Introduction to the 2018 Edition of IEEE 1584-2018 – Guide for Performing Arc-Flash Hazard Calculations

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Agenda

- Introduction
- Laboratory Testing & Model Development
- Information Needed to Conduct Study
- Calculation Examples
- Summary
- Questions

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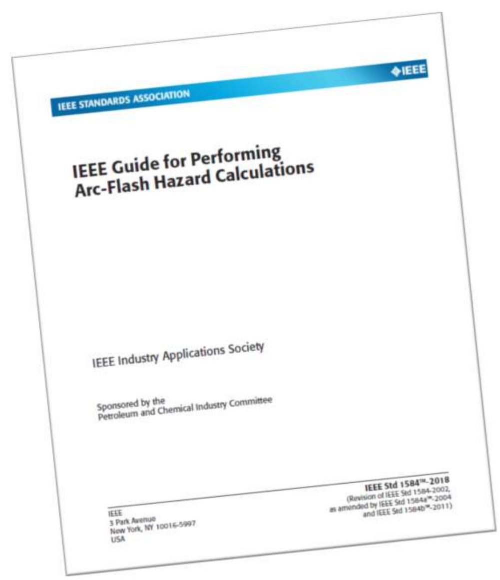
INTRODUCTION

Sections 4.1, 4.2 and 4.3 of IEEE 1584-2018



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Introduction

- Background Information
- Scope
- Purpose
- What is covered?
- What is not covered?
- Range of the Model

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Background Information

- The IEEE **1584-2002** arc-flash model was based on ~ **300** tests
- The IEEE **1584-2018** model was based on over **1800** tests
- IEEE 1584-2002 test results were also used in new model
- IEEE 1584-2002 used **2** configurations
- IEEE 1584-2018 includes **5** configurations
- **Five** different labs were used for performing the tests

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Scope

This guide provides models and an analytical process to enable calculation of the predicted thermal incident energy and the arc-flash boundary (AFB).

Applications include electrical equipment and conductors for three-phase alternating current (ac) voltages from 208 V to 15 kV.

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Purpose

The purpose of the guide is to enable ***qualified person(s)*** to analyze power systems for the purpose of calculating the incident energy to which employees could be exposed during operations and maintenance work. Contractors and facility owners can use this information *to help provide appropriate protection* for employees in accordance with the requirements of applicable electrical workplace safety standards.

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Not Covered

Not a part of the guide:

- **Calculations for single-phase ac systems** and direct current (dc) systems (but some guidance and references are provided for those applications).
- **Recommendations for personal protective equipment** (PPE) to mitigate arc-flash hazards are not included in this guide.

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Low Voltage Sustainability

"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"

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Electrode Configurations

Electrode Configurations & Orientation

Electrode Configuration	Standard	Orientation	Configuration	Termination
VOA	2002/2018	Vertical	Open air	In air
VCB	2002/2018	Vertical	In a box	In air
VCBB	2018	Vertical	In a box	Insulating Barrier
HOA	2018	Horizontal	Open air	In air
HCB	2018	Horizontal	In a box	In air

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Tests conducted

Overall Test Count by Electrode Configuration:

Electrode Configuration	Tests Performed	Voltage Range	Current Range	Gap Range
VCB	485	0.208 ~ 14.8 kV	0.5 ~ 80 kA	6 ~ 250 mm
VCBB	400	0.215 ~ 14.8 kV	0.5 ~ 65 kA	6 ~ 154 mm
HCB	460	0.215 ~ 14.8 kV	0.5 ~ 63 kA	10 ~ 254 mm
VOA	251	0.240 ~ 14.8 kV	0.5 ~ 65 kA	10 ~ 154 mm
HOA	259	0.240 ~ 14.8 kV	0.5 ~ 66 kA	10 ~ 154 mm

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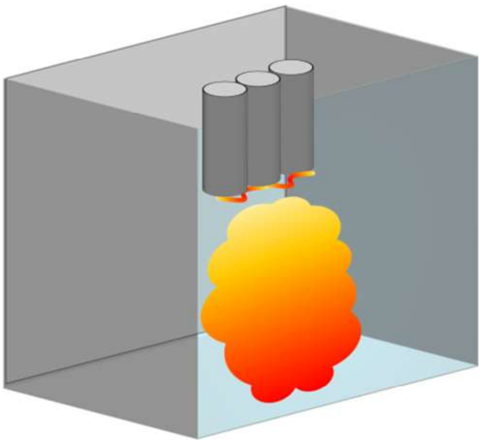
Electrode Configuration - VCB



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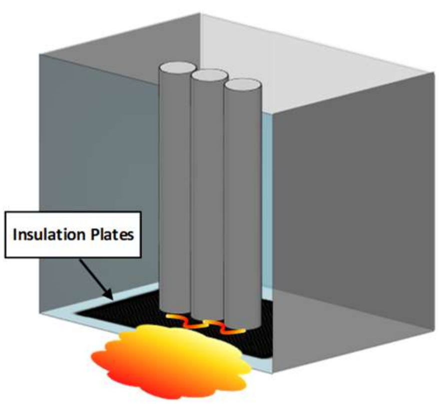
Electrode Configuration - VCBB



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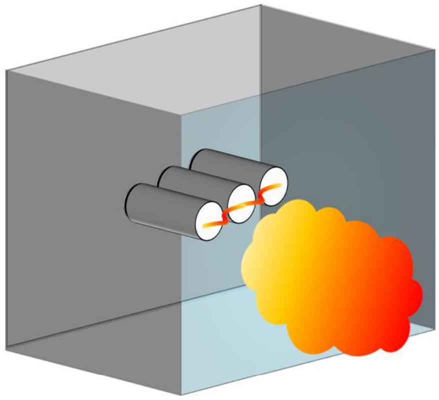
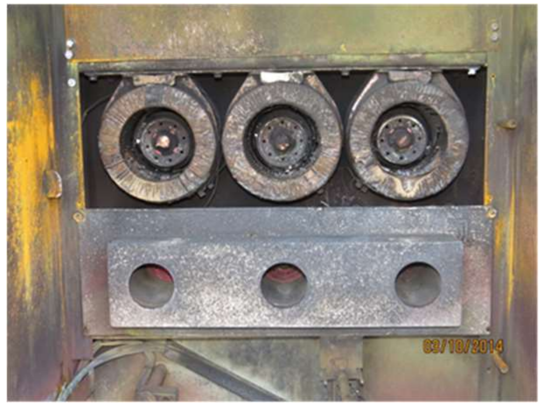
Electrode Configuration - HCB





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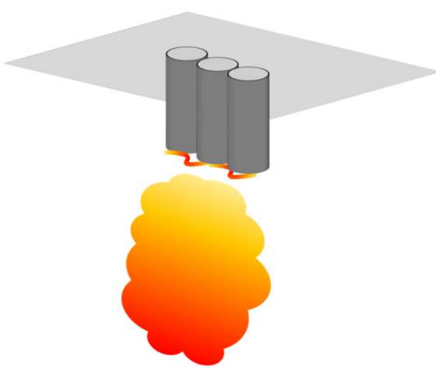
Electrode Configuration - VOA



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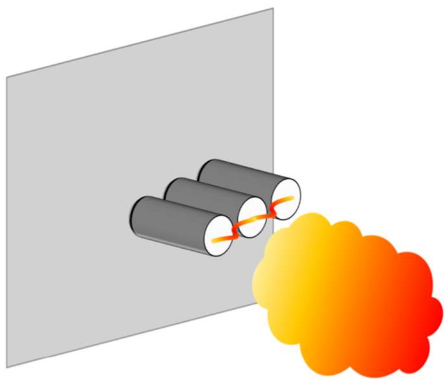
Electrode Configuration - HOA



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Range of the Model

Range of Application of the IEEE 1584-2018 Model

Voltage Range (3-P kV LL)	I_{bf} (kA)	Gap (mm)	WD (inch)	Fault Duration (cycles)
0.208 ≤ V ≤ 0.600	0.5 to 106	6.35 to 76.2	≥12	No Limit*
0.600 < V ≤ 15.0	0.2 to 65	19.05 to 254	≥ 12	No Limit

*Energy flux is assumed to be constant as a function of time

Enclosure Dimensions	(inch or in^2)
Height	14 to 49*
Width	(4 x Gap) to 49*
Opening Area	2401

Parameter	Value
Frequency	50 Hz or 60 Hz
Phases	3-Phase
Configurations	VCB, VCBB, HCB, VOA, HOA

*bigger opening sizes can be modeled, but the correction factor is calculated based on the maximum value of 49 in (for both width and height)

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Table G.18—Enclosure sizes for IEEE 1584-2018 arc-flash model

Enclosure type	Equipment class	Default bus gaps (mm)	Enclosure size (H × W × D)
1	15 kV switchgear	152	1143 mm × 762 mm × 762 mm (45 in × 30 in × 30 in)
2	15 kV MCC	152	914.4 mm × 914.4 mm × 914.4 mm (36 in × 36 in × 36 in)
3	5 kV switchgear	104	914.4 mm × 914.4 mm × 914.4 mm (36 in × 36 in × 36 in)
4	5 kV switchgear	104	1143 mm × 762 mm × 762 mm (45 in × 30 in × 30 in)
5	5 kV MCC	104	660.4 mm × 660.4 mm × 660.4 mm (26 in × 26 in × 26 in)
6	Low-voltage switchgear	32	508 mm × 508 mm × 508 mm (20 in × 20 in × 20 in)
7	Shallow low-voltage MCCs and panelboards	25	355.6 mm × 304.8 mm × ≤203.2 mm (14 in × 12 in × ≤8 in)
8	Deep low-voltage MCCs and panelboards	25	355.6 mm × 304.8 mm × >203.2 mm (14 in × 12 in × >8 in)
7 or 8	Cable junction box	13	355.6 mm × 304.8 mm × ≤203.2 mm (14 in × 12 in × ≤8 in) or 355.6 mm × 304.8 mm × >203.2 mm (14 in × 12 in × >8 in)

Similar to how IEEE 1584-2002 is being applied, the new arc-flash model can be applied to similar size equipment plus some additional sizes. This was accomplished by adjusting the incident energy model to account for the additional sizes. The new model may yield accurate or slightly conservative results for the tested sizes in Table G.18.

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Range of the Model

Input Parameters Outside the Range:

"There are alternative calculation methods for system parameters which fall outside the range of the model. However, no particular recommendation can be made since there are other application details such as bolted fault current levels, voltage, gap length, operating frequency, number of phases, types of faults, etc., etc. The user is advised to properly research alternative calculation methods an their application viability"

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Information Needed

- Single Line, Modes of Operation;
- Short-Circuit Current(s) (rms)*;
- Clearing Time (Arc Duration)**;
- Enclosure Size;
- Working Distance;
- Electrode Configurations

* Use IEEE Std. 3002.3 – 2018 for Short Circuit Study and Analysis
** See 6.9.1 IEEE Std. 1584-2018 for Detail for rational to use maximum 2-second rule

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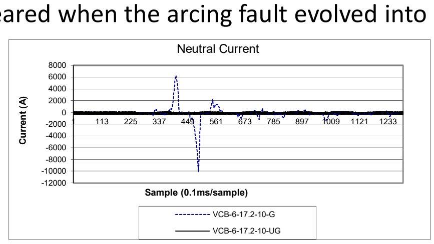
Impact of System Grounding

- Effect of Bonding and Grounding
  - IEEE Std. 1584-2002 uses K_2 in the equation to differentiate grounded and ungrounded/high impedance grounded system when calculating incident energy.
  - As a result, ungrounded/high impedance grounded system ends up with higher incident energy during similar arcing incidents.
  - After further analysis and testing, it was found that some current flew through the neutral conductor in the first few cycles due to unbalanced arcing fault.
  - The current disappeared when the arcing fault evolved into a three-phase balanced fault.



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Laboratory Tests & Model Development


IEEE Std 1584-2018
IEEE Guide for Performing Arc-Flash Hazard Calculations

Annex G

(informative)

Development of model

G.1 Summary

The new model was developed based on over 1860 tests performed by the project at different voltage levels. The model performance was also evaluated against the existing IEEE Std 1584-2002 test results (approximately 300 tests). The new model performance was evaluated against 932 tests between 0.208 kV to 0.6 kV, 325 tests at 2.7 kV, 202 tests at 4 kV, and over 400 tests between 12 kV and 15 kV.

The new IEEE 1584 arc-flash model is an empirically derived model, and just like the 2002 model, is considered to yield consistent results when applied within the recommended range of its parameters. The model was evaluated as a whole, and its performance was observed using a holistic approach. It is the conclusion that this model produces results that are more accurate than those of its predecessor for configurations common in both models. Further, the new model provides a method to evaluate the incident energy for other configurations not previously considered, such as vertical conductors in a box with a barrier and horizontal conductors in a box and without a box.

G.2 Configurations of the testing

Open-air (OA) and enclosure configurations have been used. The metal enclosures used in the test are with an open front end. Electrodes are open-tipped, and testing has been conducted with vertical and horizontal electrodes; both of which are terminated at the vertical center of the enclosure. In addition, for the "Barrier" configuration, vertical electrodes are terminated at the bottom of the box. The configurations, illustrated in Figure G.1 through Figure G.5, are defined as follows:

— VCB: Vertical Electrodes, Metal "Box" Enclosure (Figure G.1)
— VCBB: Vertical Electrodes terminated in an insulating barrier, Metal "Box" Enclosure (Figure G.2)
— HCB: Horizontal Electrodes, Metal "Box" Enclosure (Figure G.3)
— VOA: Vertical Electrodes, Open Air (Figure G.4)
— HOA: Horizontal Electrodes, Open Air (Figure G.5)

Figure G.1—VCB (vertical electrodes inside a metal "box" enclosure)

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Laboratory Testing & Model Development

- Lab Parameters Used in Testing
- Data Processing
- Arc-Flash Model Validation
- Arc-Flash Model Performance

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Important Factors to be Considered

- Bolted fault current level
- Arc duration
- Voltage level
- Electrode Orientation/Configuration (VCB, VCBB, HCB, VOA, HOA)
- Gap width between electrodes
- Calorimeter arrangement and measurement locations.
- Distance between electrode and back panel*
- Dimensions of the enclosure**

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Observation from the Testing and Other Literatures

- Plasma Trajectory for Vertical Electrodes in the Enclosure (VCBB) Configuration

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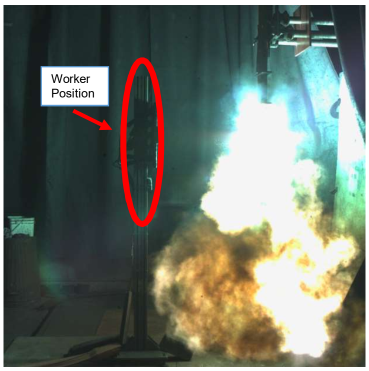
Observation from the Testing and Other Literatures

- Plasma Trajectory for Vertical Electrodes in the Air (VOA) Configuration



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Observation from the Testing and Other Literatures

- Plasma Trajectory for Horizontal Electrodes in the Air (HOA) Configuration

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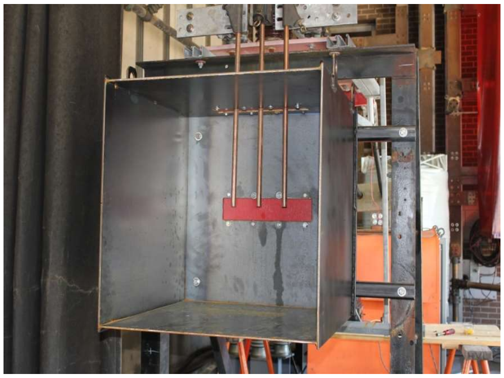
Available Configurations in IEEE 1584-2018



Vertical Electrodes in the Enclosure (VCB)
Electrodes are Terminated in the Middle of the Box

Vertical Electrodes in the Enclosure (VCBB)
Electrodes are Terminated at the Bottom of the Box (Barrier Test)

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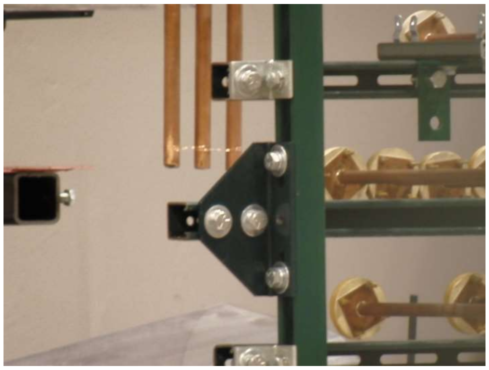
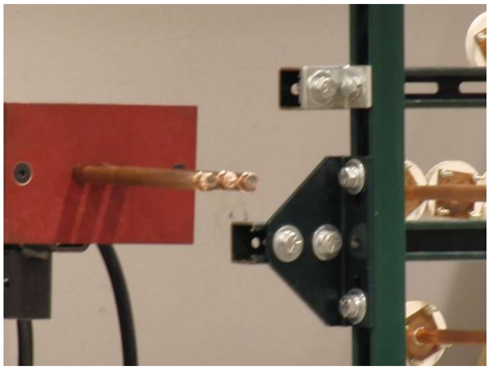
Available Configurations in IEEE 1584-2018



Vertical Electrodes in the Open Air (VOA)



Horizontal Electrodes in the Open Air (HOA)

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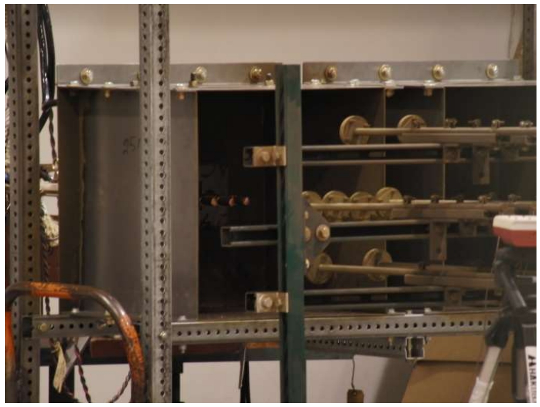
Available Configurations in IEEE 1584-2018



Horizontal Electrodes in the Enclosure (HCB)

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Design of the Testing

- Cover installations between 208V and 15kV.
- Perform extensive tests on 600V, 2.7kV/4.16kV, and 13.8kV.
- Perform select tests on 208V – 300V.
- Based upon engineering practice, select appropriate sized metal enclosure for testing. Selective tests on other dimensions to establish correction factor in the model.
- Based upon engineering practice, select appropriate distance between electrode and back panel for testing. This factor may be considered in the future revision.

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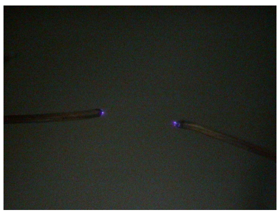
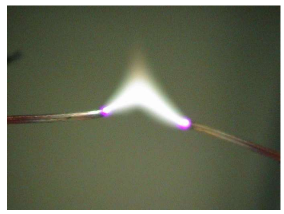
Design of the Testing

- To obtain the non-linearity of the phenomena
  - Measure IE at three different distances.
- Gaps between electrodes and over surface.
  - For medium voltage, the design is based upon the requirement of BIL (Basic Impulse Level).
  - The breakdown voltage in the dry air can reach 30 kV/cm.
  - Laboratory testing shows that the flashover voltage is around 15 kV/inch.





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Design of the Testing

- Gaps between electrodes and over surface.

Voltage (kV)	BIL (kV)	Minimum Gap (inch)	Maximum Gap (inch)	Over Surface Phase-to-ground (inch)
0.208 – 0.250	UL1558 NEMA MCC	0.25	0.75	0.5
0.251 – 0.600	UL1558	0.5	2.0	4.0
2.4	60	1.5	4.5	4.0
4.16 (5)	60	1.5	4.5	4.0
13.8	95	3.0	6.0	7.0

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Data Processing

- Reasonable arcing current estimations are critical for the whole process.
- It will be used to determine the operation of the protective devices (arc duration).
- It will be used to estimate the incident energy (IE) and protection boundary.
- Arcing current estimation
  - Depending on the fault inception angle and X/R ratio of the system, the arcing current may contain a DC component.
  - It is normal that arcing current can also have harmonic contents.

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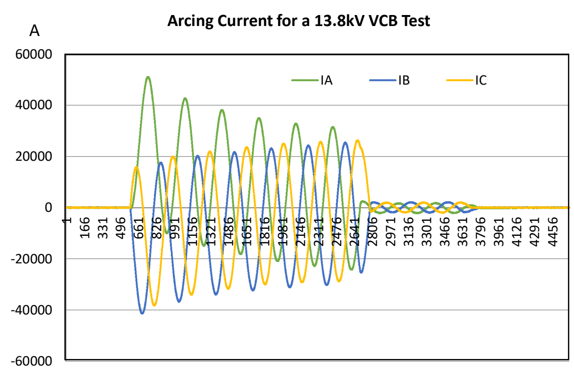
Data Processing

- The following figure shows the decaying DC offset can be seen in a 13.8kV, 20kA arc flash test.



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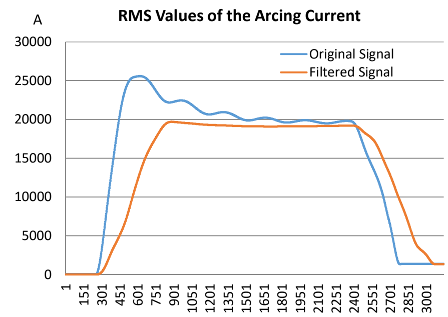
Data Processing

➢Since we don’t know when the fault will happen and normally don’t know the X/R ratio of the system, the DC offset and harmonic components of the current waveform are filtered when performing the arcing current estimation.



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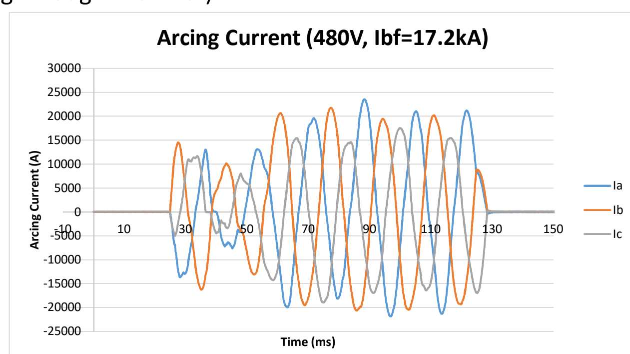
Data Processing

➢The arcing current varies during a single event.
  - ➢Cycle-by-cycle moving window is used to estimate/calculate the arcing current (after going through the filter)



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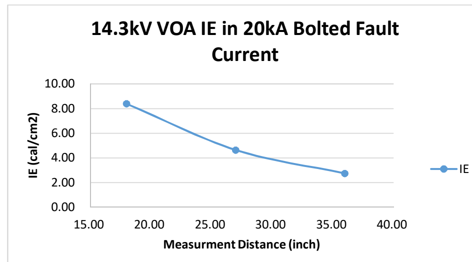
Arc Flash Model Validation

- The model validation stage is critical to ensure the consistency of the results of the new arc-flash model.
  - Review and Approve of Raw Data Processing
  - Regressing Analysis to identify the important parameters for Model Development
  - Prototyping of Model Validation Tools
  - Establishment of Model Performance Metrics
  - Determination of Final Range of Model



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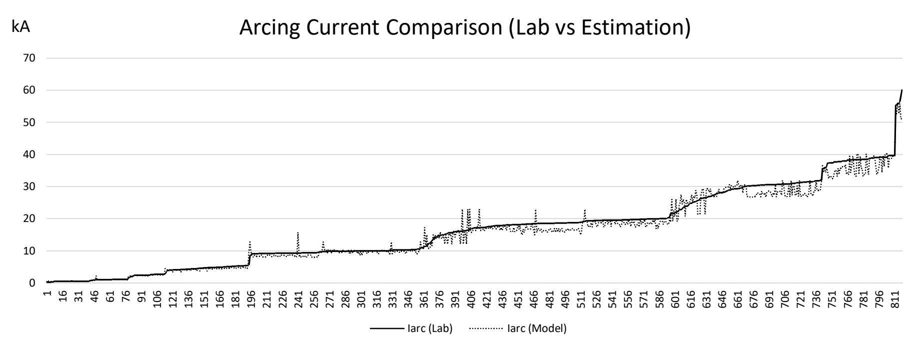
Arc Flash Model Performance

- Sample Comparison Chart



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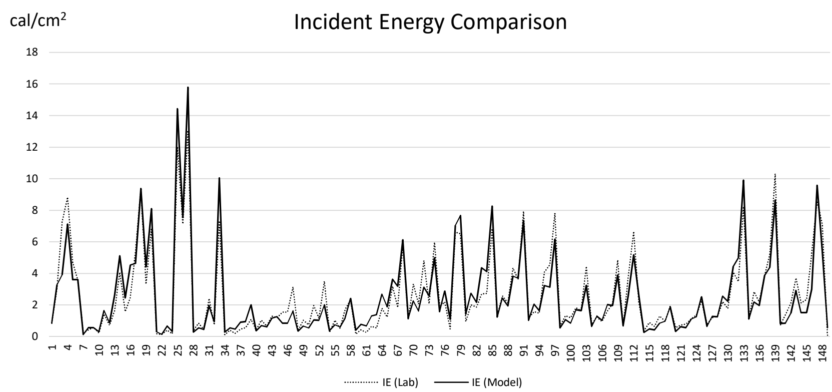
Arc Flash Model Performance

➢Sample Comparison Chart



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Something that Calorimeter Can Not Measure

➢Face Shield and Hearing Protection are Recommended for the Environment that Arc Flash May Happen

Lens was damaged by the melted copper
(10 feet from the arc point)

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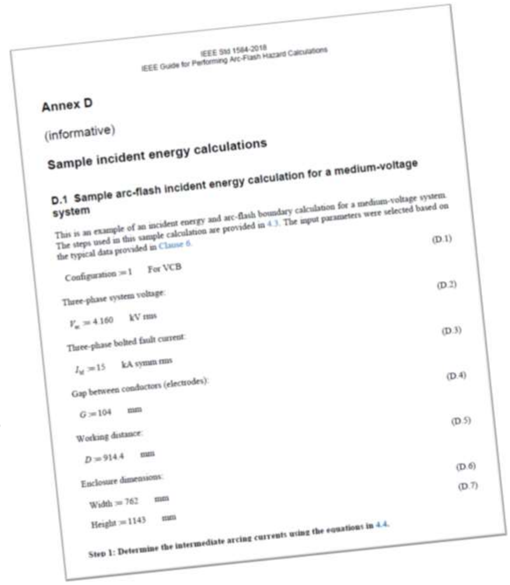
Calculation Examples

Supplement to Annex D



IEEE Std 1584-2018
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Annex D

(informative)

Sample incident energy calculations

D.1 Sample arc-flash incident energy calculation for a medium-voltage system

This is an example of an incident energy and arc-flash boundary calculation for a medium-voltage system. The steps used in this sample calculation are provided in 4.3. The input parameters were selected based on the typical data provided in Clause 6.

Configuration := 1 For VCB (D.1)

Three-phase system voltage:

$V_{oc} := 4.160$ kV rms (D.2)

Three-phase bolted fault current:

$I_{bf} := 15$ kA symm rms (D.3)

Gap between conductors (electrodes):

$G := 104$ mm (D.4)

Working distance:

$D := 914.4$ mm (D.5)

Enclosure dimensions:

Width := 762 mm (D.6)

Height := 1143 mm (D.7)

Step 1: Determine the intermediate arcing currents using the equations in 4.4.

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Calculation Examples

- 15 kV Switchgear: EC=HCB, CF for larger enclosure opening area
- 0.480 kV Switchgear: EC = VCBB, effect of reduced arc current

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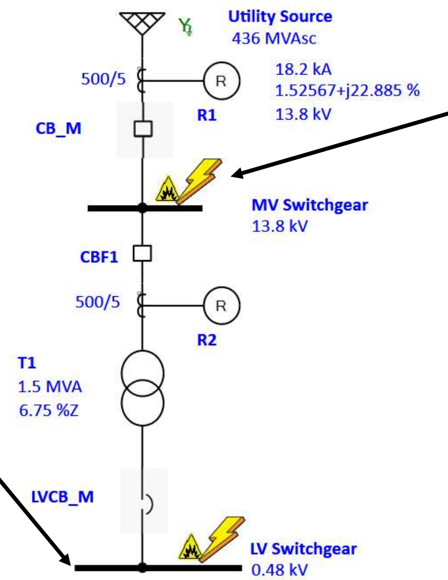

Input parameter	Value (Imp. Units)	Value (SI Units)
Voltage V_{oc}	13.8 kV	13.8 kV
Gap G	6 in	152 mm
Working Distance D	36 in	914 mm
Height	52 in	1321 mm
Width	50 in	1270 mm
Depth	45 in	1143 mm
Maximum I_{bf}	18.241 kA	
Minimum I_{bf}	15.2 kA	

Input parameter	Value (Imp. Units)	Value (SI Units)
Voltage V_{oc}	0.48 kV	0.48 kV
Gap G	1.25 in	32 mm
Working Distance D	24 in	609 mm
Height	26 in	660 mm
Width	26 in	660 mm
Depth	20 in	508 mm
Maximum I_{bf}	25.44 kA	
Minimum I_{bf}	24.02 kA	

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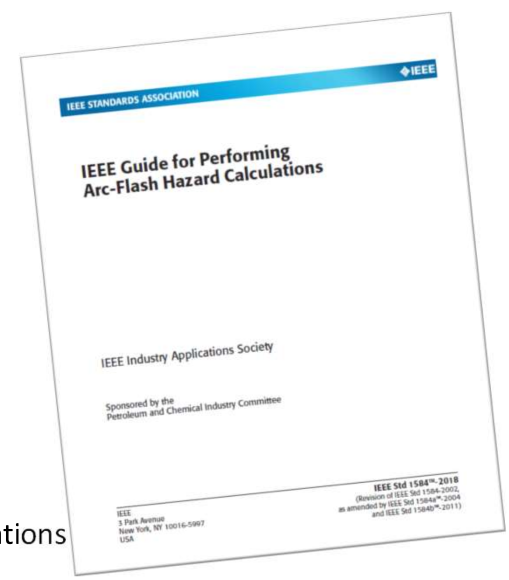
Summary

Introduction to the 2018 Edition of IEEE 1584

IEEE Guide for Performing Arc-Flash Hazard Calculations



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Summary - Model application overview

The model for incident energy calculations has been divided into the following two parts depending on the system open-circuit voltage, *V*oc:

— Model for 600 V < *V*oc ≤ 15 000 V

— Model for 208 V ≤ *V*oc ≤ 600 V

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.

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Summary

- IEEE 1584-2002 was considered a “trailblazer” in calculating arc-flash incident energy.
- It was the first arc-flash standard based on actual testing.
- Since it’s issued, multiple papers have been published based on further testing conducted and also based on physics
- Published papers documented that other electrode orientations and configurations significantly impact arc flash hazard incident energy.
- IEEE 1584-2018 tested and documented impact of both vertical and horizontal electrodes in different configurations

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Summary – Comparison with 2002

Parameter	IEEE- 1584- 2002	IEEE 1584- 2018
Voltage	208 V - 15 kV	208 V - 15 kV
Phases	3	3
Frequency	50 HZ or 60 HZ	50 HZ or 60 Hz
Bolted Fault current (RMS Symmetrical)	700A - 106kA	208V - 600 V 500 A - 106KA
		601V - 15kV 200 A- 65 kA

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Summary- Comparison with 2002

Parameter	1584-2002	1584-2018
Based on No of tests	≈ 300	Over 1800
Electrode orientation	Vertical	Vertical & Horizontal
Configurations	Two: VOA & VCB	Five: VOA, VCB, VCBB, HOA & HCB
Box Correction Factor	No	Yes

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Summary

- **Multiple** electrode orientation and configurations maybe present in electrical equipment
- It will require **qualified** person(s) knowledgeable in system analysis techniques and equipment construction and risk analysis to perform the calculations
- **IEEE 1584- 2018 does not cover**:
  - Single phase AC systems (but some guidance is provided)
  - Recommendation of selection of personal protective equipment (PPE) to reduce the risk of thermal burn based on results of IEEE 1584-2018
  - How to calculate system studies (short-circuit, coordination, etc.) covered by other IEEE standards

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Summary

Arc flash hazard energy quantification is an evolutionary work and standards will need to be updated as we learn more and perform further testing.

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Questions?

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