The Impact of the New IEEE 1584-2018 Standard on Arc Flash Studies

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Webinar Plan

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- 4. New Calculation Method in IEEE 1584-2018
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01

Webinar Objectives

Webinar Objectives

- **By the end of this webinar, participants will be able to:**
  - Define the steps required to perform arc flash calculations
  - Identify the changes in the new IEEE 1584-2018 standard with regards to the IEEE 1584-2002
  - Understand the new calculation method in the IEEE 1584-2018 standard
  - Know the impact of the parameters on the arc flash incident energy :
    - Voltage
    - Enclosure Size
    - Electrode Configuration
    - Electrode Gap
    - Fault Current
    - Working Distance

02

Changes in IEEE 1584-2018

IEEE 1584-2018: Changes

- Update of the arc flash calculation algorithm on which the CSA Z462 is based (Appendix D)
- First update since 2002, except for amendments in 2004 and 2011
- The incident energy calculation formulas were revised and replaced by models based on statistical analyses based on more than 1860 tests, while the 2002 version was based on about 300 tests
- The electrode (busbar) configuration is now used as a parameter in the equations : VCB, VCBB, HCB, VOA, HOA
- The enclosure size of the equipment is now used in the calculations : height, width, depth

IEEE 1584-2018: Changes

- IEEE 1584 model application limits were extended
  - **2002 Version:**
    - Voltage: 208 V to 15 kV, three-phase
    - Short-circuit current: 700 A to 106 kA
    - Distance between phases: 13 mm to 152 mm
  - **2018 Version:**
    - Voltage: 208 V to 15 kV, three-phase
    - Short-circuit current:
      - 208 V to 600 V: 500 A to 106 kA
      - 601 V to 15 kV: 200 A to 65 kA
    - Distance between phases:
      - 208 V to 600 V: 6.35 mm to 76.2 mm
      - 601 V to 15 kV: 19.05 mm to 254 mm

- The system grounding (delta, floating wye, wye grounded with impedance, wye solidly grounded) is no longer considered in arc flash calculations

IEEE 1584-2018: Changes

- 2 seconds limit for the duration of the arc fault still applies
  - **2002 Version** : "*It is likely that a person exposed to an arc flash will move away quickly if it is physically possible and two seconds is a reasonable maximum time for calculations.*"
  - **2018 Version** : "*It is likely that a person exposed to an arc flash will move away quickly if it is physically possible, and 2 s usually is a reasonable assumption for the arc duration to determine the incident energy.*"

- Exception for small distributions is modified, the power limit of 125 kVA is replaced by a fault current of 2 kA
  - **2002 Version** : "*Equipment below 240 V need not be considered unless it involves at least one 125 kVA or larger transformer in its immediate power supply.*"
  - **2018 Version** : "*Sustainable arcs are possible but less likely in three-phase systems operating at 240 V nominal or less with an available short-circuit current less than 2000 A.*"

2 kA equivalent in transformer power rating

208 V Secondary : $S = \sqrt{3} * V * I_{cc} * \%Z = \sqrt{3} * 208\,V * 2\,kA * 0.04 = \boldsymbol{29\,kVA}$

IEEE 1584-2018: Changes

- Motor rated power limit of ≥ 50 hp is modified and now only refers to "large motors", but other standards in reference still refer to the ≥ 50 hp limit
  - **2002 Version** : "*The study must take into account all sources, including utilities, standby and power generators, and* ***large motors*** *– those 37 kW* **(*50 hp*)** *and larger that contribute energy to short circuits.*"
  - **2018 Version** *: "Systems containing multiple sources of short-circuit current, such as generators,* ***large motors****, or more than one utility supply, can be more accurately modeled with a dynamic simulation method. Methods may include multiple calculations to account for decaying short-circuit current contributions from rotating equipment, and the effect on protective device opening times and resulting incident energy."*
  - **References** :
    - **IEEE 1584.1-2013 :** *"The higher available fault current calculations should be based on all simultaneously operating* ***large motors (greater than or equal to 50 hp)*** *turned on, and the lower calculations should be based on no large motors running."*
    - **IEEE 551-2006 (Violet Book)** *: "For application of ac medium-voltage circuit breakers, symmetrical (ac component) short-circuit current duties are calculated according to IEEE Std C37.010-1999 […]. The calculations omit all motors of less than* ***50 hp*** *each."*
    - **IEEE C37.010-2016** *: "Neglect all three-phase induction motors below 37.5kW (****50 hp****) and all single-phase motors*."

IEEE 1584-2018: Changes

- Recommended method for > 15 kV is no longer specifically the Lee method, therefore other methods such as ArcPro now are more relevant
  - **2002 Version** : "*For cases where voltage is over 15 kV, or gap is outside the range of the model, the theoretically derived Lee method can be applied and it is included in the IEEE Std 1584-2002 Incident Energy Calculators.*"
  - **2018 Version** : "*There are alternative calculation methods for system parameters that fall outside of the range of the model. However, no particular recommendation can be made because there are other application details such as bolted fault current levels, voltage, gap length, operating frequency, number of phases, types of faults, etc. The user is advised to properly research alternative calculation methods and their application viabilities.*"

- The Lee method was far too conservative compared to other software (ie. ArcPro) for voltages >> 15 kV

$$E = 5.12 \times 10^5 V I_{bf} \left(\frac{t}{D^2} \right)$$

where

E	is incident energy (cal/cm^2)
V	is system voltage (kV)
t	is arcing time (seconds)
D	is distance from possible arc point to person (mm)
I_{bf}	is bolted fault current

IEEE 1584-2018: Changes

- Single-phase systems: still not explicitly covered by IEEE 1584, but a conservative method is given
  - **2002 Version** : *"Single-phase ac systems [...] are not included in this guide."*
  - **2018 Version** : *"This model does not cover single-phase systems. Arc-flash incident energy testing for single-phase systems has not been searched 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 fnd 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."*
- DC networks: still not explicitly covered by IEEE 1584, publications (i.e. Doan) are now added as references
  - **2002 Version** : "*There is ongoing testing at dc, but it was not used in this analysis. Therefore dc and other frequencies of operation such as 400 Hz are not included in the IEEE Std 1584-2002 empirically derived model.", " [...] DC systems are not included in this guide.*"
  - **2018 Version** : "*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.*"

03

Old Calculation Method in IEEE 1584-2002

2002 Version: Old calculation method

- 1. Determine the arcing current I_{arc}
  - 1.1. For V < 1 kV : Equations 1 and 3
  - 1.2. For V ≥ 1 kV : Equations 2 and 3
- 2. Determine the arc fault duration *t* with the time-current curve
- 3. Determine the normalized incident energy E_n : Equations 4 and 5
- 4. Determine the incident energy *E :* Equation E.1
- 5. Determine the arc flash boundary *AFB* : Equation E.3
- 6. If V < 1 kV :
  - 6.1 Determine the minimum arcing current : $I_{arc\ min}$ = 85 % x I_{arc}
  - 6.2. Redo 2., 3., 4. and 5. with $I_{arc\ min}$, then t_{min}, E_{min} and AFB_{min} are obtained
  - 5.2. The final incident energy is the highest value between *E* and E_{min}
  - 5.3. The final arc flash boundary is the highest value between *AFB* and AFB_{min}

1. Determine the arcing current I_{arc}

For applications with a system voltage under 1000 V solve the equation (1):

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966\, V + 0.000526\, G + 0.5588\, V (\lg I_{bf}) - 0.00304\, G (\lg I_{bf}) \tag{1}$$

where

lg	is the $\log_{10}$
I_a	is arcing current (kA)
K	is –0.153 for open configurations and is –0.097 for box configurations
I_{bf}	is bolted fault current for three-phase faults (symmetrical RMS) (kA)
V	is system voltage (kV)
G	is the gap between conductors, (mm) (see Table 4)

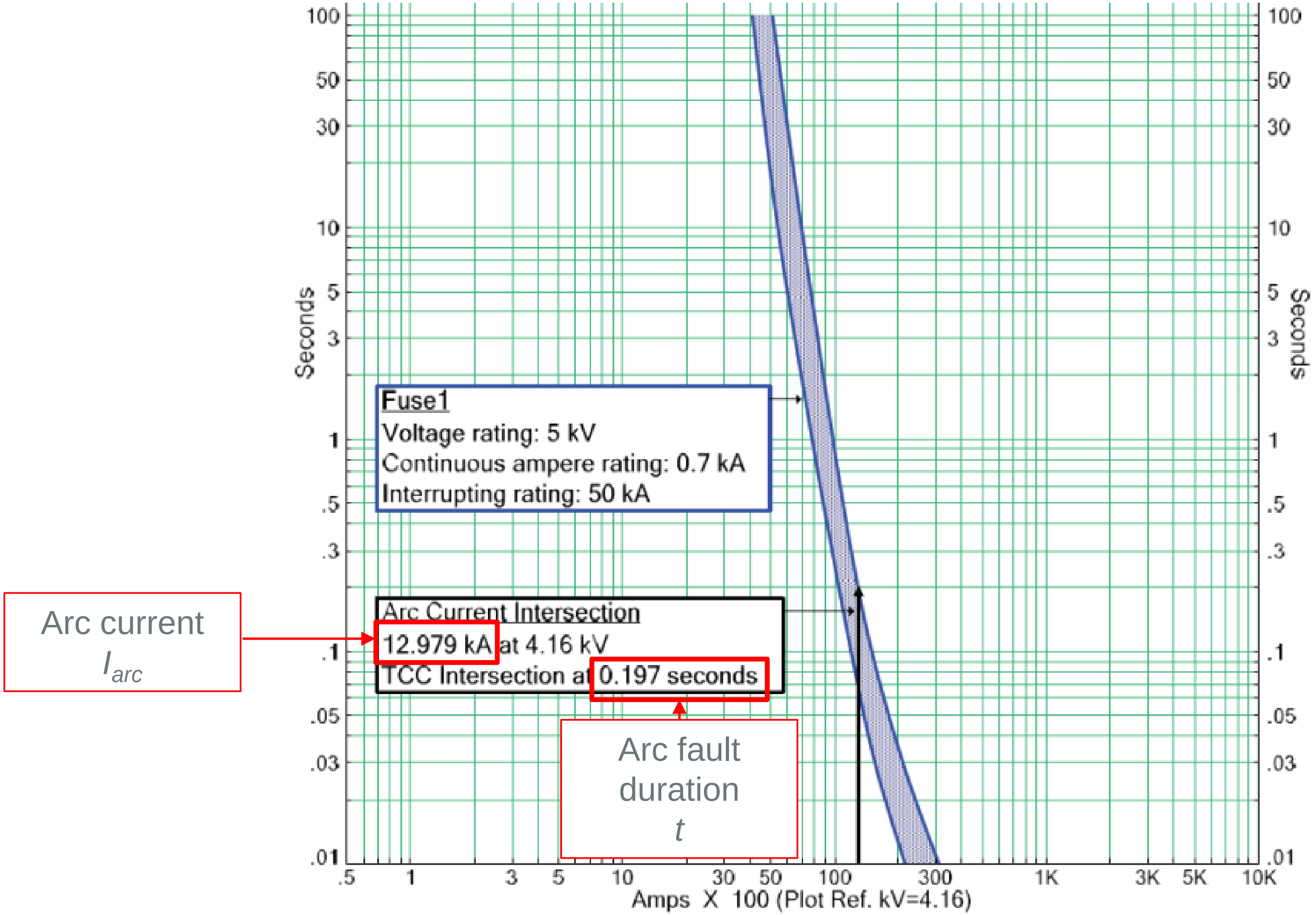
For applications with a system voltage of 1000 V and higher solve the equation (2):

$$\lg I_a = 0.00402 + 0.983 \lg I_{bf} \tag{2}$$

Convert from lg:

$$I_a = 10^{\lg I_a} \tag{3}$$

2. Determine the arc fault duration *t* with the time-current curve



3. Determine the normalized incident energy E_n : Equations 4 and 5

$$\lg E_n = K_1 + K_2 + 1.081 \lg I_a + 0.0011\, G \quad (4)$$

where

E_n	is incident energy (J/cm^2) normalized for time and distance [13]
K_1	is –0.792 for open configurations (no enclosure) and
	is –0.555 for box configurations (enclosed equipment)
K_2	is 0 for ungrounded and high-resistance grounded systems and
	is –0.113 for grounded systems
G	is the gap between conductors (mm) (see Table 4)

Then:

$$E_n = 10^{\lg E_n} \quad (5)$$

4. Determine the incident energy *E :* Equation E.1

$$E = C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right) \tag{E.1}$$

where

E	is incident energy (cal/cm^2)
C_f	is a calculation factor
	1.0 for voltages above 1kV, and
	1.5 for voltages at or below 1kV
E_n	is incident energy normalized [56]
t	is arcing time (seconds)
D	is distance from the possible arc point to the person (mm)
x	is the distance exponent from Table 4.

5. Determine the arc flash boundary *AFB* : Equation E.3

$$D_B = \left[C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{E_B}\right)\right]^{\frac{1}{x}} \tag{E.3}$$

where

D_B	is the distance of the boundary from the arcing point (mm)
C_f	is a calculation factor 1.0 for voltages above 1 kV, and 1.5 for voltages at or below 1 kV,
E_n	is incident energy normalized[59]
E_B	is incident energy in cal/cm^2 at the boundary distance
t	is time (seconds)
x	is the distance exponent from Table 4.

04 New Calculation Method in IEEE 1584-2018

2018 Version: New calculation method

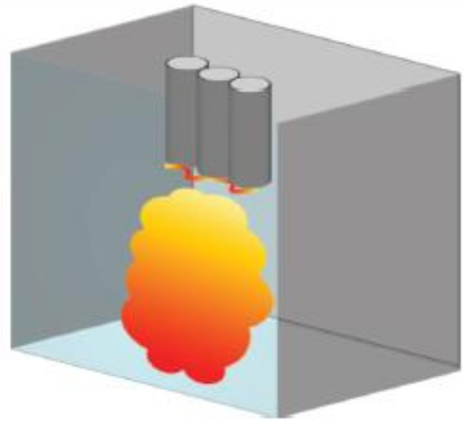
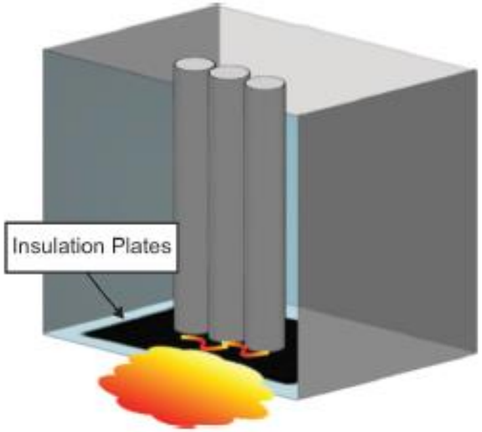
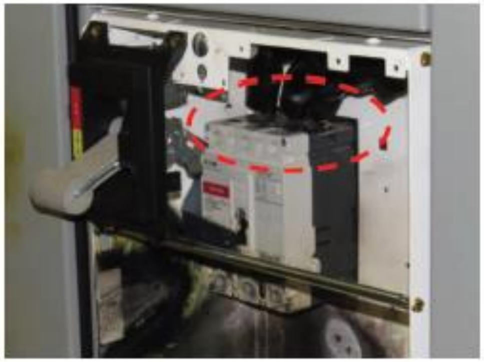
- 1. Determine the arcing current I_{arc}
  - 1.1. Determine the electrode configuration
  - 1.2. For 600 V < V_{oc} ≤ 15 kV: Equations 1, 16, 17, 18
  - 1.3. For 208 V ≤ v_{oc} ≤ 600 V: Equations 1, 25
- 2. Determine the arc fault duration T with the time-current curve
- 3. Determine the incident energy E
  - 3.1. Determine the enclosure size correction factor CF : Equations 14, 15
  - 3.2. For 600 V < V_{oc} ≤ 15 kV: Equations 3, 4, 5, 19, 20, 21
  - 3.3. For 208 V ≤ v_{oc} ≤ 600 V: Equation 6
- 4. Determine the arc flash boundary AFB
  - 4.1. For 600 V < V_{oc} ≤ 15 kV: Equations 7, 8, 9, 22, 23, 24
  - 4.2. For 208 V ≤ v_{oc} ≤ 600 V: Equation 10
- 5. Determine the minimum arcing current $I_{arc\ min}$: Equation 2
  - 5.1. Redo 2., 3. and 4. with $I_{arc\ min}$, then T_{min}, E_{min} and AFB_{min} are obtained
  - 5.2. The final incident energy is the highest value between E and E_{min}
  - 5.3. The final arc flash boundary is the highest value between AFB and AFB_{min}

1.1 Determine the electrode configuration

VCB:
Vertical conductors / electrodes inside a metal box / enclosure

VCBB:
Vertical conductors / electrodes terminated in an insulating barrier inside a metal box / enclosure

Table 9—Correlation between actual equipment and electrode configuration

	Electrode configuration in test	Electrode configuration in equipment
VCB		
VCBB		

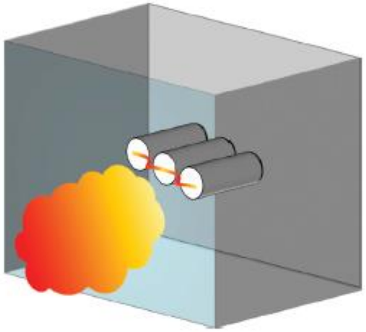
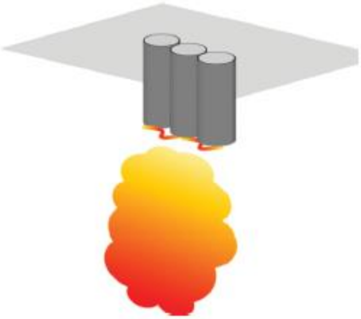
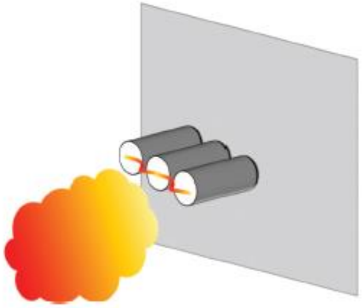
1.1 Determine the electrode configuration

HCB:
Horizontal conductors / electrodes inside a metal box / enclosure

VOA:
Vertical conductors / electrodes in open air

HOA:
Horizontal conductors / electrodes in open air

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

	Electrode configuration in test	Electrode configuration in equipment
HCB		
VOA		
HOA		

1.2. I_{arc} For 600 V < V_{oc} ≤ 15 kV: Equations 1, 16, 17, 18

$$I_{\text{arc\_Voc}} = 10^{\left(k1 + k2 \lg I_{\text{bf}} + k3 \lg G\right)} \left(k4 I_{\text{bf}}^6 + k5 I_{\text{bf}}^5 + k6 I_{\text{bf}}^4 + k7 I_{\text{bf}}^3 + k8 I_{\text{bf}}^2 + k9 I_{\text{bf}} + k10\right) \tag{1}$$

where

I_{bf}	is the bolted fault current for three-phase faults (symmetrical rms) (kA)
$I_{\text{arc\_600}}$	is the average rms arcing current at $V_{\text{oc}} = 600$ V (kA)
$I_{\text{arc\_2700}}$	is the average rms arcing current at $V_{\text{oc}} = 2700$ V (kA)
$I_{\text{arc\_14300}}$	is the average rms arcing current at $V_{\text{oc}} = 14\,300$ V (kA)
$\boxed{G}$	is the gap distance between electrodes (mm)
$\boxed{k1 \text{ to } k10}$	are the coefficients provided in Table 1
lg	is $\log_{10}$

Typical value as per Table 8 or actual equipment value

These coefficients depend on the electrode configuration (VCB, VCBB, HCB, VOA, HOA)

$$I_{\text{arc\_1}} = \frac{I_{\text{arc\_2700}} - I_{\text{arc\_600}}}{2.1}\left(V_{\text{oc}} - 2.7\right) + I_{\text{arc\_2700}} \tag{16}$$

$$I_{\text{arc\_2}} = \frac{I_{\text{arc\_14300}} - I_{\text{arc\_2700}}}{11.6}\left(V_{\text{oc}} - 14.3\right) + I_{\text{arc\_14300}} \tag{17}$$

$$I_{\text{arc\_3}} = \frac{I_{\text{arc\_1}}\left(2.7 - V_{\text{oc}}\right)}{2.1} + \frac{I_{\text{arc\_2}}\left(V_{\text{oc}} - 0.6\right)}{2.1} \tag{18}$$

If 600 V < V_{oc} ≤ 2.7 kV: $I_{\text{arc}} = I_{\text{arc\_3}}$

If V_{oc} > 2.7 kV: $I_{\text{arc}} = I_{\text{arc\_2}}$

1.3. I_{arc} For 208 V ≤ V_{oc} ≤ 600 V: Equations 1, 25

$$I_{\mathrm{arc\_Voc}} = 10^{(k1 + k2 \lg I_{\mathrm{bf}} + k3 \lg G)} \left(k4 I_{\mathrm{bf}}^6 + k5 I_{\mathrm{bf}}^5 + k6 I_{\mathrm{bf}}^4 + k7 I_{\mathrm{bf}}^3 + k8 I_{\mathrm{bf}}^2 + k9 I_{\mathrm{bf}} + k10 \right) \quad (1)$$

where

I_{bf}	is the bolted fault current for three-phase faults (symmetrical rms) (kA)
$I_{\mathrm{arc\_600}}$	is the average rms arcing current at $V_{\mathrm{oc}} = 600$ V (kA)
$\boxed{G}$	is the gap distance between electrodes (mm)
$\boxed{k1 \text{ to } k10}$	are the coefficients provided in Table 1
lg	is $\log_{10}$

Typical value as per Table 8 or actual equipment value

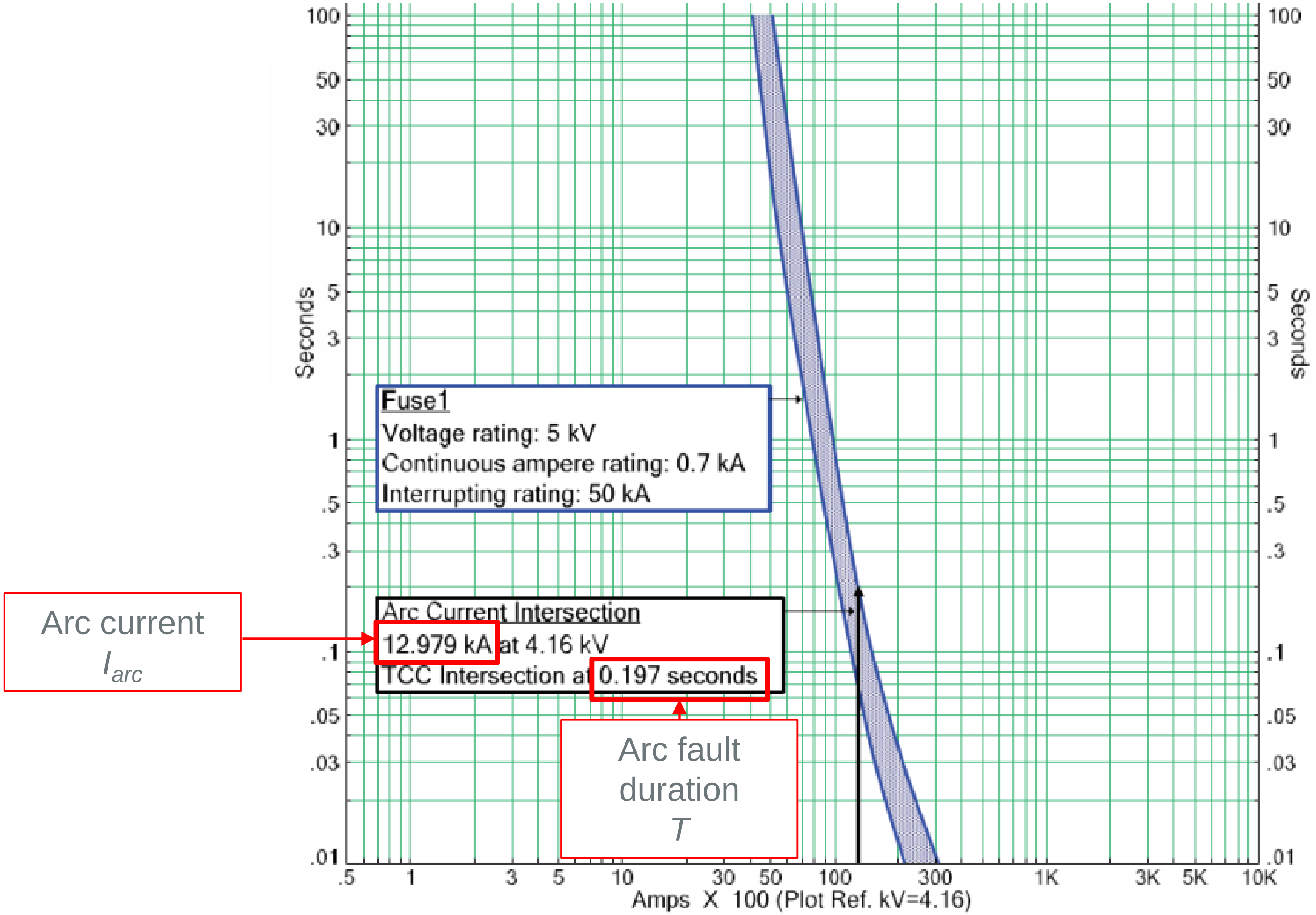
These coefficients depend on the electrode configuration (VCB, VCBB, HCB, VOA, HOA)

$$I_{\mathrm{arc}} = \frac{1}{\sqrt{\left[\frac{0.6}{V_{\mathrm{oc}}}\right]^2 \times \left[\frac{1}{I_{\mathrm{arc\_600}}{}^2} - \left(\frac{0.6^2 - V_{\mathrm{oc}}{}^2}{0.6^2 \times I_{\mathrm{bf}}{}^2}\right)\right]}} \quad (25)$$

where

V_{oc}	is the open-circuit voltage (kV)
I_{bf}	is the bolted fault current for three-phase faults (symmetrical rms) (kA)
I_{arc}	is the final rms arcing current at the specified V_{oc} (kA)
$I_{\mathrm{arc\_600}}$	is the rms arcing current at $V_{\mathrm{oc}} = 600$ V found using Equation (1) (kA)

2. Determine the arc fault duration *T* with the time-current curve



3.1. Determine the enclosure size correction factor *CF*

- "Shallow" enclosure : if voltage < 600 V, height < 20 inches, width < 20 inches and depth ≤ 8 inches
- "Typical" enclosure : all other cases

$$\text{Width}_1 = \left(660.4 + (\text{Width} - 660.4) \times \left(\frac{V_{oc} + A}{B}\right)\right) \times 25.4^{-1} \qquad (11)$$

$$\text{Height}_1 = \left(660.4 + (\text{Height} - 660.4) \times \left(\frac{V_{oc} + A}{B}\right)\right) \times 25.4^{-1} \qquad (12)$$

where

Height_1	is the equivalent enclosure height
Width_1	is the equivalent enclosure width
Width	is the actual enclosure width (mm)
Height	is the actual enclosure height (mm)
V_{oc}	is the open-circuit voltage (system voltage) (kV)
A	is a constant equal to 4 for VCB and 10 for VCBB and HCB
B	is a constant equal to 20 for VCB, 24 for VCBB, and 22 for HCB

If "Shallow":

$$CF = b1 \times EES^2 + b2 \times EES + b3$$

If "Typical":

$$CF = \frac{1}{b1 \times EES^2 + b2 \times EES + b3}$$

$$EES = \frac{\text{Height}_1 + \text{Width}_1}{2}$$

where

Height_1	is the equivalent enclosure height
Weight_1	is the equivalent enclosure width
EES	is the equivalent enclosure size

where

$b1$ to $b3$	are the coefficients for Equation (14) and Equation (15) provided in Table 7
CF	is the enclosure size correction factor used in Equation (3) through Equation (10)
EES	is the equivalent enclosure size used to find the correction factor determined using Equation (13). For typical box enclosures the minimum value of EES is 20

3.2. *E* for 600 V < V_{oc} ≤ 15 kV: Equations 3, 4, 5, 19, 20, 21

$$E_{600} = \frac{12.552}{50} T \times 10^{\left(k1 + k2 \lg G + \frac{k3 I_{arc\_600}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11 \lg I_{bf} + k12 \lg D + k13 \lg I_{arc\_600} + \lg \frac{1}{CF} \right)} \quad (3)$$

$$E_{2700} = \frac{12.552}{50} T \times 10^{\left(k1 + k2 \lg G + \frac{k3 I_{arc\_2700}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11 \lg I_{bf} + k12 \lg D + k13 \lg I_{arc\_2700} + \lg \frac{1}{CF} \right)} \quad (4)$$

$$E_{14300} = \frac{12.552}{50} T \times 10^{\left(k1 + k2 \lg G + \frac{k3 I_{arc\_14300}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11 \lg I_{bf} + k12 \lg D + k13 \lg I_{arc\_14300} + \lg \frac{1}{CF} \right)} \quad (5)$$

where

E_{600}	is the incident energy at $V_{oc} = 600$ V (J/cm²)
E_{2700}	is the incident energy at $V_{oc} = 2700$ V (J/cm²)
E_{14300}	is the incident energy at $V_{oc} = 14\,300$ V (J/cm²)
T	is the arc duration (ms)
G	is the gap distance between conductors (electrodes) (mm)
I_{arc_600}	is the rms arcing current for 600 V (kA)
I_{arc_2700}	is the rms arcing current for 2700 V (kA)
I_{arc_14300}	is the rms arcing current for 14 300 V (kA)
I_{arc}	is rms arcing current for $V_{oc} \le 600$ V [obtained using Equation (25)] (kA)
I_{bf}	is bolted fault current for three-phase faults (symmetrical rms) (kA)
D	is the distance between electrodes and calorimeters (working distance) (mm)
CF	is correction factor for enclosure size ($CF = 1$ for VOA and HOA configurations)
lg	is $\log_{10}$
$k1$ to $k13$	are the coefficients provided in Table 3, Table 4, and Table 5. For Equation (3) use Table 3, for Equation (4) use Table 4, for Equation (5) use Table 5, and for Equation (6) use Table 3

3.2. *E* for 600 V < V_{oc} ≤ 15 kV: Equations 3, 4, 5, 19, 20, 21

$$E_1 = \frac{E_{2700} - E_{600}}{2.1}\left(V_{oc} - 2.7\right) + E_{2700} \tag{19}$$

$$E_2 = \frac{E_{14300} - E_{2700}}{11.6}\left(V_{oc} - 14.3\right) + E_{14300} \tag{20}$$

$$E_3 = \frac{E_1\left(2.7 - V_{oc}\right)}{2.1} + \frac{E_2\left(V_{oc} - 0.6\right)}{2.1} \tag{21}$$

where

E_1 is the first E interpolation term between 600 V and 2700 V (J/cm²)
E_2 is the second E interpolation term used when V_{oc} is greater than 2700 V (J/cm²)
E_3 is the third E interpolation term used when V_{oc} is less than 2700 V (J/cm²)

If 600 V < V_{oc} ≤ 2.7 kV: $E = E_3$

If V_{oc} > 2.7 kV: $E = E_2$

$$1\ cal/cm^2 = \frac{1\ J/cm^2}{4{,}184}$$

3.3. *E* for 208 V ≤ V_{oc} ≤ 600 V: Equation 6

$$E_{\le 600} = \frac{12.552}{50} T \times 10^{\left(k1 + k2 \lg G + \frac{k3 I_{arc\_600}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11 \lg I_{bf} + k12 \lg D + k13 \lg I_{arc} + \lg \frac{1}{CF} \right)} \quad (6)$$

where

$E_{\le 600}$	is the incident energy for $V_{oc} \le 600$ V (J/cm²)
T	is the arc duration (ms)
G	is the gap distance between conductors (electrodes) (mm)
I_{arc_600}	is the rms arcing current for 600 V (kA)
I_{arc}	is rms arcing current for $V_{oc} \le 600$ V [obtained using Equation (25)] (kA)
I_{bf}	is bolted fault current for three-phase faults (symmetrical rms) (kA)
D	is the distance between electrodes and calorimeters (working distance) (mm)
CF	is correction factor for enclosure size ($CF = 1$ for VOA and HOA configurations)
lg	is $\log_{10}$
$k1$ to $k13$	are the coefficients provided in Table 3, Table 4, and Table 5. For Equation (3) use Table 3, for Equation (4) use Table 4, for Equation (5) use Table 5, and for Equation (6) use Table 3

$$\boxed{E = E_{\le 600}}$$

4.1. *AFB* for 600 V < V_{oc} ≤ 15 kV: Equations 7, 8, 9, 22, 23, 24

$$AFB_{600} = 10^{\left(\dfrac{k1 + k2\lg G + \dfrac{k3 I_{arc\_600}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11\lg I_{bf} + k13\lg I_{arc\_600} + \lg\left(\dfrac{1}{CF}\right) - \lg\left(\dfrac{20}{T}\right)}{-k12}\right)} \quad (7)$$

$$AFB_{2700} = 10^{\left(\dfrac{k1 + k2\lg G + \dfrac{k3 I_{arc\_2700}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11\lg I_{bf} + k13\lg I_{arc\_2700} + \lg\left(\dfrac{1}{CF}\right) - \lg\left(\dfrac{20}{T}\right)}{-k12}\right)} \quad (8)$$

$$AFB_{14300} = 10^{\left(\dfrac{k1 + k2\lg G + \dfrac{k3 I_{arc\_14300}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11\lg I_{bf} + k13\lg I_{arc\_14300} + \lg\left(\dfrac{1}{CF}\right) - \lg\left(\dfrac{20}{T}\right)}{-k12}\right)} \quad (9)$$

where

AFB_{600}	is the arc-flash boundary for V_{oc} = 600 V (mm)
AFB_{2700}	is the arc-flash boundary for V_{oc} = 2700 V (mm)
AFB_{14300}	is the arc-flash boundary for V_{oc} = 14 300 V (mm)
G	is the gap between electrodes (mm)
I_{arc_600}	is the rms arcing current for 600 V (kA)
I_{arc_2700}	is the rms arcing current for 2700 V (kA)
I_{arc_14300}	is the rms arcing current for 14 300 V (kA)
I_{bf}	is the bolted fault current for three-phase faults (symmetrical rms) (kA)
CF	is the correction factor for enclosure size (CF = 1 for VOA and HOA configurations)
T	is the arc duration (ms)
lg	is $\log_{10}$
$k1$ to $k13$	are the coefficients provided in Table 3, Table 4, and Table 5. For Equation (7) use Table 3, for Equation (8) use Table 4, for Equation (9) use Table 5, and for Equation (10) use Table 3

4.1. *AFB* for 600 V < V_{oc} ≤ 15 kV: Equations 7, 8, 9, 22, 23, 24

$$AFB_1 = \frac{AFB_{2700} - AFB_{600}}{2.1}\left(V_{oc} - 2.7\right) + AFB_{2700} \tag{22}$$

$$AFB_2 = \frac{AFB_{14300} - AFB_{2700}}{11.6}\left(V_{oc} - 14.3\right) + AFB_{14300} \tag{23}$$

$$AFB_3 = \frac{AFB_1\left(2.7 - V_{oc}\right)}{2.1} + \frac{AFB_2\left(V_{oc} - 0.6\right)}{2.1} \tag{24}$$

where

AFB_1	is the first *AFB* interpolation term between 600 V and 2700 V (mm)
AFB_2	is the second *AFB* interpolation term used when V_{oc} is greater than 2700 V (mm)
AFB_3	is the third *AFB* interpolation term used when V_{oc} is less than 2700 V (mm)

If 600 V < V_{oc} ≤ 2.7 kV: $AFB = AFB_3$

If V_{oc} > 2.7 kV: $AFB = AFB_2$

4.2. *AFB* for 208 V ≤ V_{oc} ≤ 600 V: Equation 10

$$AFB_{\le 600} = 10^{\left(\frac{k1 + k2\lg G + \frac{k3 I_{arc\_600}}{k4 I_{bf}^7 + k5 I_{bf}^6 + k6 I_{bf}^5 + k7 I_{bf}^4 + k8 I_{bf}^3 + k9 I_{bf}^2 + k10 I_{bf}} + k11\lg I_{bf} + k13\lg I_{arc} + \lg\left(\frac{1}{CF}\right) - \lg\left(\frac{20}{T}\right)}{-k12} \right)} \quad (10)$$

where

$AFB_{\le 600}$	is the arc-flash boundary for $V_{oc} \le 600$ V (mm)
G	is the gap between electrodes (mm)
I_{arc_600}	is the rms arcing current for 600 V (kA)
I_{arc}	is the rms arcing current for $V_{oc} \le 600$ V [obtained using Equation (25)] (kA)
I_{bf}	is the bolted fault current for three-phase faults (symmetrical rms) (kA)
CF	is the correction factor for enclosure size ($CF = 1$ for VOA and HOA configurations)
T	is the arc duration (ms)
lg	is $\log_{10}$
$k1$ to $k13$	are the coefficients provided in Table 3, Table 4, and Table 5. For Equation (7) use Table 3, for Equation (8) use Table 4, for Equation (9) use Table 5, and for Equation (10) use Table 3

$$\boxed{AFB = AFB_{\le 600}}$$

5. Determine the minimum arcing current $I_{arc\ min}$: Equation 2

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

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

where

$VarC_f$	is the arcing current variation correction factor
I_{arc}	is the final or intermediate rms arcing current(s) (kA) (see note)
$I_{\text{arc\_min}}$	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

- 5.1. Redo 2., 3. and 4. with $I_{arc\ min}$, then T_{min}, E_{min} and AFB_{min} are obtained
- 5.2. The final incident energy is the highest value between E and E_{min}
- 5.3. The final arc flash boundary is the highest value between AFB and AFB_{min}

05

Parameter Sensitivity Analysis for IEEE 1584-2018

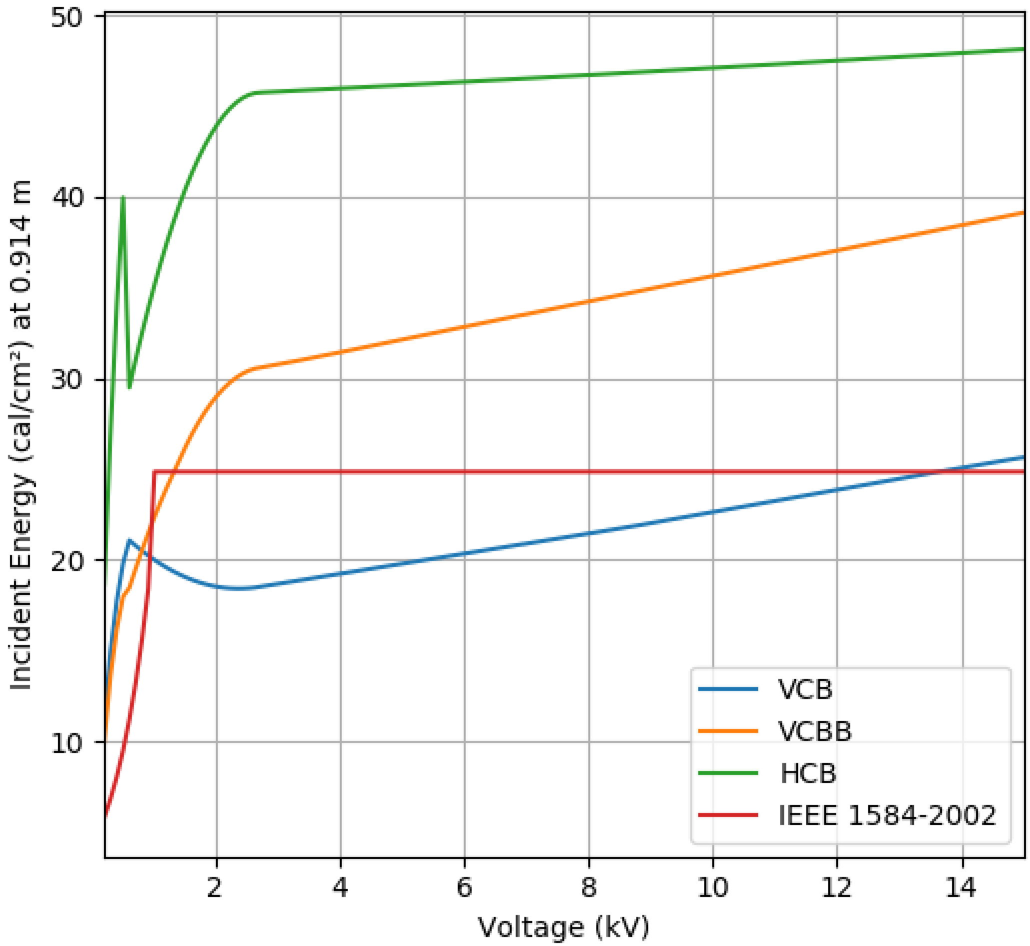
IEEE 1584-2018: Sensitivity Analysis

- The relationship between the inputs of the IEEE 1584-2018 equations and the arc flash incident energy can be hard to predict because of the complexity of the equations
- A sensitivity analysis tool using numerical methods was developed in Python in order to evaluate the impact of the parameters on the arc flash incident energy
- 4 examples are evaluated :
  - 15 kV Switchgear
  - 600 V Switchgear
  - 208 V Panel (Shallow)
  - 15 kV Breaker (Outdoor)

Example #1: 15 kV Switchgear

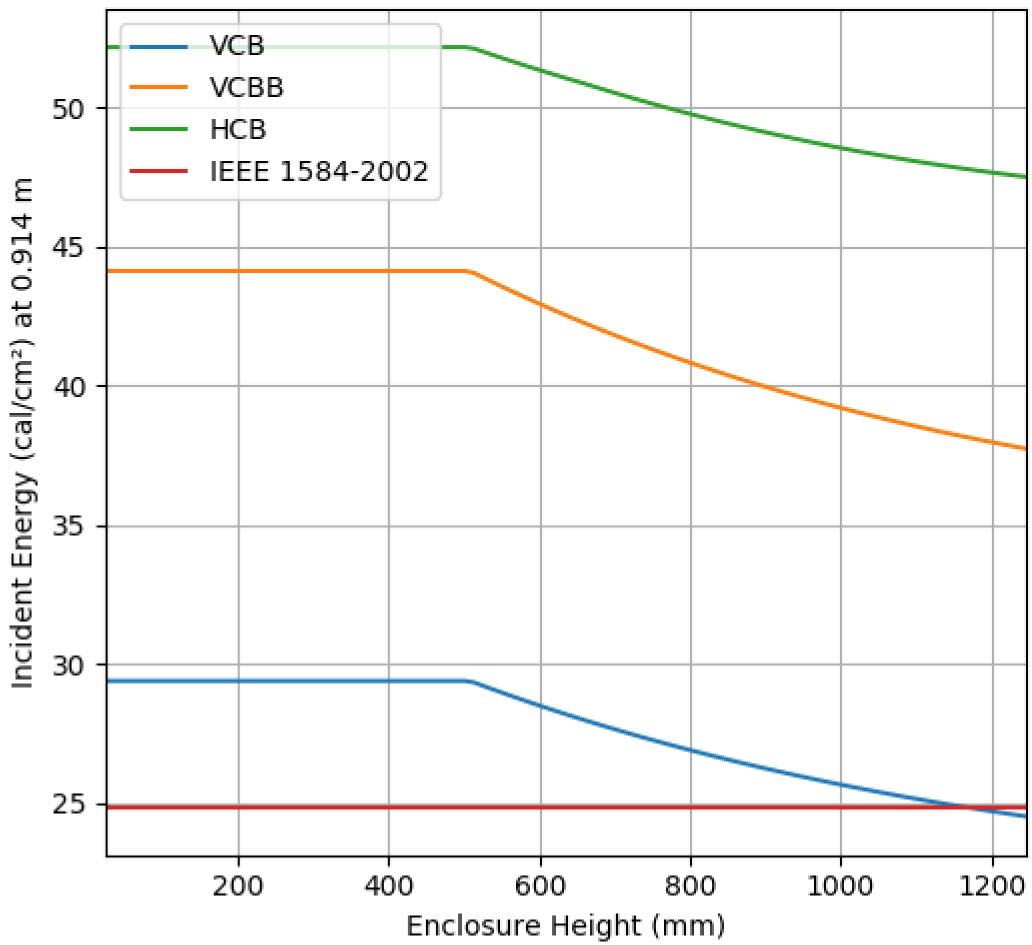
Example #1: 15 kV Switchgear

Parameter	Value
Upstream Protection	2 s rule applied
Voltage	*Independent Variable 'x'*
Enclosure Height	1143 mm (45 in)
Enclosure Width	762 mm (30 in)
Enclosure Depth	762 mm (30 in)
Electrode Gap	152 mm (6 in)
Bolted Fault Current	10 kA
Working Distance	0.914 m (36 in)



Example #1: 15 kV Switchgear

Parameter	Value
Upstream Protection	2 s rule applied
Voltage	13.8 kV
Enclosure Height	*Independent Variable 'x'*
Enclosure Width	762 mm (30 in)
Enclosure Depth	762 mm (30 in)
Electrode Gap	152 mm (6 in)
Bolted Fault Current	10 kA
Working Distance	0.914 m (36 in)



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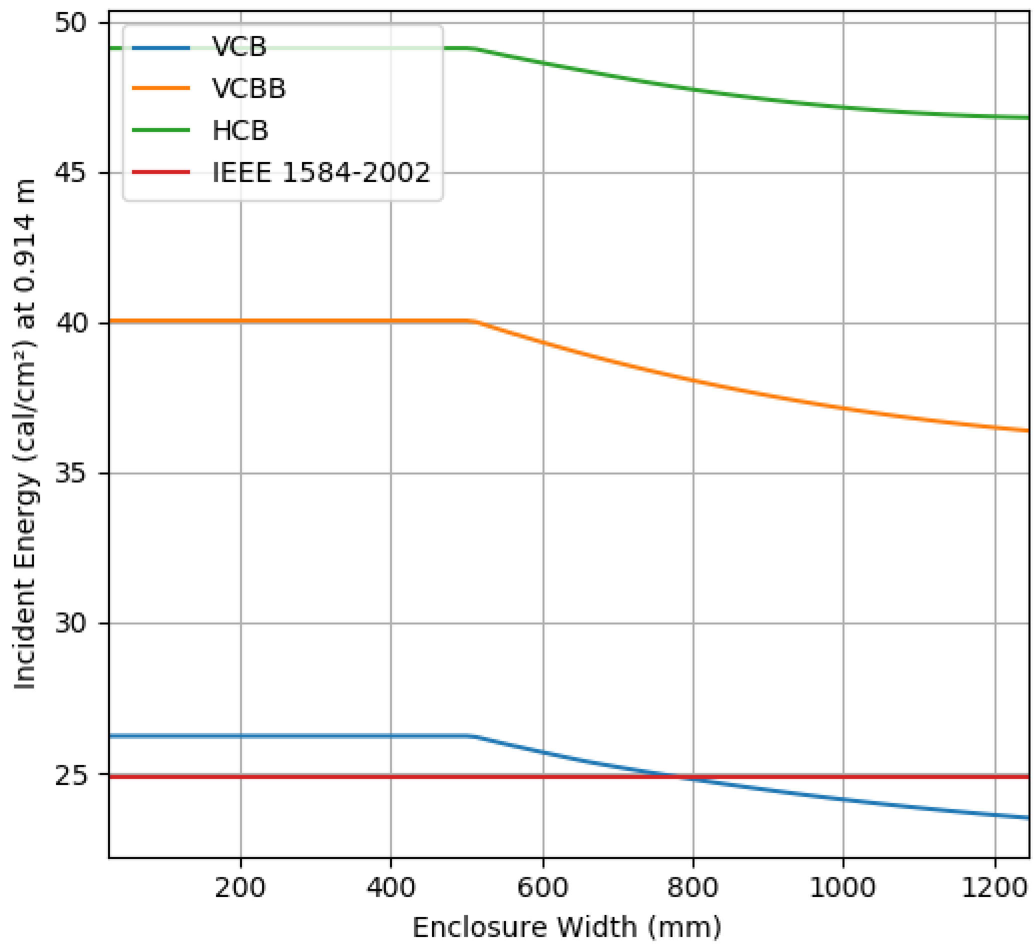

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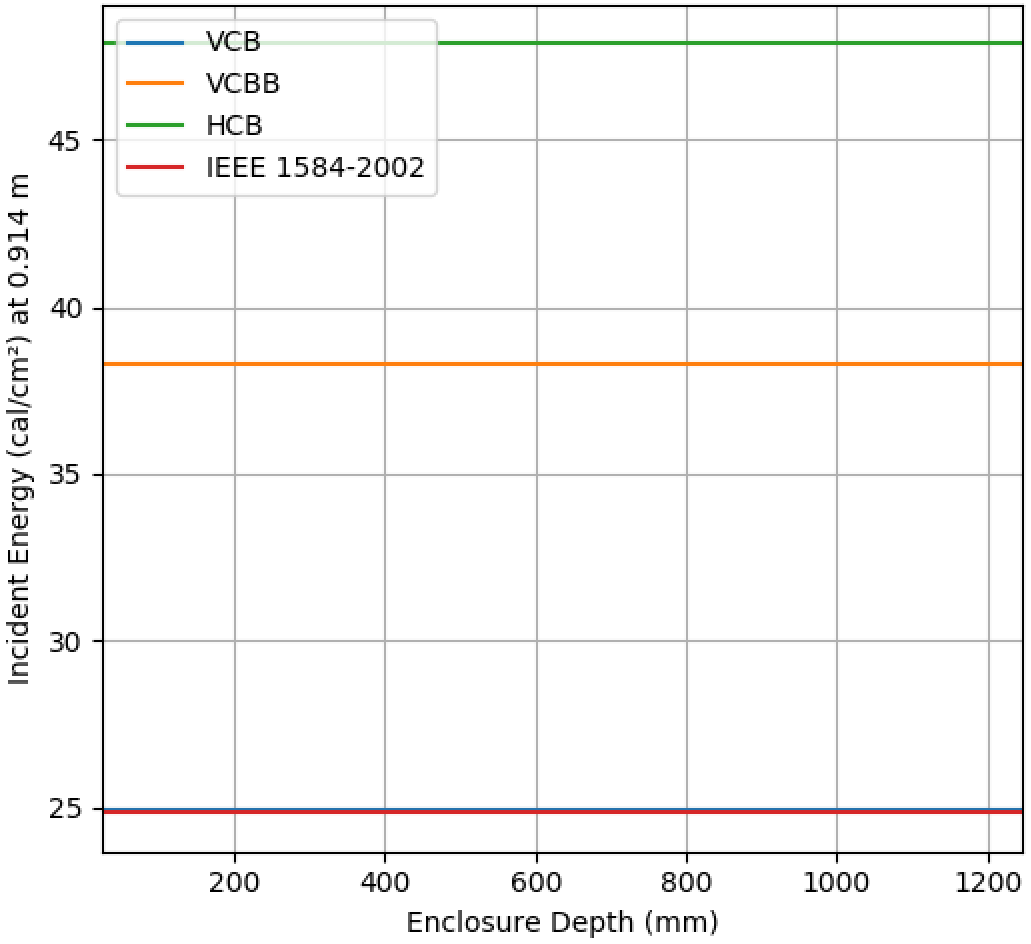

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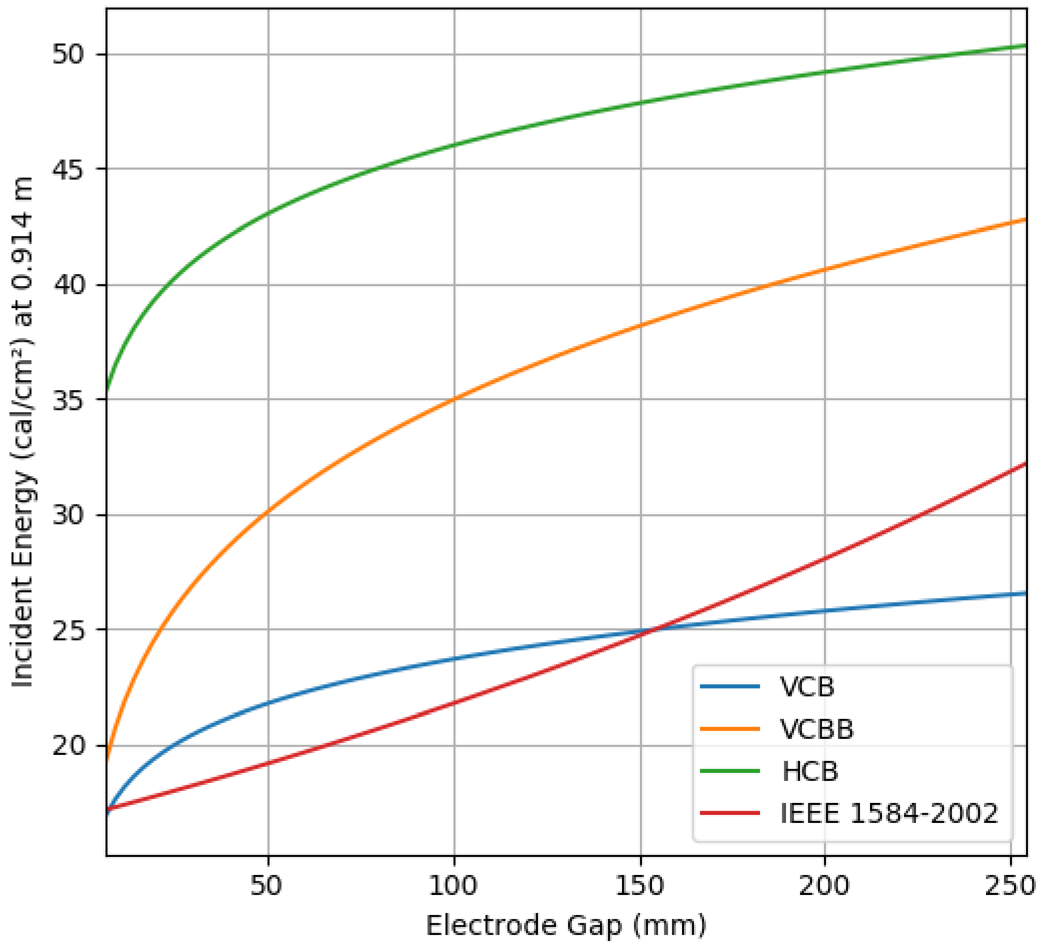

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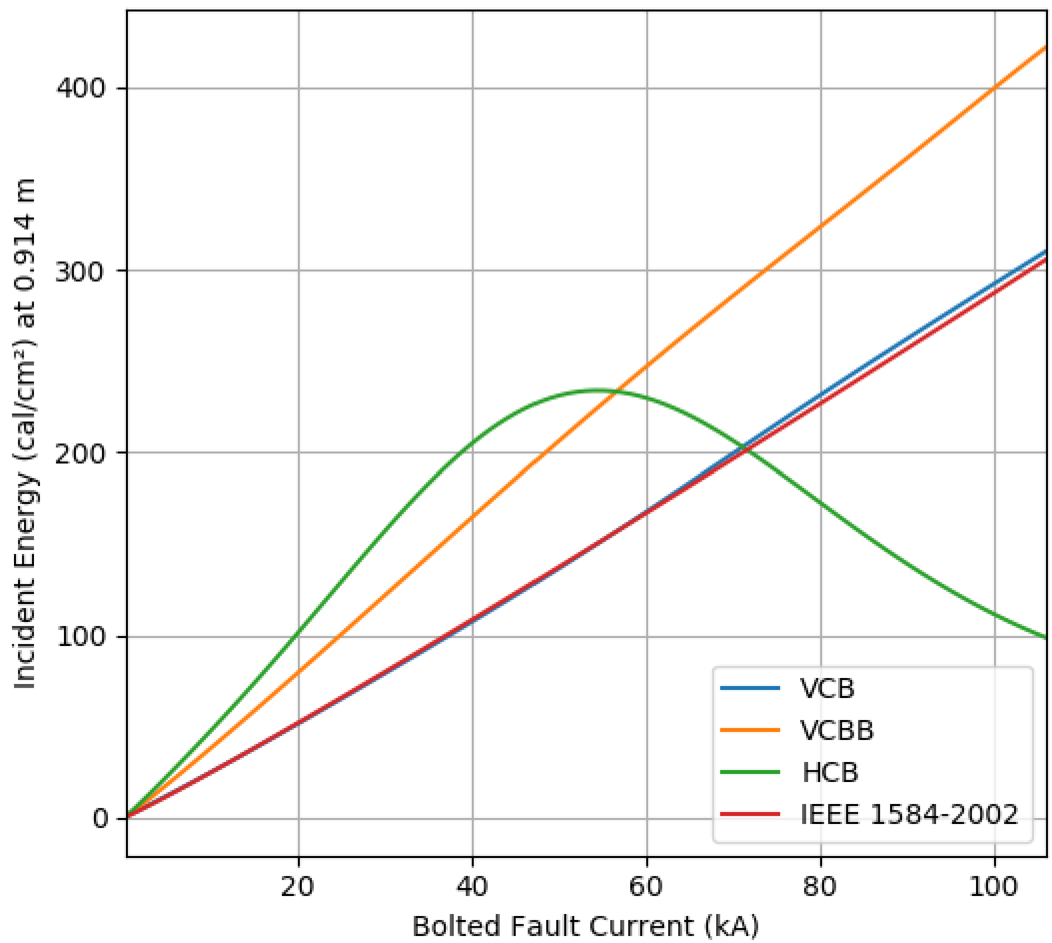

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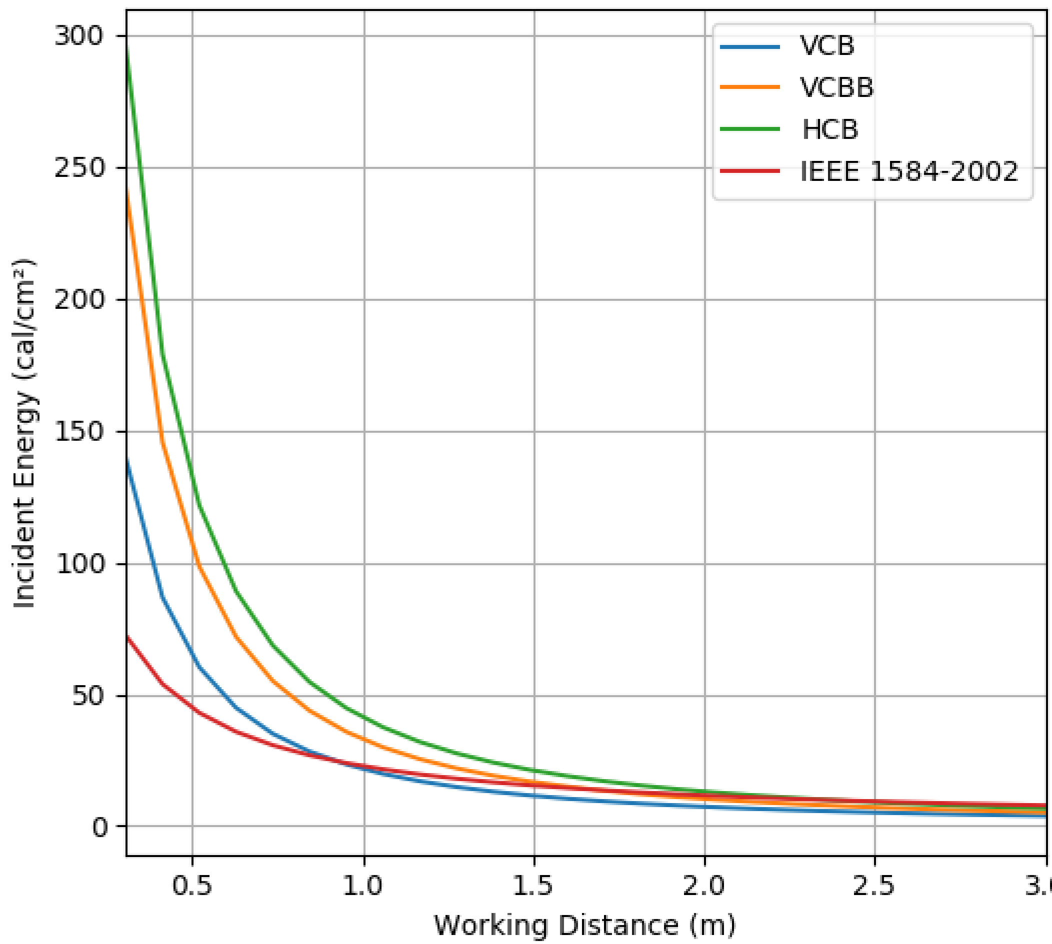

Example #2: 600 V Switchgear

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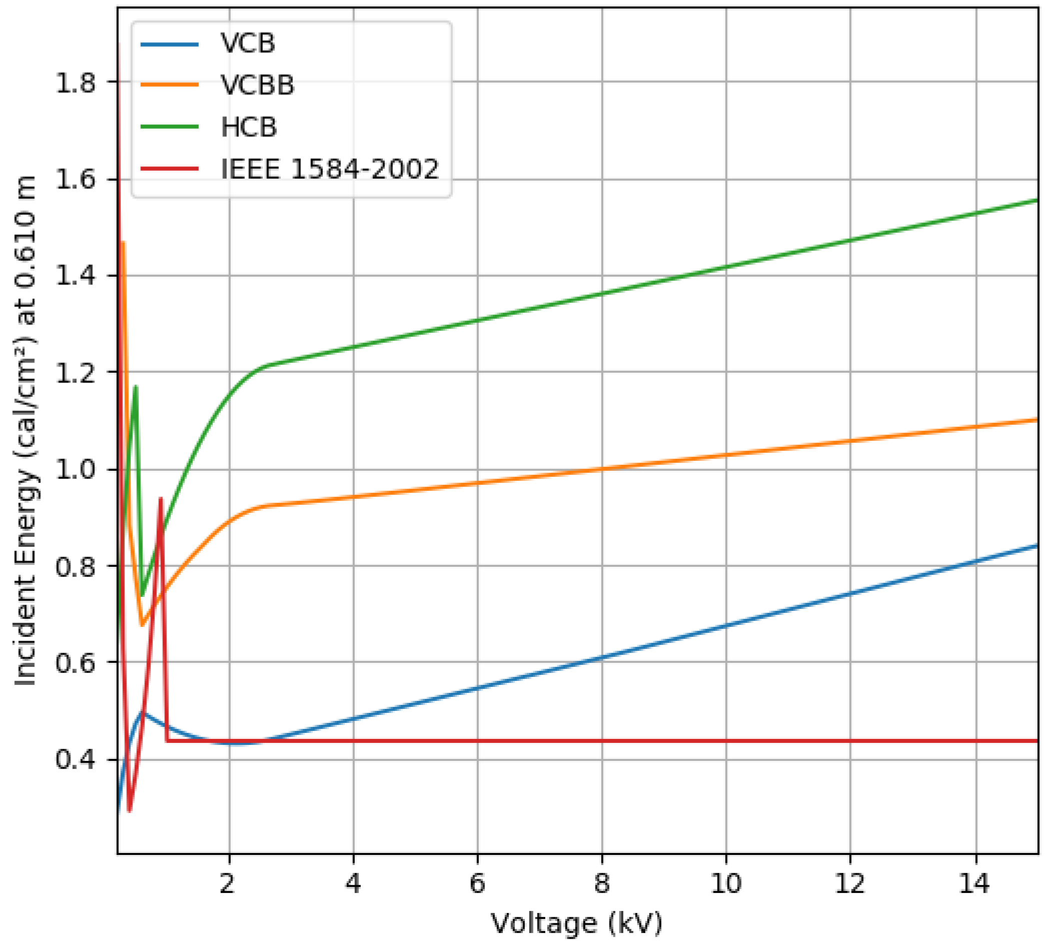
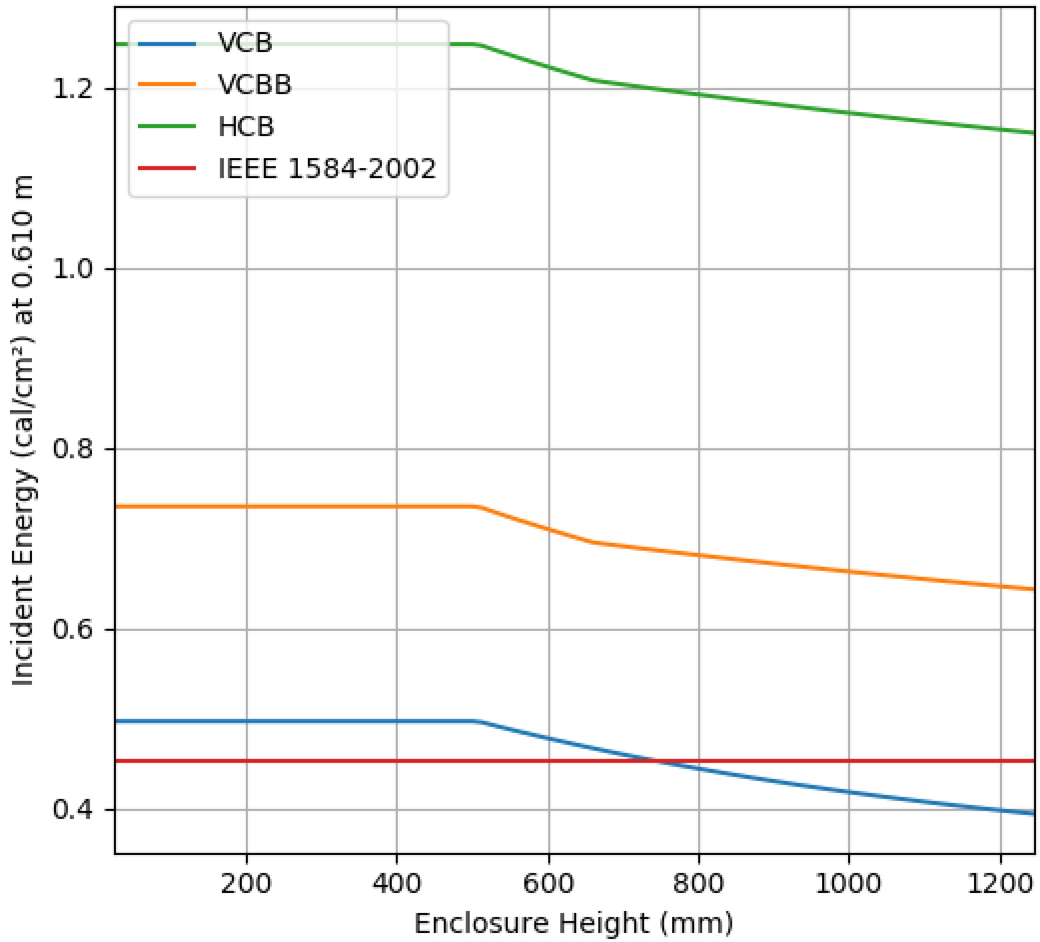
Parameter	Value
Upstream Protection	Ferraz Shawmut AJT 600 A
Voltage	***Independent Variable 'x'***
Enclosure Height	508 mm (20 in)
Enclosure Width	508 mm (20 in)
Enclosure Depth	508 mm (20 in)
Electrode Gap	32 mm (1 ¼ in)
Bolted Fault Current	30 kA
Working Distance	0.610 m (24 in)



Example #2: 600 V Switchgear

Parameter	Value
Upstream Protection	Ferraz Shawmut AJT 600 A
Voltage	600 V
Enclosure Height	***Independent Variable 'x'***
Enclosure Width	508 mm (20 in)
Enclosure Depth	508 mm (20 in)
Electrode Gap	32 mm (1 ¼ in)
Bolted Fault Current	30 kA
Working Distance	0.610 m (24 in)



Example #2: 600 V Switchgear

Parameter	Value
Upstream Protection	Ferraz Shawmut AJT 600 A
Voltage	600 V
Enclosure Height	508 mm (20 in)
Enclosure Width	***Independent Variable ‘x’***
Enclosure Depth	508 mm (20 in)
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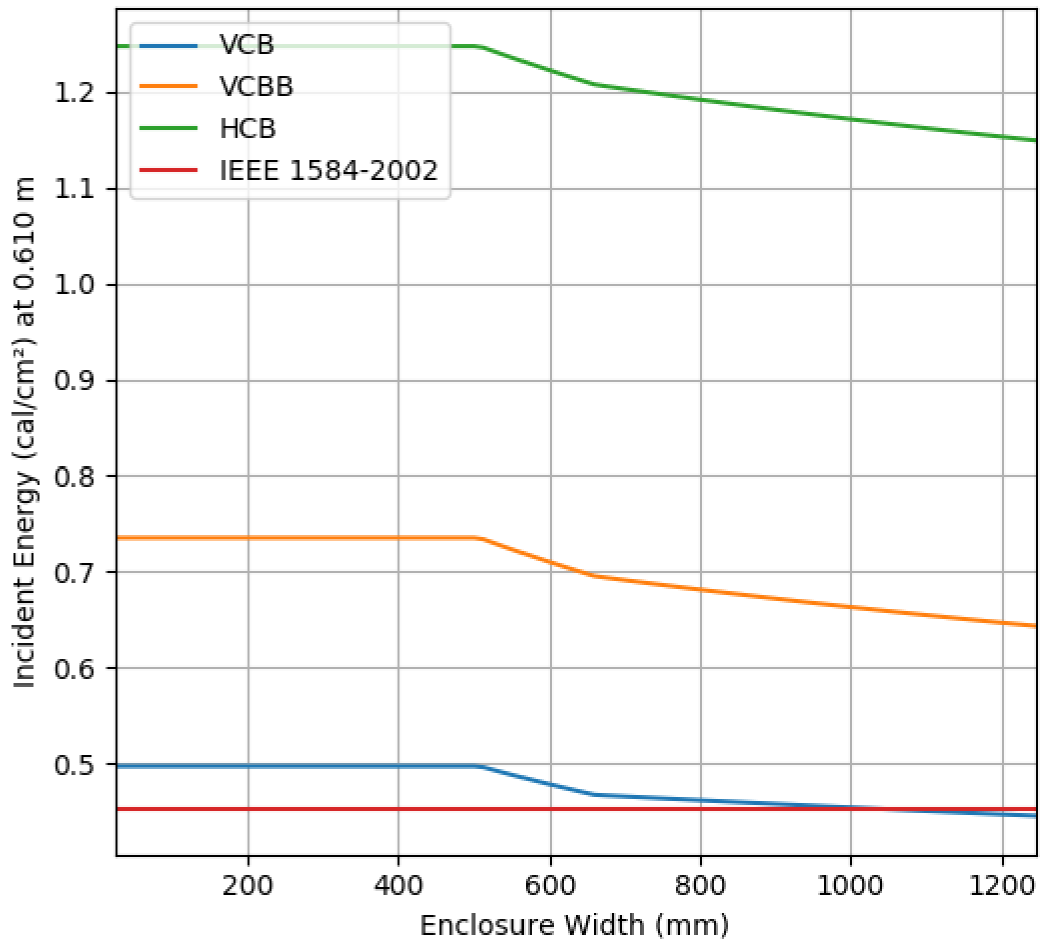

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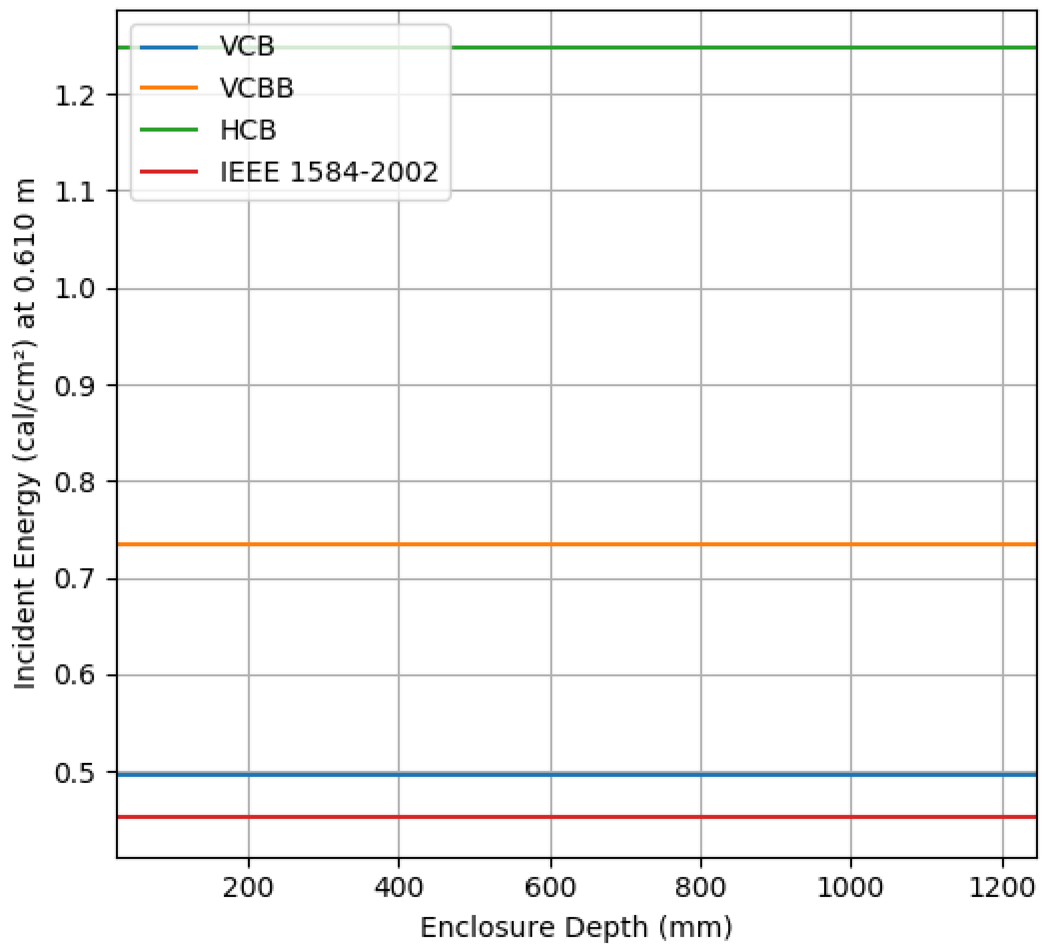

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Upstream Protection	Ferraz Shawmut AJT 600 A
Voltage	600 V
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Electrode Gap	***Independent Variable 'x'***
Bolted Fault Current	30 kA
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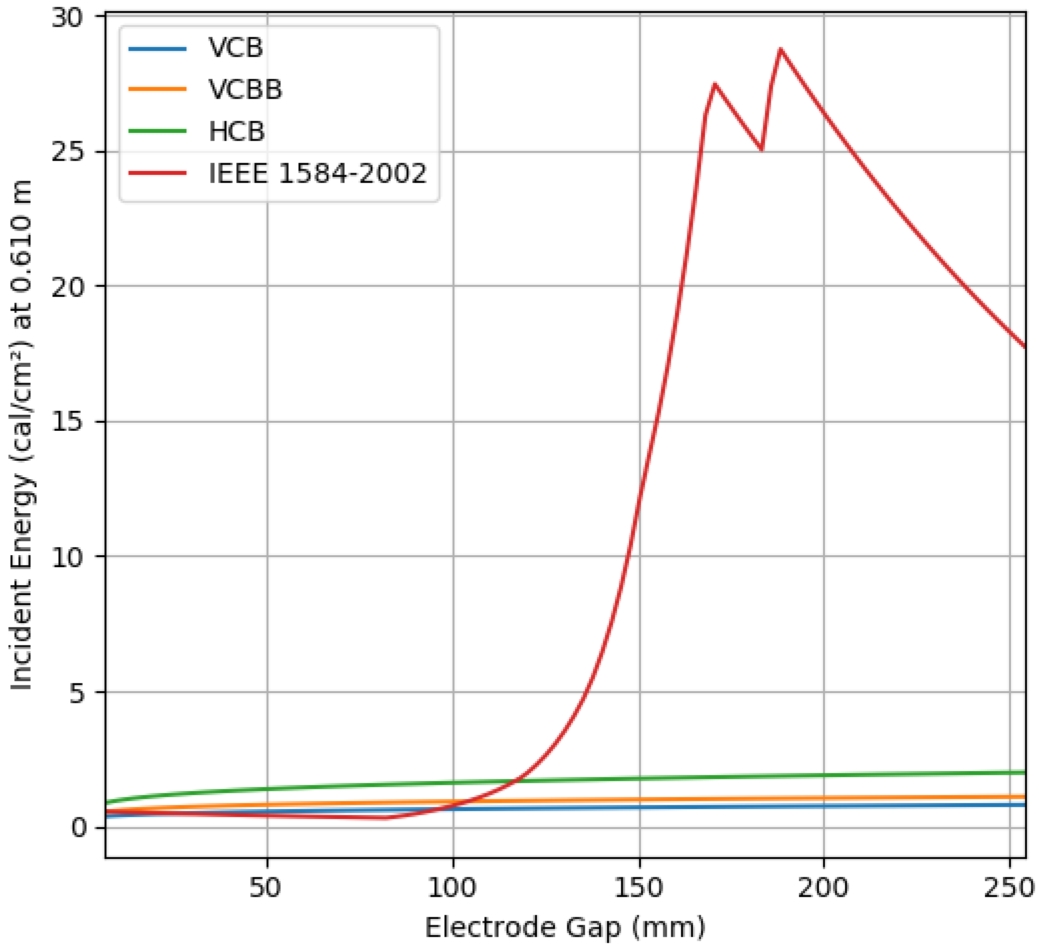

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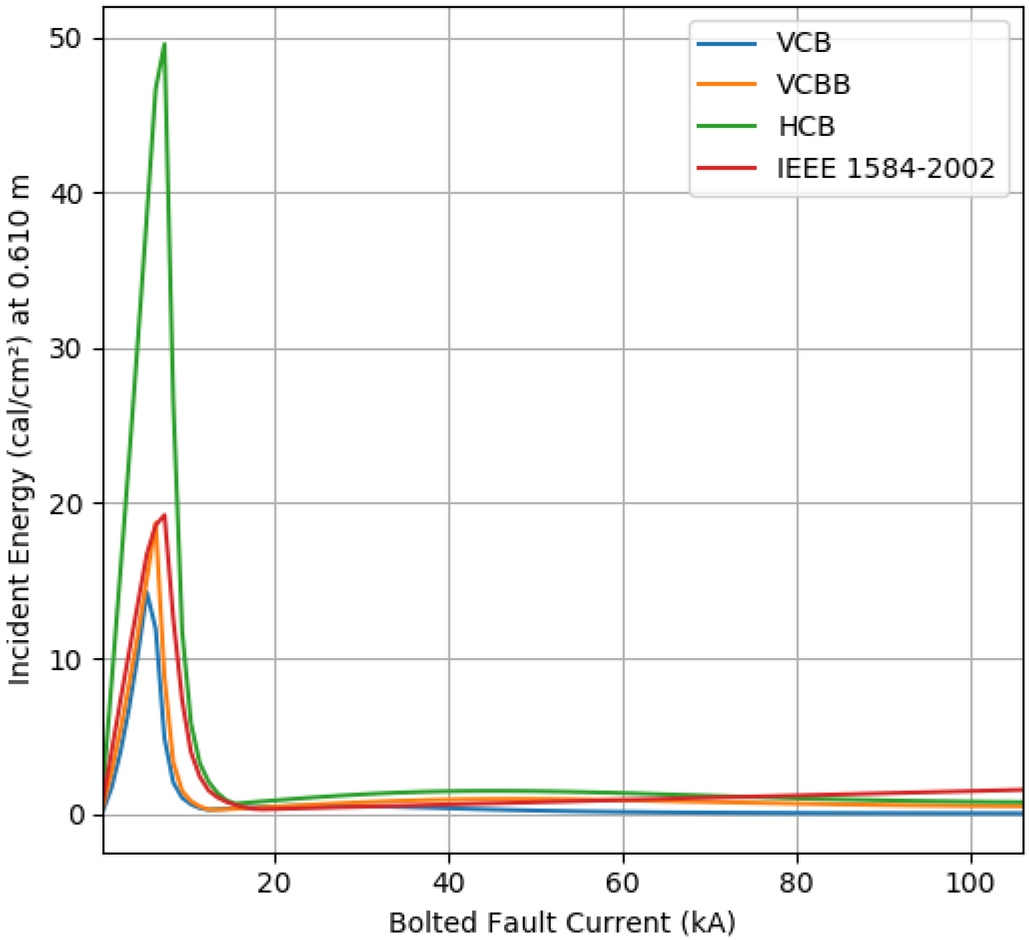
Working Distance	0.610 m (24 in)



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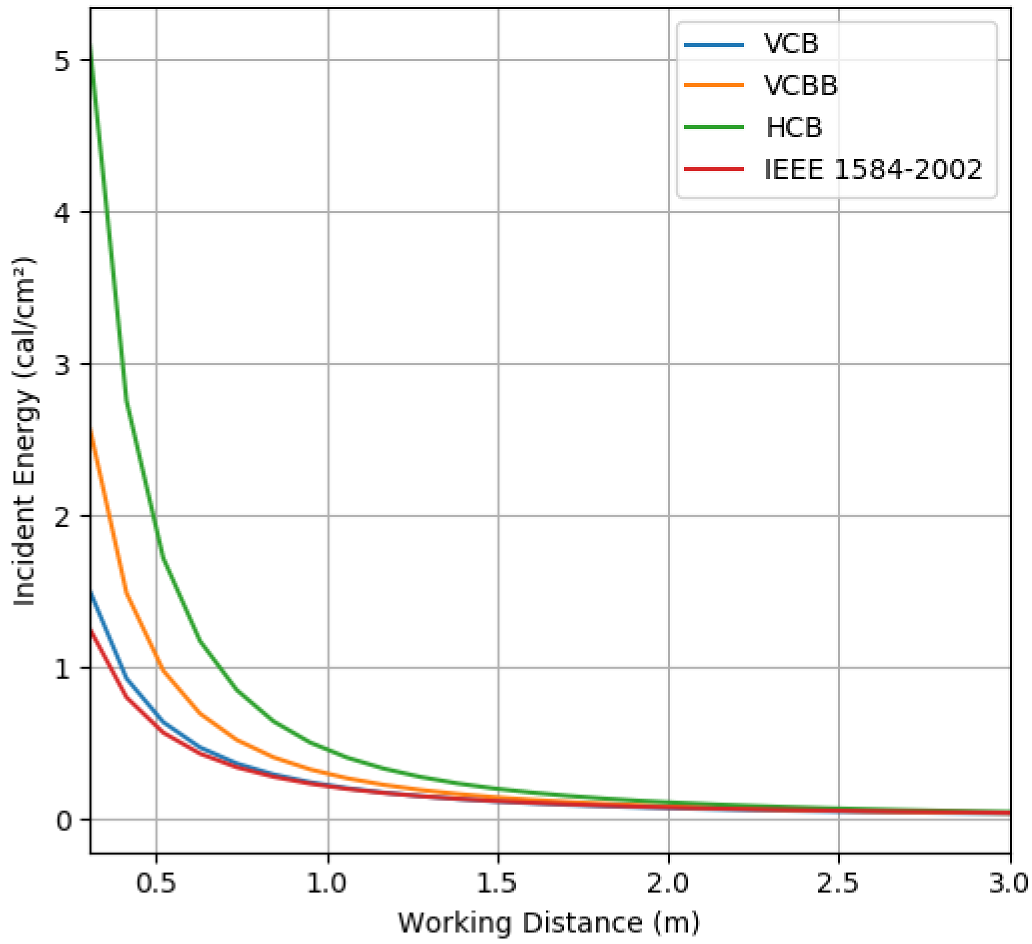
Working Distance	***Independent Variable 'x'***



Example #3: 208 V Panel (Shallow)

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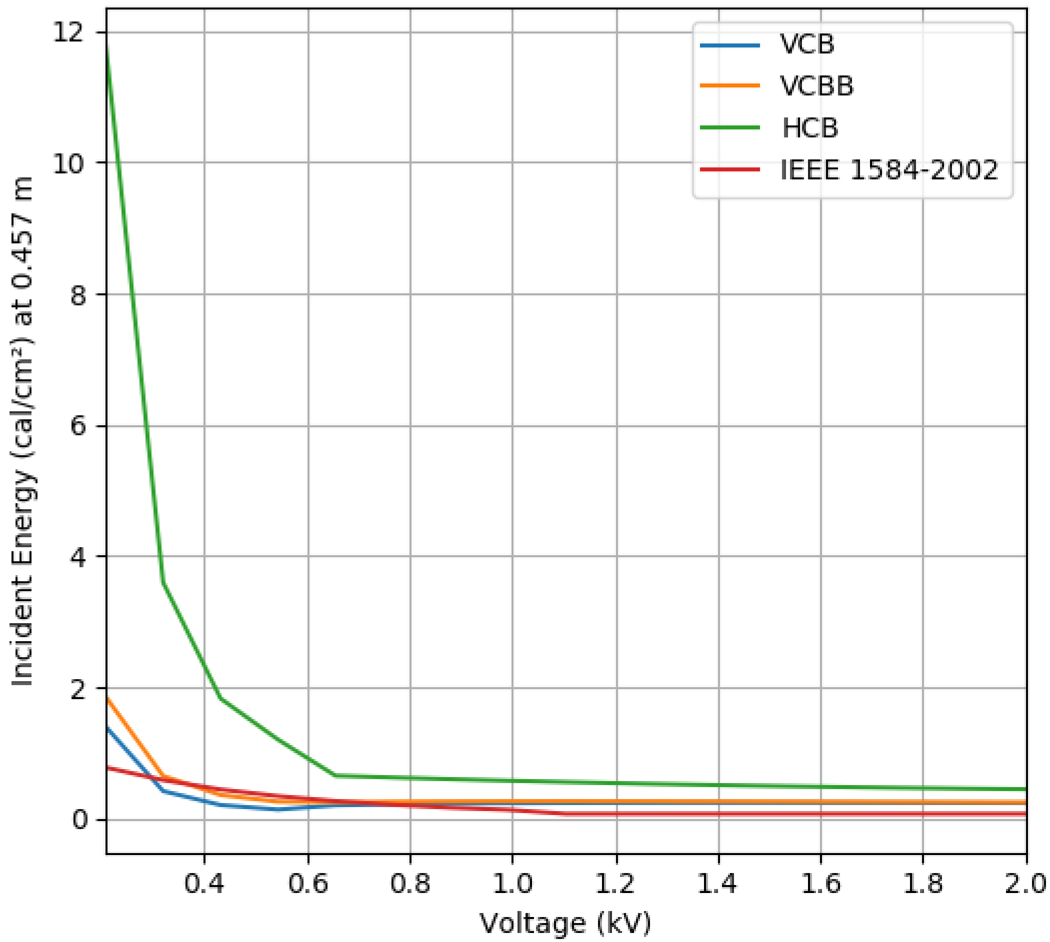
Parameter	Value
Upstream Protection	Mersen TRS-R 100 A
Voltage	***Independent Variable 'x'***
Enclosure Height	355.6 mm (14 in)
Enclosure Width	304.8 mm (12 in)
Enclosure Depth	203.2 mm (8 in)
Electrode Gap	25 mm (1 in)
Bolted Fault Current	2.5 kA
Working Distance	0.457 m (18 in)



Example #3: 208 V Panel (Shallow)

Parameter	Value
Upstream Protection	Mersen TRS-R 100 A
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Enclosure Height	***Independent Variable 'x'***
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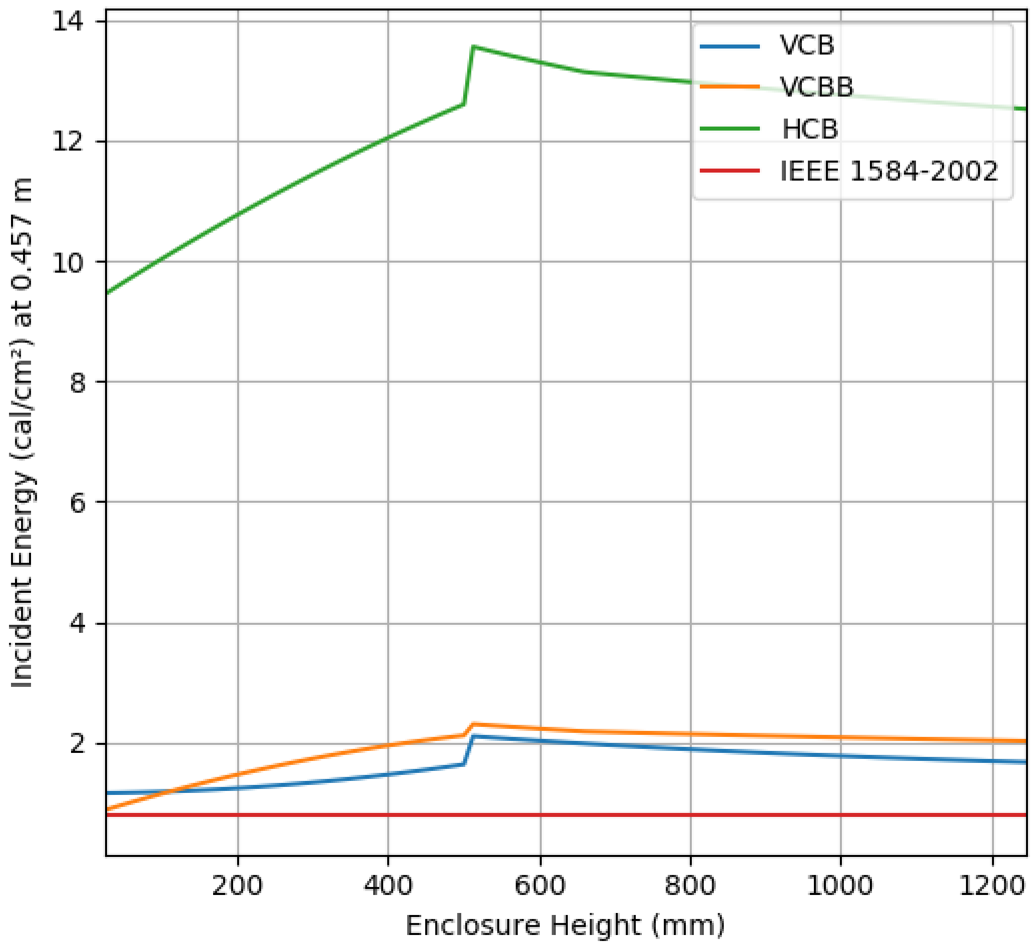

Example #3: 208 V Panel (Shallow)

Parameter	Value
Upstream Protection	Mersen TRS-R 100 A
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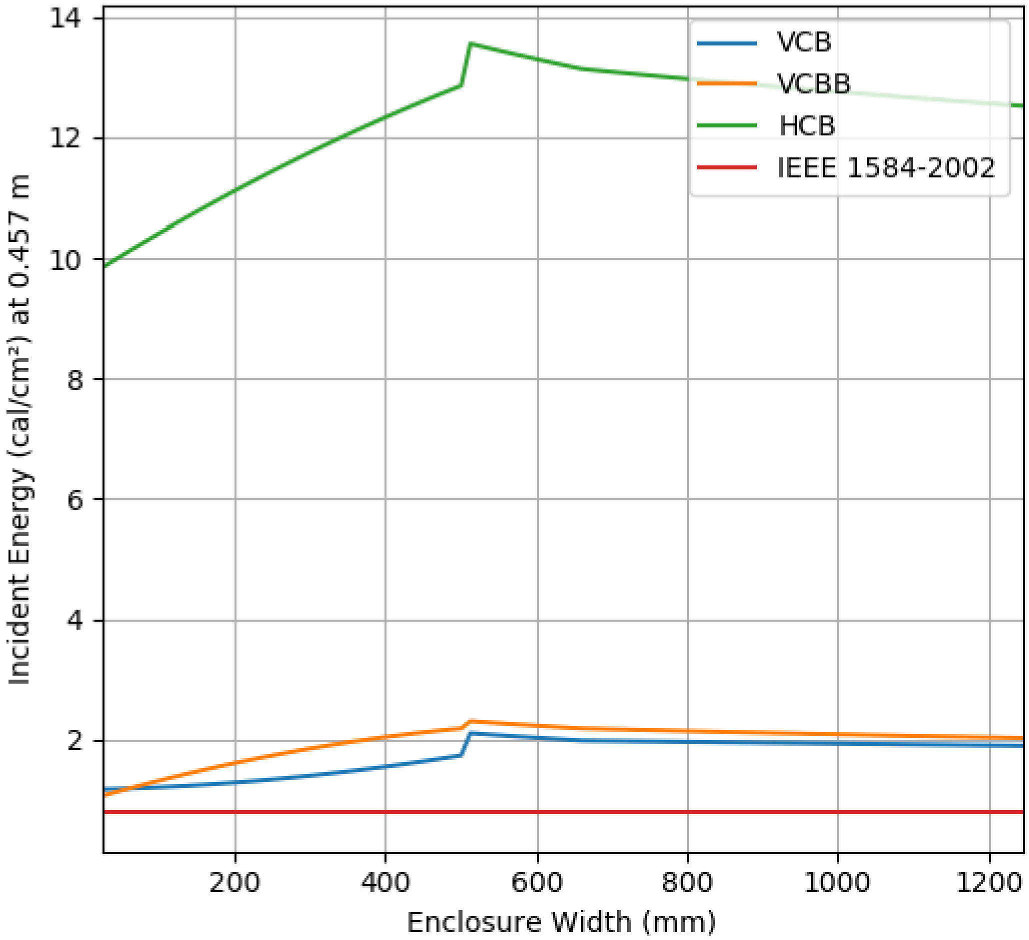

Example #3: 208 V Panel (Shallow)

Parameter	Value
Upstream Protection	Mersen TRS-R 100 A
Voltage	208 V
Enclosure Height	355.6 mm (14 in)
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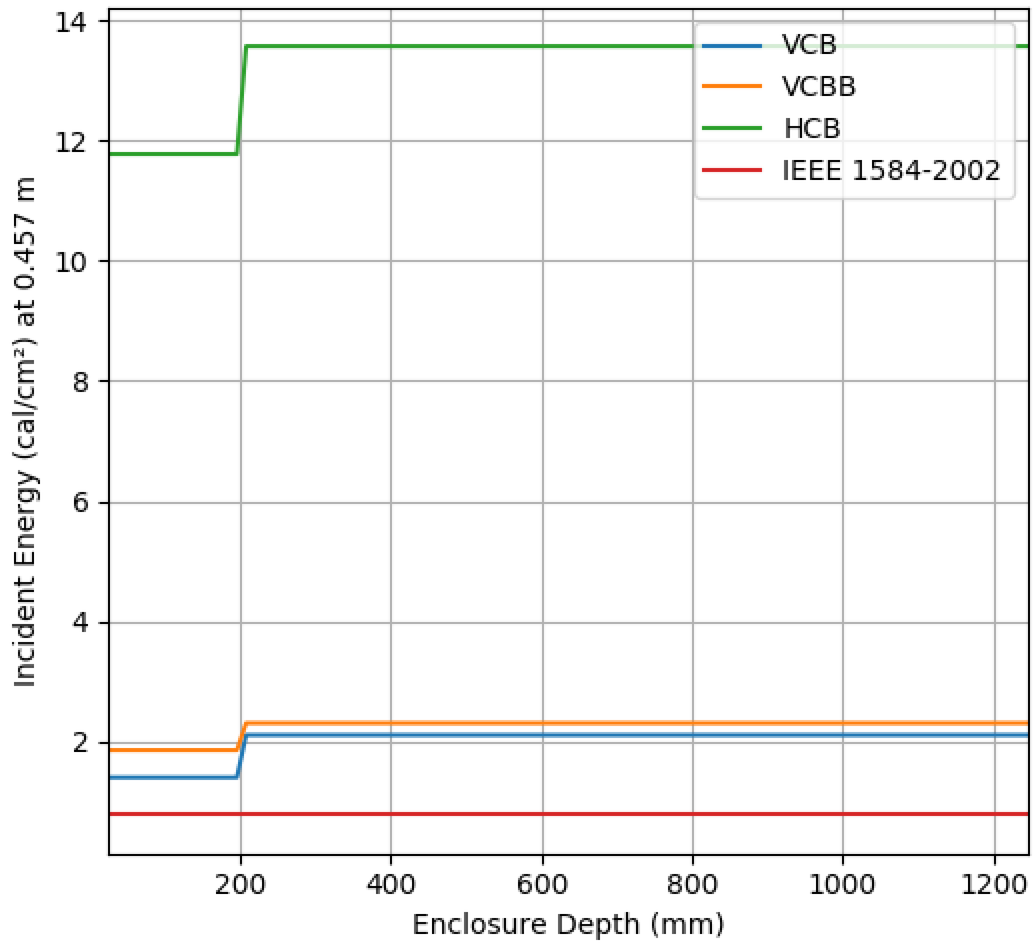

Example #3: 208 V Panel (Shallow)

Parameter	Value
Upstream Protection	Mersen TRS-R 100 A
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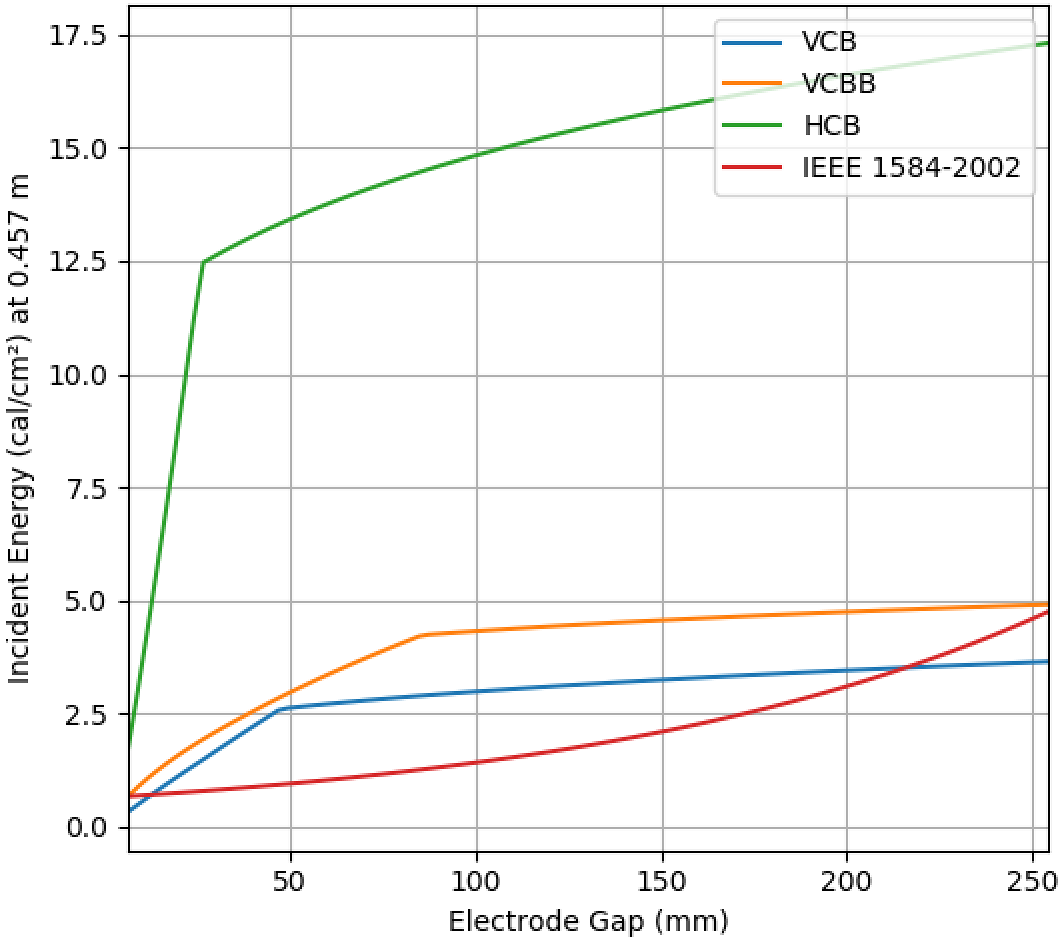
Enclosure Height	355.6 mm (14 in)
Enclosure Width	304.8 mm (12 in)
Enclosure Depth	203.2 mm (8 in)
Electrode Gap	***Independent Variable 'x'***
Bolted Fault Current	2.5 kA
Working Distance	0.457 m (18 in)



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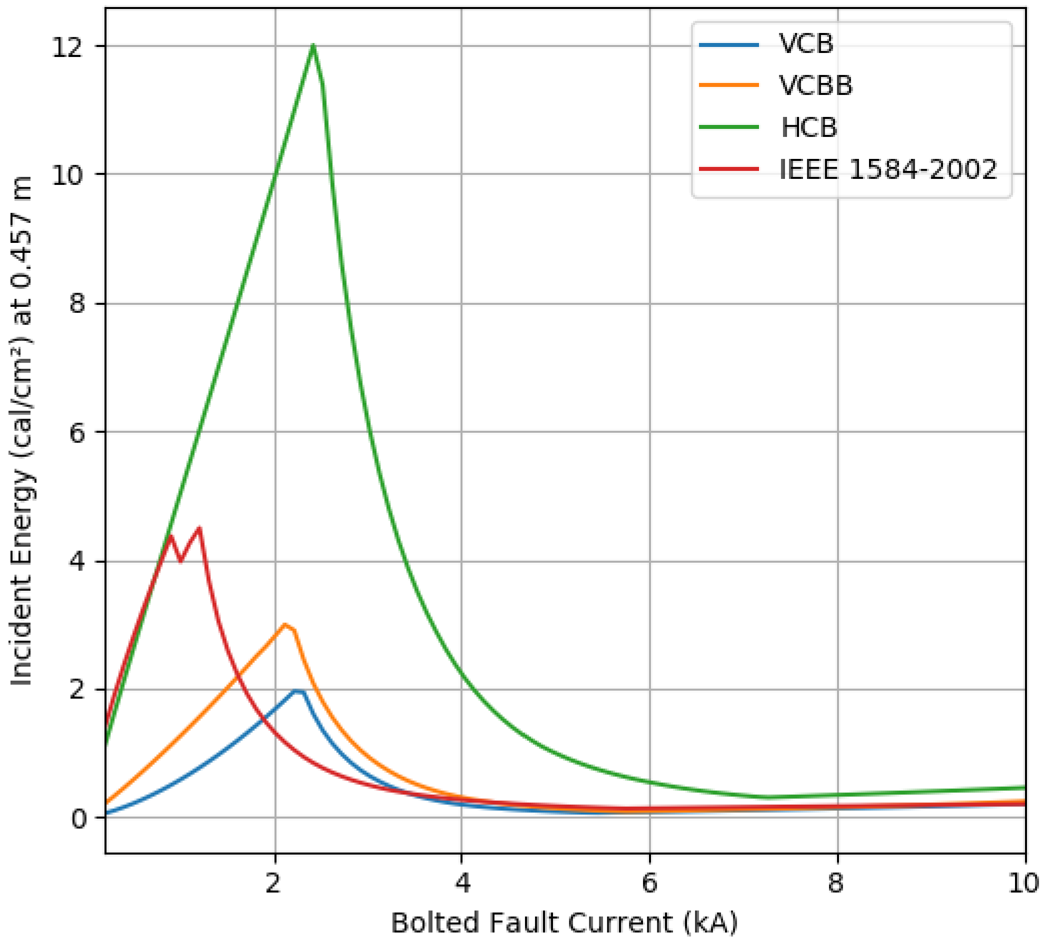
Bolted Fault Current	***Independent Variable 'x'***
Working Distance	0.457 m (18 in)



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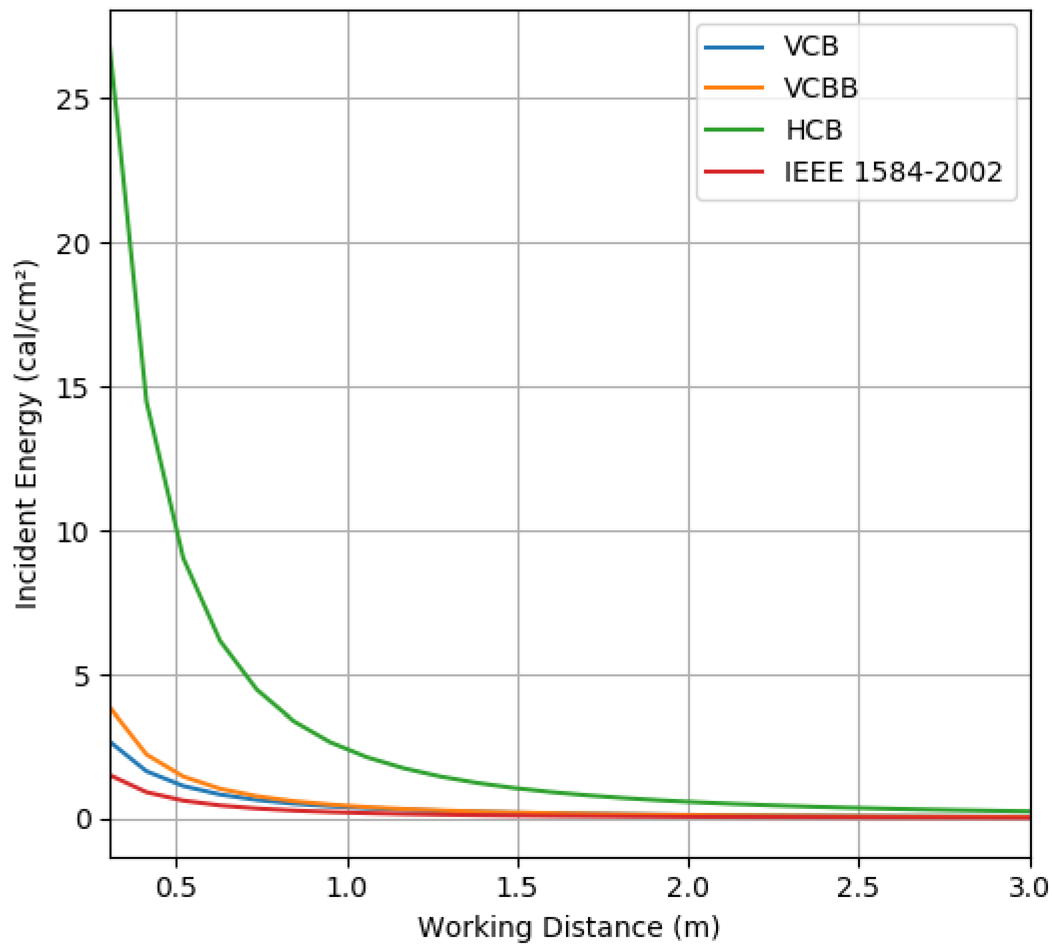
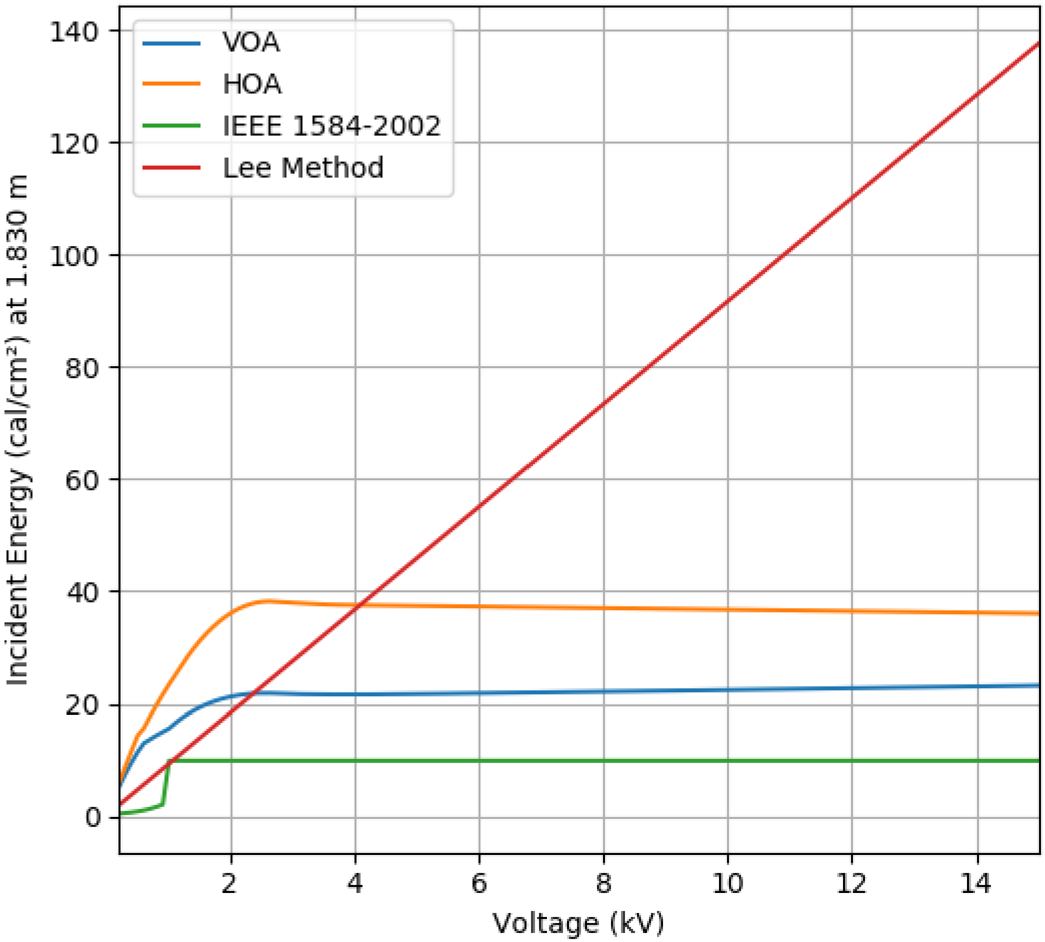
Enclosure Depth	203.2 mm (8 in)
Electrode Gap	25 mm (1 in)
Bolted Fault Current	2.5 kA
Working Distance	*Independent Variable 'x'*



Example #4: 15 kV Breaker (Outdoor)

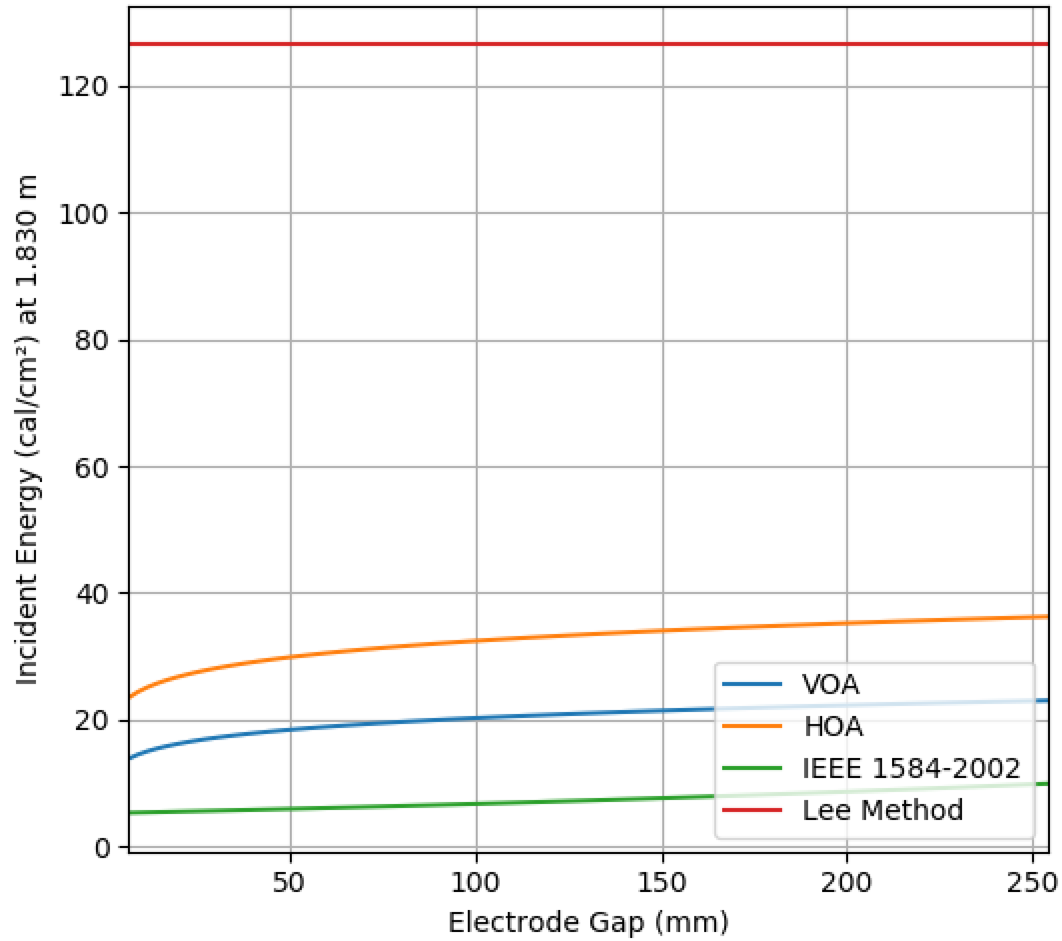
Example #4: 15 kV Breaker (Outdoor)

Parameter	Value
Upstream Protection	2 s rule applied
Voltage	***Independent Variable 'x'***
Enclosure Height	N/A
Enclosure Width	N/A
Enclosure Depth	N/A
Electrode Gap	254 mm (10 in)
Bolted Fault Current	30 kA
Working Distance	1.83 m (6 ft)



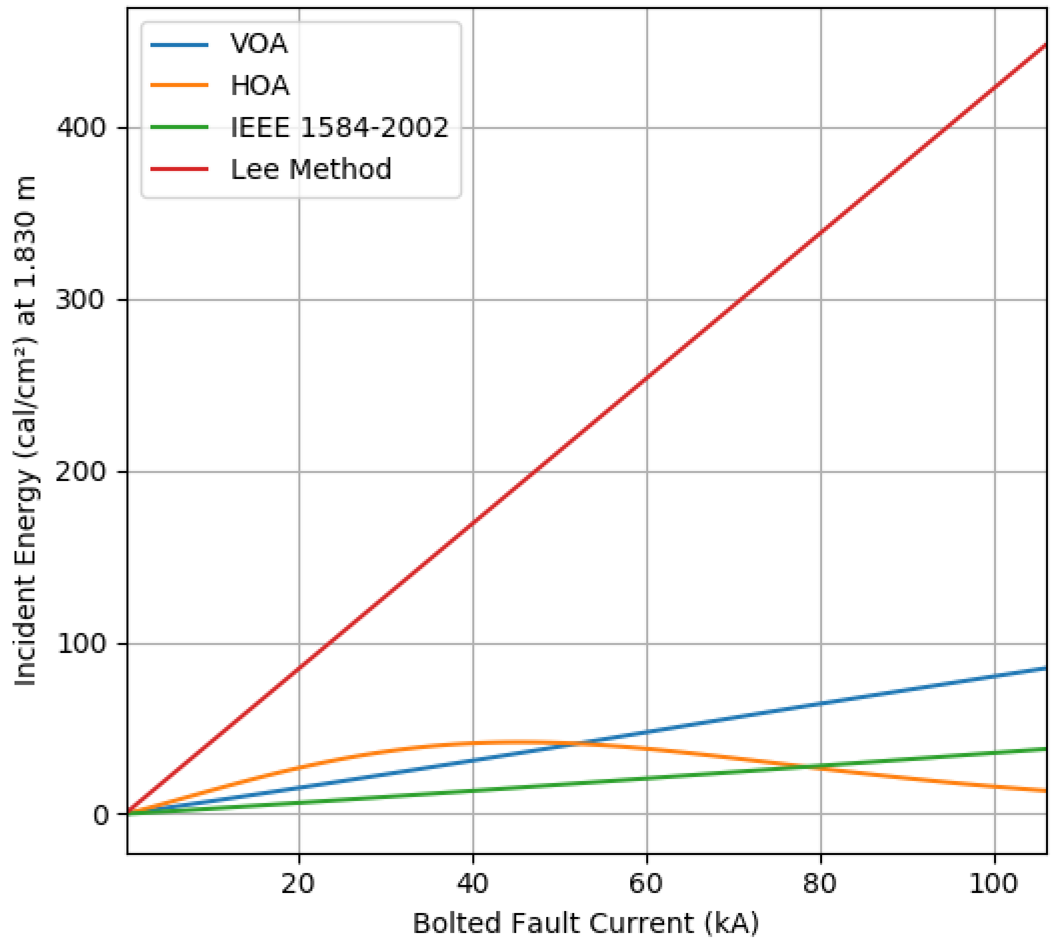
Example #4: 15 kV Breaker (Outdoor)

Parameter	Value
Upstream Protection	2 s rule applied
Voltage	13.8 kV
Enclosure Height	N/A
Enclosure Width	N/A
Enclosure Depth	N/A
Electrode Gap	***Independent Variable ‘x’***
Bolted Fault Current	30 kA
Working Distance	1.83 m (6 ft)



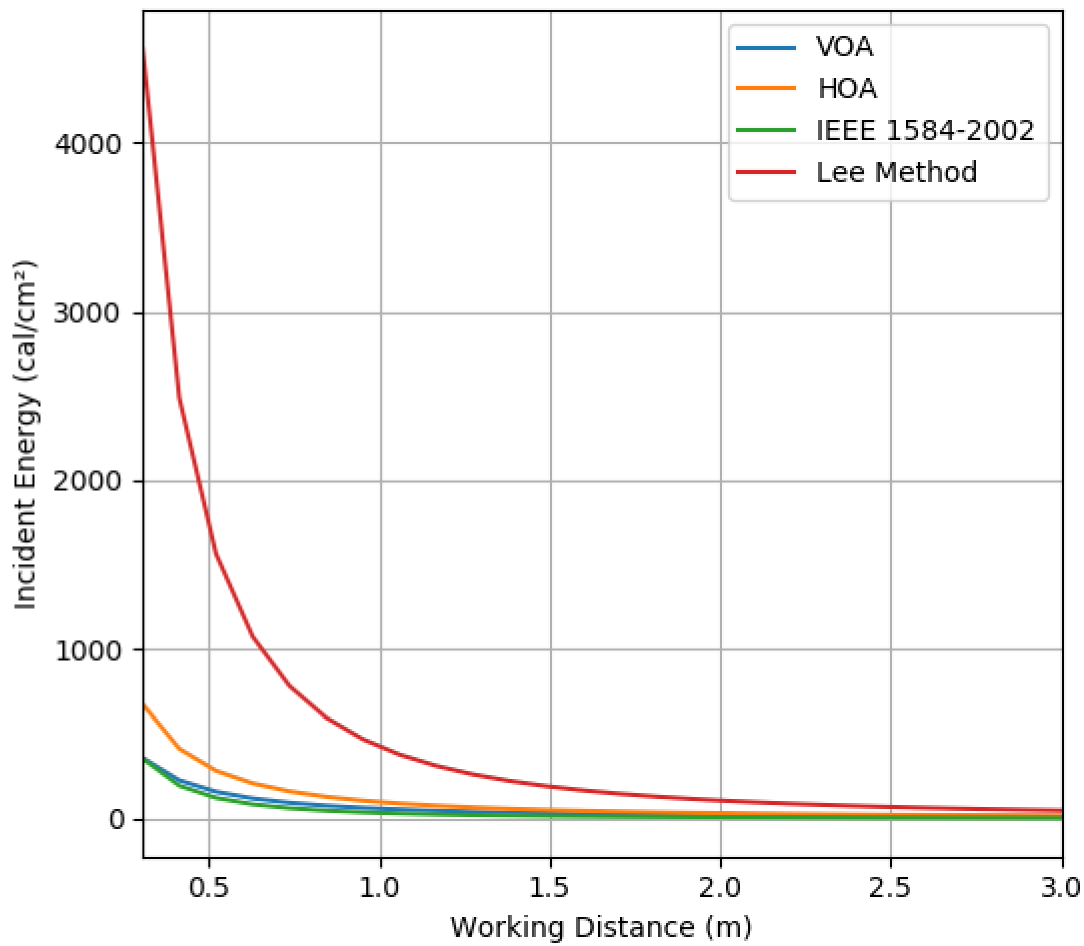
Example #4: 15 kV Breaker (Outdoor)

Parameter	Value
Upstream Protection	2 s rule applied
Voltage	13.8 kV
Enclosure Height	N/A
Enclosure Width	N/A
Enclosure Depth	N/A
Electrode Gap	254 mm (10 in)
Bolted Fault Current	***Independent Variable 'x'***
Working Distance	1.83 m (6 ft)



Example #4: 15 kV Breaker (Outdoor)

Parameter	Value
Upstream Protection	2 s rule applied
Voltage	13.8 kV
Enclosure Height	N/A
Enclosure Width	N/A
Enclosure Depth	N/A
Electrode Gap	254 mm (10 in)
Bolted Fault Current	30 kA
Working Distance	***Independent Variable 'x'***



06 Conclusion & Recommendations

Conclusions & Recommendations

- The calculation method is very different between the 2002 and 2018 versions
- It is difficult to predict the impact of the update on the incident energy at first glance, since the equations and relationships between inputs and results are very complex
- Electrode configuration & enclosure size are now parameters in the equations
- Data collection must be performed thoroughly in order to have all the required parameters
- The 125 kVA transformer exception has been replaced with a 2 kA short-circuit current exception
- The 2 seconds rule still applies
- Results can be very different with the 2018 version compared to the 2002 version, so arc flash studies done with the 2002 version should be updated to ensure the safety of workers

Questions?
(submit them through the question box)

Simon Giard-Leroux, P.Eng.

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