The New IEEE-1584 Guide for Performing Arc-Flash Calculations

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10/21/2019

hood patterson & dewar

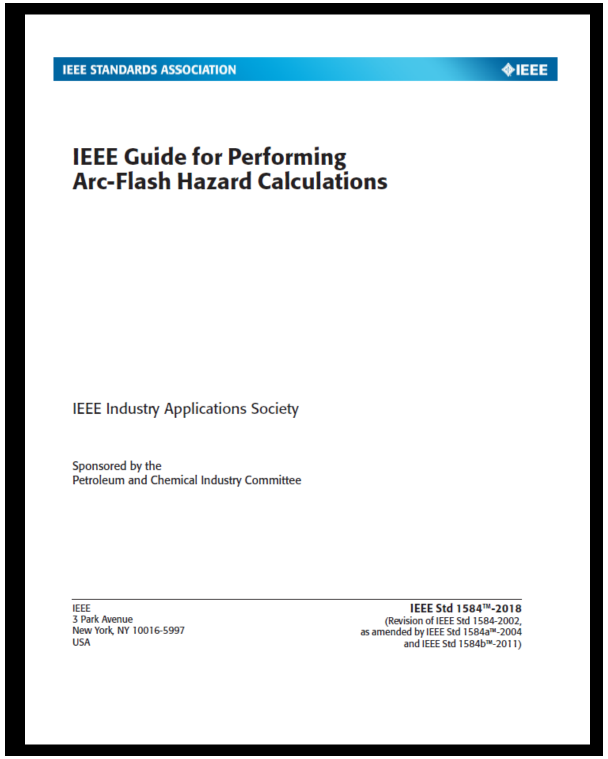
IEEE 1584

Agenda

- Standard differences
- Brief history
- Definitions
- Significant differences
- General guide line
- Where arc flash and electrical safety is heading

The Standards

What's the difference?


IEEE STANDARDS ASSOCIATION ◆IEEE

IEEE Guide for Performing
Arc-Flash Hazard Calculations

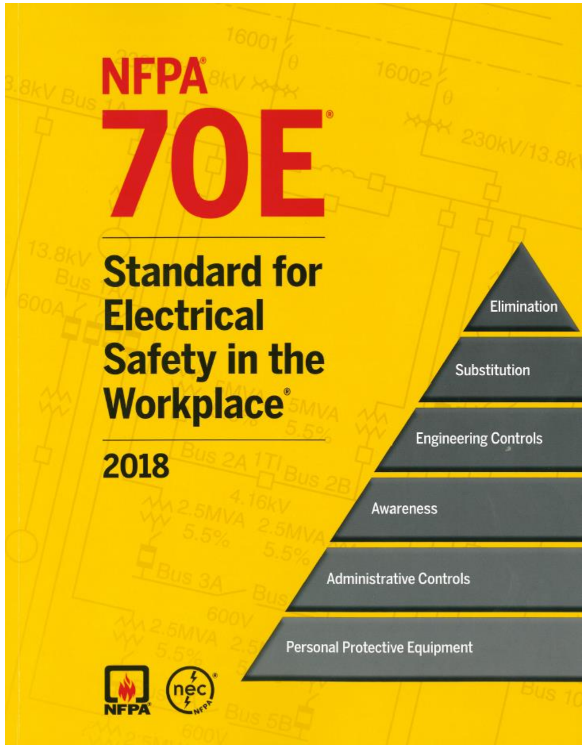
IEEE Industry Applications Society

Sponsored by the
Petroleum and Chemical Industry Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

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

Guide for Performing Arc Flash Hazard Calculations



NFPA 70E 2018

Governs Employee Workplace Safety

IEEE 1584-2018

Evolution of Incident Energy prescribed in Annex D of NFPA-70E

Source: NFPA-70E-2018

- D2. Lee Calculation Method (1981)
  - Arc as a point
- D.3 Doughy Neal Paper (2000)
  - D.3.2 Arc In open Air
  - D.3.3 Arc in a cubic box
- D.4 1584-2002 Calculation Method (2002)

Voltages	Bolted Fault Currents	Approximate Number of Tests
13.8 kV	5.4-40.4 kA	18
4.16kV	5.4-40.4kA	18
2.3kV	2.6-16.6kA	42
<1.0 kV	0.7-106kA	230

- 75k plus help from the Navy

IEEE 1584-2018

Evolution of Incident Energy

Voltage	~ Number of tests
208V (3ph) 240V (1ph)	195
480V	400
600V	340
2700V	320
4160V	180
14.3kV	270

~3.5million donated for these tests

Source: IEEE-1584-2018

IEEE 1584-2018 Highlights

Key Changes

- New arcing fault (I_{arc}) equations
- New incident energy (IE) equations
- Electrode Configuration-Very Significant!
- Enclosure size factor (CF)
- New guidance for equipment =<240V

Source: IEEE-1584-2018

IEEE 1584-2018 Highlights

Definitions

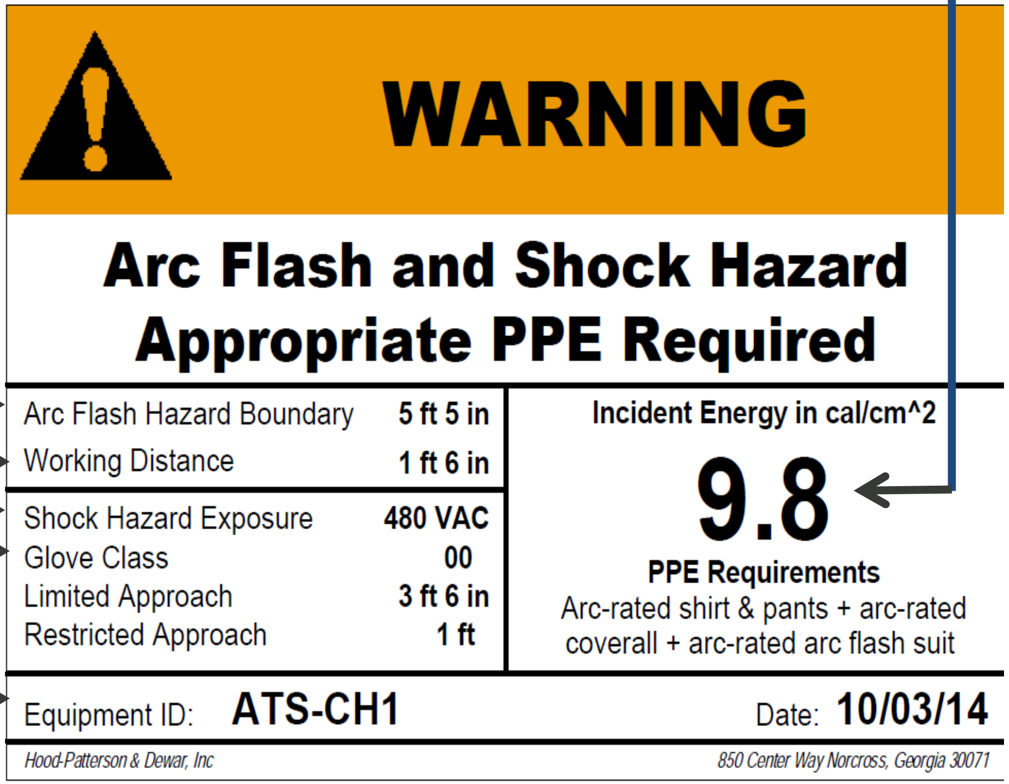
- **Arc:** Plasma cloud formed in a gap between two electrodes with sufficient potential difference
- **Arc flash:** An electric arc event with thermal energy dissipated as radiant, convective, and conductive heat.
- **Fault current:** A current that flows from one conductor to ground or to another conductor due to an abnormal connection between two conductors.
- **Bolted fault:** A short-circuit condition that assumes zero impedance exists at the point of the fault.
- **Arcing fault current (Arc current):** A fault current flowing through an electric arc plasma. General rule of thumb AF=50% of BF @480V
- **Incident Energy (IE in cal/cm^2):** the amount of thermal energy impress on a surface, a certain distance from the source, generated during an electric arc event.

Source: IEEE-1584-2018

IEEE 1584-2018 Highlights

Definitions

Incident Energy (IE) based at defined distance



Distance for 2nd degree burn

Based on PNL

Voltage at Equipment

Glove Class based on Voltage

Shock Hazard

Voltage Based Distances

Equipment of interest

* I.E. = Incident Energy

Article 100–Definitions

1.2 cal/cm^2 = second degree burn

IEEE 1584-2002
The 9 step program

- Step1:Collect system and installation data
- Step2: Determine the system modes of operation
- Step3:Determine bolted fault currents
- Step4: Determine arcing fault currents
- Step5: Find protective device characteristics and duration of arcs
- Step6: Document system voltages and classes of equipment
- Step7: Select working distances
- Step8:Determine Incident Energy(IE) for all equipment
- Step9: Determine Flash-protection boundary for all equipment

Source: IEEE-1584-2002

IEEE 1584-2018 The 10 step program

1. Collect system and installation data
2. Determine the system modes of operation
3. Determine bolted fault currents
4. Determine typical gap and enclosure size based on system voltages and classes of equipment
5. Determine equipment electrode configuration (HCB, VOA, etc.)
6. Determine working distances
7. Calculate arcing current
8. Calculate arc duration (through OCPD)
9. Calculate Incident energy (IE)
10. Determine arc flash boundary for all equipment

Note: Black=new for study engineer, Red=new for software

Source: IEEE-1584-2018

IEEE 1584-2018 Highlights

Electrode configuration

Electrode Configuration

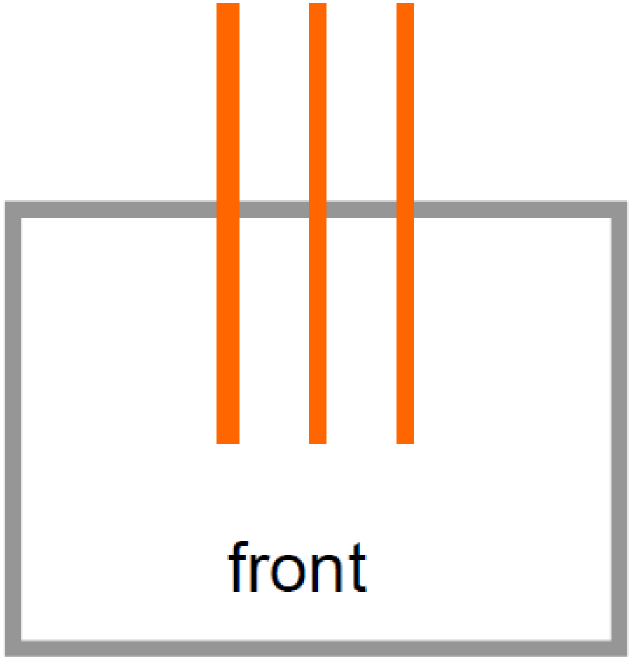
Now Includes Five Vertical *and* Horizontal Configurations

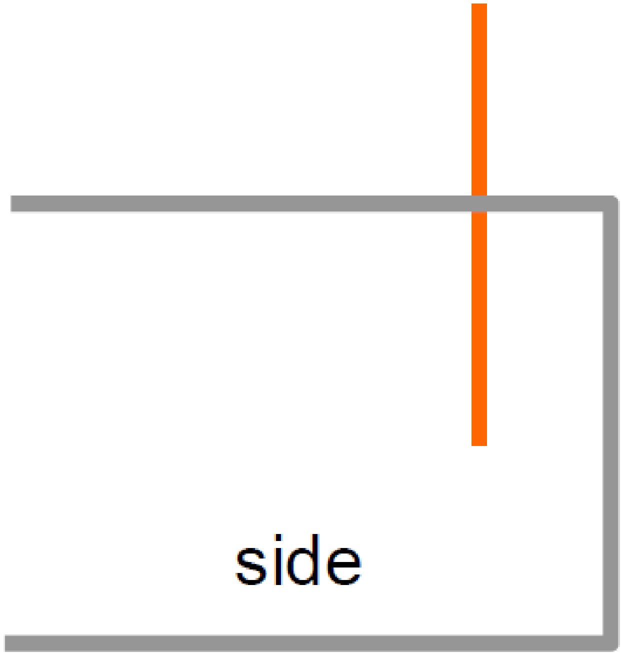
Source: IEEE-1584-2018

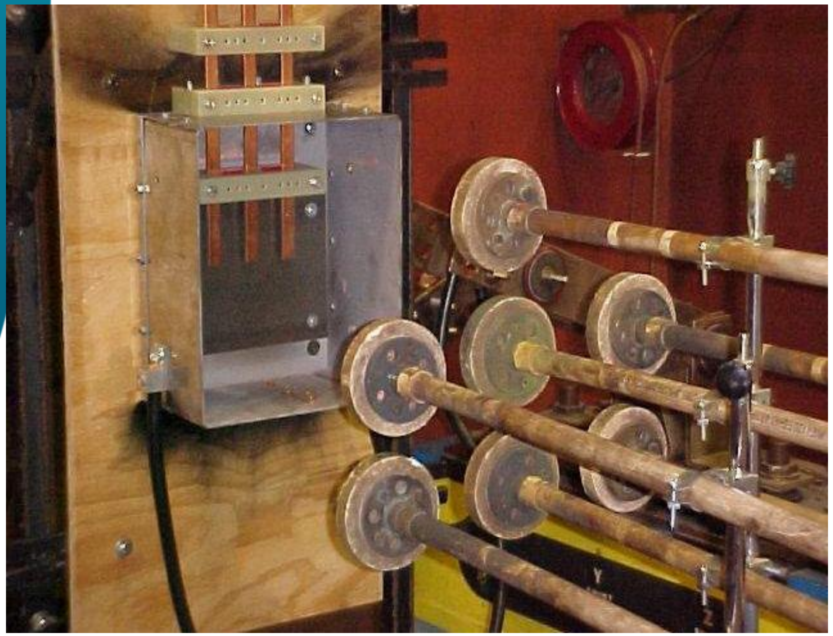
- VCB
  - Vertical Conductors in a Box (IEEE 2002)
- VCBB
  - Vertical Conductors in a Box with an insulating Barrier
- HCB
  - Horizontal Conductors in a Box
- VOA
  - Vertical Conductors in Open Air (IEEE 2002)
- HOA
  - Horizontal Conductors in Open Air

Electrode Configuration

VCB Vertical Conductors in a Box (IEEE-2002)



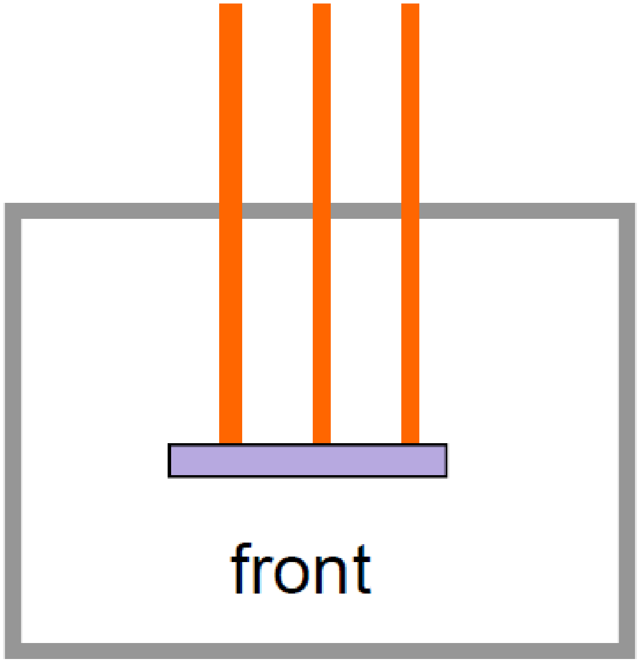


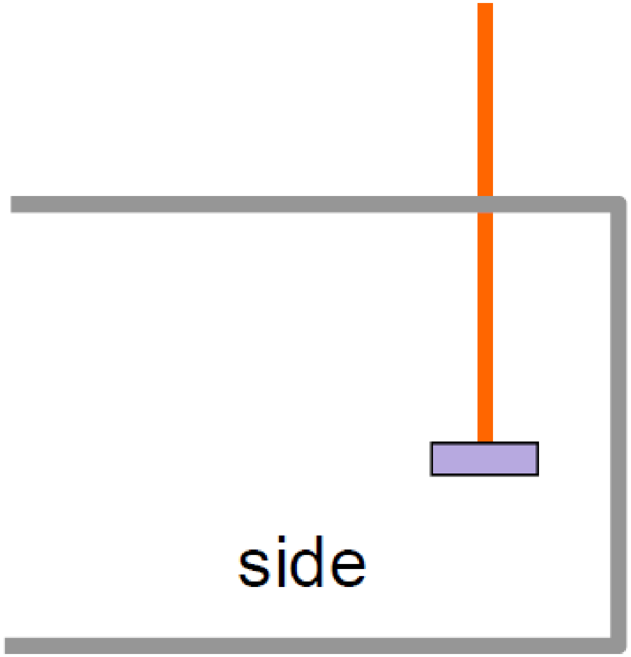


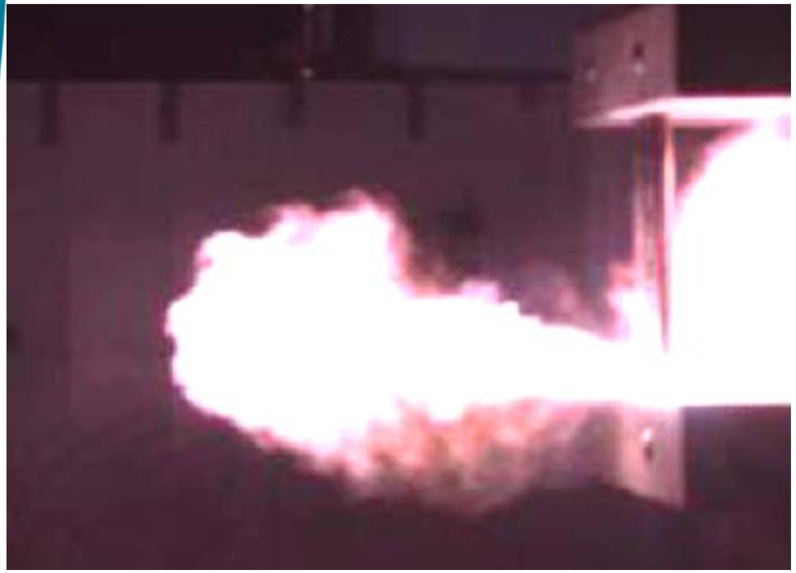
Source: PCIC-2019 Tutorial 1&7

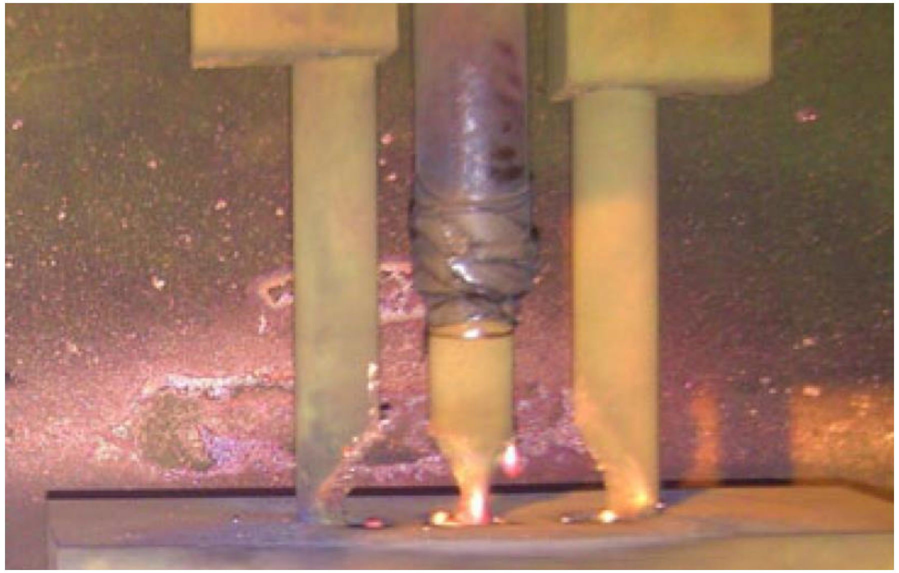
Electrode Configuration

VCBB Vertical Conductors in a Box with a Barrier









Source: PCIC-2019 Tutorial 1&7

Key Findings

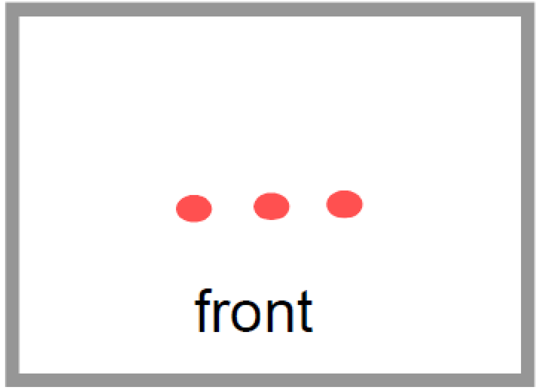
VCBB

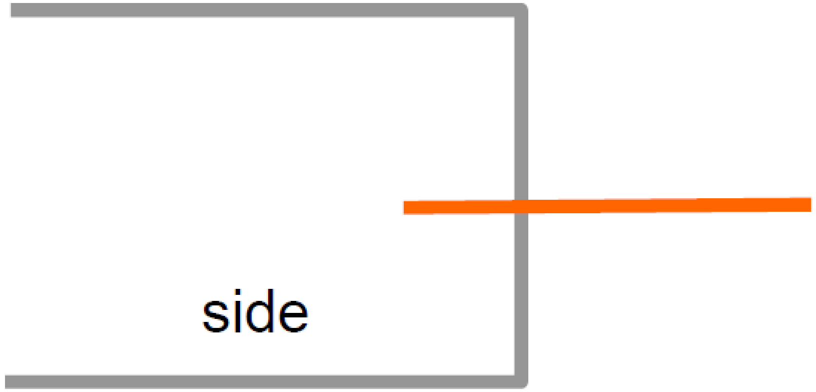
- For LV - IE up to 2x that of VCB
- Arcing current (I_{arc}) reported to be higher than VCB
- 208V arcs sustained down to 4kA
    - According to testing electrode shape and gap are important at this level

Source: PCIC-2019 Tutorial 1&7

Electrode Configuration

HCB Horizontal Conductors in a Box





Source: PCIC-2019 Tutorial 1&7

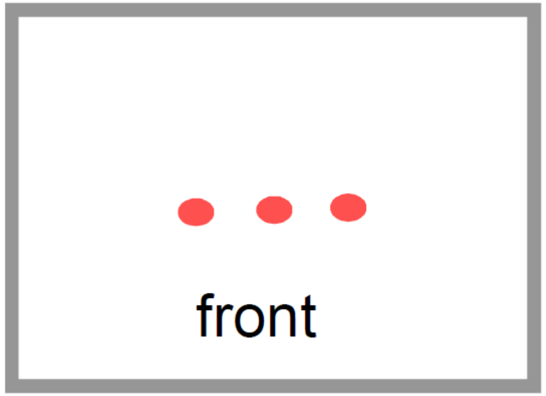
Electrode Configuration

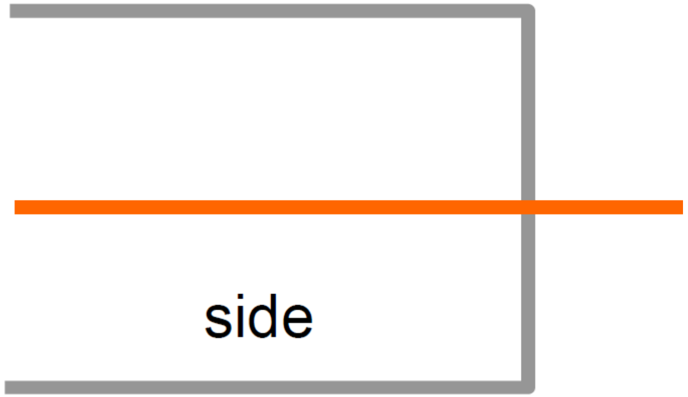
VOA Horizontal Conductors in a Open Air

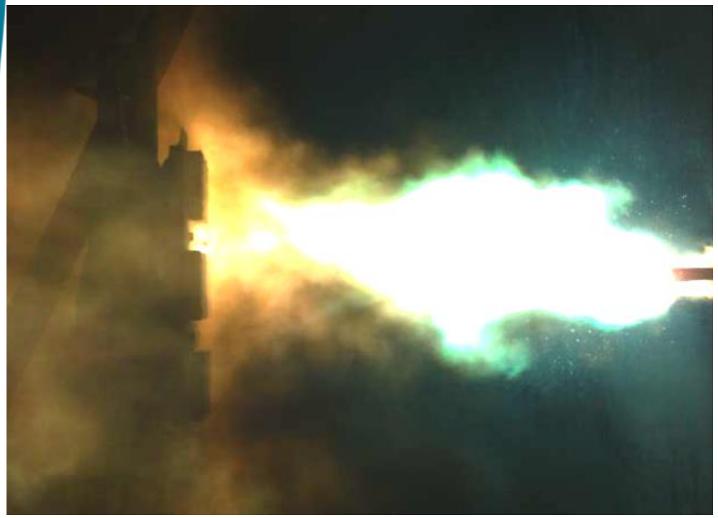
Source: PCIC-2019 Tutorial 1&7

Electrode Configuration

HOA Horizontal Conductors in a Open Air





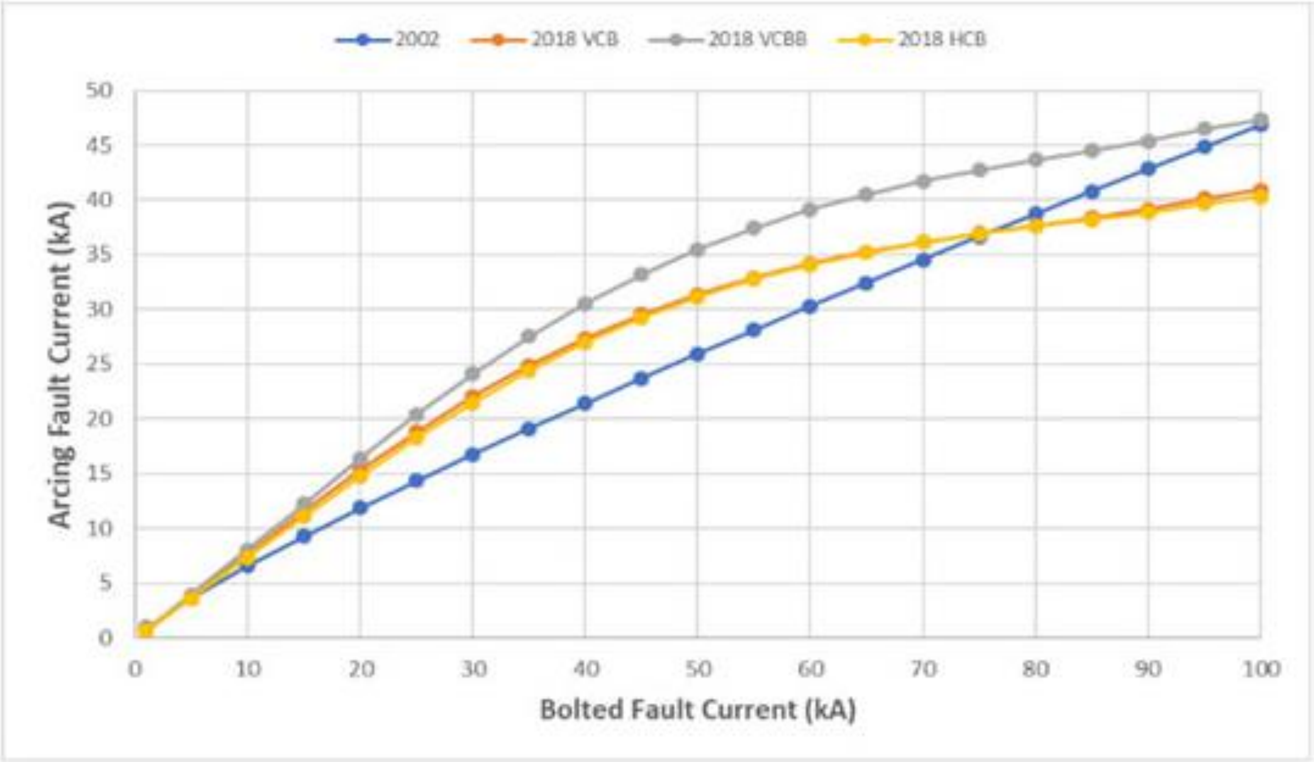


Source: PCIC-2019 Tutorial 1&7

Arcing fault
vs
Bolted fault

LV System

100ms clearing time



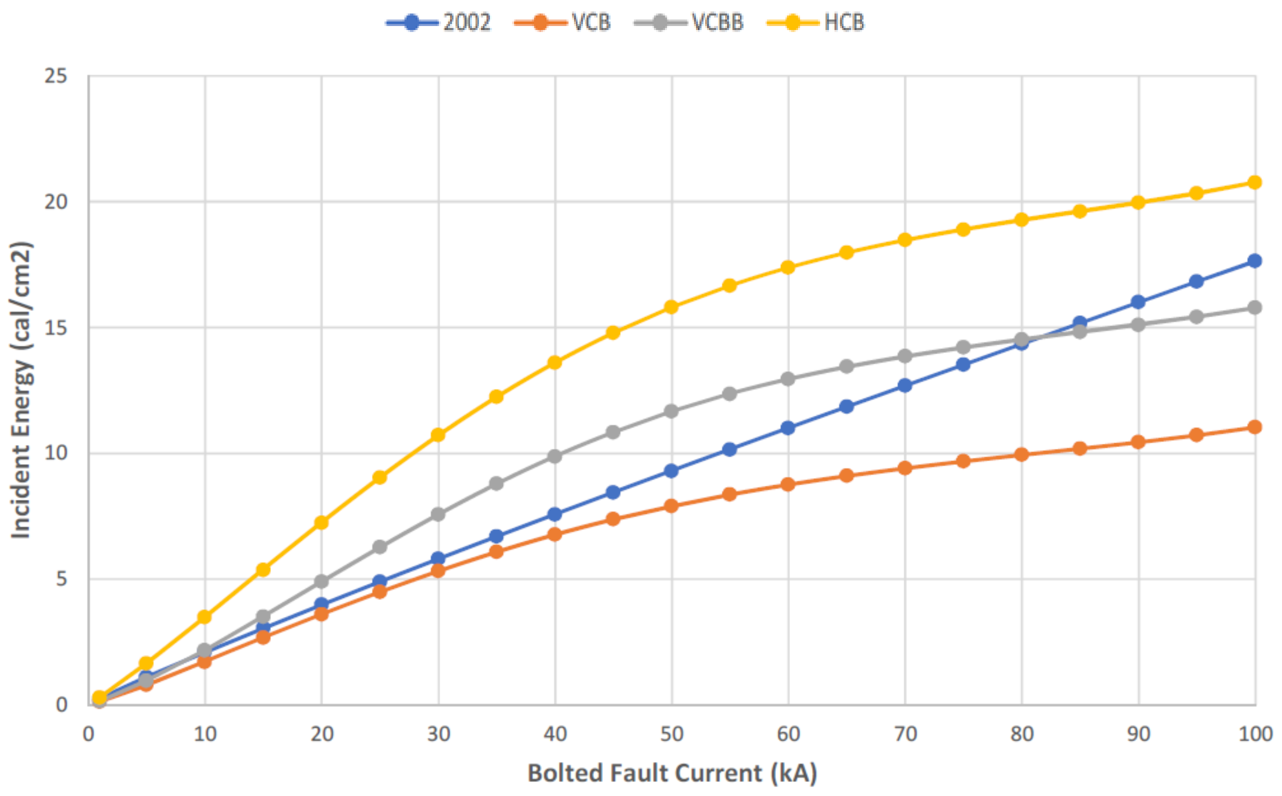
The maximum arcing fault spread is 25-40% higher

Source: PCIC-2019 Tutorial 1&7

Incident Energy vs Bolted Fault

480V system

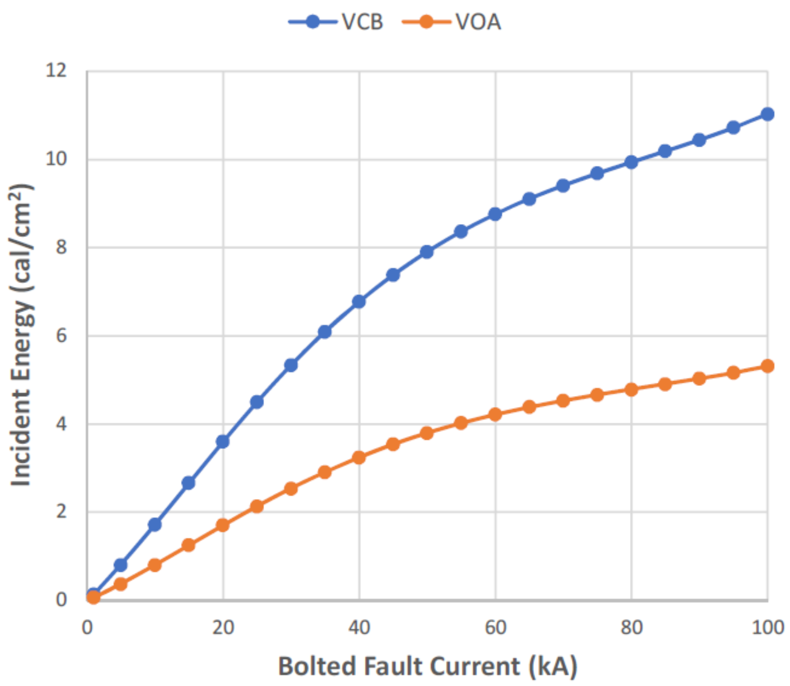
Clearing time-100ms

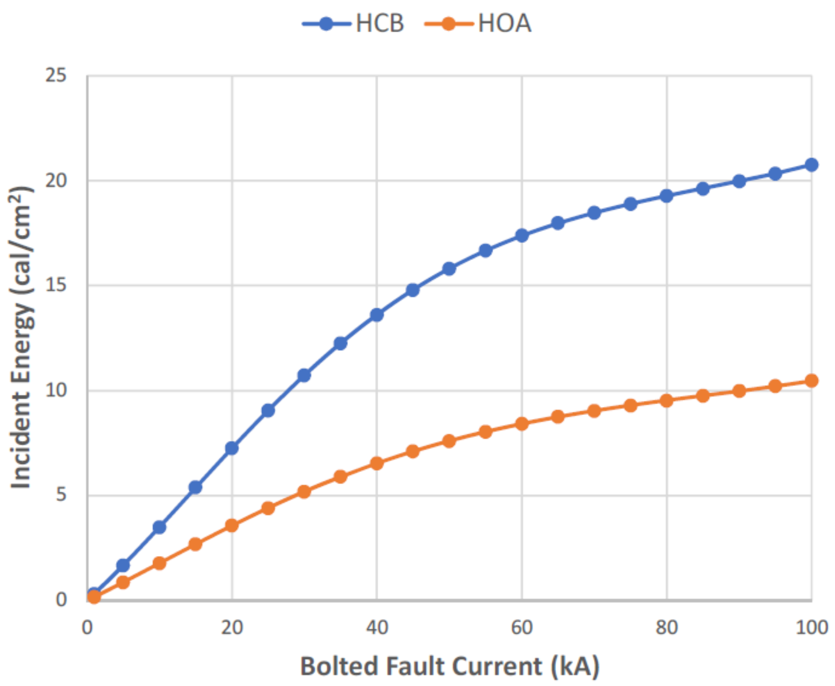


Source: PCIC-2019 Tutorial 1&7

Incident Energy vs Bolted Fault

Box vs Open Air

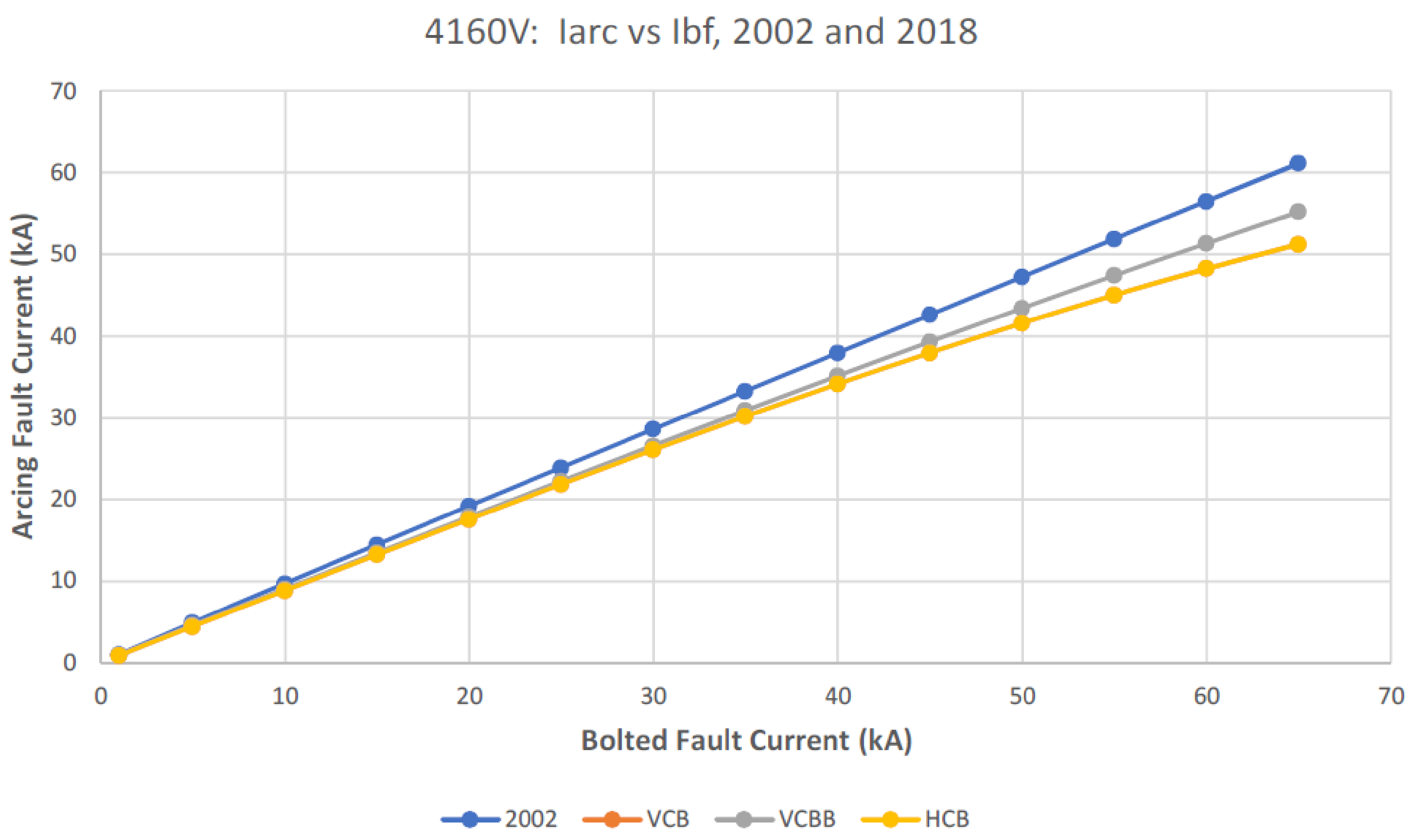




Source: PCIC-2019 Tutorial 1&7

Arc Fault
vs
Bolted Fault

MV System



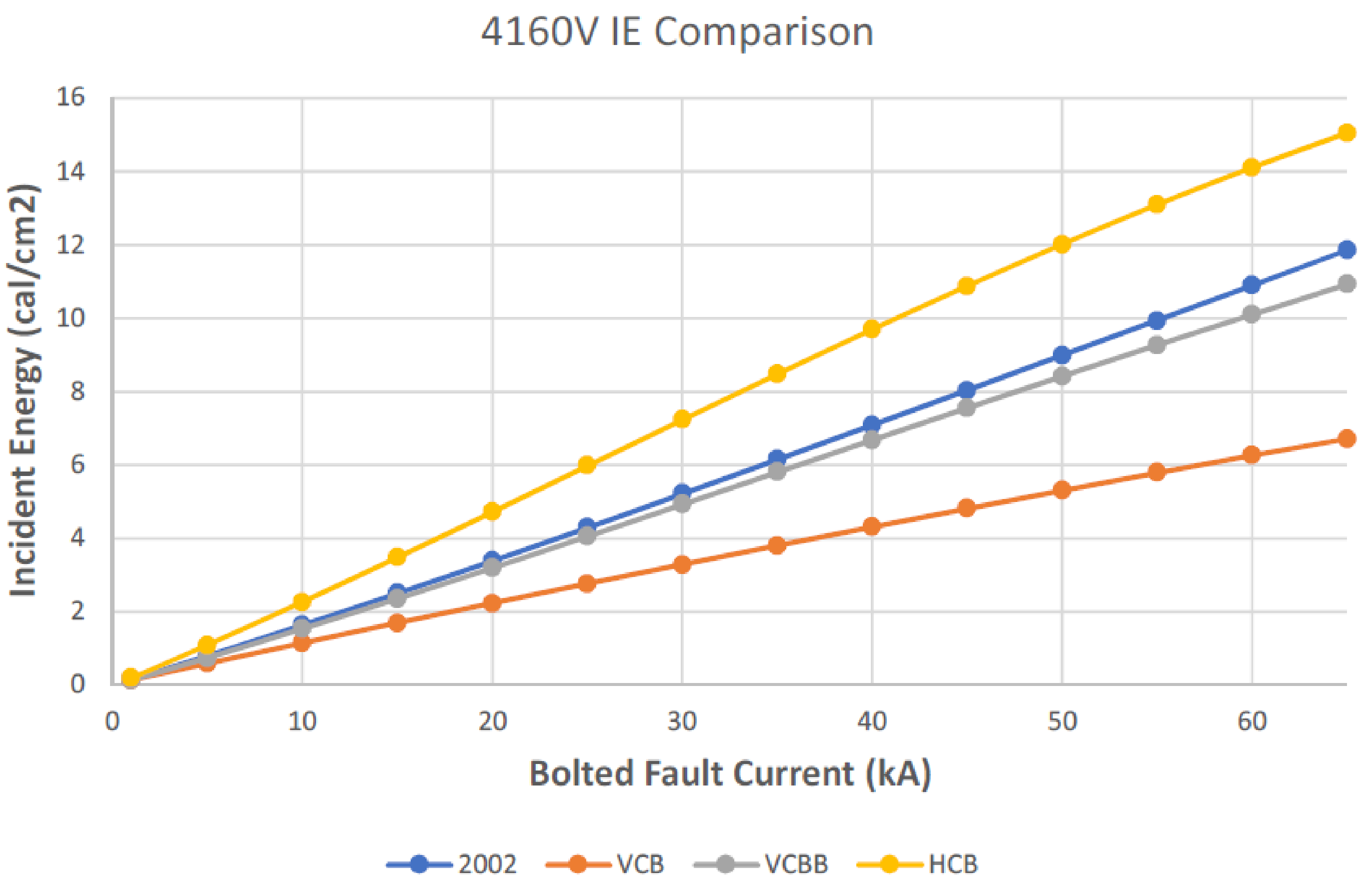
New Model considers the effect of arc impedance at high fault current levels

Source: PCIC-2019 Tutorial 1&7

Incident Energy vs Bolted Fault

4160-SWGR

Clearing time- 100ms



More linear than LV, but bigger spread

Source: PCIC-2019 Tutorial 1&7

VCBB vs. VCB

IEEE-1584-2018

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Equip Type	Equip Category	Electrode Config	Box Width (in)	Box Height (in)	Box Depth (in)	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)
1	2.4KV LBS	PB106-RELAY ML745	2.40	15.04	12.13	10.12	8.16	2.029	0.0830	SWG	5KV LBS	VCB	36	90	30	104	219	36	20.4
1	2.4KV LBS	PB106-RELAY ML745	2.40	15.04	12.87	10.12	8.65	1.729	0.0830	SWG	5KV LBS	VCBB	36	90	30	104	203	36	24.4

IEEE-1584-2002

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)
1	2.4KV LBS	PB106-RELAY ML745	2.40	15.04	14.50	10.12	9.75	1.274	0.0830	No	SWG	104	685	36	21.0

VCB vs. VCBB vs. HCB

IEEE-1584-2018

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Equip Type	Gap (mm)	Busbar Config	Box Width (in)	Box Height (in)	Box Depth (in)	Working Distance (in)	Arc Flash Boundary (in)	Incident Energy (cal/cm2)
1	PNBD0 VCB	400A FDR	0.48	6.38	6.38	4.19	0.303	0.0000	PNL	25	VCB	25	40	10	18	31	2.79
2	PNBD1 VCBB	400A FDR0	0.48	6.38	6.38	4.43	0.2761	0.0000	PNL	25	VCBB	25	40	10	18	30	3.04
3	PNBD2 HCB	400A FDR1	0.48	6.38	6.38	3.97	0.3317	0.0000	PNL	25	HCB	25	40	10	18	40	6.11

IEEE-1584-2002

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Ground	Equip Type	Gap (mm)	Working Distance (in)	Arc Flash Boundary (in)	Incident Energy (cal/cm2)
1	PNBD2002	400A FDR2	0.48	6.38	6.38	3.80	0.3577	0.0000	Yes	PNL	25	18	39	4.17

So, what is going on here??

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Equip Type	Equip Category	Electrode Config	Box Width (in)	Box Height (in)	Box Depth (in)	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)
1	#1-75KVA FED LP-RP	90A, BD CAL-2-34A2	0.208	4.76	1.76	4.76	1.76	2.781	0.0000	PNL	240V-LP-RP LG	VCB	20	20	8	25	71	18	10.6
2	#2-75KVA FED LP-RP VCBB	90A, BD CAL-2-34A6	0.208	4.76	1.94	4.76	1.94	2.119	0.0000	PNL	240V-LP-RP LG B	VCBB	20	20	8	25	54	18	8.68
3	#3-75KVA FED LP-RP 100A FDR	100A, BD CAL-2-34A3	0.208	4.76	1.76	4.76	1.76	3.684	0.0000	PNL	240V-LP-RP LG	VCB	20	20	8	25	84	18	14.0
4	#4-75KVA FED LP-RP VCBB 100A	100A, BD CAL-2-34A9	0.208	4.76	1.94	4.76	1.94	2.791	0.0000	PNL	240V-LP-RP LG B	VCBB	20	20	8	25	63	18	11.4
5	#5-75KVA FED LP-RP 125A FDR	125A, BD CAL-2-34A4	0.208	4.76	2.04	4.76	2.04	4	0.0000	PNL	240V-LP-RP LG	VCB	20	20	8	25	97	18	17.6
6	#6-75KVA FED LP-RP VCBB 125A	125A, BD CAL-2-34A1 0	0.208	4.76	1.94	4.76	1.94	4	0.0000	PNL	240V-LP-RP LG B	VCBB	20	20	8	25	77	18	16.4

Takeaways

Configuration Matters!!

- Electrode configuration makes a big difference in IE
- HCB has worst case IE
- VCB/VCBB-Which to Use? Depends on the OCPD characteristics
  - If not sure on equipment, run both and take more conservative number
- HOA & VCB- IE is close at LV

Takeaways

Electrode configuration makes the biggest difference

- Software makes study engineer choose
- HCB – Highest Incident Energy
  - Drawout Switchgear
  - Busduct stabs
  - Tranformers
  - Termination compartments

The above information is a list of examples only, only the qualified Study Engineer can decide on what selections to use.

Examples

Electrode configuration makes the biggest difference

HCB

600V Drawout Switchgear

600V Drawout Switchgear with Iron Frame

600V Drawout Switchgear breaker compartment

The above information is a list of examples only, only the qualified Study Engineer can decide on what selections to use.

Source: PCIC-2019 Tutorial 1&7

HCB-Transformers

Examples

Electrode configuration makes the biggest difference

15kV / 480V Transformer compartments

480V Transformer compartments

The above information is a list of examples only, only the qualified Study Engineer can decide on what selections to use.

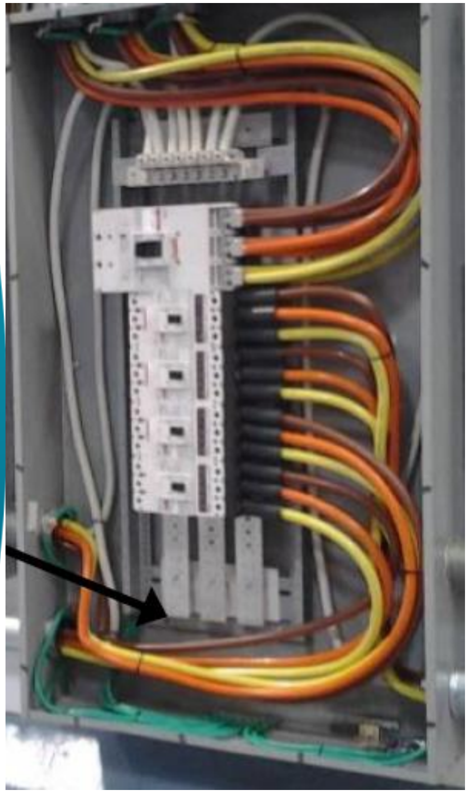
Source: PCIC-2019 Tutorial 1&7

Takeaways

Electrode configuration makes the biggest difference

Source: PCIC-2019 Tutorial 1&7

VCB vs. VCBB



Low Voltage Power Distribution PNL

Low Voltage Switchboard

Low Voltage Fused Disconnect

The above information is a list of examples only, only the qualified Study Engineer can decide on what selections to use.

IEEE 1584-2018 Highlights

Enclosure Dimensions

Enclosure Dimensions

Correction Factor for Larger Enclosures

- Equations normalized for a “typical” box size (20”x20”x20”)
- CF used when box is bigger than typical
  - Usually found in submittals
- Record enclosure height and width to determine the “equivalent” box size
  - Between 20” and 26”
  - Between 26” and 49”
    - Greater than 49” use 49”

Source: IEEE-1584-2018

Enclosure Dimensions

Shallow Option Added

- Box considered “shallow” when
  - Height and width both less than 20 inches
  - The depth is less than 8”
  - System voltage is less than 600V

Source: IEEE-1584-2018

Box Dimensions

		Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Equip Type	Equip Category	Electrode Config	Box Width (in)	Box Height (in)	Box Depth (in)	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)
Typical	1	CTL PANEL 14-12-12	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	17.34	22.70	17.25	0.05	0.0000	PNL	CTL PNL 14-12-12	VCB	12	14	12	25	25	18	2.06
Shallow	2	CTL PANEL 14-12-8	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	17.34	22.70	17.25	0.05	0.0000	PNL	CTL PNL 14-12-8	VCB	12	14	8	25	20	18	1.37
Typical	3	CTL PANEL 20-20-20	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	17.34	22.70	17.25	0.05	0.0000	PNL	CTL PNL 20-20-20	VCB	20	20	20	25	25	18	2.06
Typical	4	CTL PANEL 48-20-20	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	17.34	22.70	17.25	0.05	0.0000	PNL	CTL PNL 48-20-20	VCB	20	48	20	25	22	18	1.64
Typical	5	CTL PANEL 48-48-12	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	17.34	22.70	17.25	0.05	0.0000	PNL	CTL PNL 48-48-12	VCB	48	48	12	25	21	18	1.56
Typical	6	CTL PANEL 48-48-20	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	17.34	22.70	17.25	0.05	0.0000	PNL	CTL PNL 48-48-20	VCB	48	48	20	25	21	18	1.56

		Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Bus Arcing Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Equip Type	Equip Category	Electrode Config	Box Width (in)	Box Height (in)	Box Depth (in)	Gap (mm)	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)
Typical	1	CTL PANEL 14-12-12 B	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	18.69	22.70	18.58	0.05	0.0000	PNL	CTL PNL 14-12-12 B	VCBB	12	14	12	25	29	18	2.84
Shallow	2	CTL PANEL 14-12-8 B	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	18.69	22.70	18.58	0.05	0.0000	PNL	CTL PNL 14-12-8 B	VCBB	12	14	8	25	26	18	2.29
Typical	3	CTL PANEL 20-20-20 B	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	18.69	22.70	18.58	0.05	0.0000	PNL	CTL PNL 20-20-20 B	VCBB	20	20	20	25	29	18	2.84
Typical	4	CTL PANEL 48-20-20 B	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	18.69	22.70	18.58	0.05	0.0000	PNL	CTL PNL 48-20-20 B	VCBB	20	48	20	25	27	18	2.49
Typical	5	CTL PANEL 48-48-12 B	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	18.69	22.70	18.58	0.05	0.0000	PNL	CTL PNL 48-48-12 B	VCBB	48	48	12	25	26	18	2.29
Typical	6	CTL PANEL 48-48-20 B	SUB 7 MCC #1 7-5 ac pro	0.48	22.82	18.69	22.70	18.58	0.05	0.0000	PNL	CTL PNL 48-48-20 B	VCBB	48	48	20	25	26	18	2.29

Takeaways

Enclosure configuration

- Box configuration
  - Modest difference
    - Larger box by volume=less conservative by a little
    - Shallow box=less conservative=smaller IE
    - Default enclosure size usually sufficient
  - Software packages use defaults
    - When on the bubble between two PPE levels go back and investigate box size

The above information is a list of examples only, only the qualified Study Engineer can decide on what selections to use.

IEEE 1584-2018 Highlights

Conductor Gap

Conductor Gap – Defined

- Gap is the distance between conductors
- Greater the gap, greater arc flash incident energy
- Usually not in submittals
  - Dangerous to obtain
  - Is it worth measuring?

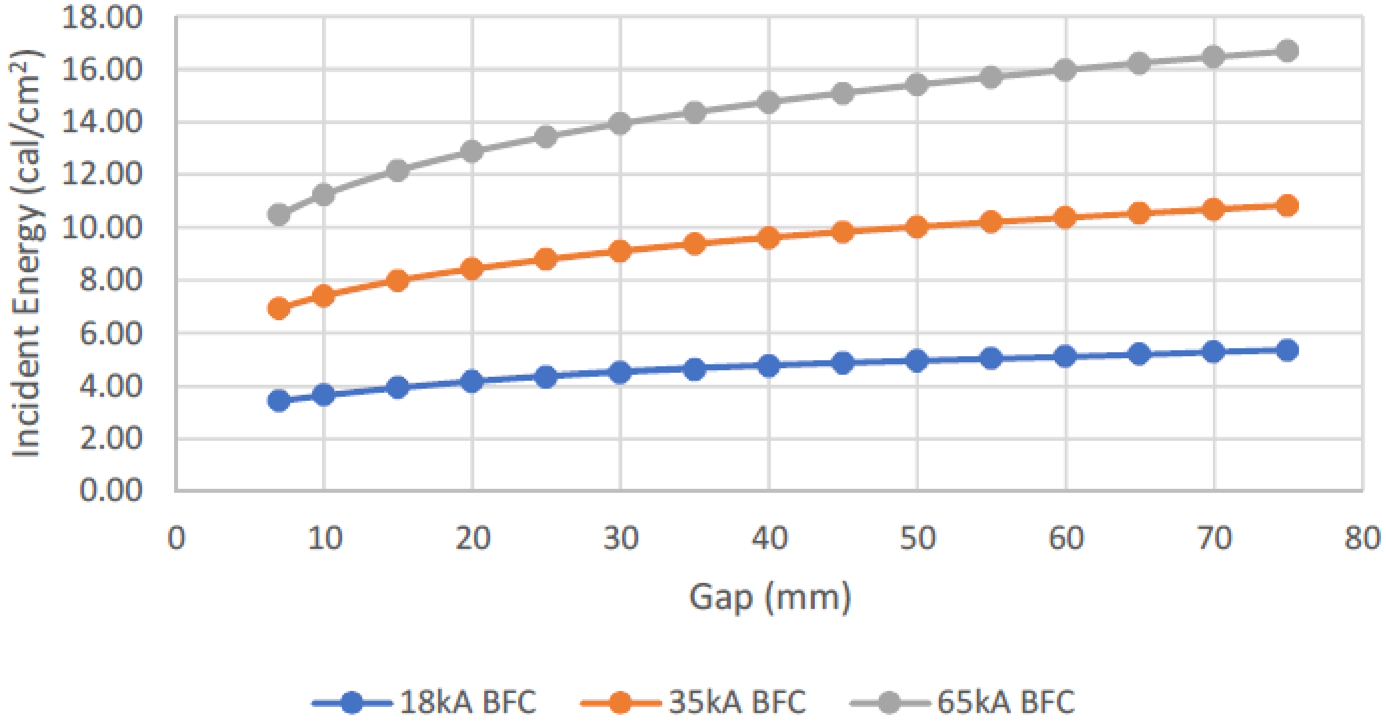
Gaps

	Bus Name	Protective Device Name	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/ Delay Time (sec.)	Breaker Opening Time/Tol (sec.)	Equip Type	Gap (mm)	Busbar Config	Box Width (in)	Box Height (in)	Box Depth (in)	Working Distance (in)	Arc Flash Boundary (in)	Incident Energy (cal/cm2)
1	VCBB 25mmGAP	400A FDR3	0.48	6.38	6.38	4.43	0.2761	0.0000	PNL	25	VCBB	25	40	10	18	30	3.04
2	VCBB 45mmGAP	400A FDR4	0.48	6.38	6.38	4.26	0.2949	0.0000	PNL	45	VCBB	25	40	10	18	33	3.63
3	VCBB 60mmGAP	400A FDR5	0.48	6.38	6.38	4.18	0.3044	0.0000	PNL	60	VCBB	25	40	10	18	35	3.96
4	VCBB 75mmGAP	400A FDR6	0.48	6.38	6.38	4.12	0.312	0.0000	PNL	75	VCBB	25	40	10	18	36	4.23

IE vs BF

LV system

VCB



Source: PCIC-2019 Tutorial 1&7

Conductor Gap – Typical

Table 8—Classes of equipment and typical bus gaps

Equipment class	Typical bus gaps (mm)	Enclosure Size (H × W × D)	
		SI units (metric)	Imperial units
15 kV switchgear	152	1143 mm × 762 mm × 762 mm	45 in × 30 in × 30 in
15 kV MCC	152	914.4 mm × 914.4 mm × 914.4 mm	36 in × 36 in × 36 in
5 kV switchgear	104	914.4 mm × 914.4 mm × 914.4 mm	36 in × 36 in × 36 in
5 kV switchgear	104	1143 mm × 762 mm × 762 mm	45 in × 30 in × 30 in
5 kV MCC	104	660.4 mm × 660.4 mm × 660.4 mm	26 in × 26 in × 26 in
Low-voltage switchgear	32	508 mm × 508 mm × 508 mm	20 in × 20 in × 20 in
Shallow low-voltage MCCs and panelboards	25	355.6 mm × 304.8 mm × ≤203.2 mm	14 in × 12 in × ≤8 in
Deep low-voltage MCCs and panelboards	25	355.6 mm × 304.8 mm × >203.2 mm	14 in × 12 in × >8 in
Cable junction box	13	355.6 mm × 304.8 mm × ≤203.2 mm or 355.6 mm × 304.8 mm × >203.2 mm	14 in × 12 in × ≤8 in or 14 in × 12 in × >8 in

Source: IEEE-1584-2018

Takeaways

For Gap

- Gap
  - Wider gap=more conservative (Higher IE)
  - Software packages use defaults
  - Be reasonable in choosing gap

The above information is a list of examples only, only the qualified Study Engineer can decide on what selections to use.

IEEE 1584-2018

Other Key Changes

125kVA Transformer Exception

2002 vs. 2018

"Equipment below 240 V need not be considered unless it involves at least one 125kVA or larger low-impedance transformer in its immediate power supply."

Replaced with "Sustainable arcs are possible but less likely in three-phase systems operating at 240V nominal or less with an available short circuit current below 2000 Amps."

Source: IEEE-1584-2018 & IEEE-1584-2002

125kVA Transformer Exception

What Does this 2018 Change Mean to You

- More equipment must be included in your study
  - Every device from your 125kVA transformers down to your 30kVA transformers
  - Could dramatically impact the scope and cost of your facility arc flash hazard analyses
  - Should be addressed during your next study update or before

2-second Rule

No Change

- Basically says most people can move away from an arc flash in less than two seconds, but could be slowed down by:
  - Obstacles or barriers
  - Being elevated in a bucket
  - Being restrained by other safety equipment, etc.
- Your studies professional must "use engineering judgement when applying any maximum arc duration time for incident energy exposure calculations"

Source: IEEE-1584-2018

In-Closing

IEEE 1584

Study Complexity

- New standard makes modeling more complex
  - Based on test data (not theoretical)
  - More accurate
    - Some arc flash values are higher, some lower
- Strongly suggest using commercial software for analysis

General Guide

- Stay in communication with your Qualified Arc Flash Engineer/ Client on what is going on, be reasonable in your assumptions.
  - Vendors are not opening/maintaining equipment if AFIE high
- One label per equipment, keep it simple
- Manufacturers – Spending $$ on lowering AFIE in their equipment
- Design Engineers – Safety by design
  - Must decide if critical load can be de-energized, if not, how to maintain it?

NFPA-70E

Shut down

It's the law!!

130.1- Electrically Safe Work Conditions.

Energized electrical conductors and circuit parts operating at voltages equal to or greater than 50 volts shall be put into an electrically safe work condition before an employee performs work....

130.1(A)- Energized Work.

(1) 130.1(A)(1)- Additional Hazards or Increased Risk.

Energized work shall be permitted where the employer can demonstrate that de-energizing introduces additional hazards or increased risk.

- Interruption of life support
- Deactivation of emergency alarm systems
- Shutdown of hazardous location ventilation equipment

(2) 130.1(A)(2)- Infeasibility

Energized work shall be permitted where the employer can demonstrate that the task to be performed is infeasible in a de-energized state due to equipment design or operation limitations.

- Diagnostics and testing
- Integral part of a continuous process

Source: NFPA 70E-2018

Thank You

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