

Arc Flash Calculation (IEEE 1584 - 2018)

Introduction

An arc flash is a violent eruption of heat and light caused by an electrical explosion. Arc flashes can seriously injure electricians, with fierce burns posing a significant risk to life. Other hazards include shrapnel and a pressure wave (often called an arc blast).



The electrical explosion results from an unwanted electrical connection through the air, perhaps to ground or another conductor.

To protect from the effects of an arc flash, electricians working on high-power equipment must wear protective clothing when within the hazard zone, and be aware of how far that zone stretches.

This application determines the minimum safe working distance from an arc flash, following the empirical methodology presented in IEEE 1584 - 2018. Specifically, the application calculates the

- intermediate average arcing current
- arcing current variation factor
- box size variation factor
- incident energy - amount of thermal energy on a surface at a specific distance (2nd degree burns are caused by an incident energy of 5 J/cm²)
- arc flash boundary - minimum distance from an arc flash to prevent 2nd degree burns

The system studied is a high voltage 15 kV switchgear. The electrode configuration can be switched between VCB (vertical conductors in a metal box, VCBB (vertical conductors terminated into a metal box's insulation barrier), HCB (horizontal conductors in a metal box), VOA (vertical conductors in open air) and HOA (horizontal conductors in open air).

Parameters

Open-circuit voltage/system voltage	$V_{oc} := 13.8 \text{ kV}$
Maximum short circuit current/bolted fault current for three phase faults	$I_{bf} := 18.241 \text{ kA}$
Gap between the conductors or electrodes	$G := 152.0 \text{ mm}$
Working distance	$Dis := 914.0 \text{ mm}$
Enclosure height	$Height := 1244.6 \text{ mm}$
Enclosure height	$Width := 1244.6 \text{ mm}$
Enclosure depth	$Depth := 1143.0 \text{ mm}$
Arc duration	$T := 191.0 \text{ ms}$
Configuration ("VCB", "VCBB", "HCB", "VOA" or "HOA")	$electrode_config := \text{"HCB"}$

Constants from IEEE 1584-2018

Intermediate Average Arcing Current

```
IE_coeffs := Matrix(
[ ["EC / Voc ", 0., "k1 ", "k2 ", "k3 ", "k4 ", "k5 ", "k6 ", "k7 ", "k8 ", "k9 ", "k10"],
["VCB", "600 V", -0.04287, 1.035, -0.083, 0., 0., -4.783·10-9, 1.962·10-6, -0.000229, 0.003141, 1.092],
["VCB", "2700 V", 0.0065, 1.001, -0.024, -1.557E-12, 4.556·10-10, -4.186·10-8, 8.346·10-7, 0.00005482, -0.003191, 0.9729],
["VCB", "14300 V", 0.005795, 1.015, -0.011, -1.557E-12, 4.556·10-10, -4.186·10-8, 8.346·10-7, 0.00005482, -0.003191, 0.9729],
["VCBB", "600 V", -0.017432, 0.98, -0.05, 0., 0., -5.767E-09, 2.524·10-6, -0.00034, 0.01187, 1.013],
["VCBB", "2700 V", 0.002823, 0.995, -0.0125, 0., -9.204E-11, 2.901·10-8, -3.262·10-6, 0.0001569, -0.004003, 0.9825],
["VCBB", "14300 V", 0.014827, 1.01, -0.01, 0., -9.204E-11, 2.901·10-8, -3.262·10-6, 0.0001569, -0.004003, 0.9825],
["HCB", "600 V", 0.054922, 0.988, -0.11, 0., 0., -5.382E-09, 2.316·10-6, -0.000302, 0.0091, 0.9725],
["HCB", "2700 V", 0.001011, 1.003, -0.0249, 0., 0., 4.859·10-10, -1.814·10-7, -9.128·10-6, -0.0007, 0.9881],
["HCB", "14300 V", 0.008693, 0.999, -0.02, 0., 0., -5.043·10-11, 2.233·10-8, -3.046·10-6, 0.000116, -0.001145, 0.9839],
["VOA", "600 V", 0.043785, 1.04, -0.18, 0., 0., -4.783·10-9, 1.962·10-6, -0.000229, 0.003141, 1.092],
["VOA", "2700 V", -0.02395, 1.006, -0.0188, -1.557·10-12, 4.556·10-10, -4.186·10-8, 8.346·10-7, 0.00005482, -0.003191, 0.972],
["VOA", "14300 V", 0.005371, 1.0102, -0.029, -1.557·10-12, 4.556·10-10, -4.186·10-8, 8.346·10-7, 0.00005482, -0.003191, 0.972],
["HOA", "600 V", 0.111147, 1.008, -0.24, 0., 0., -3.895·10-9, 1.641·10-6, -0.000197, 0.002615, 1.1],
["HOA", "2700 V", 0.000435, 1.006, -0.038, 0., 0., 7.859·10-10, -1.914·10-7, -9.128·10-6, -0.0007, 0.9981],
["HOA", "14300 V", 0.000904, 0.999, -0.02, 0., 0., 7.859·10-10, -1.914·10-7, -9.128·10-6, -0.0007, 0.9981]])
```

Arcing Current Variation Factor

```
VarC_coeffs := Matrix(
[ ["E.C.", "k1 ", "k2 ", "k3 ", "k4 ", "k5 ", "k6 ", "k7 "],
["VCB ", 0., -0.0000014269, 0.000083137, -0.0019382, 0.022366, -0.12645, 0.30226],
["VCBB ", 1.138 × 10-6, -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 ", 9.5606 × 10-7, -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]])
```

Box Size Correction Factor (Table 7)

```
typical_enclosure_coeffs := Matrix(
[ ["E.C", "b1", "b2", "b3"],
["VCB", -0.000302, 0.03441, 0.4325],
["VCBB", -0.0002976, 0.032, 0.479],
["HCB", -0.0001923, 0.01935, 0.6899]])
```

```
shallow_enclosure_coeffs := Matrix(
[ ["E.C", "b1", "b2", "b3"],
["VCB", 0.002222, -0.02556, 0.6222],
["VCBB", -0.002778, 0.1194, -0.2778],
["HCB", -0.0005556, 0.03722, 0.4778]])
```

Incident Energy

```
incident_energy_600_coeffs := Matrix(  
  [ [ "600 V", "k1", "k2", "k3", "k4", "k5", "k6", "k7", "k8", "k9", "k10", "k11", "k12", "k13"],  
    [ "VCB", 0.753364, 0.566, 1.752636, 0., 0.,  $-4.783 \times 10^{-9}$ ,  $1.962 \times 10^{-6}$ ,  $-0.000229$ , 0.003141, 1.092, 0.,  $-1.598$ , 0.957 ],  
    [ "VCBB", 3.068459, 0.26,  $-0.098107$ , 0., 0.,  $-5.767 \times 10^{-9}$ ,  $2.524 \times 10^{-6}$ ,  $-0.00034$ , 0.01187, 1.013,  $-0.06$ ,  $-1.809$ , 1.19 ],  
    [ "HCB", 4.073745, 0.344,  $-0.370259$ , 0., 0.,  $-5.382 \times 10^{-9}$ ,  $2.316 \times 10^{-6}$ ,  $-0.000302$ , 0.0091, 0.9725, 0.,  $-2.03$ , 1.036 ],  
    [ "VOA", 0.679294, 0.746, 1.222636, 0., 0.,  $-4.783 \times 10^{-9}$ ,  $1.962 \times 10^{-6}$ ,  $-0.000229$ , 0.003141, 1.092, 0.,  $-1.598$ , 0.997 ],  
    [ "HOA", 3.470417, 0.465,  $-0.261863$ , 0., 0.,  $-3.895 \times 10^{-9}$ ,  $1.641 \times 10^{-6}$ ,  $-0.000197$ , 0.002615, 1.1, 0.,  $-1.99$ , 1.04 ] ] )
```

```
incident_energy_2700_coeffs := Matrix(  
  [ [ "2700 V", "k1", "k2", "k3", "k4", "k5", "k6", "k7", "k8", "k9", "k10", "k11", "k12", "k13"],  
    [ "VCB", 2.40021, 0.165, 0.354202,  $-1.557 \times 10^{-12}$ ,  $4.556 \times 10^{-10}$ ,  $-4.186 \times 10^{-8}$ ,  $8.346 \times 10^{-7}$ , 0.00005482,  $-0.003191$ , 0.9729, 0.,  $-1.569$ , 0.9778 ],  
    [ "VCBB", 3.870592, 0.185,  $-0.736618$ , 0.,  $-9.204 \times 10^{-11}$ ,  $2.901 \times 10^{-8}$ ,  $-3.262 \times 10^{-6}$ , 0.0001569,  $-0.004003$ , 0.9825, 0.,  $-1.742$ , 1.09 ],  
    [ "HCB", 3.486391, 0.177,  $-0.193101$ , 0., 0.,  $4.859 \times 10^{-10}$ ,  $-1.814 \times 10^{-7}$ ,  $-9.128 \times 10^{-6}$ ,  $-0.00070$ , 0.9881, 0.027,  $-1.723$ , 1.055 ],  
    [ "VOA", 3.880724, 0.105,  $-1.906033$ ,  $-1.557 \times 10^{-12}$ ,  $4.556 \times 10^{-10}$ ,  $-4.186 \times 10^{-8}$ ,  $8.346 \times 10^{-7}$ , 0.00005482,  $-0.003191$ , 0.9729, 0.,  $-1.515$ , 1.115 ],  
    [ "HOA", 3.616266, 0.149,  $-0.761561$ , 0., 0.,  $7.859 \times 10^{-10}$ ,  $-1.914 \times 10^{-7}$ ,  $-9.128 \times 10^{-6}$ ,  $-0.00070$ , 0.9981, 0.,  $-1.639$ , 1.078 ] ] )
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```
incident_energy_14300_coeffs := Matrix(  
  [ [ "14300 V", "k1", "k2", "k3", "k4", "k5", "k6", "k7", "k8", "k9", "k10", "k11", "k12", "k13"],  
    [ "VCB", 3.825917, 0.11,  $-0.999749$ ,  $-1.557 \times 10^{-12}$ ,  $4.556 \times 10^{-10}$ ,  $-4.186 \times 10^{-8}$ ,  $8.346 \times 10^{-7}$ , 0.00005482,  $-0.003191$ , 0.9729, 0.,  $-1.568$ , 0.99 ],  
    [ "VCBB", 3.644309, 0.215,  $-0.585522$ , 0.,  $-9.204 \times 10^{-11}$ ,  $2.901 \times 10^{-8}$ ,  $-3.262 \times 10^{-6}$ , 0.0001569,  $-0.004003$ , 0.9825, 0.,  $-1.677$ , 1.06 ],  
    [ "HCB", 3.044516, 0.125, 0.245106, 0.,  $-5.043 \times 10^{-11}$ ,  $2.233 \times 10^{-8}$ ,  $-3.046 \times 10^{-6}$ , 0.000116,  $-0.001145$ , 0.9839, 0.,  $-1.655$ , 1.084 ],  
    [ "VOA", 3.405454, 0.12,  $-0.93245$ ,  $-1.557 \times 10^{-12}$ ,  $4.556 \times 10^{-10}$ ,  $-4.186 \times 10^{-8}$ ,  $8.346 \times 10^{-7}$ , 0.00005482,  $-0.003191$ , 0.9729, 0.,  $-1.534$ , 0.979 ],  
    [ "HOA", 2.04049, 0.177, 1.005092, 0., 0.,  $7.859 \times 10^{-10}$ ,  $-1.914 \times 10^{-7}$ ,  $-9.128 \times 10^{-6}$ ,  $-0.00070$ , 0.9981,  $-0.05$ ,  $-1.633$ , 1.151 ] ] )
```

Intermediate Average Arcing Current

$$k_{IE} := \begin{cases} IE_coeffs[2..4, 3..] & electrode_config = "VCB" \\ IE_coeffs[5..7, 3..] & electrode_config = "VCBB" \\ IE_coeffs[8..10, 3..] & electrode_config = "HCB" \\ IE_coeffs[11..13, 3..] & electrode_config = "VOA" \\ IE_coeffs[14..16, 3..] & electrode_config = "HOA" \end{cases}$$

Average RMS arcing current

$$I_{arc_Voc} := (k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8, k_9, k_{10}) \\ \rightarrow 10^{\left(k_1 + k_2 \cdot \log_{10}\left(\frac{I_{bf}}{kA}\right) + k_3 \cdot \log_{10}\left(\frac{G}{mm}\right) \right)} \\ \times \left(k_4 \cdot \left(\frac{I_{bf}}{kA}\right)^6 + k_5 \cdot \left(\frac{I_{bf}}{kA}\right)^5 + k_6 \cdot \left(\frac{I_{bf}}{kA}\right)^4 + k_7 \cdot \left(\frac{I_{bf}}{kA}\right)^3 + k_8 \cdot \left(\frac{I_{bf}}{kA}\right)^2 + k_9 \cdot \left(\frac{I_{bf}}{kA}\right) + k_{10} \right) kA$$

Average RMS arcing currents at voltage levels Voc of 600 V, 2700 V and 14300 V

$$I_{arc_600} := I_{arc_Voc}(k_{IE}[1, 1], k_{IE}[1, 2], k_{IE}[1, 3], k_{IE}[1, 4], k_{IE}[1, 5], \\ k_{IE}[1, 6], k_{IE}[1, 7], k_{IE}[1, 8], k_{IE}[1, 9], k_{IE}[1, 10]) = 12.096 \text{ kA}$$

$$I_{arc_2700} := I_{arc_Voc}(k_{IE}[2, 1], k_{IE}[2, 2], k_{IE}[2, 3], k_{IE}[2, 4], k_{IE}[2, 5], \\ k_{IE}[2, 6], k_{IE}[2, 7], k_{IE}[2, 8], k_{IE}[2, 9], k_{IE}[2, 10]) = 15.807 \text{ kA}$$

$$I_{arc_14300} := I_{arc_Voc}(k_{IE}[3, 1], k_{IE}[3, 2], k_{IE}[3, 3], k_{IE}[3, 4], k_{IE}[3, 5], \\ k_{IE}[3, 6], k_{IE}[3, 7], k_{IE}[3, 8], k_{IE}[3, 9], k_{IE}[3, 10]) = 16.539 \text{ kA}$$

Arcing Current Variation Factor

The reduced arcing current I_{arc_min} determines if the arcing current variation influences the operating time of protective devices.

- If the arcing fault current is low, protective devices take more time to interrupt the fault current, resulting in a high incident energy.
- If arcing fault current is high, then protective devices take less time to interrupt the fault current, resulting in a low incident energy.

Empirical coefficients

$$k_VarC := \begin{cases} VarC_coeffs[2, 2 ..] & \text{electrode_config} = \text{"VCB"} \\ VarC_coeffs[3, 2 ..] & \text{electrode_config} = \text{"VCBB"} \\ VarC_coeffs[4, 2 ..] & \text{electrode_config} = \text{"HCB"} \\ VarC_coeffs[5, 2 ..] & \text{electrode_config} = \text{"VOA"} \\ VarC_coeffs[6, 2 ..] & \text{electrode_config} = \text{"HOA"} \end{cases}$$

Arcing current variation correction factor

$$\begin{aligned} VarC_f := & k_VarC[1] \cdot \left(\frac{V_{oc}}{kV} \right)^6 + k_VarC[2] \cdot \left(\frac{V_{oc}}{kV} \right)^5 + k_VarC[3] \cdot \left(\frac{V_{oc}}{kV} \right)^4 \\ & + k_VarC[4] \cdot \left(\frac{V_{oc}}{kV} \right)^3 + k_VarC[5] \cdot \left(\frac{V_{oc}}{kV} \right)^2 + k_VarC[6] \cdot \left(\frac{V_{oc}}{kV} \right) \\ & + k_VarC[7] = 0.023 \end{aligned}$$

$$I_{arc_600_min} := I_{arc_600} \cdot (1 - 0.5 \cdot VarC_f) = 11.955 \text{ kA}$$

$$I_{arc_2700_min} := I_{arc_2700} \cdot (1 - 0.5 \cdot VarC_f) = 15.623 \text{ kA}$$

$$I_{arc_14300_min} := I_{arc_14300} \cdot (1 - 0.5 \cdot VarC_f) = 16.346 \text{ kA}$$

Interpolation equation for arcing current I_{arc} (equation 16 - 18)

First I_{arc} interpolation term between 600 V and 2700 V

$$I_{arc_1} := \frac{I_{arc_2700_min} - I_{arc_600_min}}{2.7 \text{ kV} - 0.6 \text{ kV}} \cdot (V_{oc} - 2.7 \text{ kV}) + I_{arc_2700_min} = 3.501 \times 10^4 \text{ A}$$

Second I_{arc} interpolation term (kA) used when V_{oc} is greater than 2700 V

$$I_{arc_2} := \frac{I_{arc_14300_min} - I_{arc_2700_min}}{14.3 \text{ kV} - 2.7 \text{ kV}} \cdot (V_{oc} - 14.3 \text{ kV}) + I_{arc_14300_min} = 1.631 \times 10^4 \text{ A}$$

Third I_{arc} interpolation term (kA) used when V_{oc} is less than 2700 V

$$I_{arc_3} := \frac{I_{arc_1} \cdot (2.7 \text{ kV} - V_{oc})}{2.7 \text{ kV} - 0.6 \text{ kV}} + \frac{I_{arc_2} \cdot (V_{oc} - 0.6 \text{ kV})}{2.7 \text{ kV} - 0.6 \text{ kV}} = -8.250 \times 10^4 \text{ A}$$

Final arcing current is found from I_{arc_2} since $V_{oc} > 2700$ volts

$$I_{arc} := \begin{cases} I_{arc_2} & V_{oc} > 2.7 \text{ kV} \\ I_{arc_3} & \text{otherwise} \end{cases} = 1.631 \times 10^4 \text{ A}$$

Box Size Correction Factor

Determine if the enclosure is typical or shallow.

- Shallow enclosure: depth ≤ 203.2 mm
- Typical enclosure: depth > 203.2 mm

The effect of depth is only considered if the system voltage is less than 600 V. Since the switchgear voltage is higher than 600 V and the depth is higher than 203.2 mm, the enclosure is typical.

Next, the equivalent width and height can be determined based on the reasoning provided in Table 6 (section 4.8.3 IEEE 1584-2018).

Using equations 11 and 12, since the width and height are greater than 1244.6 mm, both equations are solved with a value 1244.6 (maximum width or height).

$$A := \begin{cases} 4 & \text{electrode_config} = \text{"VCB"} \\ 10 & \text{electrode_config} = \text{"VCBB"} \\ 10 & \text{electrode_config} = \text{"HCB"} \\ 1 & \text{otherwise} \end{cases} = 10$$

$$B := \begin{cases} 20 & \text{electrode_config} = \text{"VCB"} \\ 24 & \text{electrode_config} = \text{"VCBB"} \\ 22 & \text{electrode_config} = \text{"HCB"} \\ 1 & \text{otherwise} \end{cases} = 22$$

$$\text{Width}_1 := \left(660.4 \text{ mm} + (\text{Width} - 660.4 \text{ mm}) \cdot \left(\frac{\frac{V_{oc}}{\text{kV}} + A}{B} \right) \right) \cdot 25.4^{-1} = 50.882 \text{ mm}$$

$$\text{Height}_1 := \left(660.4 \text{ mm} + (\text{Height} - 660.4 \text{ mm}) \cdot \left(\frac{\frac{V_{oc}}{\text{kV}} + A}{B} \right) \right) \cdot 25.4^{-1} = 50.882 \text{ mm}$$

Equivalent enclosure size used to find the correction factor.

For typical box enclosures, EES > 20

$$\text{EES} := \frac{\text{Height}_1 + \text{Width}_1}{2} = 50.882 \text{ mm}$$

Emperical coefficients

$$b_EES_coeffs := \begin{cases} \text{typical_enclosure_coeffs}[2, 2 ..] & \text{electrode_config} = \text{"VCB"} \\ \text{typical_enclosure_coeffs}[3, 2 ..] & \text{electrode_config} = \text{"VCBB"} \\ \text{typical_enclosure_coeffs}[4, 2 ..] & \text{electrode_config} = \text{"HCB"} \end{cases}$$

Enclosure size correction factor (equation 14 since the enclosure is "Typical")

$$CF := \begin{cases} b_EES_coeffs[1] \cdot \left(\frac{EES}{mm} \right)^2 + b_EES_coeffs[2] \cdot \left(\frac{EES}{mm} \right) + b_EES_coeffs[3] & \text{electrode_config} = \text{"VCB"} \\ b_EES_coeffs[1] \cdot \left(\frac{EES}{mm} \right)^2 + b_EES_coeffs[2] \cdot \left(\frac{EES}{mm} \right) + b_EES_coeffs[3] & \text{electrode_config} = \text{"VCBB"} \\ b_EES_coeffs[1] \cdot \left(\frac{EES}{mm} \right)^2 + b_EES_coeffs[2] \cdot \left(\frac{EES}{mm} \right) + b_EES_coeffs[3] & \text{electrode_config} = \text{"HCB"} \\ 1 & \text{otherwise} \end{cases}$$

$$CF = 1.177$$

Incident Energy

$$k_{IE_600} := \begin{cases} \text{incident_energy_600_coeffs}[2, 2 \dots] & \text{electrode_config} = \text{"VCB"} \\ \text{incident_energy_600_coeffs}[3, 2 \dots] & \text{electrode_config} = \text{"VCBB"} \\ \text{incident_energy_600_coeffs}[4, 2 \dots] & \text{electrode_config} = \text{"HCB"} \\ \text{incident_energy_600_coeffs}[5, 2 \dots] & \text{electrode_config} = \text{"VOA"} \\ \text{incident_energy_600_coeffs}[6, 2 \dots] & \text{electrode_config} = \text{"HOA"} \end{cases}$$

$$k_{IE_2700} := \begin{cases} \text{incident_energy_2700_coeffs}[2, 2 \dots] & \text{electrode_config} = \text{"VCB"} \\ \text{incident_energy_2700_coeffs}[3, 2 \dots] & \text{electrode_config} = \text{"VCBB"} \\ \text{incident_energy_2700_coeffs}[4, 2 \dots] & \text{electrode_config} = \text{"HCB"} \\ \text{incident_energy_2700_coeffs}[5, 2 \dots] & \text{electrode_config} = \text{"VOA"} \\ \text{incident_energy_2700_coeffs}[6, 2 \dots] & \text{electrode_config} = \text{"HOA"} \end{cases}$$

$$k_{IE_14300} := \begin{cases} \text{incident_energy_14300_coeffs}[2, 2 \dots] & \text{electrode_config} = \text{"VCB"} \\ \text{incident_energy_14300_coeffs}[3, 2 \dots] & \text{electrode_config} = \text{"VCBB"} \\ \text{incident_energy_14300_coeffs}[4, 2 \dots] & \text{electrode_config} = \text{"HCB"} \\ \text{incident_energy_14300_coeffs}[5, 2 \dots] & \text{electrode_config} = \text{"VOA"} \\ \text{incident_energy_14300_coeffs}[6, 2 \dots] & \text{electrode_config} = \text{"HOA"} \end{cases}$$

$$E := \left(T, G, I_{arc}, Dis, CF, I_{bf}, k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8, k_9, k_{10}, k_{11}, k_{12}, k_{13} \right) \rightarrow$$

$$\frac{12.552}{50} \cdot \left(\frac{T}{ms} \right) \times$$

$$10^{\left(\begin{aligned} & k_1 + k_2 \cdot \log_{10} \left(\frac{G}{mm} \right) + \frac{k_3 \cdot \left(\frac{I_{arc}}{kA} \right)}{k_4 \cdot \left(\frac{I_{bf}}{kA} \right)^7 + k_5 \cdot \left(\frac{I_{bf}}{kA} \right)^6 + k_6 \cdot \left(\frac{I_{bf}}{kA} \right)^5 + k_7 \cdot \left(\frac{I_{bf}}{kA} \right)^4 + k_8 \cdot \left(\frac{I_{bf}}{kA} \right)^3 + k_9 \cdot \left(\frac{I_{bf}}{kA} \right)^2 + k_{10} \cdot \left(\frac{I_{bf}}{kA} \right)} + k_{11} \cdot \log_{10} \left(\frac{I_{bf}}{kA} \right) + k_{12} \cdot \log_{10} \left(\frac{Dis}{mm} \right) + k_{13} \cdot \log_{10} \left(\frac{I_{arc}}{kA} \right) + \log_{10} \left(\frac{1}{CF} \right) \right) \frac{J}{cm^2}$$

Incident energy for 600 V, 2700 V and 14300 V.

$$E_{600} := E \left(T, G, I_{arc_600}, Dis, CF, I_{bf}, k_{IE_600}[1], k_{IE_600}[2], \right.$$

$$k_{IE_600}[3], k_{IE_600}[4], k_{IE_600}[5], k_{IE_600}[6],$$

$$k_{IE_600}[7], k_{IE_600}[8], k_{IE_600}[9], k_{IE_600}[10],$$

$$k_{IE_600}[11], k_{IE_600}[12], k_{IE_600}[13] \left. \right) = 20.503 \frac{J}{cm^2}$$

$$E_{2700} := E\left(T, G, I_{\text{arc}_2700}, Dis, CF, I_{bf}, k_{IE_2700}[1], k_{IE_2700}[2], k_{IE_2700}[3], k_{IE_2700}[4], k_{IE_2700}[5], k_{IE_2700}[6], k_{IE_2700}[7], k_{IE_2700}[8], k_{IE_2700}[9], k_{IE_2700}[10], k_{IE_2700}[11], k_{IE_2700}[12], k_{IE_2700}[13]\right) = 32.178 \frac{\text{J}}{\text{cm}^2}$$

$$E_{14300} := E\left(T, G, I_{\text{arc}_14300}, Dis, CF, I_{bf}, k_{IE_14300}[1], k_{IE_14300}[2], k_{IE_14300}[3], k_{IE_14300}[4], k_{IE_14300}[5], k_{IE_14300}[6], k_{IE_14300}[7], k_{IE_14300}[8], k_{IE_14300}[9], k_{IE_14300}[10], k_{IE_14300}[11], k_{IE_14300}[12], k_{IE_14300}[13]\right) = 37.444 \frac{\text{J}}{\text{cm}^2}$$

First E interpolation term when V_{oc} is between 600 V and 2700 V

$$E_1 := \frac{E_{2700} - E_{600}}{2.7 \text{ kV} - 0.6 \text{ kV}} \cdot (V_{oc} - 2.7 \text{ kV}) + E_{2700} = 93.885 \frac{\text{J}}{\text{cm}^2}$$

Second E interpolation term when V_{oc} is greater than 2700 V

$$E_2 := \frac{E_{14300} - E_{2700}}{14.3 \text{ kV} - 2.7 \text{ kV}} \cdot (V_{oc} - 14.3 \text{ kV}) + E_{14300} = 37.217 \frac{\text{J}}{\text{cm}^2}$$

Third E interpolation term when V_{oc} is less than 2700 V

$$E_3 := \frac{E_1 \cdot (2.7 \text{ kV} - V_{oc})}{2.7 \text{ kV} - 0.6 \text{ kV}} + \frac{E_2 \cdot (V_{oc} - 0.6 \text{ kV})}{2.7 \text{ kV} - 0.6 \text{ kV}} = -262.313 \frac{\text{J}}{\text{cm}^2}$$

The final incident energy is found from E_2 since the voltage $V_{oc} > 2700$ volts

$$E := \begin{cases} E_2 & V_{oc} > 2.7 \text{ kV} \\ E_3 & \text{otherwise} \end{cases} = 37.217 \frac{\text{J}}{\text{cm}^2}$$

Arc Flash Boundary

IEEE 1584-2018 provides two intermediate equations (22 and 23) to determine the intermediate arc-flash boundary values.

Arc flash boundary

$$AFB := \left(T, G, I_{bf}, I_{arc_min}, CF, k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8, k_9, k_{10}, k_{11}, k_{12}, k_{13} \right) \rightarrow$$

$$10^{-k_1} \cdot \left(k_2 + k_3 \cdot \log_{10} \left(\frac{G}{mm} \right) + \frac{k_4 \cdot \left(\frac{I_{arc}}{kA} \right)}{k_5 \cdot \left(\frac{I_{bf}}{kA} \right)^7 + k_6 \cdot \left(\frac{I_{bf}}{kA} \right)^6 + k_7 \cdot \left(\frac{I_{bf}}{kA} \right)^5 + k_8 \cdot \left(\frac{I_{bf}}{kA} \right)^4 + k_9 \cdot \left(\frac{I_{bf}}{kA} \right)^3 + k_{10} \cdot \left(\frac{I_{bf}}{kA} \right)^2 + k_{11} \cdot \log_{10} \left(\frac{I_{bf}}{kA} \right) + k_{12} \cdot \log_{10} \left(\frac{I_{arc_min}}{kA} \right) + \log_{10} \left(\frac{1}{CF} \right) - \log_{10} \left(\frac{20}{ms} \right)} \right) mm$$

Coefficients

$$k_{IE_600} := incident_energy_600_coeffs[4, 2 ..]$$

$$k_{IE_2700} := incident_energy_2700_coeffs[4, 2 ..]$$

$$k_{IE_14300} := incident_energy_14300_coeffs[4, 2 ..]$$

Arc-flash boundary for 600 V, 2700 V and 14300 V

$$AFB_{600} := AFB \left(T, G, I_{bf}, I_{arc_600}, I_{arc_600_min}, CF, k_{IE_600}[1], k_{IE_600}[2], k_{IE_600}[3], k_{IE_600}[4], k_{IE_600}[5], k_{IE_600}[6], k_{IE_600}[7], k_{IE_600}[8], k_{IE_600}[9], k_{IE_600}[10], k_{IE_600}[11], k_{IE_600}[12], k_{IE_600}[13] \right) = 1.817 \times 10^3 mm$$

$$AFB_{2700} := AFB \left(T, G, I_{bf}, I_{arc_2700}, I_{arc_2700_min}, CF, k_{IE_2700}[1], k_{IE_2700}[2], k_{IE_2700}[3], k_{IE_2700}[4], k_{IE_2700}[5], k_{IE_2700}[6], k_{IE_2700}[7], k_{IE_2700}[8], k_{IE_2700}[9], k_{IE_2700}[10], k_{IE_2700}[11], k_{IE_2700}[12], k_{IE_2700}[13] \right) = 2.667 \times 10^3 mm$$

$$AFB_{14300} := AFB \left(T, G, I_{bf}, I_{arc_14300}, I_{arc_14300_min}, CF, k_{IE_14300}[1], k_{IE_14300}[2], k_{IE_14300}[3], k_{IE_14300}[4], k_{IE_14300}[5], k_{IE_14300}[6], k_{IE_14300}[7], k_{IE_14300}[8], k_{IE_14300}[9], k_{IE_14300}[10], k_{IE_14300}[11], k_{IE_14300}[12], k_{IE_14300}[13] \right) = 3.054 \times 10^3 mm$$

Determine the final arc flash boundary.

First AFB interpolation term (mm) used when V_{oc} is between 600 V and 2700 V

$$AFB_1 := \frac{AFB_{2700} - AFB_{600}}{2.7 \text{ kV} - 0.6 \text{ kV}} \cdot (V_{oc} - 2.7 \text{ kV}) + AFB_{2700} = 7.162 \times 10^3 \text{ mm}$$

Second AFB interpolation term used when V_{oc} is greater than 2700 V

$$AFB_2 := \frac{AFB_{14300} - AFB_{2700}}{14.3 \text{ kV} - 2.7 \text{ kV}} \cdot (V_{oc} - 14.3 \text{ kV}) + AFB_{14300} = 3.037 \times 10^3 \text{ mm}$$

Third AFB interpolation term used when V_{oc} is less than 2700 V

$$AFB_3 := \frac{AFB_1 \cdot (2.7 \text{ kV} - V_{oc})}{2.7 \text{ kV} - 0.6 \text{ kV}} + \frac{AFB_2 \cdot (V_{oc} - 0.6 \text{ kV})}{2.7 \text{ kV} - 0.6 \text{ kV}} = -1.876 \times 10^4 \text{ mm}$$

The final arc-flash boundary is found from AFB_2 (AFB_{2700}) since $V_{oc} > 2700 \text{ V}$

$$AFB := \begin{cases} AFB_2 & V_{oc} > 2.7 \text{ kV} \\ AFB_3 & \text{otherwise} \end{cases} = 3.037 \times 10^3 \text{ mm}$$