sufficient potential difference.

arc current: *See:* **arcing fault current**.

arc duration: *See:* **clearing time**.

arc flash: An electric arc event with thermal energy dissipated as radiant, convective, and conductive heat.

NOTE—See Annex E for additional information.[8]

arc-flash boundary: A distance from a prospective arc source at which the incident energy is calculated to be 5.0 J/cm² (1.2 cal/cm²).

arc-flash hazard: A dangerous condition associated with an electric arc likely to cause possible injury.

arc-flash hazard calculation: The use of equations to compute the incident energy at a specific working distance and the arc-flash boundary.

arcing fault current: A fault current flowing through an electrical arc plasma. *Syn:* **arc current**.

available short-circuit current: At a given point in a circuit, the maximum current that the power system can deliver through a given circuit to any negligible-impedance short circuit applied at the given point, or at any other point that causes the highest current to flow through the given point. "Available short-circuit current" and "bolted fault current" are equivalent for a zero fault impedance.

bolted fault: A short-circuit condition that assumes zero impedance exists at the point of the fault.

circuit: A conductor or system of conductors through which an electric current flows.

3.2 Acronyms and abbreviations

ac	alternating current
CF	correction factor
dc	direct current
E.C.	electrode configuration
HCB	horizontal conductors/electrodes inside a metal box/enclosure
HOA	horizontal conductors/electrodes in open air
LV	low voltage
MCC	motor control center
MV	medium voltage
OA	open air
PDU	power distribution unit
PPE	personal protective equipment
TCC	time current characteristic
UPS	uninterruptible power supplies
VCB	vertical conductors/electrodes inside a metal box/enclosure
VCBB	vertical conductors/electrodes terminated in an insulating barrier inside a metal box/ enclosure
VOA	vertical conductors/electrodes in open air

4.2 Range of model

The following empirically derived model, based upon statistical analysis and curve-fitting programs as well as an understanding of electrical arc physics, is applicable for systems with the following parameter range:

- Voltages in the range of 208 V to 15 000 V, three-phase (line-to-line)

  Tests were performed in laboratory conditions using selected open-circuit voltages (V_{oc}). While the model utilizes V_{oc}, pre-fault voltage (system nominal voltage, utilization voltage, etc.) can be used for application of this model.

- Frequency of 50 Hz or 60 Hz
- Bolted fault current (rms symmetrical)
  - 208 V to 600 V: 500 A to 106 000 A
  - 601 V to 15 000 V: 200 A to 65 000 A
- Gaps between conductors
  - 208 V to 600 V: 6.35 mm to 76.2 mm (0.25 in to 3 in)
  - 601 V to 15 000 V: 19.05 mm to 254 mm (0.75 in to 10 in)

4.5 Arcing current variation correction factor

Calculate a second set of arc duration, using the reduced arcing current I_{arc_min} to determine if the arcing current variation has an effect on the operating time of protective devices and consequently incident energy. The arcing current variation applies for all system open-circuit voltages within the valid range of the model (208 V to 15 000 V), but it is expected to have the most impact between 208 V and 600 V.

To determine a lower bound of the average rms arcing current, use Equation (2) as follows and the coefficients provided in Table 2:

$$I_{arc\ min} = I_{arc} \times (1 - 0.5 \times VarC_f) \quad (2)$$

$$VarC_f = k1V_{oc}^6 + k2V_{oc}^5 + k3V_{oc}^4 + k4V_{oc}^3 + k5V_{oc}^2 + k6V_{oc} + k7$$

where

$VarC_f$	is the arcing current variation correction factor
I_{arc}	is the final or intermediate rms arcing current(s) (kA) (see note)
I_{arc_min}	is a second rms arcing current reduced based on the variation correction factor (kA)
V_{oc}	is the open-circuit voltage between 0.208 kV and 15.0 kV
$k1$ to $k7$	are the coefficients provided in Table 2

Table 2—Coefficients for Equation (2)

E.C.	*k*1	*k*2	*k*3	*k*4	*k*5	*k*6	*k*7
VCB	0	−0.0000014269	0.000083137	−0.0019382	0.022366	−0.12645	0.30226
VCBB	1.138e-06	−6.0287e-05	0.0012758	−0.013778	0.080217	−0.24066	0.33524
HCB	0	−3.097e-06	0.00016405	−0.0033609	0.033308	−0.16182	0.34627
VOA	9.5606E-07	−5.1543E-05	0.0011161	−0.01242	0.075125	−0.23584	0.33696
HOA	0	−3.1555e-06	0.0001682	−0.0034607	0.034124	−0.1599	0.34629

NOTE—The correction factor $(1 - (0.5 \times VarC_f))$ is applied as follows:

4.11 Single-phase systems

This model does not cover single-phase systems. Arc-flash incident energy testing for single-phase systems has not been researched with enough detail to determine a method for estimating the incident energy. Single-phase systems can be analyzed by using the single-phase bolted fault current to determine the single-phase arcing current (using the equations provided in 4.4 and 4.10). The voltage of the single-phase system (line-to-line, line-to-ground, center tap voltage, etc.) can be used to determine the arcing current. The arcing current can then be used to find the protective device opening time and incident energy by using the three-phase equations provided in this guide. The incident energy result is expected to be conservative.

4.12 DC systems

Arc-flash incident energy calculation for dc systems is not part of this model. However, publication references (Ammerman et al. [B1], Das [B16], [B17], Doan [B25], Klement [B62]) provide some guidance for incident energy calculation.

Process

Step 1: Collect the system and installation data
Step 2: Determine the system modes of operation (SCENARIOS)
Step 3: Determine the bolted fault currents
Step 4: Determine typical gap and enclosure size based upon system voltages and classes of equipment
Step 5: Determine the equipment electrode configuration
Step 6: Determine the working distances (18”, 24”, 36”)
Step 7: Calculation of arcing current ~1/2 bolt faut
Step 8: Determine the arc duration (fuse, CB, 2 sec rule)
Step 9: Calculate the incident energy (e.g., 3.8 cal/cm^2)
Step 10: Determine the arc-flash boundary for all equipment (e.g., AFB = 2’-6”)

Table 9—Correlation between actual equipment and electrode configuration

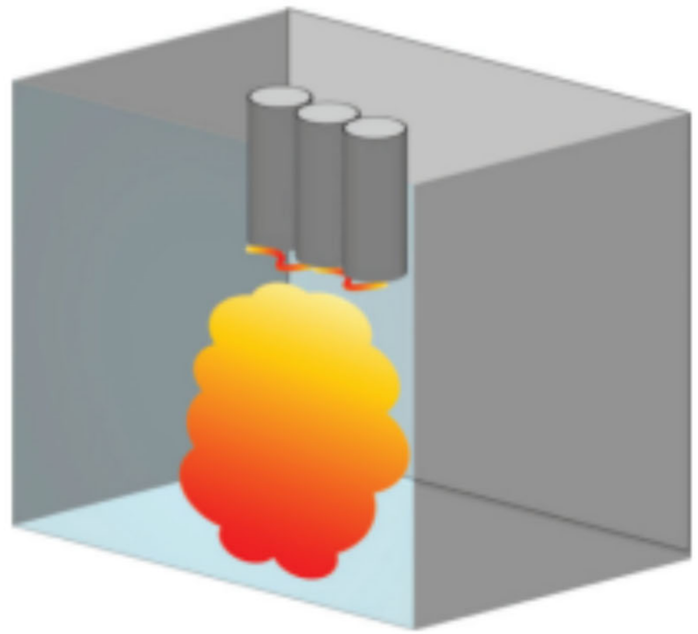
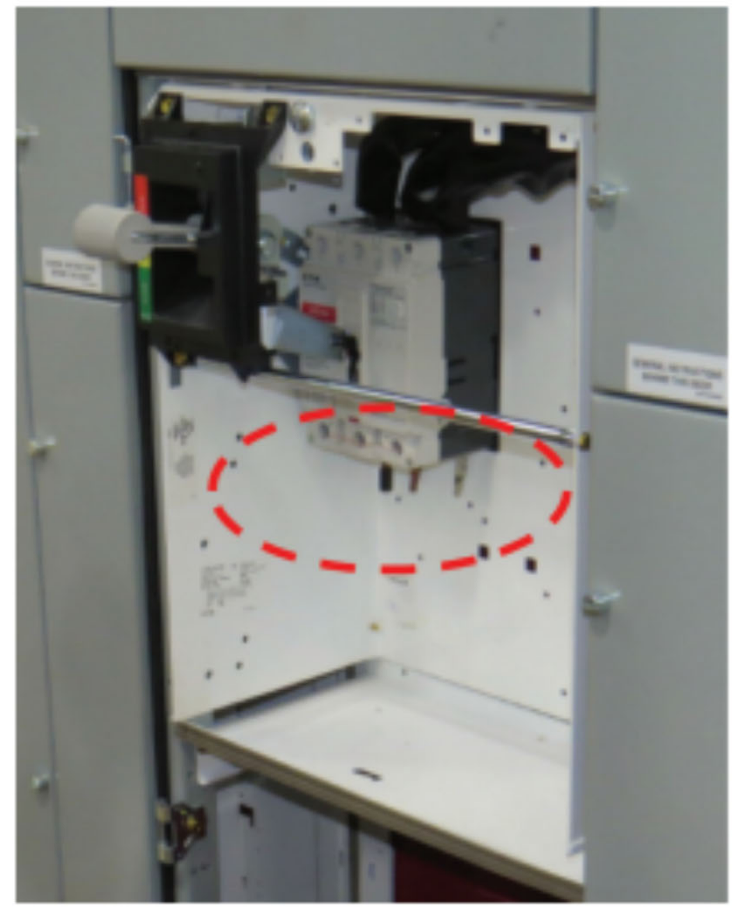
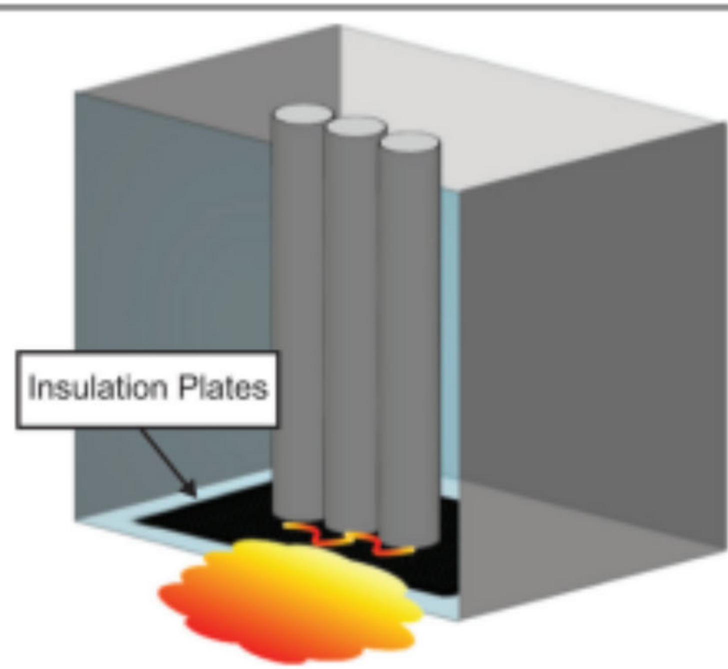
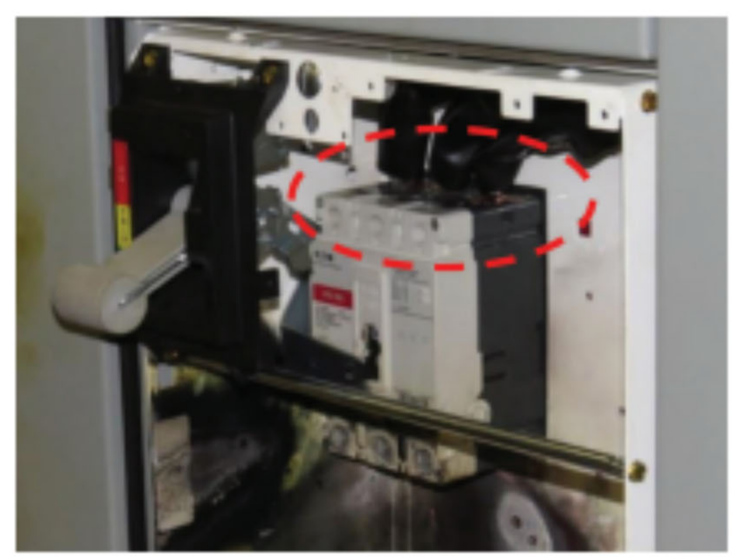
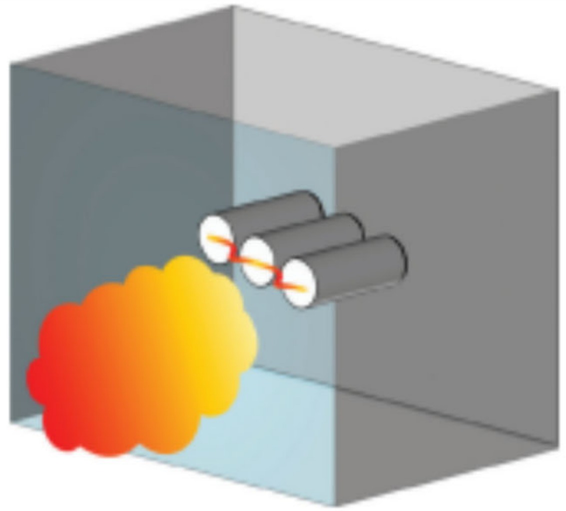
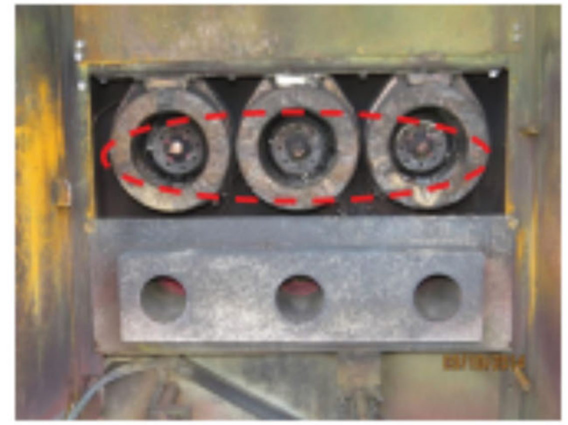
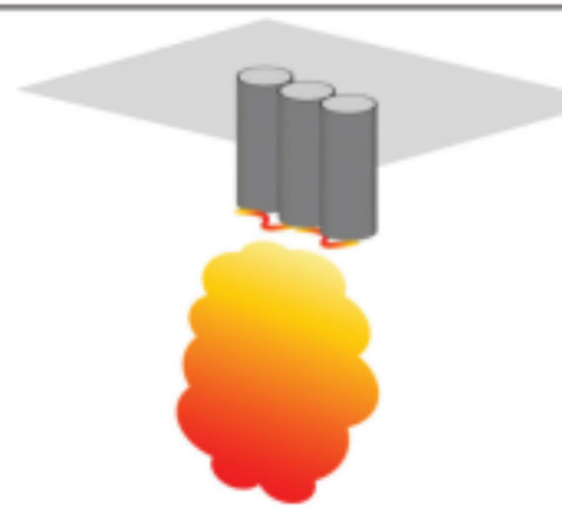
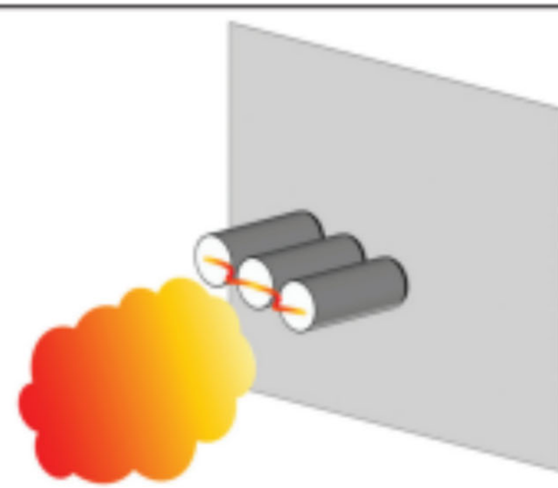
	Electrode configuration in test	Electrode configuration in equipment
VCB		
VCBB		

Table 9—Correlation between actual equipment and electrode configuration *(continued)*

	Electrode configuration in test	Electrode configuration in equipment
HCB		
VOA		
HOA		

N **Table 130.5(G) Selection of Arc-Rated Clothing and Other PPE When the Incident Energy Analysis Method Is Used**

Incident energy exposures equal to 1.2 cal/cm^2 up to 12 cal/cm^2
Arc-rated clothing with an arc rating equal to or greater than the estimated incident energy[a]
Long-sleeve shirt and pants or coverall or arc flash suit (SR)
Arc-rated face shield and arc-rated balaclava or arc flash suit hood (SR)[b]
Arc-rated outerwear (e.g., jacket, parka, rainwear, hard hat liner) (AN)
Heavy-duty leather gloves, arc-rated gloves, or rubber insulating gloves with leather protectors (SR)[c]
Hard hat
Safety glasses or safety goggles (SR)
Hearing protection
Leather footwear
Incident energy exposures greater than 12 cal/cm^2
Arc-rated clothing with an arc rating equal to or greater than the estimated incident energy[a]
Long-sleeve shirt and pants or coverall or arc flash suit (SR)
Arc-rated arc flash suit hood
Arc-rated outerwear (e.g., jacket, parka, rainwear, hard hat liner) (AN)
Arc-rated gloves or rubber insulating gloves with leather protectors (SR)[c]
Hard hat
Safety glasses or safety goggles (SR)
Hearing protection
Leather footwear

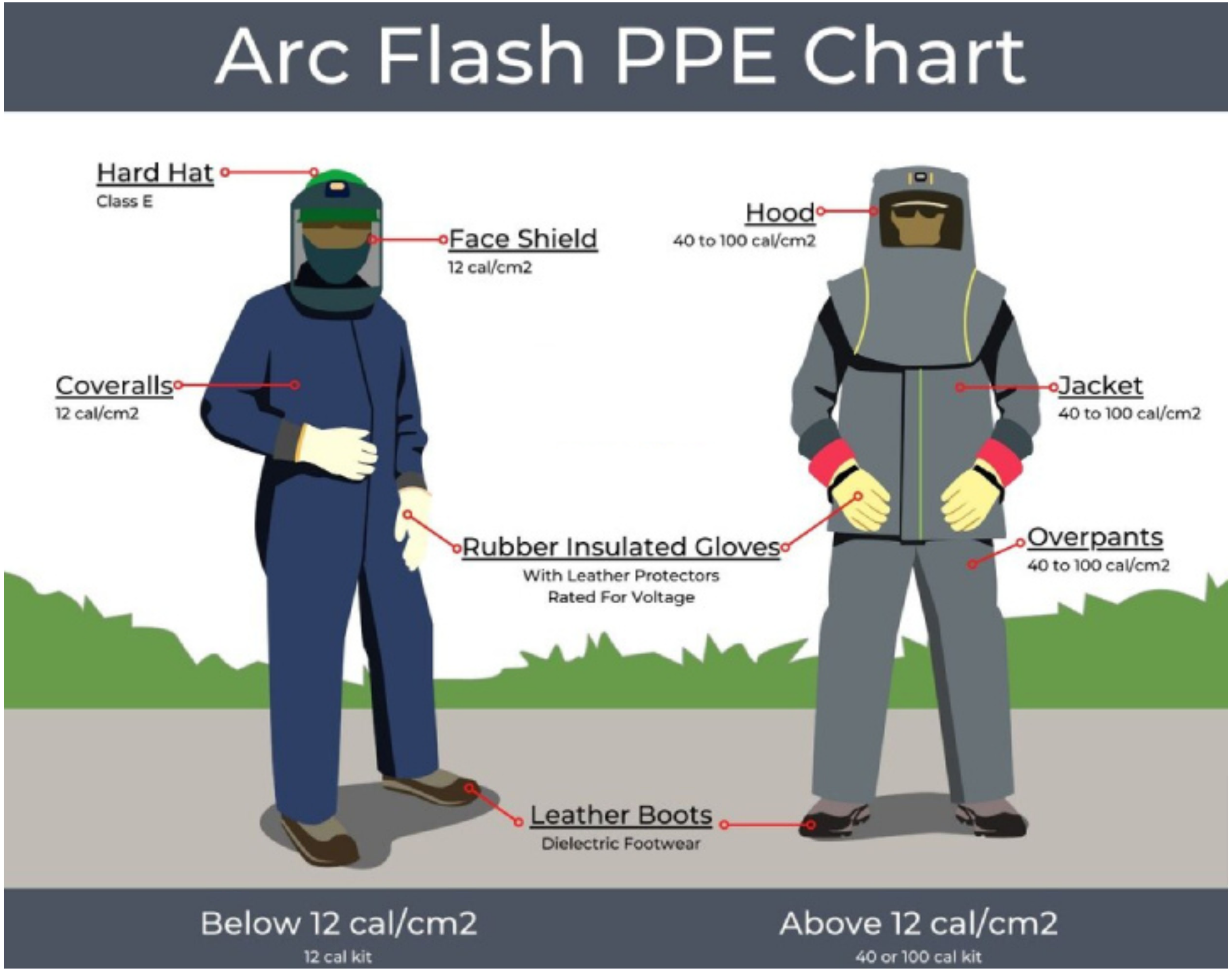
SR: Selection of one in group is required.

AN: As needed.

[a]Arc ratings can be for a single layer, such as an arc-rated shirt and pants or a coverall, or for an arc flash suit or a multi-layer system if tested as a combination consisting of an arc-rated shirt and pants, coverall, and arc flash suit.

[b]Face shields with a wrap-around guarding to protect the face, chin, forehead, ears, and neck area are required by 130.7(C)(10)(c). Where the back of the head is inside the arc flash boundary, a balaclava or an arc flash hood shall be required for full head and neck protection.

[c]Rubber insulating gloves with leather protectors provide arc flash protection in addition to shock protection


Arc Flash PPE Chart
Hard Hat
Class E
Face Shield
12 cal/cm2
Hood
40 to 100 cal/cm2
Coveralls
12 cal/cm2
Jacket
40 to 100 cal/cm2
Rubber Insulated Gloves
With Leather Protectors
Rated For Voltage
Overpants
40 to 100 cal/cm2
Leather Boots
Dielectric Footwear
Below 12 cal/cm2
12 cal kit
Above 12 cal/cm2
40 or 100 cal kit

Questions

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