

## Substation Arc-Flash (In Open Air)

### Eblen (Adj Exponent Heat Flux)

Nominal Rating (see Note a)	Blue-Bk Fault Curr (max kA)	Adj Exp Heat Flux at the smallest possible MAD (cal/cm <sup>2</sup> /sec)	Clearing Time (sec)
5.1 to 15 kVac	75.0	115.77	2.00
18 to 34.5 kVac	75.0	123.80	2.00
46 to 69 kVac	75.0	90.98	2.00
100 to 115 kVac	75.0	201.44	0.28
138 kVac	75.0	185.37	0.28
161 kVac	75.0	198.58	0.28
230 kVac	75.0	262.41	0.22
287 kVac	75.0	731.85	0.22
300 to 345 kVac	75.0	320.18	0.22
525 kVac (all designs)	75.0	490.16	0.20
525 kVac (series caps)	75.0	69.73	0.20
80 kVdc (neut bus)	15.6	10.56	0.500
400 kVdc	15.6	20.53	0.500
448 kVdc	15.6	27.05	0.500
500 kVdc	15.6	14.62	0.500
520 kVdc	15.6	11.65	0.500
565 kVdc	15.6	7.85	0.500

### QUALIFIED PERSON

Select **Applicable AF Working Dist**, compare with **APM Rule M-1 MAD**, select **MAX** of the two distances.

Incident Energy at the smallest possible MAD (cal/cm <sup>2</sup> )	14 cal/cm <sup>2</sup> Distance	8 cal/cm <sup>2</sup> Distance
231.5	8'-4"	10'-11"
247.6	9'-9"	12'-9"
182.0	10'-2"	13'-3"
57.1	5'-2"	6'-6"
52.5	5'-2"	6'-4"
56.3	5'-9"	7'-0"
56.9	6'-6"	7'-11"
158.6	8'-4"	9'-10"
69.4	8'-6"	10'-2"
98.0	11'-1"	13'-0"
13.9	11'-3"	13'-2"
5.3	2'-4"	2'-10"
10.3	7'-2"	8'-2"
13.5	8'-9"	9'-11"
7.3	8'-11"	10'-0"
5.8	8'-10"	9'-11"
3.9	8'-10"	9'-11"

### UNQUALIFIED PERSON

Select **MAX Boundary**

Limited-Approach Boundary	1.2 cal/cm <sup>2</sup> Arc-Flash Boundary
10'	27'-11"
10'	32'-5"
10'	33'-2"
15'	15'-0"
15'	14'-2"
15'	15'-7"
15'	16'-8"
15'	20'-0"
15'	20'-9"
20'	25'-2"
20'	25'-7"
20'	6'-3"
20'	14'-8"
20'	17'-2"
20'	17'-6"
20'	17'-4"
20'	17'-3"



### STEPS

- SubStation Arc-Flash tab:** Filter for appropriate **Nominal Rating** (column A)
- Blue-Book Data tab:** If dealing with HVDC (kVdc): no Blue-Bk data exists / worst-case fault curr & clearing time combo already listed / jump to step 3.
  - Filter for appropriate substation **BUS** location. *The Blue-Book has no 287-kV bus, because the only 287-kV part of the system is the Olympia - G.Coulee No. 1 which is a transformer-terminated line.*
  - Filter for appropriate **KV**
- SubStation Arc-Flash tab:** To protect individuals from **shock AND arc-flash** hazards, select the **MAX of Applicable AF Working Distance & Applicable APM Rule M-1 MAD** (QUALIFIED PERSON) and **MAX Boundary** (UNQUALIFIED PERSON)

### NOTES & EQUATIONS

**Blue-Bk Fault Curr (max kA):** See info under "STEPS" 2A-2B. For HVDC, no Blue-Bk info is available - value is taken from ABB test reports for new Conv 1 & 2 equipment.

**Adj Exp Heat Flux at the smallest possible MAD (cal/cm<sup>2</sup>/sec):** Conservative curves generated by Marcia Eblen. Equations are listed under **HeatFLux.Eblen** tab.

**Clearing time:** Reasonable clearing time as determined by BPA or industry-recognized SME's.

**Incident Energy at the smallest possible MAD (cal/cm<sup>2</sup>)** = Adj Exponent Heat flux (cal/cm<sup>2</sup>/sec) x clearing time (sec). Calculated at the closest distance that workers will ever get (taking into account elevation and Hold Order status), generates worst-case. **Workers must still use APM Rule M-1, Tables A-C to determine the appropriate MAD for shock protection.**

**14 cal/cm<sup>2</sup> Distance** = [ (2\*ArcGap<sub>(in)</sub>) + (Dist to arc<sub>(in)</sub> \* SQRT (Incident Energy/14)) ] / 12.

**8 cal/cm<sup>2</sup> Distance** = [ (2\*ArcGap<sub>(in)</sub>) + (Dist to arc<sub>(in)</sub> \* SQRT (Incident Energy/8)) ] / 12.

**Limited-Approach Boundary:** Provides shock protection for UNQUALIFIED PERSON.

**1.2 cal/cm<sup>2</sup> Arc-Flash Boundary** = [ (2\*ArcGap<sub>(in)</sub>) + (Dist to arc<sub>(in)</sub> \* SQRT (Incident Energy/1.2)) ] / 12. Provides arc-flash protection for UNQUALIFIED PERSON.

AF Boundary is the distance at which Incident Energy is 1.2 cal/cm<sup>2</sup> (onset of 2nd degree burns). Going inside the arc-flash boundary requires Arc-Flash PPE.

**Note (a)** For voltages 5-kV & below - request an Arc-Flash study prior to performing energized work.

## Transmission Line Arc-Flash (In Open Air)

### Eblen (Adj Exponent Heat Flux)

Nominal Rating (see Note a)	Blue-Bk Fault Curr (max kA)	Adj Exp Heat Flux at the smallest possible MAD (cal/cm <sup>2</sup> /sec)	Clearing Time (sec)
5.1 to 15 kVac	75.0	115.77	2.00
18 to 34.5 kVac	75.0	123.80	2.00
46 to 69 kVac	75.0	90.98	2.00
100 to 115 kVac	75.0	201.44	0.28
138 kVac	75.0	185.37	0.28
161 kVac	75.0	198.58	0.28
230 kVac	75.0	262.41	0.22
287 kVac	75.0	731.85	0.22
300 to 345 kVac	75.0	320.18	0.22
525 kVac (all designs)	75.0	490.16	0.20
525 kVac (series caps)	75.0	69.73	0.20
80 kVdc (metallic return)	23.9	18.98	0.304
400 kVdc	23.9	35.18	0.304
448 kVdc	23.9	46.57	0.304
500 kVdc	23.9	25.28	0.304
520 kVdc	23.9	19.96	0.304
565 kVdc	23.9	13.51	0.304

### QUALIFIED PERSON

Select **Applicable AF Working Dist**, compare with **APM Rule M-1 MAD**, select **MAX** of the two distances.

Incident Energy at the smallest possible MAD (cal/cm <sup>2</sup> )	14 cal/cm <sup>2</sup> Distance	8 cal/cm <sup>2</sup> Distance
231.5	8'-4"	10'-11"
247.6	9'-9"	12'-9"
182.0	10'-2"	13'-3"
57.1	5'-2"	6'-6"
52.5	5'-2"	6'-4"
56.3	5'-9"	7'-0"
56.9	6'-6"	7'-11"
158.6	8'-4"	9'-10"
69.4	8'-6"	10'-2"
98.0	11'-1"	13'-0"
13.9	11'-3"	13'-2"
5.8	2'-5"	2'-11"
10.7	7'-3"	8'-3"
14.2	8'-10"	10'-0"
7.7	9'-0"	10'-2"
6.1	8'-11"	10'-1"
4.1	8'-11"	10'-0"

### UNQUALIFIED PERSON

Select **MAX Boundary**

Limited- Approach Boundary	1.2 cal/cm <sup>2</sup> Arc-Flash Boundary
10'	27'-11"
10'	32'-5"
10'	33'-2"
15'	15'-0"
15'	14'-2"
15'	15'-7"
15'	16'-8"
15'	20'-0"
15'	20'-9"
20'	25'-2"
20'	25'-7"
20'	6'-6"
20'	14'-10"
20'	17'-5"
20'	17'-10"
20'	17'-7"
20'	17'-7"



### STEPS

- TransLine Arc-Flash tab:** Filter for appropriate **Nominal Rating** (column A)
- Blue-Book Data tab:** If dealing with HVDC (kVdc): no Blue-Bk data exists / max fault current is already listed / jump to step 3.
  - Filter for appropriate **BUS** locations that correspond to **ALL terminals associated with the line** that the crew will be working on. *The only 287-kV line is the Olympia - G.Coulee No. 1 which is transformer-terminated. For this line, filter using Olympia & G.Coulee 230-kV buses.*
  - Filter for appropriate **KV**
- TransLine Arc-Flash tab:**
  - To protect individuals from **shock AND arc-flash hazards**, select the **MAX of Applicable AF Working Distance & Applicable APM Rule M-1 MAD** (QUALIFIED PERSON) and **MAX Boundary** (UNQUALIFIED PERSON)
  - For **unworkable distances at 14 cal/cm<sup>2</sup> or 8 cal/cm<sup>2</sup>** (QUALIFIED PERSON):
    - Contact SPC to get actual ASPEN fault magnitude (kA) at the worksite.
    - Enter that number (kA) column E, **"Blue-Bk Fault Curr (max kA)"** to determine **Incident Energy (cal/cm<sup>2</sup>) & Arc-Flash Boundary (ft)**

### NOTES & EQUATIONS

**Blue-Bk Fault Curr (max kA):** See info under "STEPS" 2A-2B. *For HVDC*, no Blue-Bk info is available - value is taken from ABB test reports for new Conv 1 & 2 equipment.  
**Adj Exp Heat Flux at the smallest possible MAD (cal/cm<sup>2</sup>/sec):** Conservative curves generated by Marcia Eblen. Equations are listed under **HeatFLUX.Eblen** tab.  
**Clearing time:** Reasonable clearing time as determined by BPA or industry-recognized SME's.

**Incident Energy at the smallest possible MAD (cal/cm<sup>2</sup>)** = Adj Exponent Heat flux (cal/cm<sup>2</sup>/sec) x clearing time (sec). **Calculated at the closest distance that workers will ever get (taking into account elevation and Hold Order status), generates worst-case. Workers must still use APM Rule M-1, Tables A-C to determine the appropriate MAD for shock protection.**

$$14 \text{ cal/cm}^2 \text{ Distance} = [ (2 * \text{ArcGap}_{(in)}) + (\text{Dist to arc}_{(in)} * \text{SQRT}(\text{Incident Energy}/14)) ] / 12.$$

$$8 \text{ cal/cm}^2 \text{ Distance} = [ (2 * \text{ArcGap}_{(in)}) + (\text{Dist to arc}_{(in)} * \text{SQRT}(\text{Incident Energy}/8)) ] / 12.$$

**Limited-Approach Boundary:** Provides shock protection for UNQUALIFIED PERSON.

$$1.2 \text{ cal/cm}^2 \text{ Arc-Flash Boundary} = [ (2 * \text{ArcGap}_{(in)}) + (\text{Dist to arc}_{(in)} * \text{SQRT}(\text{Incident Energy}/1.2)) ] / 12. \text{ Provides arc-flash protection for UNQUALIFIED PERSON.}$$

AF Boundary is the distance at which Incident Energy is 1.2 cal/cm<sup>2</sup> (onset of 2nd degree burns). Going inside the arc-flash boundary requires Arc-Flash PPE.

**Note (a)** For voltages 5-kV & below - request an Arc-Flash study prior to performing energized work.

# Arc-Flash (Enclosure)

## Elben (IEEE 1584 Conservative Derived / EPRI PMH Formula)

Nominal Rating & Equipment Type	Blue-Bk Fault Curr (max kA)	Heat Flux at 48 inches (cal/cm <sup>2</sup> /sec)	Clearing Time (sec)
1 kV to 15 kV - dead-front with separable elbows (circuits <i>are not accessible</i> when enclosure is open)	75.0	99.6	0.50
1 kV to 15 kV - live-front terminations (circuits <i>are accessible</i> when enclosure is open)	75.0	298.9	0.50
1 kV to 15 kV - rackable metal-clad breakers	75.0	398.5	0.50
1 kV to 15 kV - pad-mounted / fused switches (circuits <i>may be accessible</i> when enclosure is open)	75.0	N/A	0.50

## QUALIFIED PERSON

Incident Energy at 48 inches (cal/cm <sup>2</sup> )	Select <b>MAX</b> Applic Working Dist	
	Dist to Arc	8 cal/cm <sup>2</sup> Distance
49.8	4'-0"	10'-0"
149.5	4'-0"	17'-3"
199.3	4'-0"	20'-0"
266.5	4'-0"	23'-1"

## UNQUALIFIED PERSON

Select <b>MAX</b> Boundary	
Limited-Approach Boundary	1.2 cal/cm <sup>2</sup> Arc-Flash Boundary
10'	25'-9"
10'	44'-8"
10'	51'-7"
10'	59'-7"



## STEPS

- Arc-Flash (enclosure) tab:** Filter for appropriate **Nominal Rating & Equipment Type** (column A)
- Blue-Book Data tab:**
  - Filter for appropriate substation **BUS** location.
  - Filter for appropriate **KV**
- Arc-Flash (enclosure) tab:** To protect individuals from **shock AND arc-flash** hazards, select the **MAX Applicable Working Distance** (QUALIFIED PERSON) and **MAX Boundary** (UNQUALIFIED PERSON)

## NOTES & EQUATIONS

**Blue-Bk Fault Curr (max kA):** See info under "STEPS" 2A-2B.

**Heat Flux at 48 inches (cal/cm<sup>2</sup>/sec):** Conservative curves generated by Marcia Eblen. Equations are listed under **HeatFLux.Eblen** tab.

**Clearing time:** Reasonable clearing time as determined by BPA or industry-recognized SME's.

**Incident Energy at 48 inches (cal/cm<sup>2</sup>):**

Dead-front, live-front, rackable ckt bkr: Heat flux (cal/cm<sup>2</sup>/sec) x clearing time (sec)

Pad-mount fused switch:  $[ 3547 ] \times [ \text{Fault Curr (kA)}^{1.5} ] \times [ \text{Clearing Time (sec)}^{1.35} ] / [ \text{Dist to Arc (inches)}^{2.1} ]$

**Dist to Arc:** selected to be 4'-0" inches as per discussion with Jim Cramer & Marcia Eblen (shock protection).

**8 cal/cm<sup>2</sup> Distance** =  $[ \text{Dist to arc}_{(in)} * \text{SQRT} (\text{Incident Energy}/8) ] / 12.$

**Limited-Approach Boundary:** Provides shock protection for UNQUALIFIED PERSON.

**1.2 cal/cm<sup>2</sup> Arc-Flash Boundary** =  $[ \text{Dist to arc}_{(in)} * \text{SQRT} (\text{Incident Energy}/1.2) ] / 12.$  Provides arc-flash protection for UNQUALIFIED PERSON.

AF Boundary is the distance at which Incident Energy is 1.2 cal/cm<sup>2</sup> (onset of 2nd degree burns). Going inside the arc-flash boundary requires Arc-Flash PPE.























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## Revision Jurisdiction

- Blue-book updates:** TESM (Steve Lowder) gets SharePoint e-mail notifications when the Blue Book is updated. When Blue-Book Data is changed, TESM will modify "Blue-Book Data" tab as follows:
  - Change date in cell D3 to match modification date on the Sharepoint Site.
  - Copy/paste new data from Blue-Book spreadsheet.
- MAD Changes / Updates:** TESM (Christine Goldsworthy) + Safety Office jurisdiction. Any changes to MADs will affect HeatFlux calcs.
- OSHA Changes:** Safety Office jurisdiction / need to coordinate with TESM to roll changes in.
- Upload locations:** a) Safety AF Resources (POC - Cindra Rehman / Safety Office). b) BPA WS ThumbDrive folder, Sect 11 (POC - Steve Lowder / TESM)
  - <http://internal.bpa.gov/Policy/Safety/ResourcesArc/Forms/Arc%20View.aspx>
  - [\\rs3f01\wrgrp\SubMaintGlobal\BPA WS's & Sub Maint SG's Download \(thumbdrive\)\BPA Work Standards\11 \(New\) Personnel Safety Procedures](\\rs3f01\wrgrp\SubMaintGlobal\BPA WS's & Sub Maint SG's Download (thumbdrive)\BPA Work Standards\11 (New) Personnel Safety Procedures)

## Revision History (most recent at top of list)

Date	Comments
2018.01.05	<b>Blue-Book Data tab:</b> Updated with info from the <b>Blue Book BPA 12-28-17.xlsx</b> file. Updated link to where the Blue Book Excel file is located.
2016.09.20	<b>SubStation Arc-Flash (open air) / TransLine Arc-Flash (open air) / Arc-Flash (enclosure)</b> tabs: Changed "QUALIFIED INDIVIDUAL" to "QUALIFIED PERSON". Changed "UNQUALIFIED INDIVIDUAL" to "UNQUALIFIED PERSON". This was done to match wording changes associated with the WS 11-6 update.
2016.05.31	Changed filename from "BPAHotStick Curves yyyy.mm.dd (Dynamic Use)" to "Arc-Flash yyyy.mm.dd Dynamic Use" to align file name with what it's used for. Changed wording in WS 11-6 to match.
2016.04.06	<b>Blue-Book Data tab:</b> Hand entered info on <i>Toledo Bank 1: 13.8kV tertiary bus / Toledo Bank 2: 13.8kV tertiary bus / Tahkenitch Bank 1: 13.8 kV tertiary bus</i> based on 2016.04.04 ASPEN study performed by Jerry Richards.
2016.03.31	1) <b>SubStation Arc-Flash (open air)</b> tab: a) Increased "neutral bus" nominal voltage rating from 69 kVdc to 80 kVdc as per direction from Christine Goldsworthy. MAD stays the same. b) Increased nominal voltage rating of 560 kVdc to 565 kVdc to match proposed change to APM Rule M-1, Table F, "DC MAD".. Kept MAD used to calculate heat flux at 11'-11" instead of increasing to 12'-0". 2) <b>TransLine Arc-Flash (open air)</b> tab: a) Added info on "80 kVdc (metallic return)" for TLM usage. Used same fault current & clearing time as for all other HVDC / transmission line nominal voltages. b) Increased nominal voltage rating of 560 kVdc to 565 kVdc to match proposed change to APM Rule M-1, Table F, "DC MAD". Kept MAD used to calculate heat flux at 11'-11" instead of increasing to 12'-0". 3) <b>SubStation Arc-Flash (open air) / TransLine Arc-Flash (open air) / Arc-Flash (enclosure)</b> tabs: Modified LAB's to align with proposed new values for APM M-1 Rule, Table F: 50 V to 69 kV: 10'. All DC 80 kV & above: 20'. 4) <b>Blue-Book Data</b> tab: Changed SharePoint hyperlink after discussion with Jolene Schafman (person who will be in charge of BlueBook data since Jeff Newton retired). 5) <b>Heatflux.Eblen</b> tab: Explained logic behind using 69 kVdc ArcPro heatflux equation for 80 kVdc because the following are the same for both: MAD (40"), arc-gap, dist to arc. 6) <b>Clearing Times</b> tab: Changed "69 kVdc (neutral bus)" to "80 kVdc (neutral bus)". Added info on 80 kVdc (metallic return) transmission line clearing time = .304 sec. 7) Added back in <b>DC Fault Curr Comparison</b> tab to highlight how DC fault curr & clearing times were selected to generate worst-case
2016.02.01	<b>Incident Energy calcs for AF hazard must generate worst-case for each voltage class (taking into account elevation and Hold Order status): As such, all calcs must be changed from "at MAD with Hold Order" to "at the smallest possible MAD", since that is where incident energy is largest. Listed below are the changes triggered by this requirement.</b> 1) <b>SubStation Arc-Flash (open air) / TransLine Arc-Flash (open air)</b> tabs: a) 525 kVac (series caps): 2016.01 APM shows minimum MAD for this scenario is 11'-3" (135") and pertains to MAD <i>without</i> Hold Order / elevation <3000ft. Adjusted AF calculations using M.Eblen equation for 135" MAD. b) Changed all references of "BPA MAD with Hold Order" to "smallest possible MAD" to match how worst-case calcs were done. c) Changed all references of "Incident Energy at MAD" to "Incident Energy at the smallest possible MAD". d) Changes all references of "Adj Exp Heat Flux at the MAD" to "Adj Exp Heat Flux at the smallest possible MAD". e) Deleted column S: Eliminates possible confusion that smallest possible MAD is the actual MAD for a given scenario. f) Modified column Q info under "NOTES & EQUATIONS" section to clarify that: minimum MAD generates worst-case incident energy / workers must still use APM Rule M-1, Tables A-C to determine appropriate MAD for shock protection (since MAD distances vary with elevation and Hold Order status). g) Clarified that worker must "Select Applicable AF working Dist, compare with Applicable APM Rule M-1 MAD, select MAX of the two distances" to protect QUALIFIED INDIVIDUALS from shock & arc-flash hazard. 2) <b>HeatFlux.Eblen</b> tab: Updated equation for "525 (series caps)" using Eblen R6 info.
2015.12.02	1) <b>SubStation Arc-Flash (open air) / TransLine Arc-Flash (open air) / Arc-Flash (enclosure) / Blue-Book Data</b> tabs: modified "filter" columns to reflect only those that are selected by the user. 2) <b>Arc-Flash (enclosure)</b> tab: removed 14 cal/cm <sup>2</sup> distance because: a) 10 cal/cm <sup>2</sup> faceshields cannot be applied above nameplated rating when working in an enclosure, b) 10 cal/cm <sup>2</sup> distance is too close to the 8 cal/cm <sup>2</sup> distance already listed.
2015.11.20	Global - across all tabs: Removed references to "Categories".
2015.09.09	1) <b>Arc-Flash (enclosure)</b> tab: a) Incorporated "Incident Energy at 48 inches" column as part of "QUALIFIED INDIVIDUAL" section. b) Hide columns B / E / G. c) Clarified that for pad-mounted / fused switches: No heat flux equation. Incident energy calc'd directly using EPRI PMH Formula. 2) <b>SubStation Arc-Flash (open air) / TransLine Arc-Flash (open air)</b> tabs: a) Incorporated "Incident Energy at MAD" column as part of "QUALIFIED INDIVIDUAL" section. b) Hide columns B-D / G / I. 3) Added <b>WS Table 4.4 (worst-case AF)</b> tab to show "worst-case" numbers for Arc-Flash (open air).
2015.09.01	1) <b>Arc-Flash (enclosure) / SubStation Arc-Flash (open air) / TransLine Arc-Flash (open air)</b> tabs: a) Clarified which items provide shock protection & which provide arc-flash protection: <b>Modified wording in Notes. Added shock &amp; arc-flash logos underneath applicable columns.</b> b) Clarified that MAXIMUM distance must be selected to protect against shock & arc-flash hazards: <b>Changed wording in column headers for QUALIFIED &amp; UNQUALIFIED INDIVIDUALS + wording in Step 3.</b> c) <b>Incident Energy Column:</b> Highted values in green to show that they pertain to a QUALIFIED INDIVIDUAL. 2) <b>Arc-Flash (enclosure) tab / Notes:</b> a) Added for clarity - <b>Dist to Arc: ... (shock protection).</b>
2015.08.31	First distribution for field use. Coincides with 2015.08.31 version of BPA WS "Shock & Arc-Flash Personal Protective Equipment".

# Heat Flux Formulas

## Eblen R3

kVac (in open air)	MAD with HOLD Order for Tools
15	$y = 0.0855(x)^{1.67}$
34.5	$y = 0.1535(x)^{1.55}$
69	$y = 0.2454(x)^{1.37}$
115	$y = 0.6185(x)^{1.34}$
138	$y = 0.77(x)^{1.27}$
161	$y = 0.79(x)^{1.28}$
230	$y = 1.09(x)^{1.27}$
287	$y = 3.04(x)^{1.27}$
345	$y = 1.33(x)^{1.27}$
525 (100-inch)	$y = 1.95(x)^{1.28}$
525 (all others)	$y = 1.95(x)^{1.28}$

## Equation documentation

working distance	Equation Derivation
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points
MAD with HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points

## Eblen R6

kVac (in open air)	MAD with HOLD Order for Tools
525 (series caps)	$y = 0.2774(x)^{1.28}$

## Equation documentation

working distance	Equation Derivation
MAD without HOLD Order for Tools	ArcPro + Eblen AdjExp eq's to encompass all points

## Eblen R4 +HVdc

kVdc (in open air)	Pole-Ground MAD for Tools Restart Blocked
69	$y = 0.2454(x)^{1.37}$
80	$y = 0.2454(x)^{1.37}$
400	$y = 0.645(x)^{1.26}$
448	$y = 0.827(x)^{1.27}$
500	$y = 0.435(x)^{1.28}$
520	$y = 0.366(x)^{1.26}$
560	$y = 0.24(x)^{1.27}$

## Equation documentation

working distance	Equation Derivation
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points. <i>As per 2015.07.09 telecon with Marcia Eblen: Can use same ArcPro Heatflux for 69 kVdc as used for 69 kVac because the following are the same: MAD (40"), arc-gap, dist to arc.</i>
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points. <i>As per 2015.07.09 telecon with Marcia Eblen: Can use same ArcPro Heatflux for 69 kVdc as used for 69 kVac because the following are the same: MAD (40"), arc-gap, dist to arc. Lowerder (2016.03.29): Same logic: Apply ArcPro Heatflux formula from 69 kVac to 80 kVdc because following are the same: MAD (40"), arc-gap, dist to arc.</i>
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points
Pole-Gnd MAD for Tools / Restart Blocked	ArcPro + Eblen AdjExp eq's to encompass all points

## BPA MV Encl v01

kVac (enclosure)	48 inches
Dead Front	$y = 1.3396(x) - 0.8787$
Live Front	$y = 4.0189(x) - 2.6361$
Racking Ckt Bkr	$y = 5.3585(x) - 3.5148$
Pad-Mount Fused Switch	n/a - see <b>Note 1</b>

## Equation documentation

working distance	Equation Derivation
48 inches (from prospective arc source to employee's face/chest area)	IEEE 1584 Conservative Derived
48 inches (from prospective arc source to employee's face/chest area)	IEEE 1584 Conservative Derived
48 inches (from prospective arc source to employee's face/chest area)	IEEE 1584 Conservative Derived
48 inches (from prospective arc source to employee's face/chest area)	EPRI PMH Formula

x = fault current (kA)  
y = heat flux (cal/cm<sup>2</sup>/sec)

**Note 1** EPRI formula for *Pad-Mount Fused Switch* generates Incident Energy directly as a function of time. Heat Flux is not calculated.  
Incident Energy (cal/cm<sup>2</sup>) @ 48" =  $(3547(x)^{1.5} * (t)^{1.35}) / (d)^{2.1}$ ; where x = fault current (kA), t = time (sec), d = distance from arc (inches)

# Fault Clearing Times

## In Open Air

Nominal Rating (see Note a)	Clearing Time (cycles)	Clearing Time (sec)	documentation
5.1 to 15 kVac	120	2.00	Marcia Eblen (worst-case / no study) - 2015.07.16 telecon
18 to 34.5 kVac	120	2.00	Marcia Eblen (worst-case / no study) - 2015.07.16 telecon
46 to 69 kVac	120	2.00	Marcia Eblen (worst-case / no study) - 2015.07.16 telecon
100 to 115 kVac	17	0.28	Dean Bender - 2015.06.19 e-mail
138 kVac	17	0.28	Dean Bender - 2015.06.19 e-mail
161 kVac	17	0.28	Dean Bender - 2015.06.19 e-mail
230 kVac	13	0.22	Dean Bender - 2015.06.19 e-mail
287 kVac	13	0.22	Dean Bender - 2015.06.19 e-mail
300 to 345 kVac	13	0.22	Dean Bender - 2015.06.19 e-mail
525 kVac (all designs)	12	0.20	Dean Bender - 2015.06.19 e-mail
525 kVac (series caps)	12	0.20	Dean Bender - 2015.06.19 e-mail

Nominal Rating (see Note a)	Clearing time (sec)		documentation
	Inside Sub	Outside Sub	
80 kVdc (neut bus)	0.500	--	DC clearing times are different based on fault-curr mag (.2 to 3.808 kA, 3.809 to 15.583 kA, 15.584 kA & above). <b>Clearing time listed generates worst-case Incident Energy (cal/cm<sup>2</sup>).</b>
80 kVdc (metallic return)	--	0.304	
400 kVdc	0.500	0.304	
448 kVdc	0.500	0.304	
500 kVdc	0.500	0.304	
520 kVdc	0.500	0.304	
560 kVdc	0.500	0.304	
560 kVdc	0.500	0.304	

## Enclosure

Nominal Rating (see Note a)	Clearing Time (cycles)	Clearing Time (sec)	documentation
<b>1 kV to 15 kV</b> - dead-front with separable elbows (circuits <i>are not accessible</i> when enclosure is open)	30	0.50	Jim Cramer& Marcia Eblen - 2015.07.01 telecon
<b>1 kV to 15 kV</b> - live-front terminations (circuits <i>are accessible</i> when enclosure is open)	30	0.50	Jim Cramer& Marcia Eblen - 2015.07.01 telecon
<b>1 kV to 15 kV</b> - rackable metal-clad breakers	30	0.50	Jim Cramer& Marcia Eblen - 2015.07.01 telecon
<b>1 kV to 15 kV</b> - pad-mounted / fused switches (circuits <i>may be accessible</i> when enclosure is open)	30	0.50	Jim Cramer& Marcia Eblen - 2015.07.01 telecon

## Inside Substation Arc-Flash (In Open Air)

Eblen (Adj Exponent Heat Flux)

Nominal Rating (see Note a)	BPA MAD with Hold Order (in)	Arc-Gap (in)	Dist to Arc (in)	Fault Curr (max kA)	Adj Exp Heat Flux at the MAD (cal/cm <sup>2</sup> /sec)	Clearing Time (cycles)	Clearing Time (sec)	Incident Energy at the MAD (cal/cm <sup>2</sup> )
<b>Above 15.584 kADC (values from 1JNL217247_A_en_Transient_Currents.pdf / Table 9 "Results" (G.Lee))</b>								
69 kVdc (neut bus)	40	4.2	31.6	22.5	17.47	--	0.250	4.4
400 kVdc	92	24.3	43.4	23.9	35.18	--	0.250	8.8
448 kVdc	106	31.8	42.4	23.9	46.57	--	0.250	11.6
500 kVdc	123	31.8	59.4	23.9	25.28	--	0.250	6.3
520 kVdc	129	31.8	65.4	23.9	19.96	--	0.250	5.0
560 kVdc	143	31.8	79.4	23.9	13.51	--	0.250	3.4

<b>3.809 to 15.583 kADC</b>								
69 kVdc (neut bus)	40	4.2	31.6	15.6	10.56	--	0.500	5.3
400 kVdc	92	24.3	43.4	15.6	20.53	--	0.500	10.3
448 kVdc	106	31.8	42.4	15.6	27.05	--	0.500	13.5
500 kVdc	123	31.8	59.4	15.6	14.62	--	0.500	7.3
520 kVdc	129	31.8	65.4	15.6	11.65	--	0.500	5.8
560 kVdc	143	31.8	79.4	15.6	7.85	--	0.500	3.9

worst case incident energy  
worst case incident energy  
worst case incident energy  
worst case incident energy  
worst case incident energy  
worst case incident energy

<b>.200 to 3.808 kADC</b>								
69 kVdc (neut bus)	40	4.2	31.6	3.8	1.53	--	1.750	2.7
400 kVdc	92	24.3	43.4	3.8	3.48	--	1.750	6.1
448 kVdc	106	31.8	42.4	3.8	4.52	--	1.750	7.9
500 kVdc	123	31.8	59.4	3.8	2.41	--	1.750	4.2
520 kVdc	129	31.8	65.4	3.8	1.97	--	1.750	3.5
560 kVdc	143	31.8	79.4	3.8	1.31	--	1.750	2.3

## Transmission Line Arc-Flash (In Open Air)

Eblen (Adj Exponent Heat Flux)

Nominal Rating (see Note a)	BPA MAD with Hold Order (in)	Arc-Gap (in)	Dist to Arc (in)	Blue-Bk Fault Curr (max kA)	Adj Exp Heat Flux at the MAD (cal/cm <sup>2</sup> /sec)	Clearing Time (cycles)	Clearing Time (sec)	Incident Energy at the MAD (cal/cm <sup>2</sup> )
<b>Above 15.584 kADC (values from 1JNL217247_A_en_Transient_Currents.pdf / Table 9 "Results" (G.Lee))</b>								
400 kVdc	92	24.3	43.4	23.9	35.18	--	0.304	10.7
448 kVdc	106	31.8	42.4	23.9	46.57	--	0.304	14.2
500 kVdc	123	31.8	59.4	23.9	25.28	--	0.304	7.7
520 kVdc	129	31.8	65.4	23.9	19.96	--	0.304	6.1
560 kVdc	143	31.8	79.4	23.9	13.51	--	0.304	4.1

worst case incident energy  
worst case incident energy  
worst case incident energy  
worst case incident energy  
worst case incident energy

<b>3.809 to 15.583 kADC</b>								
400 kVdc	92	24.3	43.4	15.6	20.53	--	0.500	10.3
448 kVdc	106	31.8	42.4	15.6	27.05	--	0.500	13.5
500 kVdc	123	31.8	59.4	15.6	14.62	--	0.500	7.3
520 kVdc	129	31.8	65.4	15.6	11.65	--	0.500	5.8
560 kVdc	143	31.8	79.4	15.6	7.85	--	0.500	3.9

<b>.200 to 3.808 kADC</b>								
400 kVdc	92	24.3	43.4	3.8	3.48	--	1.750	6.1
448 kVdc	106	31.8	42.4	3.8	4.52	--	1.750	7.9
500 kVdc	123	31.8	59.4	3.8	2.41	--	1.750	4.2
520 kVdc	129	31.8	65.4	3.8	1.97	--	1.750	3.5
560 kVdc	143	31.8	79.4	3.8	1.31	--	1.750	2.3

### STEPS

- SubStation Arc-Flash tab:** Filter for appropriate Nominal (kV, L-L)
- Blue-Book Data tab:**
  - Filter for appropriate KV
  - Filter for appropriate substation BUS location. *The Blue-Book has no 287-kV bus, because the only 287-kV part of the system is the Olympia - G.Coulee No. 1 which is a transformer-terminated line.*
- SubStation Arc-Flash tab:** Obtain **MAX Applicable Working Distance** (QUALIFIED INDIVIDUAL) and **MAX Boundary** (UNQUALIFIED INDIVIDUAL).

### NOTES & EQUATIONS

**BPA MAD with Hold Order:** From APM, Sect 1, Table A, "MAD with Hold Order for Tools"

**Arc Gap (in):** From Marcia Eblen Report, Tables 2 & 3

**Dist to arc (in) =**  $[MAD_{(in)} - (2 * ArcGap_{(in)})]$

**Blue-Bk Fault Curr (max kA):** See info under "STEPS" 2B. For HVDC, no Blue-Bk info is available - value is taken from ABB test reports for new Conv 1 & 2 equipment.

**Adj Exp Heat Flux at the MAD (cal/cm<sup>2</sup>/sec):** Conservative curves generated by Marcia Eblen. Equations are listed under **HeatFlux.Eblen** tab.

**Clearing time:** Reasonable clearing time as determined by BPA or industry-recognized SME's.

**Incident Energy at the MAD (cal/cm<sup>2</sup>) =** Adj Exponent Heat flux (cal/cm<sup>2</sup>/sec) x clearing time (sec)

**14 cal/cm<sup>2</sup> Distance (ft) =**  $[ (2 * ArcGap_{(in)}) + (Dist to arc_{(in)} * SQRT (Incident Energy / 14)) ] / 12$ .

**8 cal/cm<sup>2</sup> Distance (ft) =**  $[ (2 * ArcGap_{(in)}) + (Dist to arc_{(in)} * SQRT (Incident Energy / 8)) ] / 12$ .

**Arc-Flash Boundary (ft) =**  $[ (2 * ArcGap_{(in)}) + (Dist to arc_{(in)} * SQRT (Incident Energy / 1.2)) ] / 12$ . AF Boundary is the distance at which Incident Energy is 1.2 cal/cm<sup>2</sup> (onset of 2nd degree burns). Going inside the arc-flash boundary requires Arc-Flash PPE.

**Note (a)** For voltages 5-kV & below - request an Arc-Flash study prior to performing energized work.



**Table 4.3. 8 cal/cm<sup>2</sup> AF PPE Limits & Parameters - Unlabeled Circuits (Enclosures)**

Nominal Rating	QUALIFIED INDIVIDUAL	UNQUALIFIED INDIVIDUAL - Select <b>MAX</b>		info source
	Max Fault Current & Clearing Time for 8 cal/cm <sup>2</sup> at listed distance (see Note b)	Limited Approach Boundary (see Note b)	1.2 cal/cm <sup>2</sup> AF Boundary (see Note b)	
600 Vac & below panelboards / cabinets	25 kA for 2 cycles @ 18 inches (see Note c)	10'	3'	NFPA 70E-2015, Table 130.7.C.15.A.b Item 1 & 2
600 Vac-class MCC's / equipment	65 kA for 2 cycles @ 18 inches (see Note c)	10'	5'	NFPA 70E-2015, Table 130.7.C.15.A.b Item 3 & 6
101 to 249 Vdc batteries / switchboards / supply source	6.99 kA for 2 seconds @ 18 inches (see Note c)	10'	4'	NFPA 70E-2015, Table 130.7.C.15.B 101-249Vdc / Item 2
250 to 600 Vdc batteries / switchboards / supply source	2.99 kA for 2 seconds @ 18 inches (see Note c)	10'	4'	NFPA 70E-2015, Table 130.7.C.15.B 250-600Vdc / Item 2

Note (b): Shock-protection distances and arc-flash distances are independent of each other, and the *greater of the two* **shall** be used to protect personnel.

Note (c): Distance used to calculate Incident Energy = 18 inches (from prospective arc source to employee's face/chest area).