Understanding the New IEEE 1584-2018 Guide for Performing Arc-Flash Hazard Calculations and the 2017 NEC Arc Energy Reduction Articles

MIPSYCON Safety/Security Session

Tuesday, November 12th, 2019

1-2pm

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ABB

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Agenda

- Understanding the New IEEE 1584-2018 Guide, NFPA 70E, and OSHA
  - IEEE 1584-2018 Inputs: Working Distance, Electrode Gap, Electrode Orientations, and Size Information
  - Multiple and Varying Arcing Currents with IEEE 1584-2018

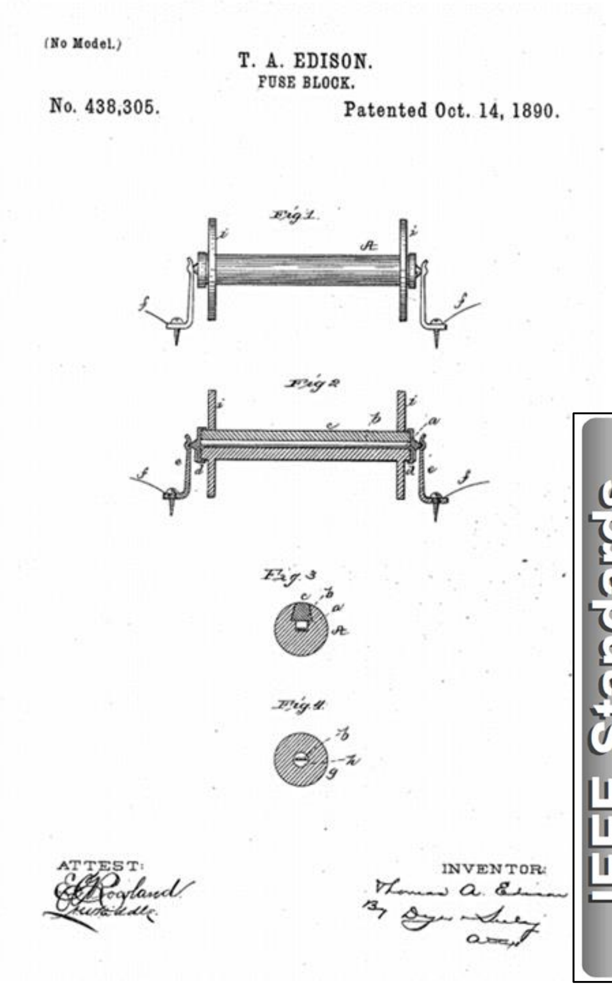
- Review Fuse Clearing Time Problems and the 2020 / 2017 NEC 240.67 Article
  - Case #1: Varying Cable Lengths
  - Case #2, Parts I-III: Varying Transformer Sizes

- 15kV and Below Solutions for New and Retrofit Applications
  - Review Arc Energy Reduction Solutions per 2020 / 2017 NEC 240.67 and 240.87
  - CEU (Continuing Education Unit) Exercises:
    - 240.67 (B)(2)
    - 240.67 (B)(3) and 240.87(B)(4)

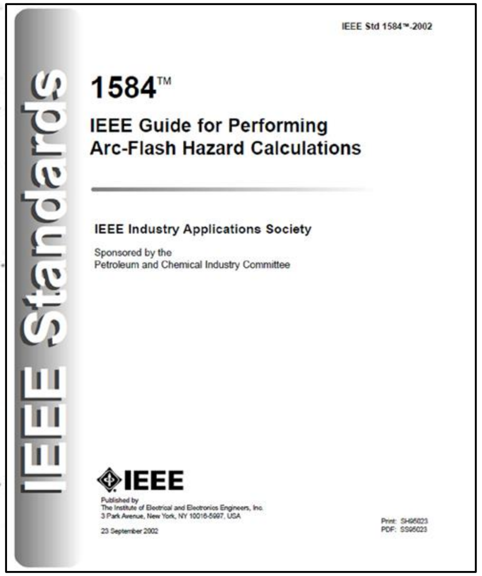
- Understand the Present / Pending Enforcement Maps of the 2020 / 2017 NEC

History

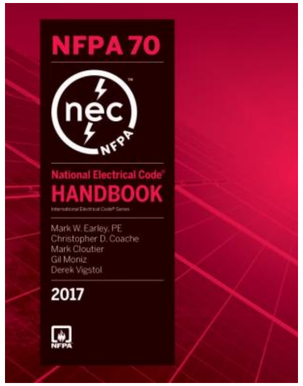
Technology → Standards → Enforcement → Digital → Safety

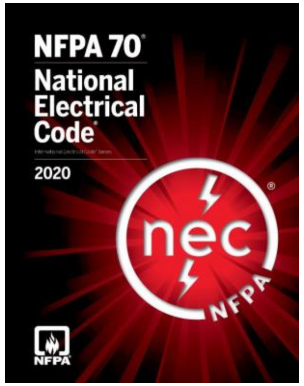


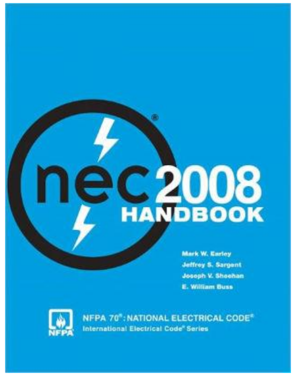
IEEE 1584-2002

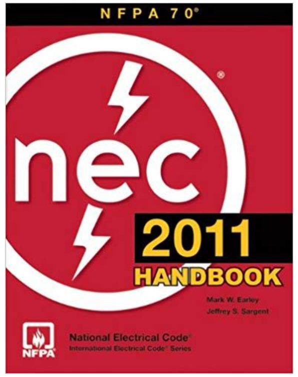


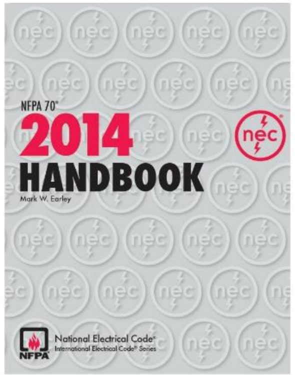
National Electrical Codes*











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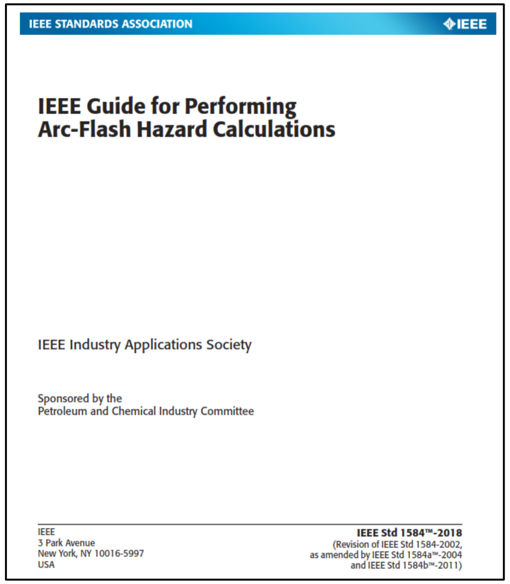
IEEE 1584-2018**



***2017 NEC Reference:** https://www.nfpa.org/NEC/About-the-NEC/Explore-the-2017-NEC
****IEEE 1584-2018 Reference:** https://standards.ieee.org/standard/1584-2018.html

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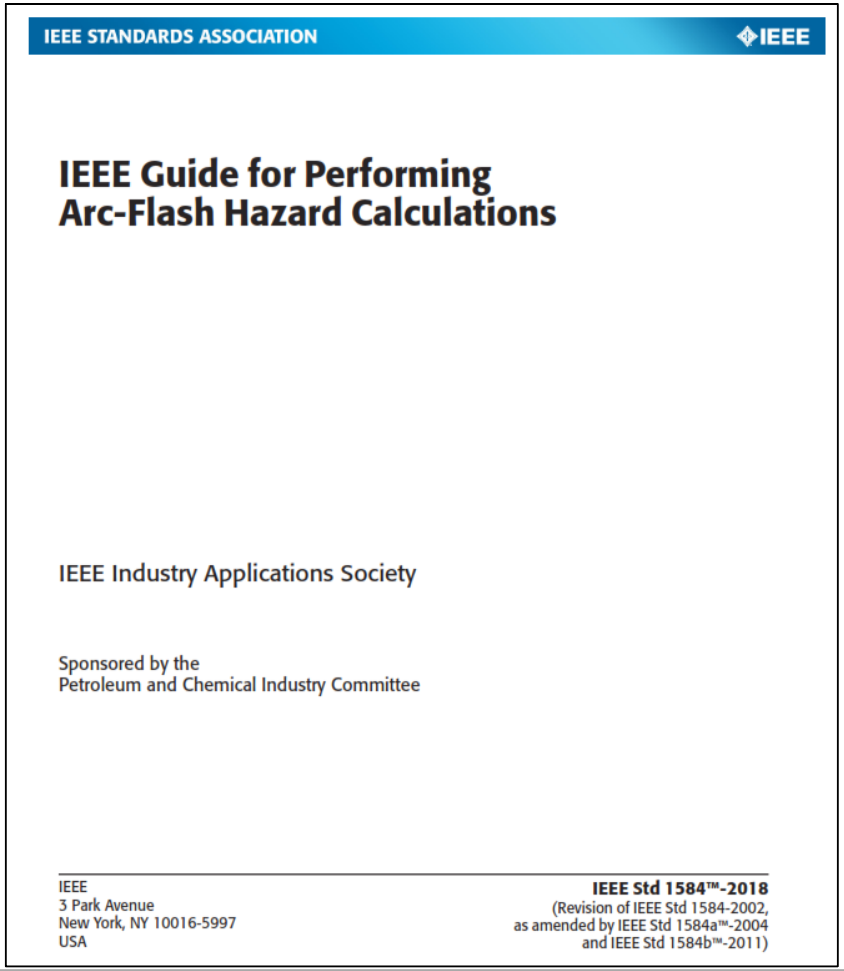
New Equations of Calculating Incident Energy

IEEE 1584 2.0 model is more complex vs. 2002



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)

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

4.6 Intermediate incident energy (*E*)

Use Equation (3) to Equation (6) as follows and Table 3, Table 4, and Table 5 to determine the intermediate incident energy values:

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

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

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

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

where

E_{600}	is the incident energy at $V_{oc} = 600$ V (J/cm^2)
E_{2700}	is the incident energy at $V_{oc} = 2700$ V (J/cm^2)
E_{14300}	is the incident energy at $V_{oc} = 14\,300$ V (J/cm^2)
$E_{\le 600}$	is the incident energy for $V_{oc} \le 600$ V (J/cm^2)

IEEE 1584-2002 vs. IEEE 1584-2018

What is the difference?

IEEE 1584-2002 (version 1.0) calculation variables:

- Gap (G) (equipment type driven)
- Working distance (D)
- Operating voltage (V_{oc})
- Available short circuit current (I_{bf})
- Grounding (yes/no) *(not new model)*
- Box (yes/no)

New IEEE 1584-2018 (version 2.0) adds:

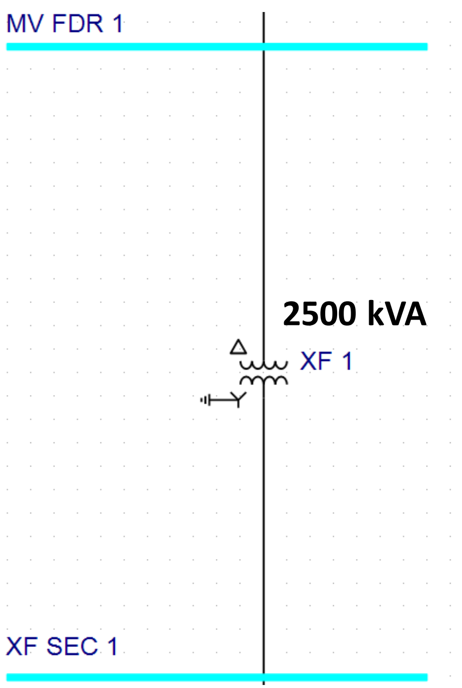
- Electrode orientation
- Electrode environment (barriers?)
- Box size considerations
- More variable gap considerations
- Results may vary significantly
- Arcing Current (Ia)
- Incident Energy (Ei)
- Approach Boundary

Understanding Arc Flash Hazard Calculations

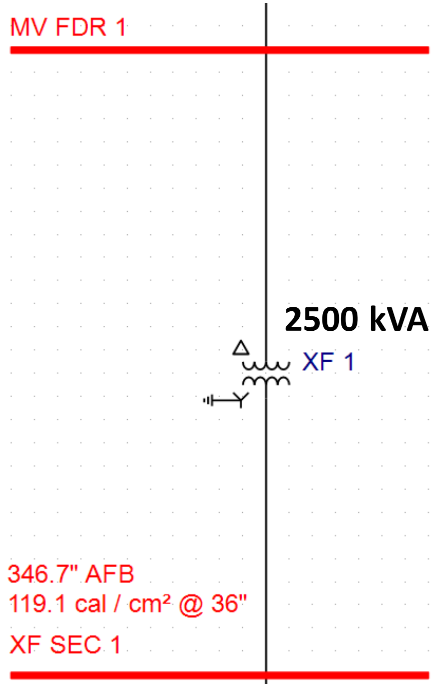
Momentary vs. IEEE 1584-2018/IEEE 1584-2002 Integrated

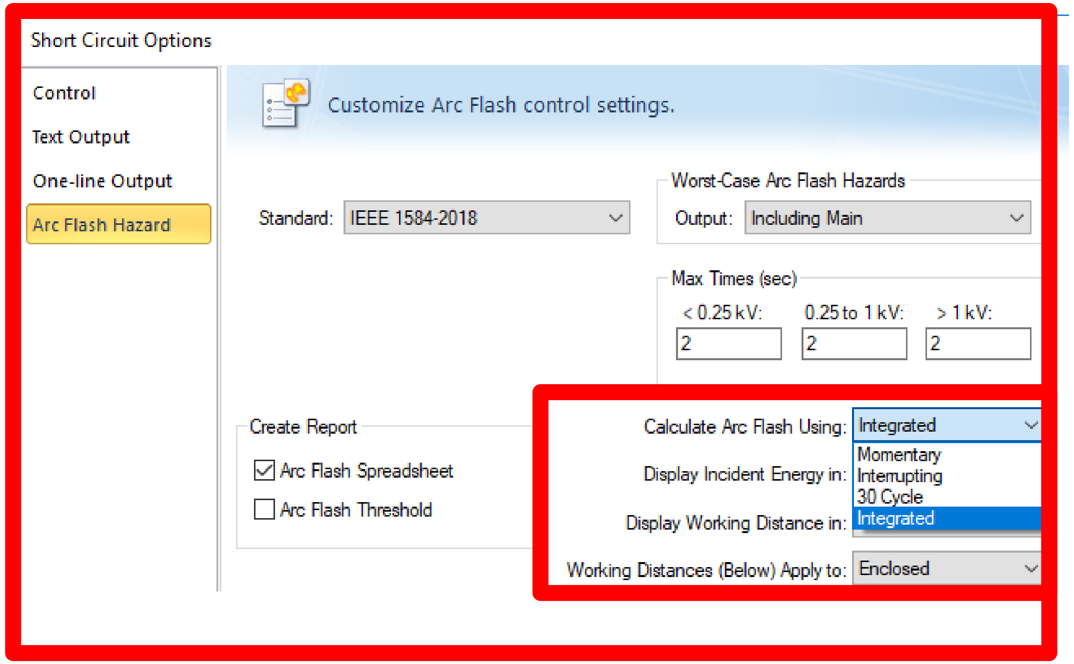
Phase currents and voltages were measured digitally and rms values were computed. Arc power was computed by integrating the products of phase current and voltage and summing the results. Arc energy was computed by integrating arc power over the arc duration. Typically, all of the described data manipulation was performed using the menu/computation functions resident on the digital oscilloscope.

Momentary



Integrated*





*EasyPower Webinar "Basics Steps in EasyPower to Conduct and Arc Flash Study Using the New IEEE 1584–2018 Model": https://www.easypower.com/resources/webinars

Electrode Configuration is a Big Change!

From two (2) event modes to five (5)

- The orientation and arrangement of the electrodes used in the testing evolved.
- Electrodes placed in **open-air ("OA")** or **enclosed ("B")** (open front).
- Electrodes were also **oriented vertically ("V")** or **horizontally ("H")**.
- Open space & **barrier-terminated ("B")** electrode configurations also used.
- Electrode configurations defined and listed in the model:

Event Modes

1) **VCB**: Vertical electrodes inside a metal "box" enclosure.
2) **VCBB**: Vertical electrodes terminated in a "barrier," inside a metal "box".
3) **HCB**: Horizontal electrodes inside a metal "box".
4) **VOA**: Vertical electrodes in open air.
5) **HOA**: Horizontal electrodes in open air.

Biggest Difference is Electrode Direction

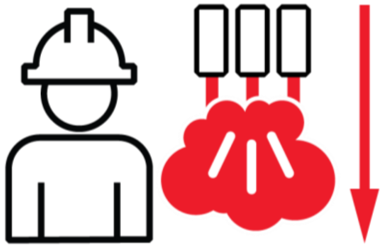
Horizontal versus vertical makes a big difference.

Horizontal electrodes aim plasma at the worker!

Common sense → more dangerous… "plasma rail" aiming at worker!

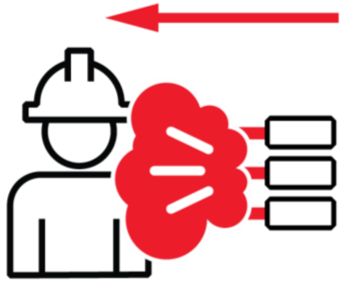
The data confirms it!

OLD MODEL



Heat & plasma bounce around the box & get pushed out via radiation & pressure

Additional in NEW MODEL



Lorentz force pushes arc (plasma) away from "end" of electrodes

Heat & plasma focused on worker

***EasyPower Webinar "Arc Flash the Easy Way - Part 2, Data Collection":**
https://www.easypower.com/resources/article/arc-flash-the-easy-way-part-1-regulations-and-industry-standards

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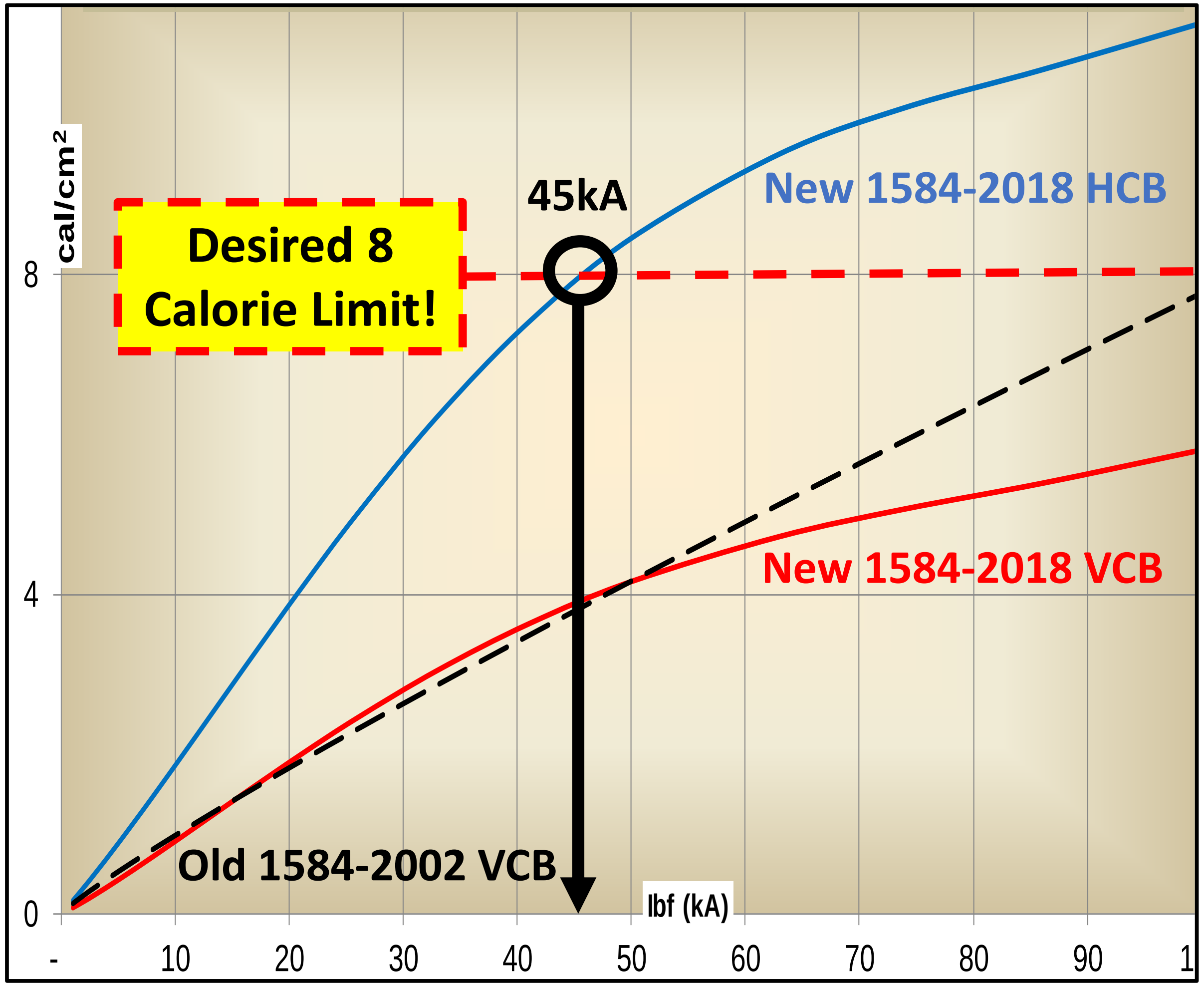
Common Performance Target*

8 cal/cm^2

- Criteria: 0.48/0.277kV Switchgear/Switchboard/MCC, 32mm Working Gap, 18” Working Distance, 0.05 second Clearing Time
- **VCB**: ≤ 8 cal/cm^2 per old or new VCB to 100kA
- **HCB**: ≥ 45kA, 3 cycle clearing time not good enough
- **Protection speed even more important!**

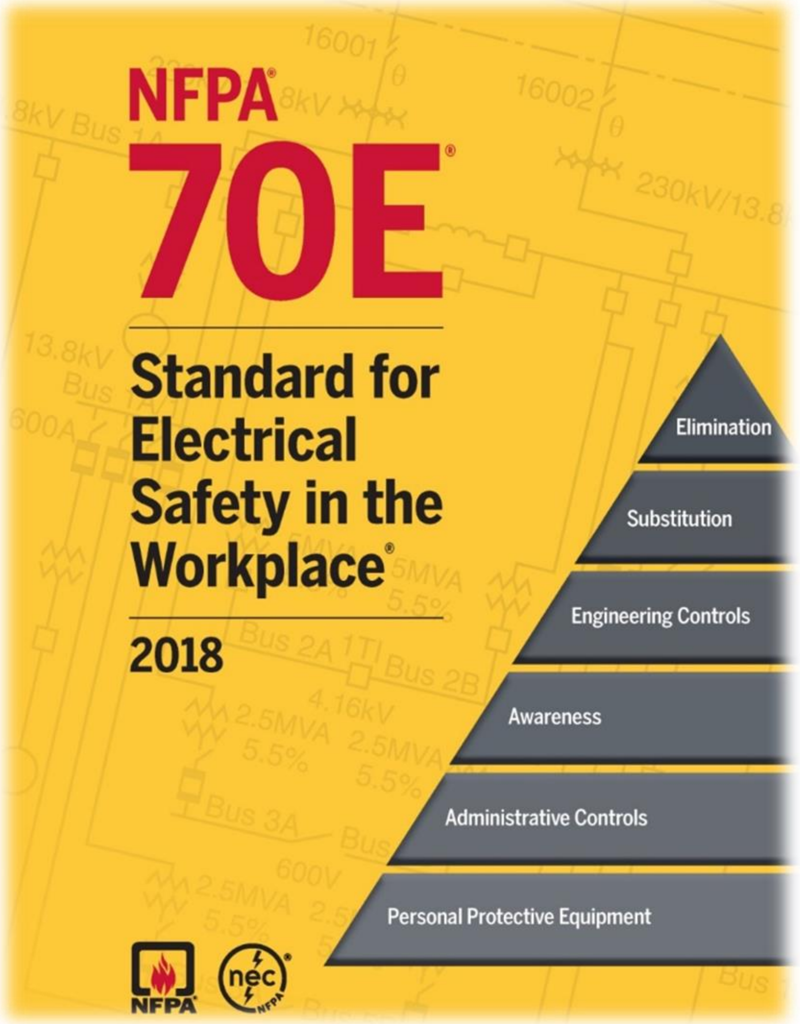
IEEE 1584-2018 vs. IEEE 1584-2002 Analysis

3 Cycle Clearing Time= 0.05 seconds or 50 ms



*IEEE Twin Cities PES/IAS: IEEE 1584 Revolutionary Changes Coming, October 2018: https://meetings.vtools.ieee.org/m/176768
*IEEE San Francisco IAS: NFPA 70E / IEEE 1584: Significant Changes, February 2019: https://events.vtools.ieee.org/m/183482
*IEEE Arrowhead: IEEE 1584 Revolutionary Changes Coming, March 2019: http://sites.ieee.org/arrowhead/event/pes-technical-meeting-ieee-1584-revolutionary-changes-coming/

Hierarchy of Risk Control Methods



Each method is considered less effective than the one before

1) Elimination of the hazard: **Physically removing the hazard** (eliminate switchgear sections, perform de-energized work / turn power off, etc.)

2) Substitution: Replace the hazard with proper design to **lessen the hazard**.

3) Engineering Controls: Isolate people from the hazard with 2020 / 2017 NEC Articles 240.87 and 240.67, **address human error**, etc.

4) Awareness: Education in NEC codes (PDH, CEUs, etc.), safety training, meetings, signage, and culture → **It is up to the individual.**

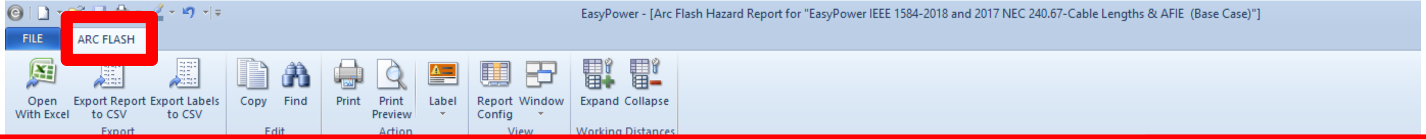
5) Administrative Controls: Document risk procedures/assessments to **address human error**.

6) PPE: IEEE 1584-2018 will guide consultants and end-users to appropriate PPE levels with available technologies. → **It is up to the employer (end-user) to protect workers.**

***EasyPower Webinar "Arc Flash The Easy Way – Part 1, Regulations and Industry Standards":**
https://www.easypower.com/resources/article/arc-flash-the-easy-way-part-1-regulations-and-industry-standards

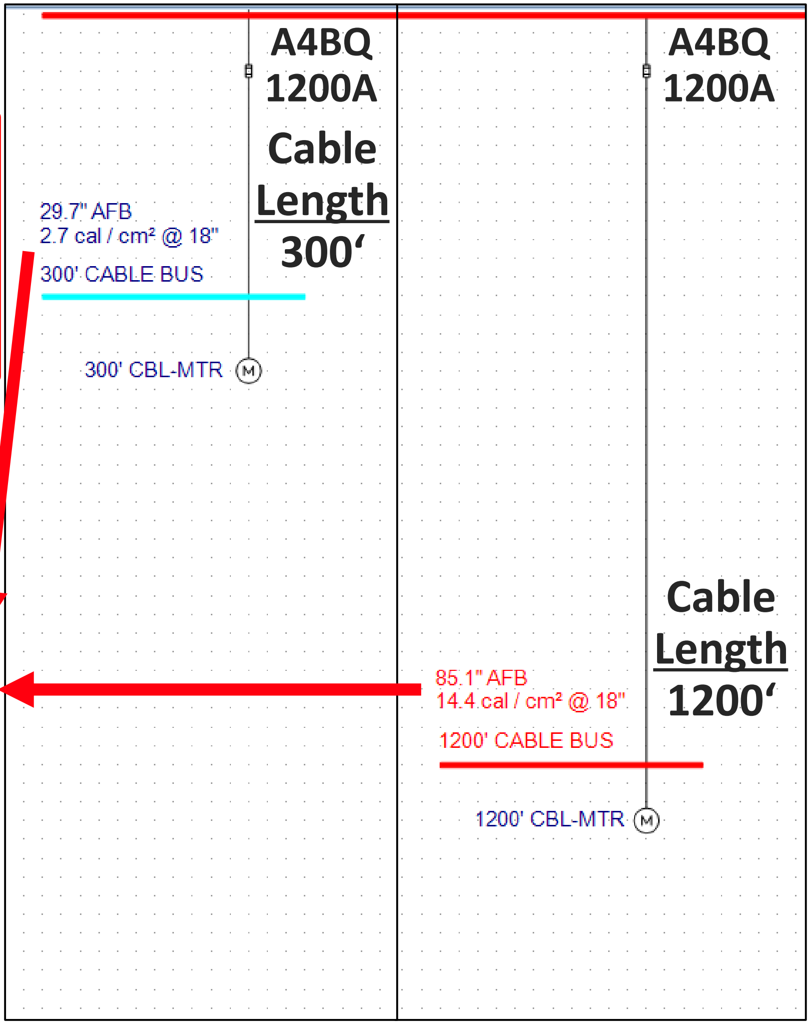
Case #1: Varying Cable Lengths w/ LV Current Limiting Fuses

IEEE 1584-2018
Arcing Current Method



Fuse OCPD		Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
1200A		300' CABLE BUS	0.48	Control Panel	VCB	25	39.874		0.01	+	2.7
1200A		600' CABLE BUS	0.48	Control Panel	VCB	25	28.183		0.015	+	8.9
1200A		900' CABLE BUS	0.48	Control Panel	VCB	25	22.167		0.043	+	10.8
1200A		1200' CABLE BUS	0.48	Control Panel	VCB	25	18.537	12.491	0.489	+	14.4
1200A		1500' CABLE BUS	0.48	Control Panel	VCB	25	16.12	10.892	1.27	+	32.2

Arc Time (sec)		Incident Energy (cal/cm2)
0.01	+	2.7
0.489	+	14.4



4.6 Intermediate Incident Energy (E), pg. 25*

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

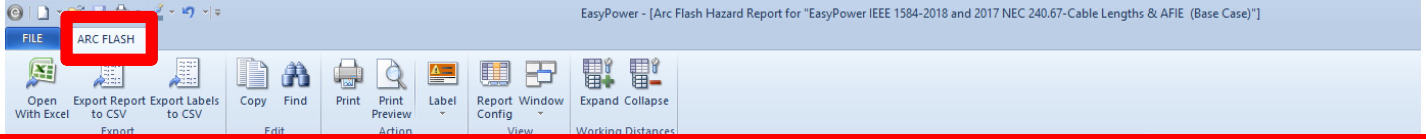
$E_{\le 600}$ is the incident energy for $V_{oc} \le 600$ V (J/cm²)

T is the arc duration (ms)

***IEEE 1584-2018 Reference:** https://standards.ieee.org/standard/1584-2018.html

IEEE 1584-2018
Arcing Current Method

Case #1: Varying Cable Lengths w/ LV Current Limiting Fuses



Fuse OCPD		Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
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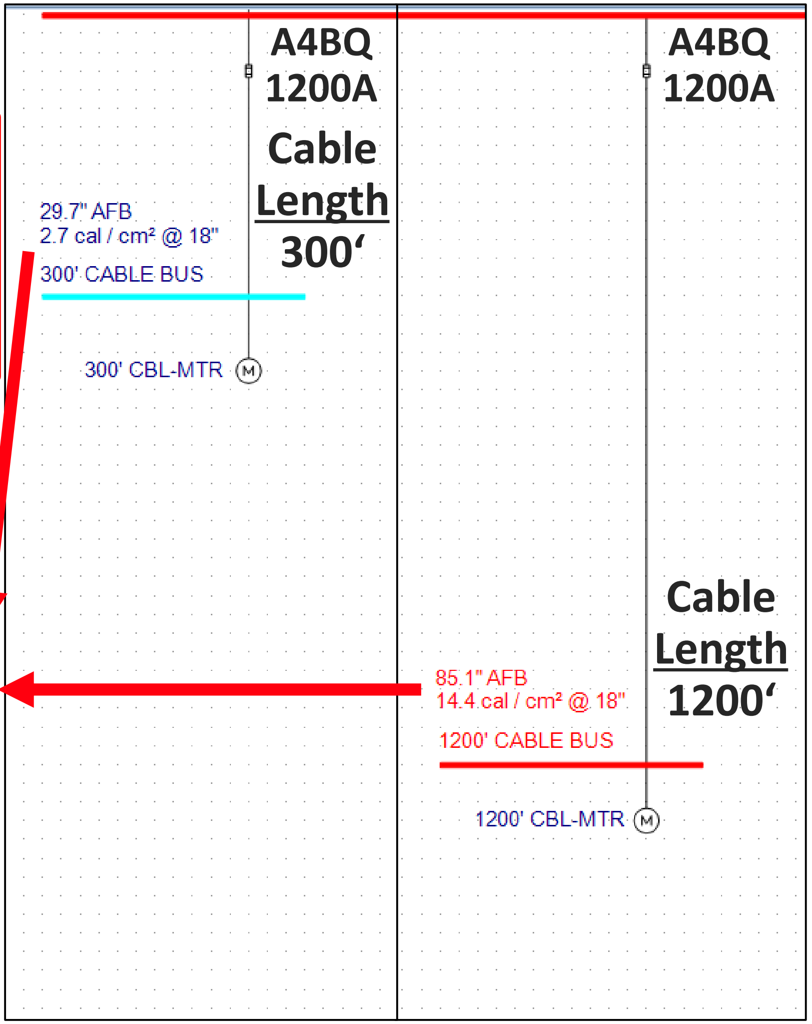
1200A		1200' CABLE BUS	0.48	Control Panel	VCB	25	18.537	12.491	0.489	+	14.4
1200A		1500' CABLE BUS	0.48	Control Panel	VCB	25	16.12	10.892	1.27	+	32.2

Arc Time (sec)		Incident Energy (cal/cm2)
0.01	+	2.7
0.489	+	14.4



4.6 Intermediate Incident Energy (E), pg. 25*

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

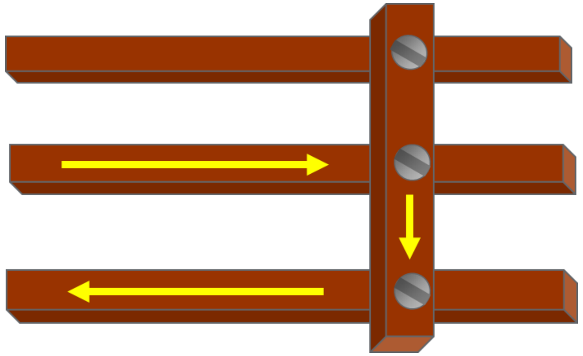
$E_{\le 600}$ is the incident energy for $V_{oc} \le 600$ V (J/cm²)

T is the arc duration (ms)

***IEEE 1584-2018 Reference:** https://standards.ieee.org/standard/1584-2018.html

Bolted Fault Background

Bolted Fault Event



I. **Worst Case Fault Magnitude**

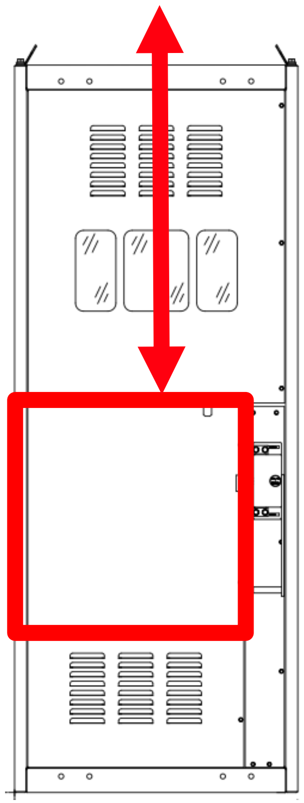
II. **Types**

- Three Phase Bolted Faults
- Bolted Line-to-Line Faults
- Line-to-Line-to-Ground Faults
- Line-to-Ground Faults

Baseline Examples

13.8kV Fused Switch*

Main Fused Switch 200A



H=90", W=35", D=50"

Short Circuit Options

- Control
- Text Output
- One-line Output
- Arc Flash Hazard

Customize Arc Flash control settings

Standard: IEEE 1584-2002

Use worst case arcing current (<1kV buses only)

100 % of Calc Arcing kA

and 85 % of Calc Arcing kA

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
XF PRI	13.8	Switchgear	VCB	152	8.628	8.395	0.01	+	0.1

IEEE 1584-2018

13.8kV: Lower Arcing Currents*

Bus Bolted Fault (kA)=8.628

VCB: Bus Arc Fault (kA)= 8.395 or 97%

Arc Flash Hazard

Standard: IEEE 1584-2018

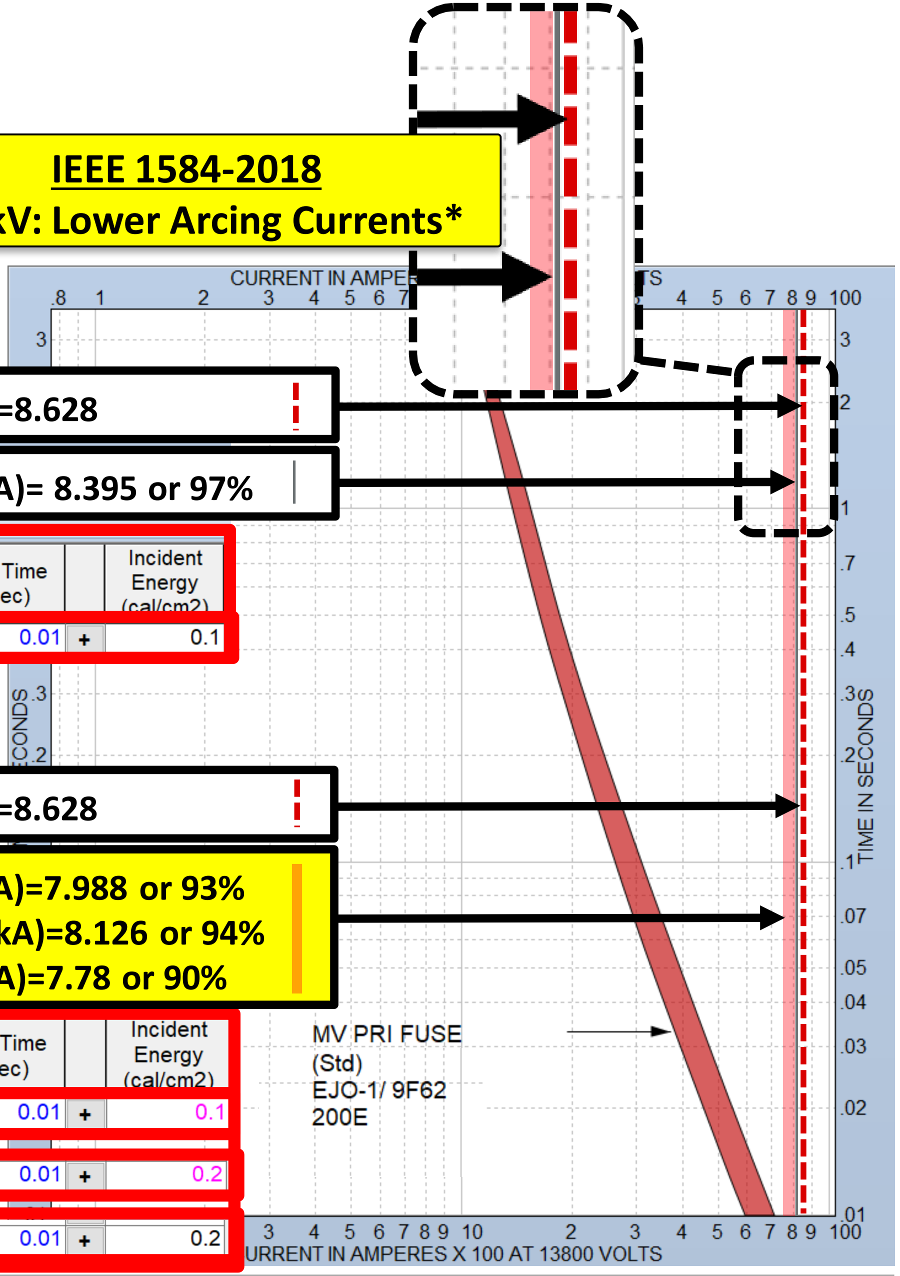
Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
XF PRI	13.8	Switchgear	VCB	152	8.628	7.988	0.01	+	0.1
XF PRI	13.8	Switchgear	VCBB	152	8.628	8.126	0.01	+	0.2
XF PRI	13.8	Switchgear	HCB	152	8.628	7.78	0.01	+	0.2

Bus Bolted Fault (kA)=8.628

VCB: Bus Arc Fault (kA)=7.988 or 93%

VCBB: Bus Arc Fault (kA)=8.126 or 94%

HCB: Bus Arc Fault (kA)=7.78 or 90%



*Working Distances (WD)=36", Electrode Gap=152mm, Electrode Configuration=VCB, VCBB, and HCB, Switchgear Dimensions: H=90", W=40", D=35

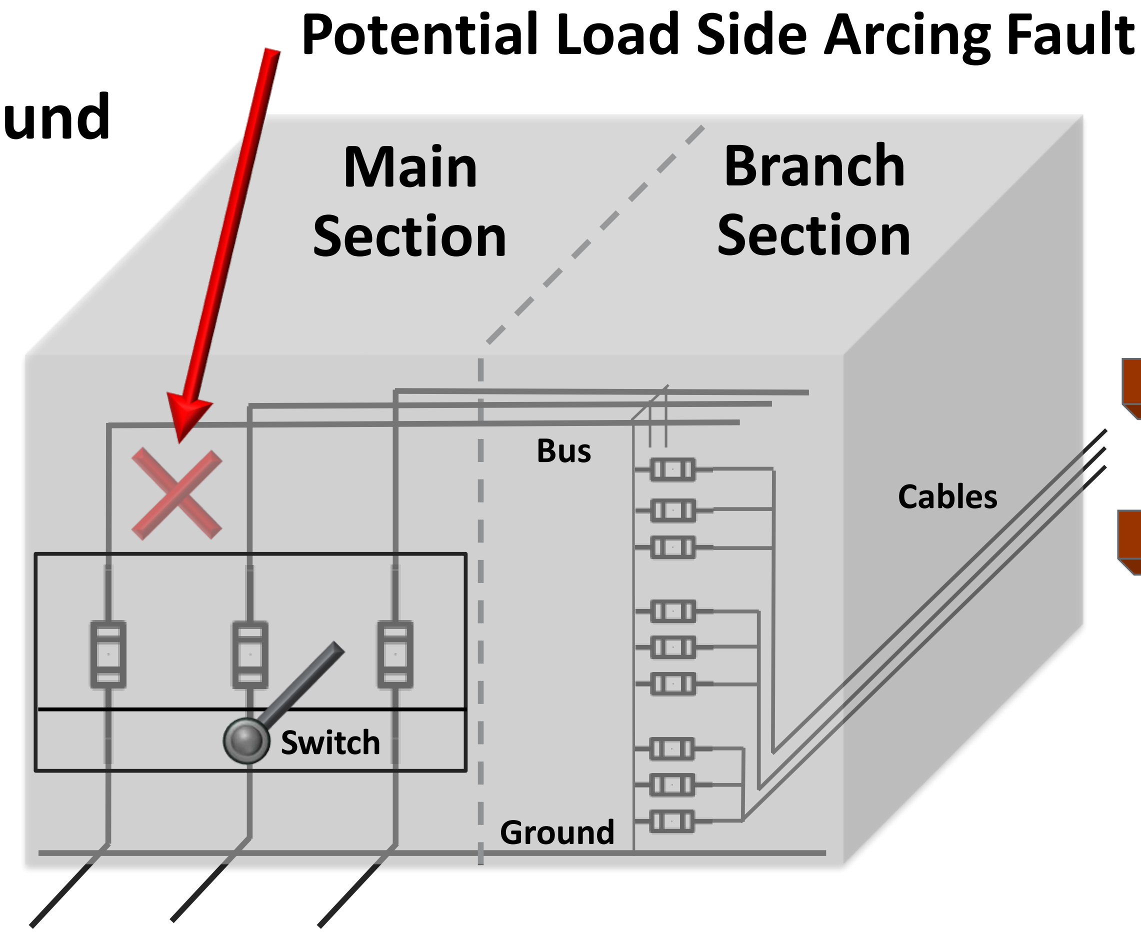
Arcing Fault Background

I. Types

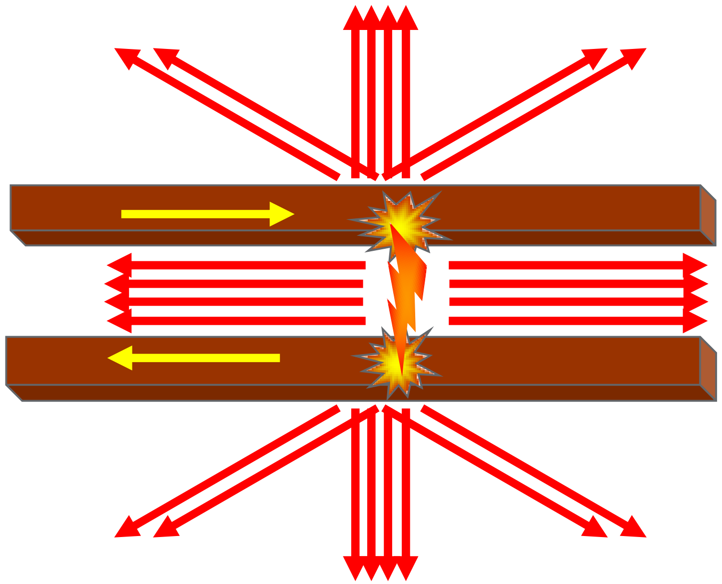
- Three Phase
- Line-Line
- Line-Ground
- Line-Line-Ground

II. Reasons

- Human Factor
- Foreign Objects (wrenches, creatures, etc.)
- Electrical Wire or Cable Insulation Failure*



Arcing Fault Event



*NFPA Electrical Fires Research: https://www.nfpa.org/-/media/Files/News-and-Research/Fire-statistics-and-reports/US-Fire-Problem/Fire-causes/osHomeElectricalFires.ashx?la=en

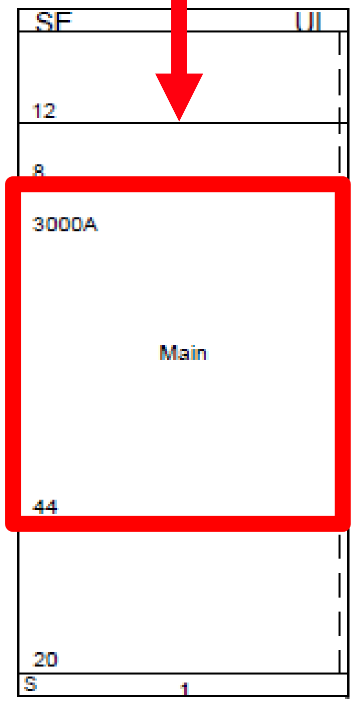
Baseline Examples

0.48kV Fused SWBD*

Switchboard

Main Fused Switch

3000A



H=90”, W=40”, D=35”

Short Circuit Options

Control

Text Output

One-line Output

Arc Flash Hazard

Customize Arc Flash control settings

Standard: IEEE 1584-2002

Use worst case arcing current (<1kV buses only)

100 % of Calc Arcing kA

and 85 % of Calc Arcing kA

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)	Incident Energy (cal/cm2)
LV MAIN BUS_2000	0.48	Switchboard	VCB	32	58.196	23.21	1.708	136.6

Arc Flash Hazard

Standard: IEEE 1584-2018

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)	Incident Energy (cal/cm2)
LV MAIN BUS_2000	0.48	Switchboard	VCB	32	58.196	28.868	0.522	31.7
LV MAIN BUS_2000	0.48	Switchboard	VCBB	32	58.196	33.474	0.209	19.7
LV MAIN BUS_2000	0.48	Switchboard	HCB	32	58.196	28.085	0.609	84.8

IEEE 1584-2018

0.48kV: Higher Arcing Currents*

Bus Bolted Fault (kA)=58.196

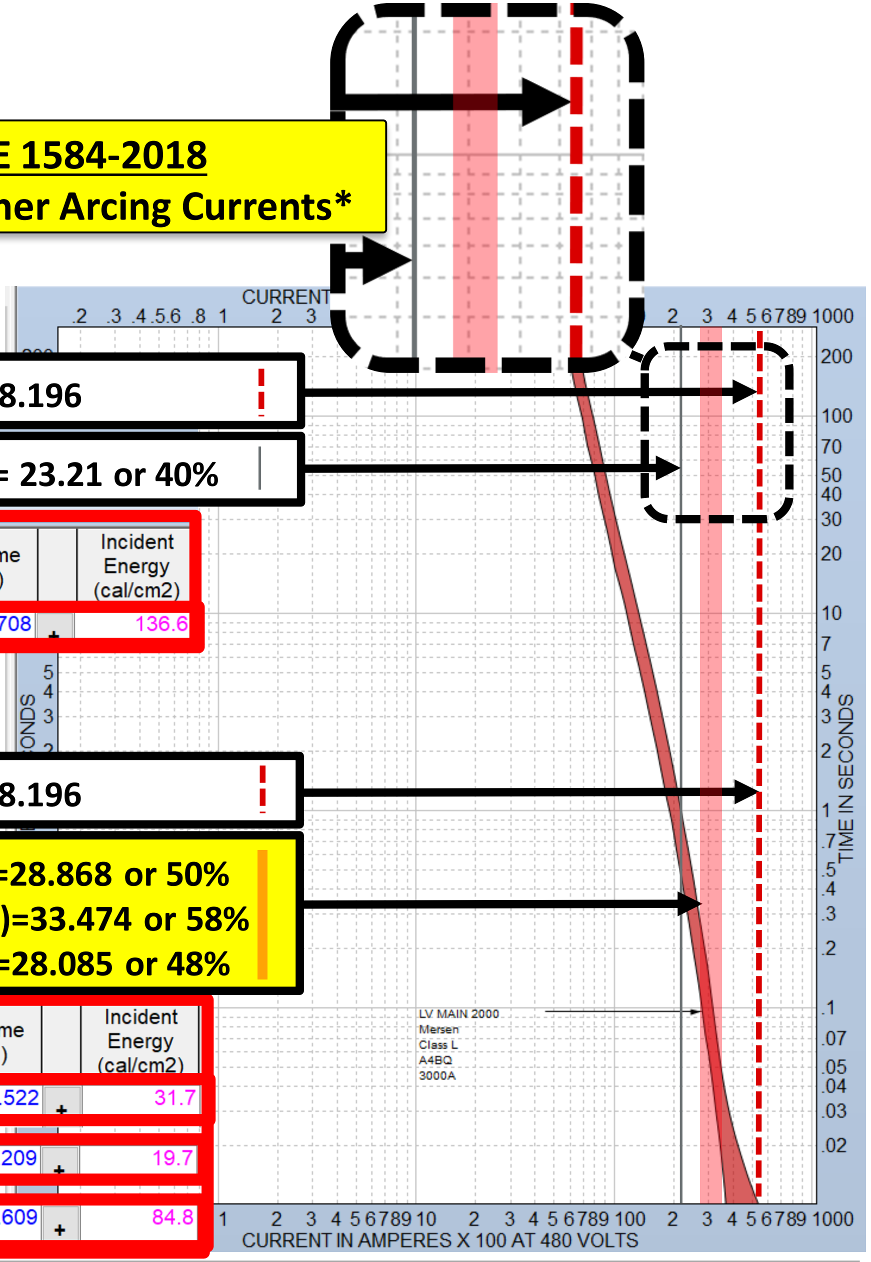
VCB: Bus Arc Fault (kA)= 23.21 or 40%

Bus Bolted Fault (kA)=58.196

VCB: Bus Arc Fault (kA)=28.868 or 50%

VCBB: Bus Arc Fault (kA)=33.474 or 58%

HCB: Bus Arc Fault (kA)=28.085 or 48%

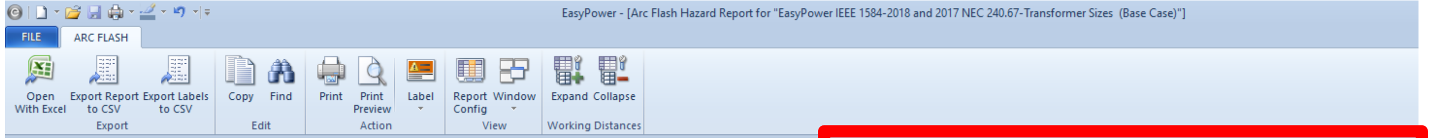


***Working Distances (WD)=18” (range 18-24”), Electrode Gap=32mm, Electrode Configuration=VCB, VCBB, and HCB, Switchboard Dimensions: H=90”, W=40”, D=35**

Case #2, Part I: Varying Transformer Sizes, 24" WD

IEEE 1584-2018
Arcing Current Method

1000 / 1150 kVA, OA/FA, Oil Transformer, 5.75%
0.48kV Substation*



Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN BUS_1000	0.48	Switchboard	VCB	32	53.424	31.648	0.01	+	0.4
LV MAIN BUS_1000	0.48	Switchboard	VCBB	32	53.424	36.312	0.01	+	0.6
LV MAIN BUS_1000	0.48	Switchboard	HCB	32	53.424	31.246	0.01	+	0.9

Arc Flash Hazard | Standard: IEEE 1584-2018

VCB
Incident Energy
0.4 cal/cm²

VCB

Vertical electrodes inside a metal enclosure.

VCBB
Incident Energy
0.6 cal/cm² (1.5x VCB)

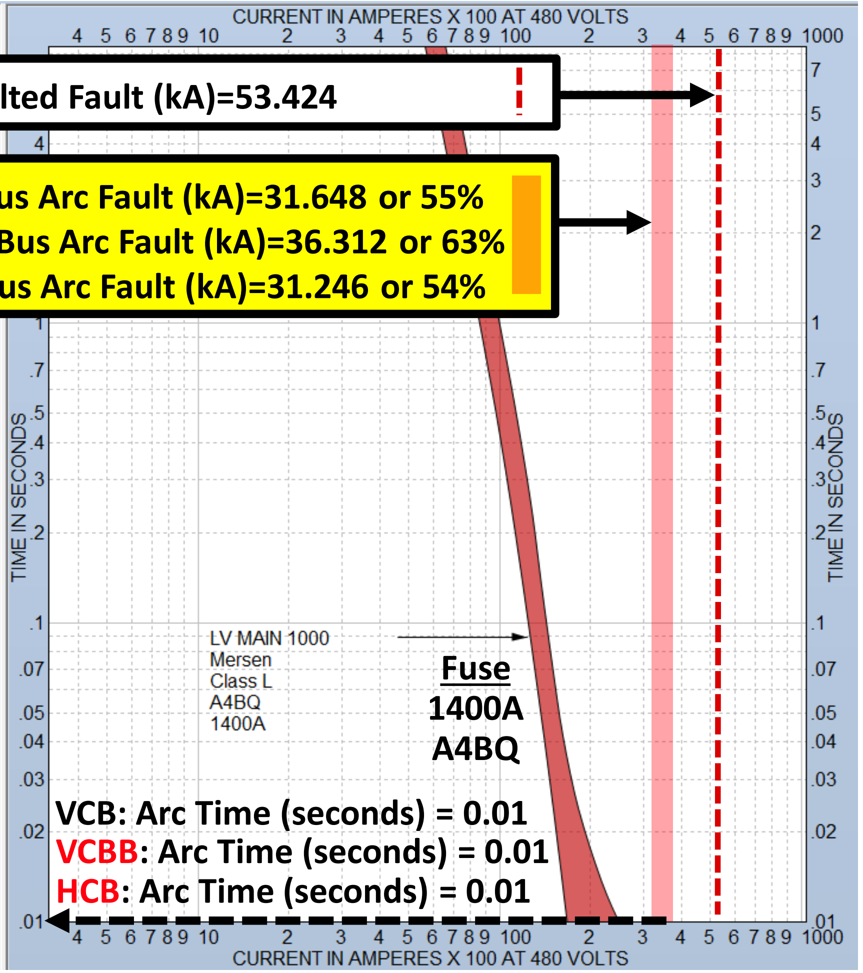
VCBB

Vertical electrodes terminated in an insulating barrier inside a metal enclosure.

HCB
Incident Energy
0.9 cal/cm², (2.3x VCB)

HCB

Horizontal electrodes inside a metal enclosure.



***Working Distances (WD)=24" (range 18-24"), Electrode Gap=32mm, Electrode Configuration=VCB, VCBB, and HCB, Switchboard Dimensions: H=90", W=40", D=35**

Case #2, Part II: Varying Transformer Sizes, 24" WD

IEEE 1584-2018
Arcing Current Method

2000 / 2300 kVA, OA/FA, Oil Transformer, 5.75% 0.48kV Substation*

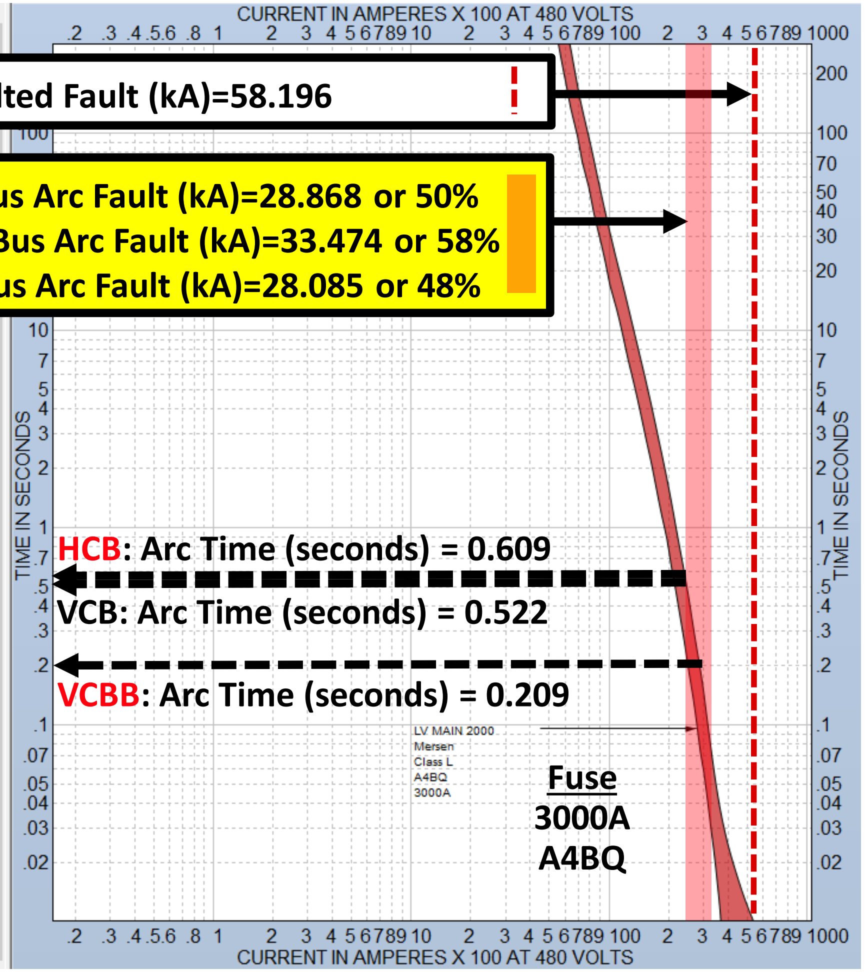
EasyPower - [Arc Flash Hazard Report for "EasyPower IEEE 1584-2018 and 2017 NEC 240.67-Transformer Sizes (Base Case)"]

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN BUS_2000	0.48	Switchboard	VCB	32	58.196	28.868	0.522	+	20.0
LV MAIN BUS_2000	0.48	Switchboard	VCBB	32	58.196	33.474	0.209	+	11.7
LV MAIN BUS_2000	0.48	Switchboard	HCB	32	58.196	28.085	0.609	+	47.3

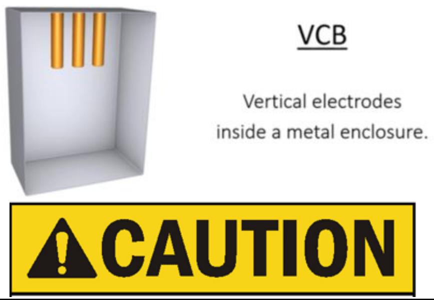
Arc Flash Hazard — Standard: IEEE 1584-2018

Bus Bolted Fault (kA)=58.196

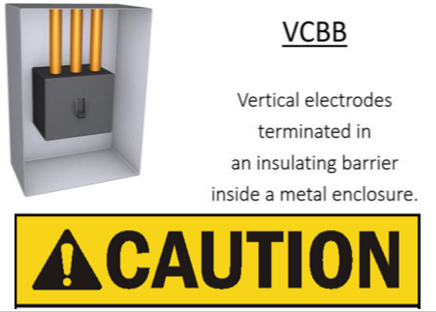
VCB: Bus Arc Fault (kA)=28.868 or 50%
VCBB: Bus Arc Fault (kA)=33.474 or 58%
HCB: Bus Arc Fault (kA)=28.085 or 48%



VCB
Incident Energy
20.0 cal/cm²



VCBB
Incident Energy
11.7 cal/cm² (0.6x VCB)



HCB
Incident Energy
47.3 cal/cm², (2.4x VCB)

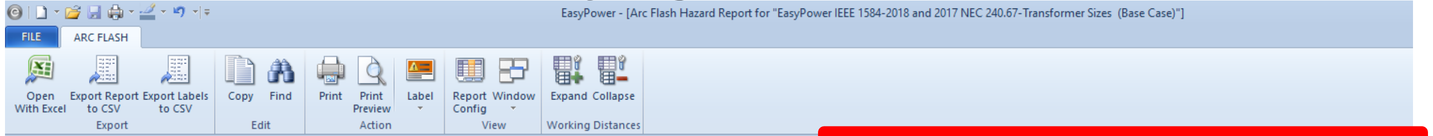
***Working Distances (WD)=24" (range 18-24"), Electrode Gap=32mm, Electrode Configuration=VCB, VCBB, and HCB,**
Switchboard Dimensions: H=90", W=40", D=35

MIPSYCON

Case #2, Part III: Varying Transformer Sizes, 24" WD

IEEE 1584-2018
Arcing Current Method

2500 / 2875 kVA, OA/FA, Oil Transformer, 5.75% 0.48kV Substation*



Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Electrode Gap (mm)	Bus Bolted Fault (kA)	Bus Arc Fault (kA)	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN BUS_2500	0.48	Switchboard	VCB	32	58.291	32.95	2	+	87.2
LV MAIN BUS_2500	0.48	Switchboard	VCBB	32	58.291	33.501	1.851	+	103.6
LV MAIN BUS_2500	0.48	Switchboard	HCB	32	58.291	32.603	2	+	181.2

Arc Flash Hazard | Standard: IEEE 1584-2018

VCB
Incident Energy
87.2 cal/cm²

VCB
Vertical electrodes inside a metal enclosure.

DANGER

VCBB
Incident Energy
103.6 cal/cm² (1.2x VCB)

VCBB
Vertical electrodes terminated in an insulating barrier inside a metal enclosure.

DANGER

HCB
Incident Energy
181.2 cal/cm², (2.1x VCB)

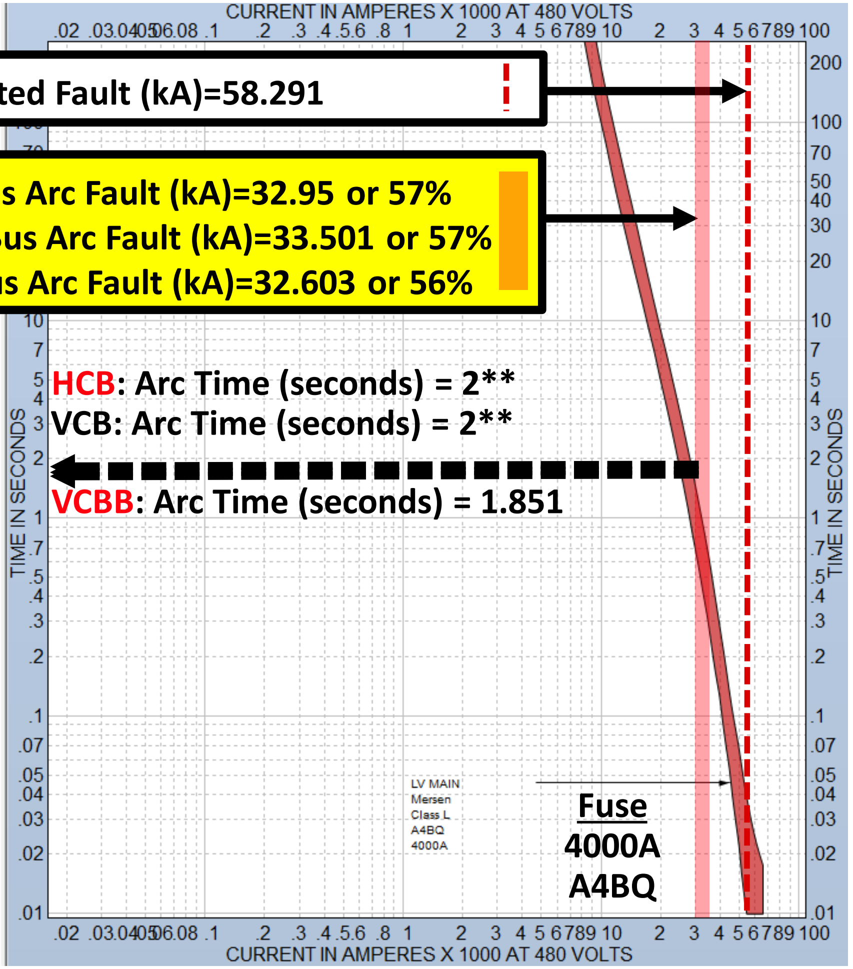
HCB
Horizontal electrodes inside a metal enclosure.

DANGER

Bus Bolted Fault (kA)=58.291

VCB: Bus Arc Fault (kA)=32.95 or 57%
VCBB: Bus Arc Fault (kA)=33.501 or 57%
HCB: Bus Arc Fault (kA)=32.603 or 56%

HCB: Arc Time (seconds) = 2**
VCB: Arc Time (seconds) = 2**
VCBB: Arc Time (seconds) = 1.851



*Working Distances (WD)=24" (range 18-24"), Electrode Gap=32mm, Electrode Configuration=VCB, VCBB, and HCB, Switchboard Dimensions: H=90", W=40", D=35
**SC Options, Arc Flash Hazard - IEEE 1584-2018 Max Time (sec) = 2

MIPSYCON

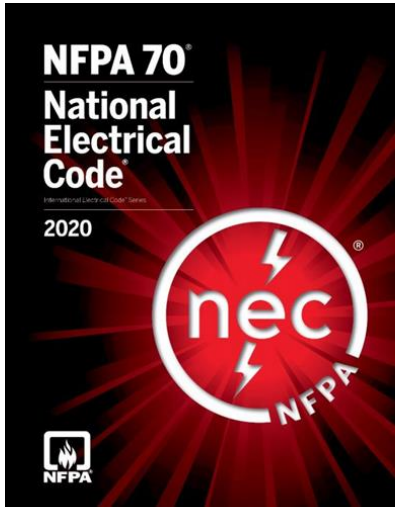
2020 / 2017 National Electric Code Article 240.67

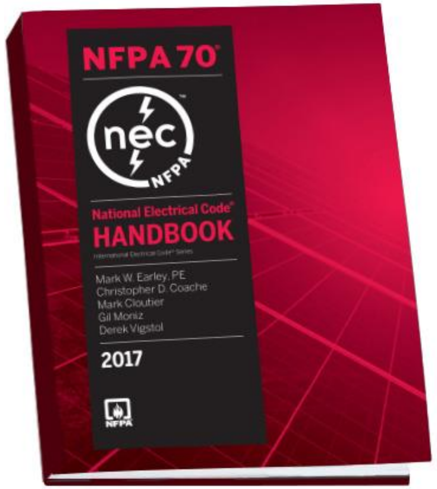
240.67 Arc Energy Reduction. Where fuses rated 1200A or higher are installed, 240.67(A) and (B) shall apply. This requirement shall become effective January 1, 2020.

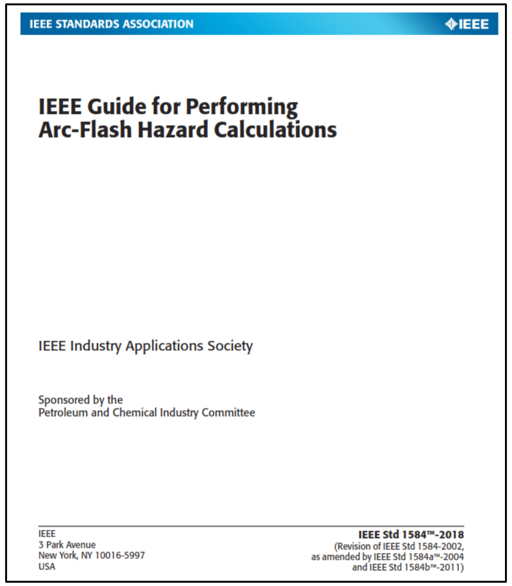
(A) Documentation. Documentation shall be available to those authorized to design, install, operate, or inspect the installation as to the location of the fuses.

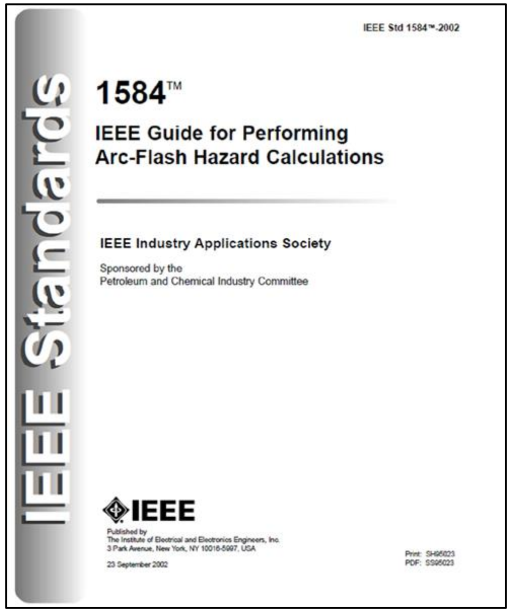
(B) Method to Reduce Clearing Time. A fuse shall have a clearing time of 0.07 seconds or less at the available arcing current, or one of the following shall be provided:

(1) Differential relaying
(2) Energy-reducing maintenance switching with local status indicator
(3) Energy-reducing active arc flash mitigation system
(4) An approved equivalent means





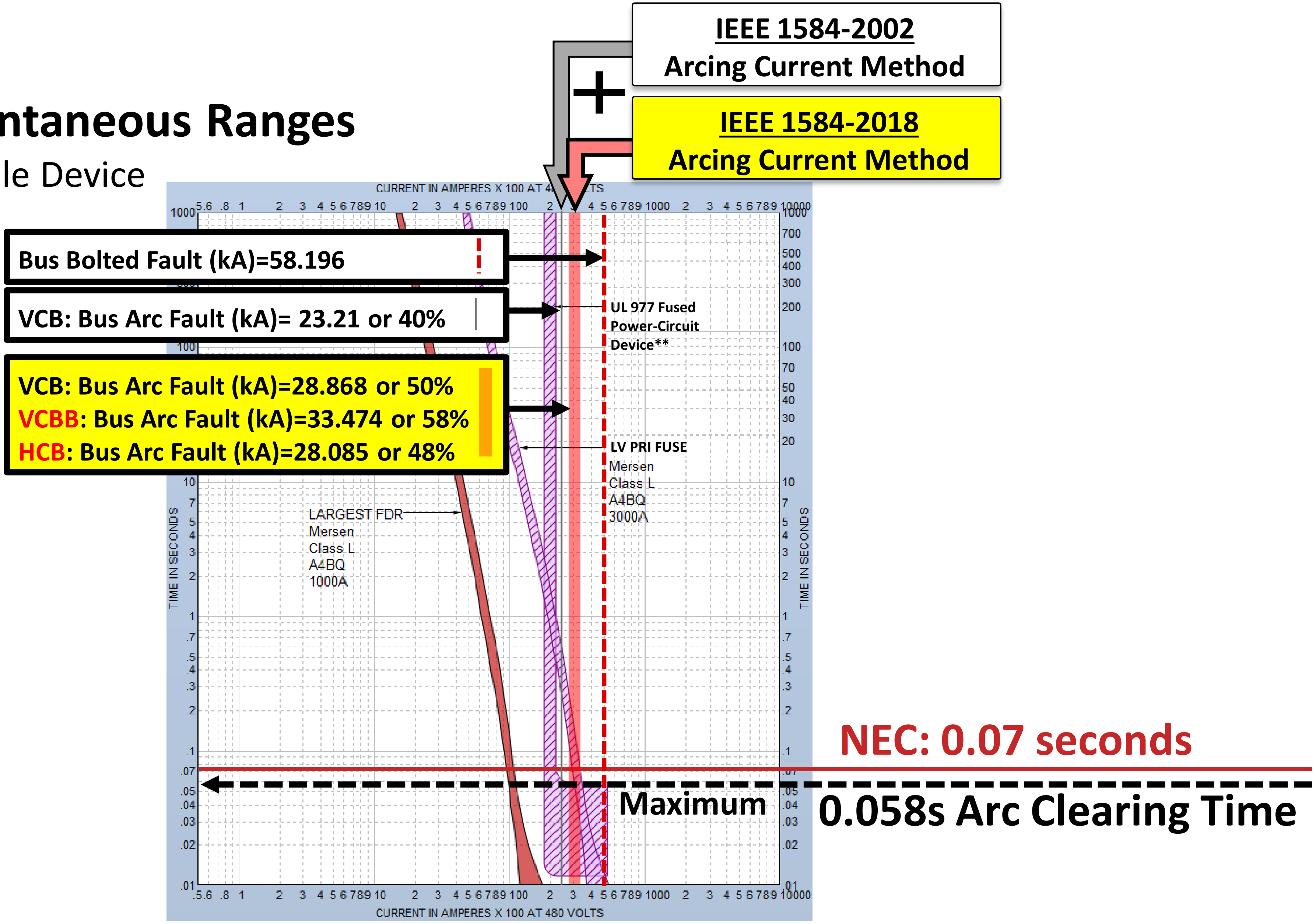




Informational Note No. 3: IEEE 1584, IEEE Guide for Performing Arc Flash Hazard Calculations, is one of the available methods that provides guidance in determining arcing current.

Modeling Fused Instantaneous Ranges

240.67 (B): LV Main Adjustable Device



*Working Distances (WD)=18" (range 18-24"), Electrode Gap=32mm, Electrode Configuration=VCB, VCBB, and HCB, Switchboard Dimensions: H=90", W=40", D=35

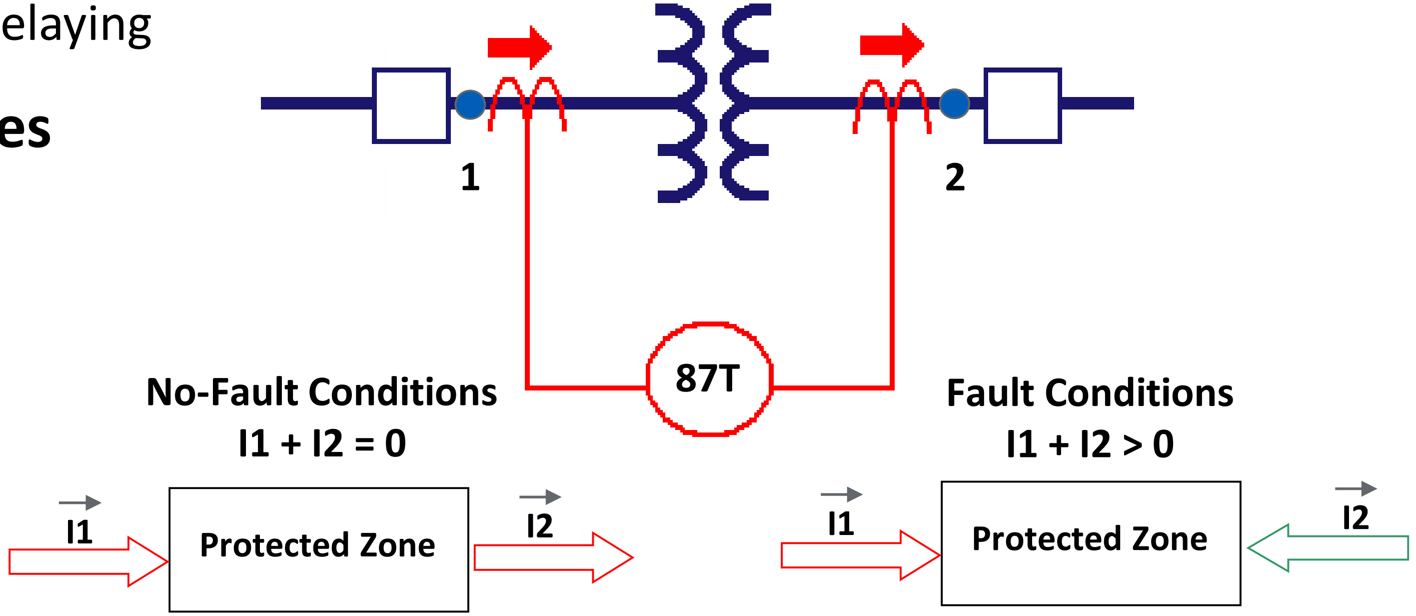
**IEEE Paper: "Improving Selectivity & Arc-Flash Protection through Optimized Instantaneous Settings"

Differential Protective Relaying

240.67 (B)(1) and 240.87 (B)(2): Differential Relaying

I. Transformer Fault Type Examples

- Phase-to-Phase Faults
- Three-Phase Faults
- Ground Faults
- Core Faults
- Tank Faults

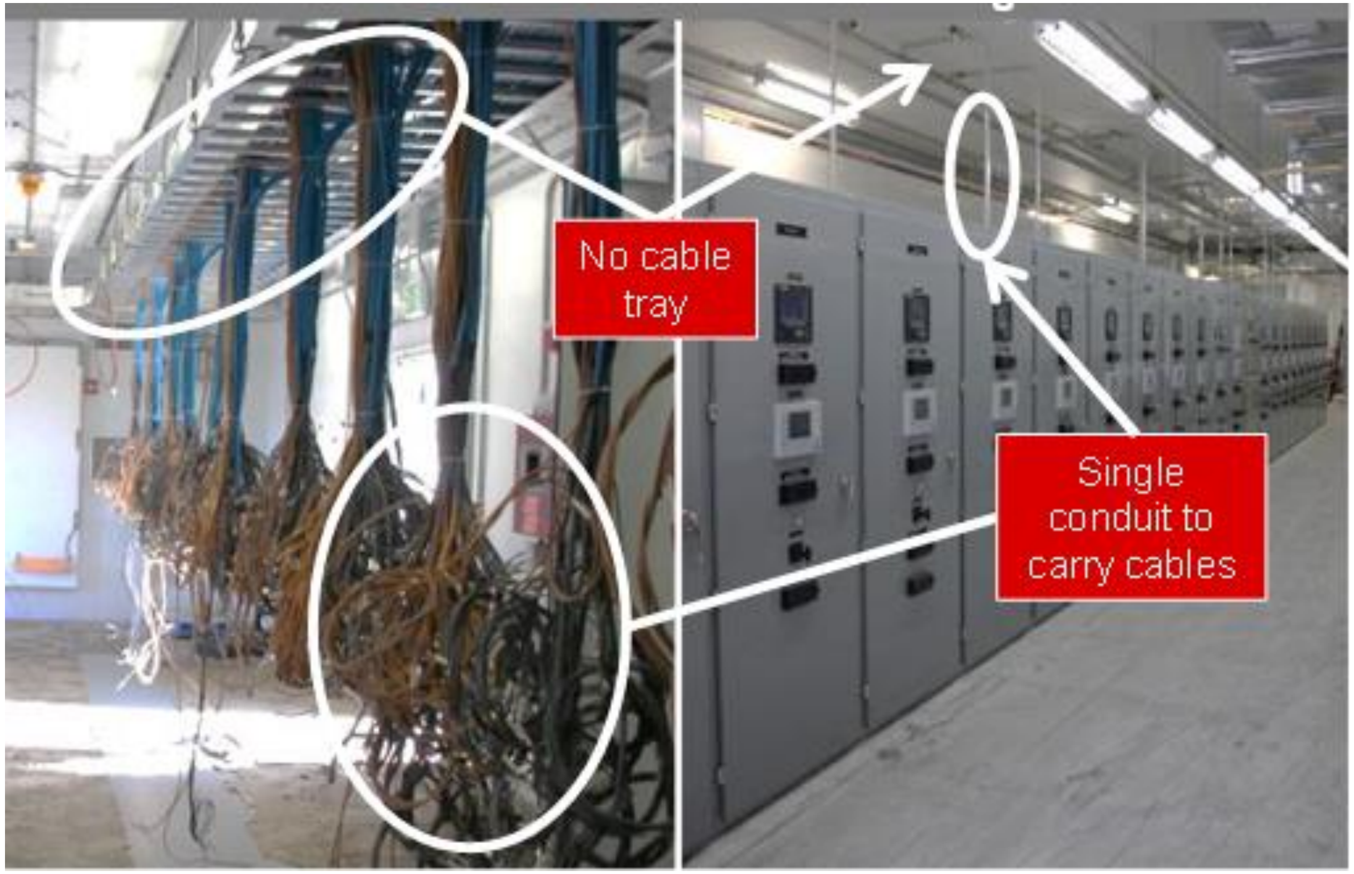


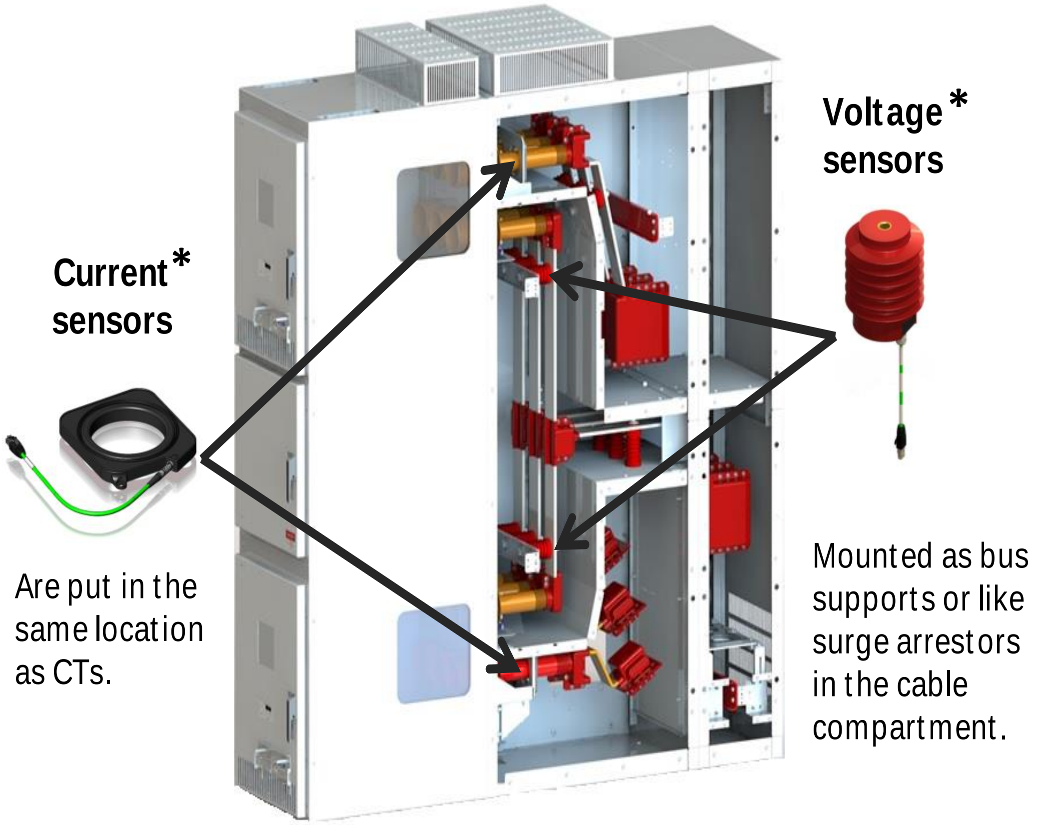
Differential Protection (87T) compares the current going into the zone against the current leaving the zone

Medium Voltage ANSI/IEEE/UL Switchgear*

240.67(B)(1) and 240.87(B)(2): Differential Relaying per ANSI 87T and ANSI 87B Switchgear Applications

Conventional **IEC 61850* / Digital***

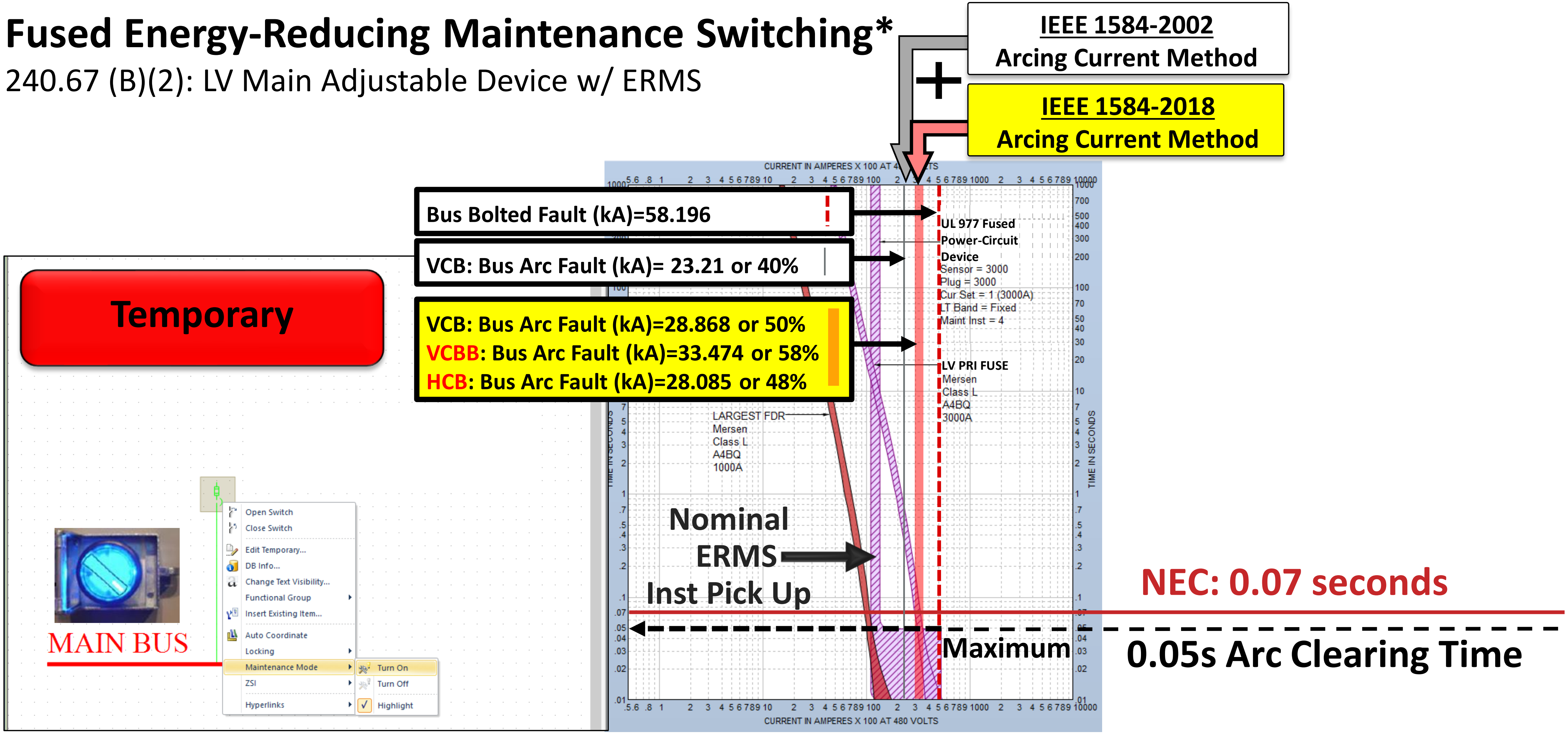




*IEEE Twin Cities PES/IAS, St. Paul, MN, May 2019: Digital Switchgear Technology and Application of IEC 61850 for Medium Voltage Switchgear Protection and Control: https://events.vtools.ieee.org/m/187174
*IEEE PCIC 2019 Vancouver, British Columbia, Canada, September 2019 "The Next Phase in the Evolution of Safety by Design – Digital Switchgear": https://2019conference.ieeepcic.com/technical-program.html

Fused Energy-Reducing Maintenance Switching*

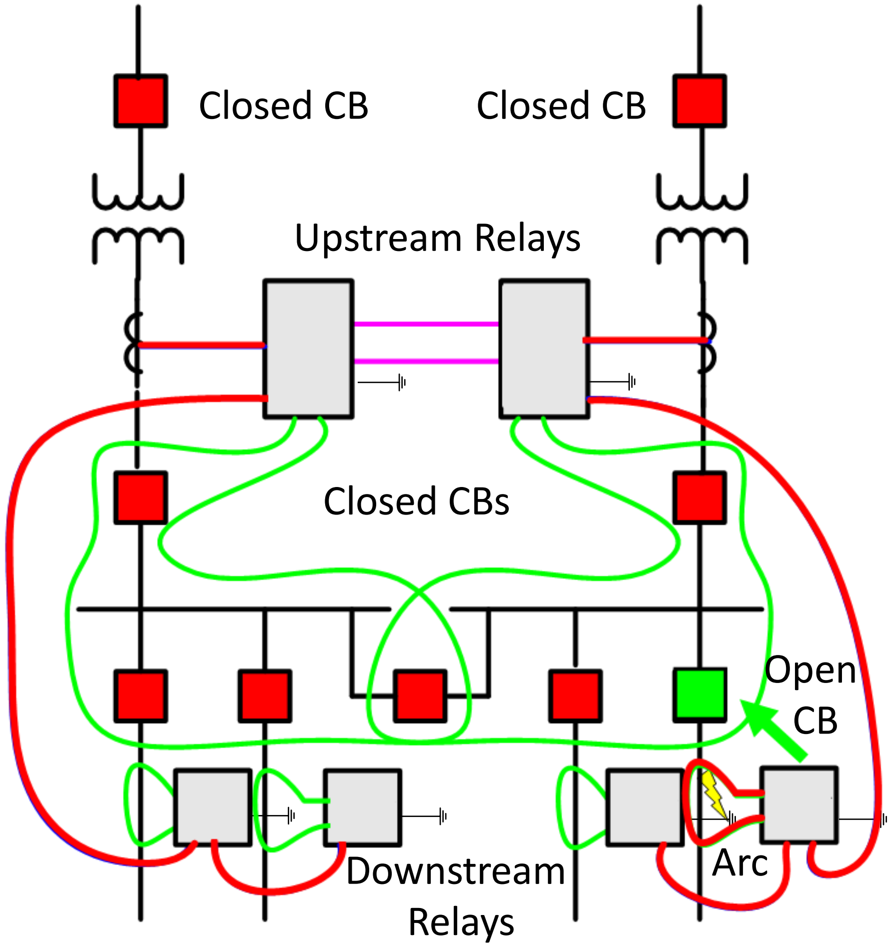
240.67 (B)(2): LV Main Adjustable Device w/ ERMS



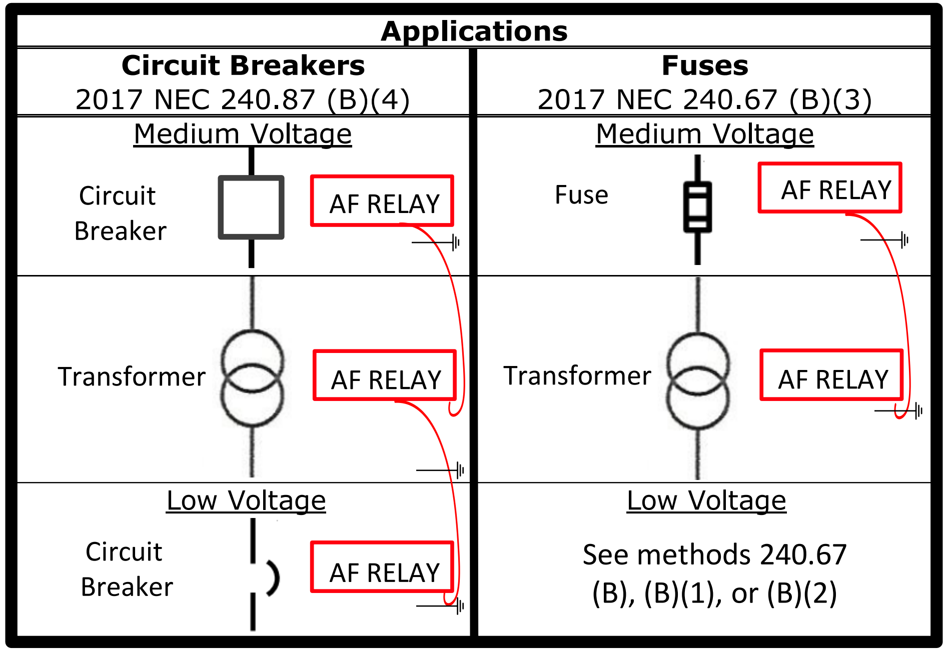
*Does not influence NFPA 70E Arc Flash Label. Working Distances (WD)=18" (range 18-24"), Electrode Gap=32mm, Electrode Configuration=VCB, VCBB, and HCB, Switchboard Dimensions: H=90", W=40", D=35

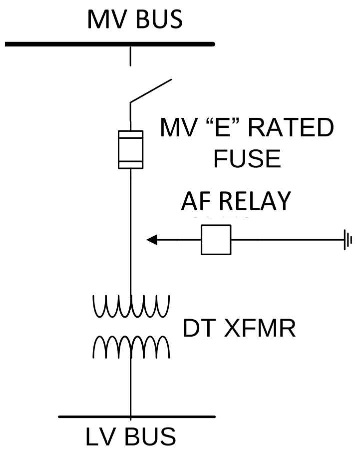
Energy-reducing Active Arc Flash Mitigation System*

240.67 (B)(3) and 240.87(B)(4): Arc Flash Detection Relays Clearing as fast as 0.004 seconds (4 ms).



- Arc in a cable compartment
- Relay detects light and both relays detect overcurrent
- Both relays send the current information to all connected units
- Only the affected feeder circuit breaker (CB) is opened





APPLICABLE SYSTEM

*IEEE Paper: “Arc Flash – New Regulations and the Advantages of the Ultra Fast Earthing Grounding Switch”

CEU (Continuing Education Unit) Exercise #1

Applying 2020 / 2017 NEC Article 240.67 (B)(2)

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN BUS_2500	0.48	Switchboard	VCB	T2= 2	+	AE1= 87.2
LV MAIN BUS_2500	0.48	Switchboard	VCBB	T2= 1.851	+	AE1= 103.6
LV MAIN BUS_2500	0.48	Switchboard	HCB	T2= 2	+	AE1= 181.2

Step #1 **Step #2**

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN 2500_2	0.48	Switchboard	VCB	T1= 0.05	+	AE2= 2.2
LV MAIN 2500_2	0.48	Switchboard	VCBB	T1= 0.05	+	AE2= 3.2
LV MAIN 2500_2	0.48	Switchboard	HCB	T1= 0.05	+	AE2= 4.5

Step #1

$$\frac{T1}{T2} = 0.025 \text{ or } 2.5\%$$

Step #2

$$\frac{T1}{T2} * AE1 = AE2$$

Summary*: *Time has a linear relationship with Incident Energy.

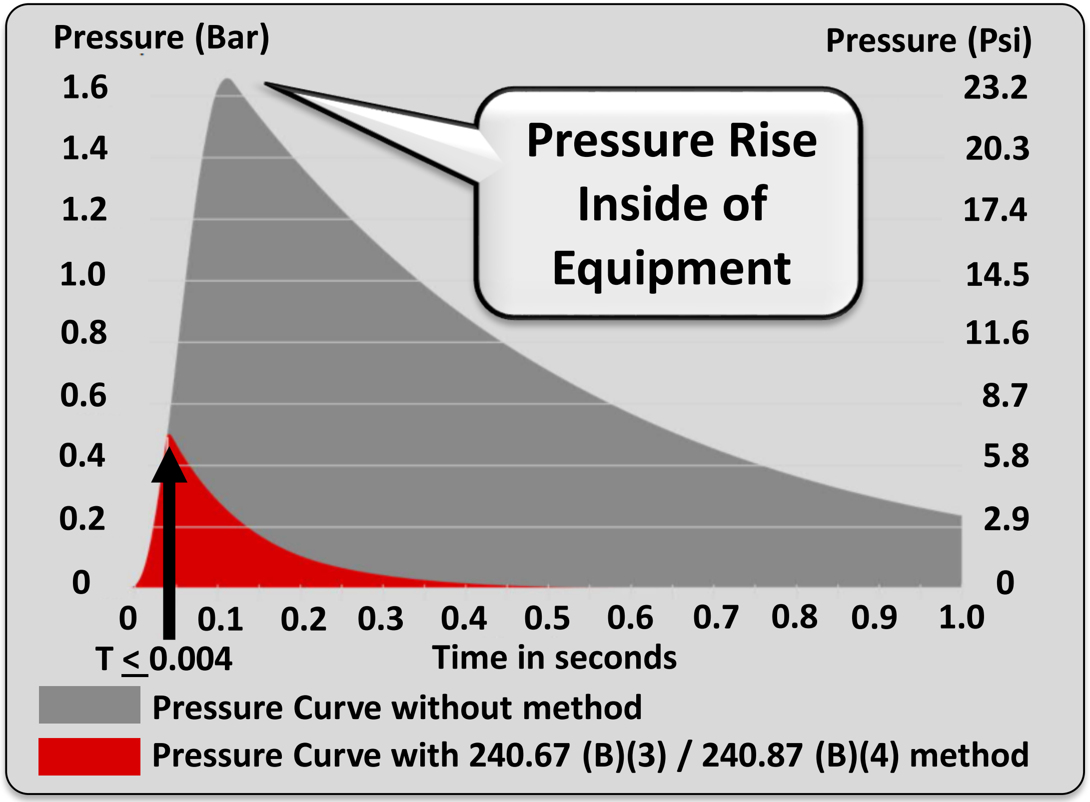
CEU (Continuing Education Unit) Exercise #2

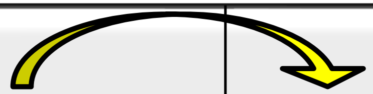
Applying 2020 / 2017 NEC Article 240.67 (B)(3) / 240.87 (B)(4)

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN BUS_2500	0.48	Switchgear	VCB	T2= 2	+	AE1= 87.2
LV MAIN BUS_2500	0.48	Switchgear	VCBB	T2= 1.851	+	AE1= 103.6
LV MAIN BUS_2500	0.48	Switchgear	HCB	T2= 2	+	AE1=181.2

Step #1 Step #2

Arc Fault Bus Name	Arc Fault Bus kV	Equip Type	Electrode Configuration	Arc Time (sec)		Incident Energy (cal/cm2)
LV MAIN 2500_B3	0.48	Switchgear	VCB	T1= 0.004	+	AE2= 0.2
LV MAIN 2500_B3	0.48	Switchgear	VCBB	T1= 0.004	+	AE2= 0.3
LV MAIN 2500_B3	0.48	Switchgear	HCB	T1= 0.004	+	AE2= 0.4





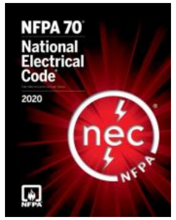
$$\frac{T1}{T2} = 0.002 \text{ or } 0.2\%$$

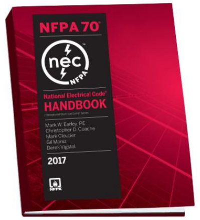
$$\frac{T1}{T2} * AE1 = AE2$$

***Summary**: Time has a linear relationship with Incident Energy.*

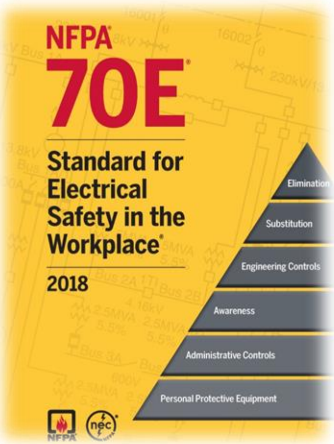
Summary for Fuses per 240.67

- The new IEEE 1584-2018 Guide is more accurate, much more technical, requires more inputs and time.
- Previous power system studies will be updated and may require protection adjustments for protective relays, electronic trip units, etc.
- The 2017 NEC Article 240.67 for Fuses 1200 or Higher requires methods for Arc Energy Reduction and to solve fused clearing time problems by January 1st, 2020 by the state or local authority.





Clearing Times (seconds)				NFPA 70E
2017 NEC Article 240.67 Methods	**Circuit Breaker**	**Electronic Device**	**TOTAL**	**Label Influence**
(B) Less than 0.07 Seconds		0.058	**0.058**	**Yes**
(B)(1) Differential Relaying	0.045-0.06	0.006-0.013	**0.051-0.073**	**Yes**
(B)(2) Energy-reducing maintenance switching with local status indicator		0.05	**0.05**	**No**
(B)(3) Energy-reducing active arc flash mitigation system		0.004	**0.004**	**Yes**



- EasyPower/SKM/ETAP incorporates the new IEEE 1584-2018 equations, inputs, etc. with libraries for available and compliant technologies per the 2017 Article 240.67 for Fuses 1200A or Higher.

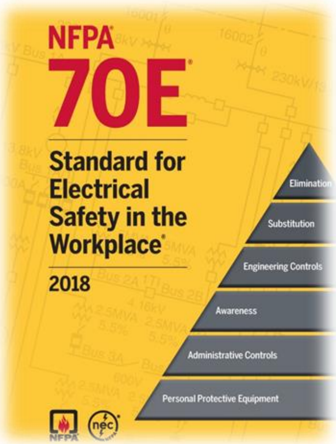
Summary for Fuses per 240.67

- The new IEEE 1584-2018 Guide is more accurate, much more technical, requires more inputs and time.

- Previous power system studies will be updated and may require protection adjustments for protective relays, electronic trip units, etc.

- The 2017 NEC Article 240.67 for Fuses 1200 or Higher requires methods for Arc Energy Reduction and to solve fused clearing time problems by January 1st, 2020 by the state or local authority.

Clearing Times (seconds)				NFPA 70E
2017 NEC Article 240.67 Methods	**Circuit Breaker**	**Electronic Device**	**TOTAL**	**Label Influence**
(B) Less than 0.07 Seconds		0.058	**0.058**	**Yes**
(B)(1) Differential Relaying	0.045-0.06 +	0.006-0.013	**0.051-0.073**	**Yes**
(B)(2) Energy-reducing maintenance switching with local status indicator	**Temporary**	0.05	**0.05**	**No**
(B)(3) Energy-reducing active arc flash mitigation system		0.004	**0.004**	**Yes**



- EasyPower/SKM/ETAP incorporates the new IEEE 1584-2018 equations, inputs, etc. with libraries for available and compliant technologies per the 2017 Article 240.67 for Fuses 1200A or Higher.

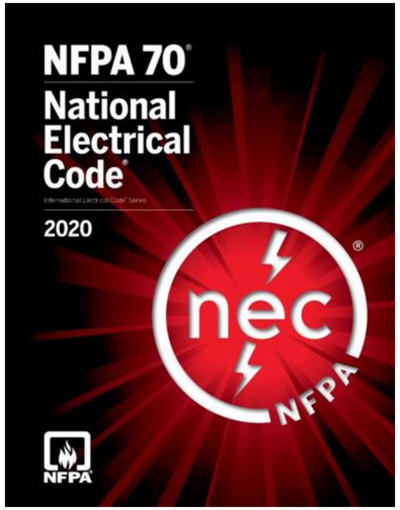
2017 National Electric Code Article 240.87

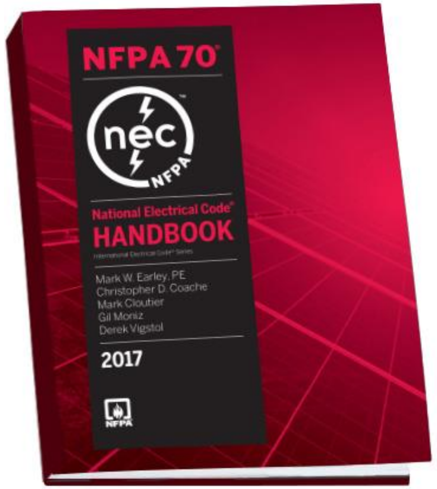
240.87 Arc Energy Reduction. Where the highest continuous current trip setting for which the actual overcurrent device installed in a circuit breaker is rated or can be adjusted is 1200A or higher, 240.87(A) and (B) shall apply:

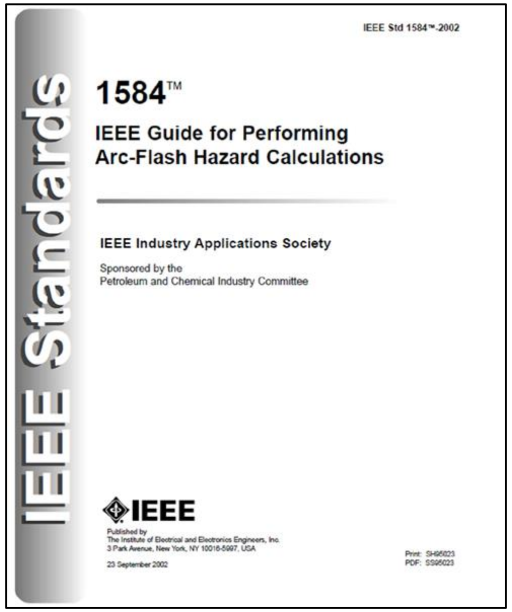
(A) Documentation. Documentation shall be available to those authorized to design, install, operate, or inspect the installation as to the location of the circuit breaker(s).

(B) Method to Reduce Clearing Time. One of the following means shall be provided:

(1) Zone Selective Interlocking
(2) Differential relaying
(3) Energy-reducing maintenance switching with local status indicator
(4) Energy-reducing active arc flash mitigation system
(5) An instantaneous trip setting that is less than the available arcing current
(6) An instantaneous override that is less than the available arcing current
(7) An approved equivalent means







Informational Note No. 3: IEEE 1584-2002, IEEE Guide for Performing Arc Flash Hazard Calculations, is one of the available methods that provides guidance in determining arcing current.

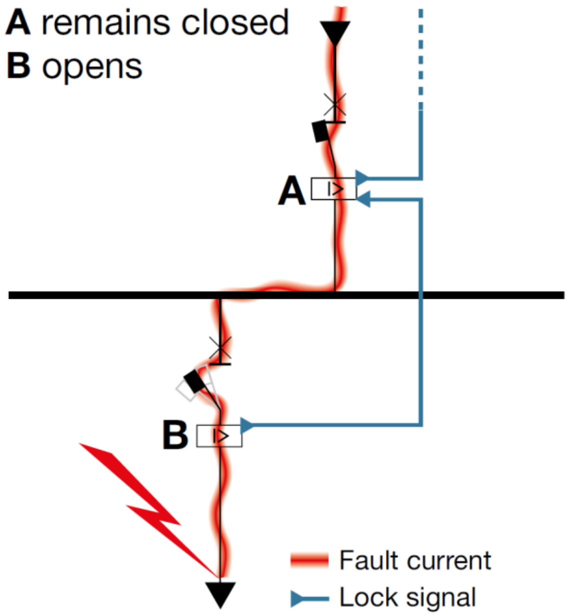
Zone Selective Interlocking

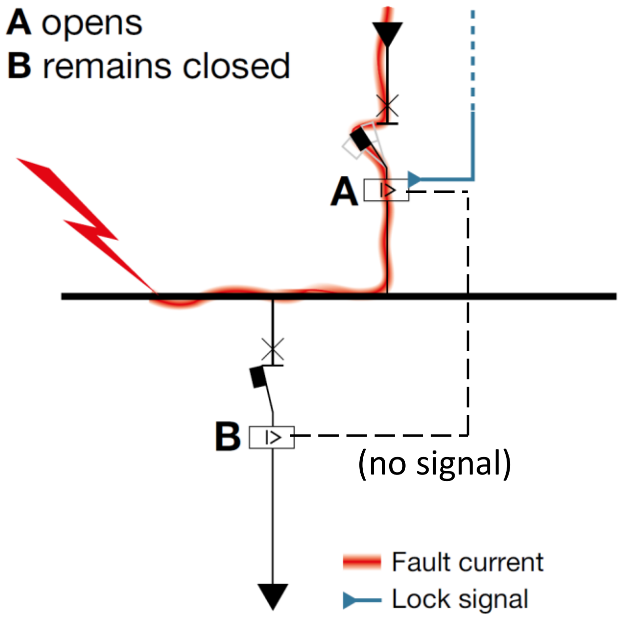
240.87 (B)(1): Application

NFPA 70E Annex O:

"Zone-selective interlocking. A method that allows two or more circuit breakers to communicate with each other so that a short circuit or ground fault will be cleared by the breaker closest to the fault with no intentional delay. Clearing the fault in the shortest time aids in reducing the incident energy."

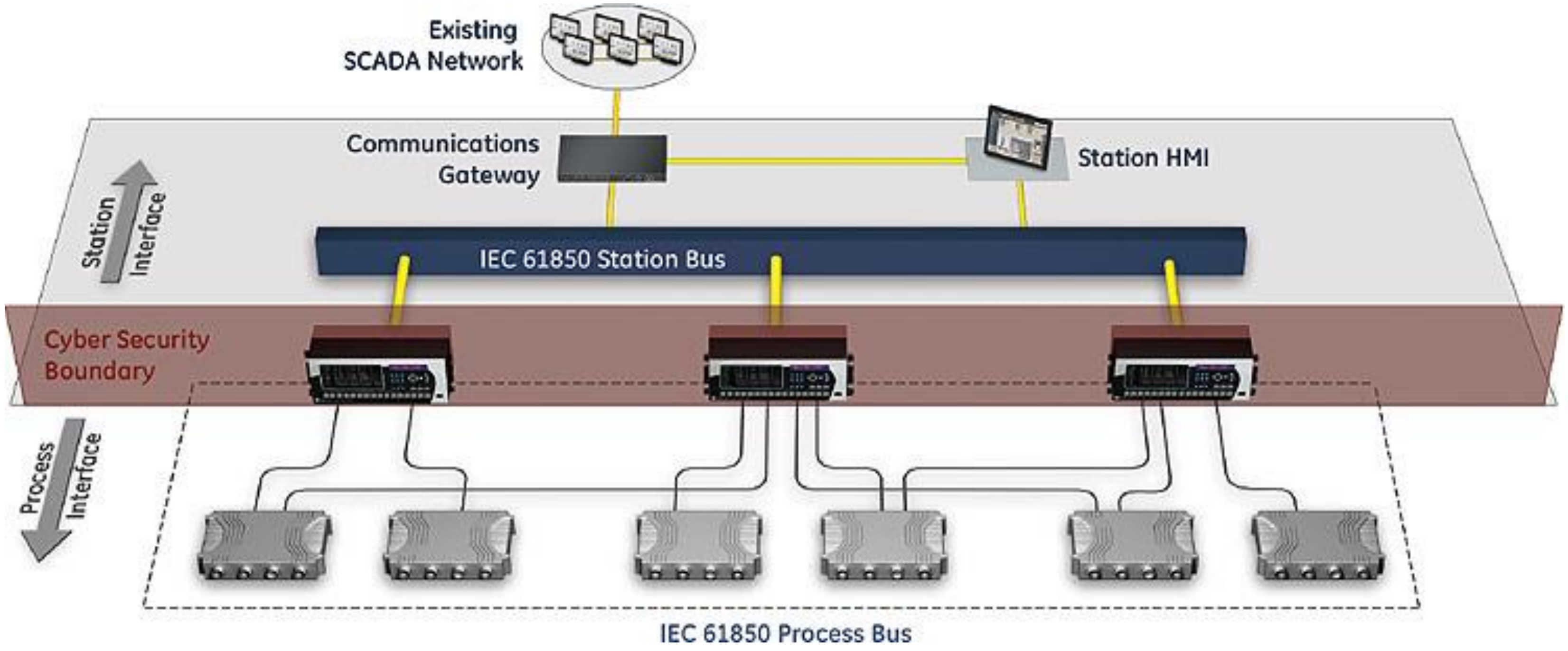
- Requires a physical connection between the circuit breakers involved.
- For LV specifications, the term zone-selective interlocking by itself is inadequate. Must identify the type of ZSI and the circuit breakers involved

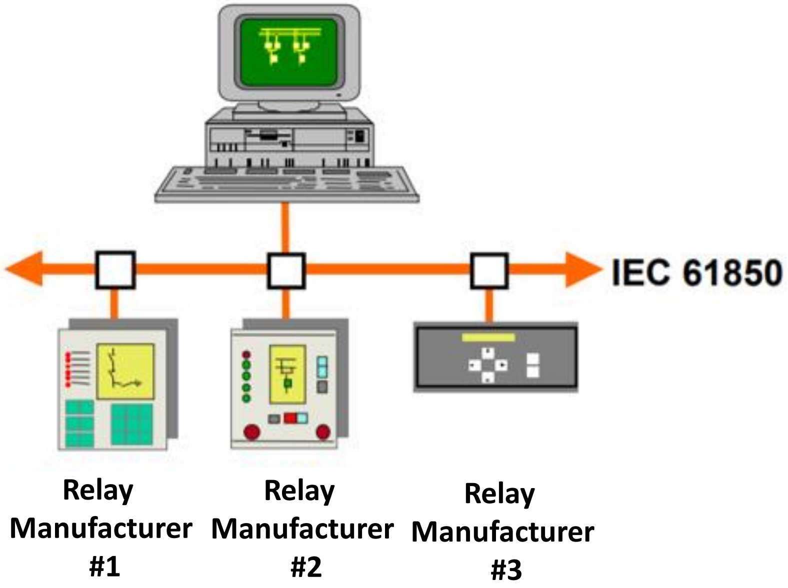




IEC 61850 Digital Substation Design

Communication Protocol: IEC 61850-9-2 Process Bus Technology

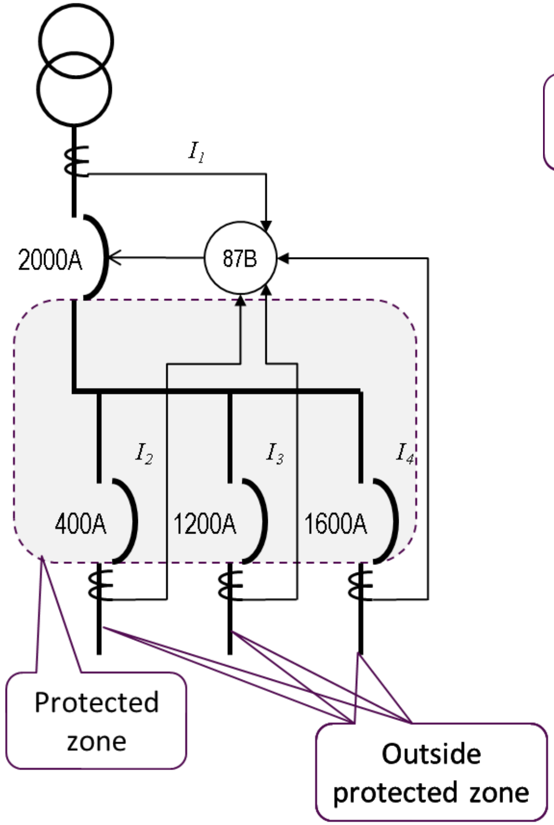


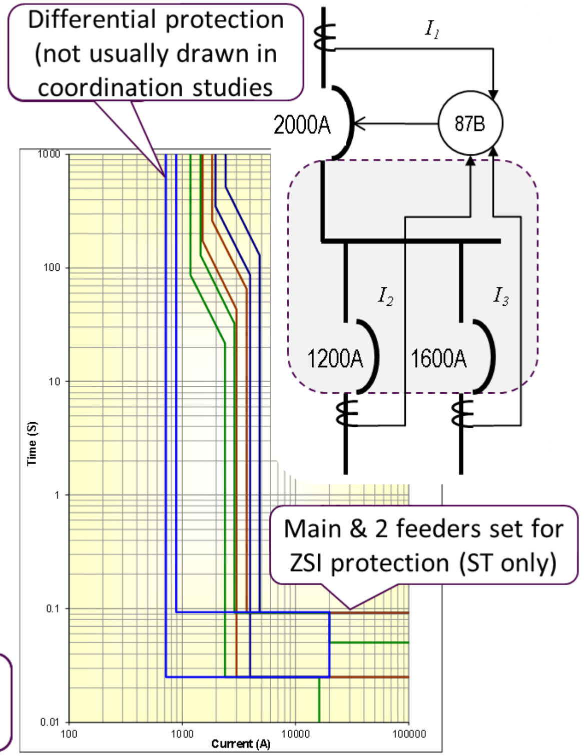


Low Voltage ANSI/IEEE/UL 87B Basics

240.87 (B)(2): Differential Relaying

- Differential protection is zone protection where the zone is defined by the sensors used to sense the current going in and going out.
- If no fault I1-I2-I3-I4 = 0, if there is a fault on the main bus then I1-I2-I3-I4 = I fault
- A fault below any of the feeders is ignored by this scheme. Only faults on the bus are detected.
- “Inherently selective”
- Provides continuous 24/7 protection (Engineering Control)
- Can influence NFPA 70E arc flash label





Low Voltage ANSI/IEEE/UL 87B Switchgear

240.87 (B)(2): Differential Relaying per ANSI 87B UL 1558 Switchgear Applications

Conventional

IEC 61850 / Digital

An instantaneous setting that is less than the available arcing current

240.87 (B)(5)

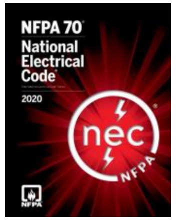
Some possible pitfalls:

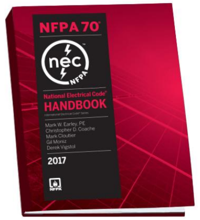
- Maximum adjustable setting of the breaker is less than the arcing current?
- Documentation requirements? Report? Warning labels?
- Commissioning report documenting the setting that was applied?
- Is breaker a main or a feeder? Location of arcing current? Zone of protection?
- How does this setting affect system reliability? Is system selectivity maintained or compromised?
- What assumptions were used for the available fault current?

Summary for Circuit Breakers per 240.87

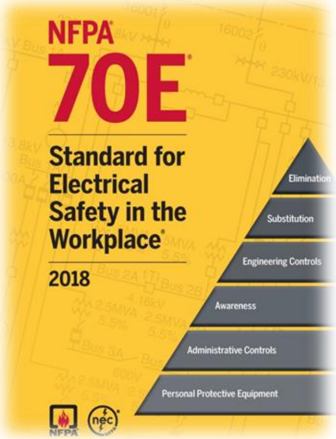
- The new IEEE 1584-2018 Guide is more accurate, much more technical, requires more inputs and time.

- Previous power system studies will be updated and may require protection adjustments for protective relays, electronic trip units, etc.





Clearing Times (seconds)				NFPA 70E
2017 NEC Article 240.87 Methods	Circuit Breaker	Electronic Device	TOTAL	Label Influence
(B)(1) Zone-Selective Interlocking	0.05		**0.05**	**Yes**
(B)(2) Differential Relaying: ANSI 87T	0.045-0.06 +	0.006-0.013	**0.051-0.073**	**Yes**
(B)(2) Differential Relaying: ANSI 87B	0.05		**0.05**	**Yes**
(B)(3) Energy-reducing maintenance switching with local status indicator		0.032	**0.032**	**No**
(B)(4) Energy-reducing active arc flash mitigation system		0.004	**0.004**	**Yes**



- EasyPower/SKM/ETAP incorporates the new IEEE 1584-2018 equations, inputs, etc. with libraries for available and compliant technologies per the 2017 Article 240.87 for Circuit Breakers 1200A or Higher.

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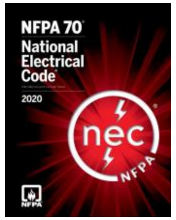

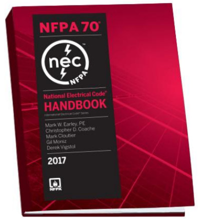

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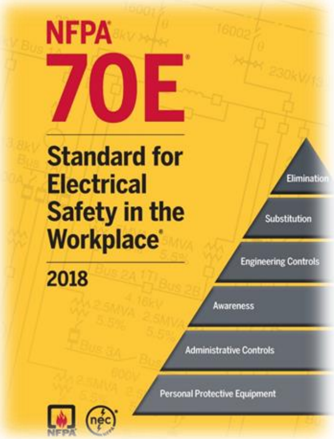
(B)(2) Differential Relaying: ANSI 87B	0.05		**0.05**	**Yes**
(B)(3) Energy-reducing maintenance switching with local status indicator	**Temporary**	0.032	**0.032**	**No**
(B)(4) Energy-reducing active arc flash mitigation system		0.004	**0.004**	**Yes**



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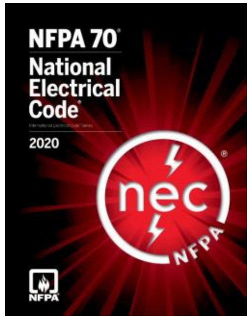
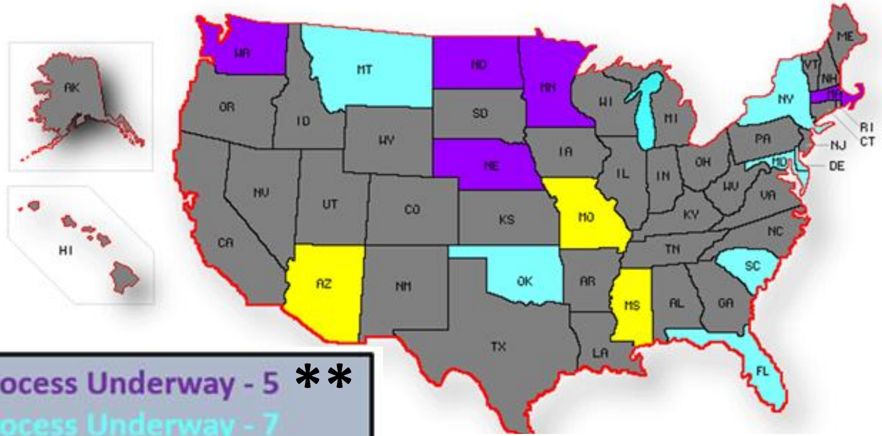
United States 2020 / 2017 NEC Maps*

NFPA

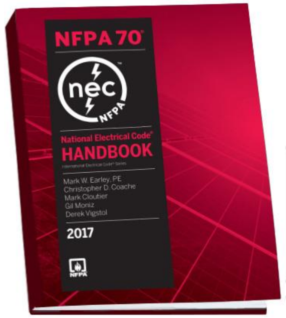


NEC® Update Process In Progress
10/1/2019

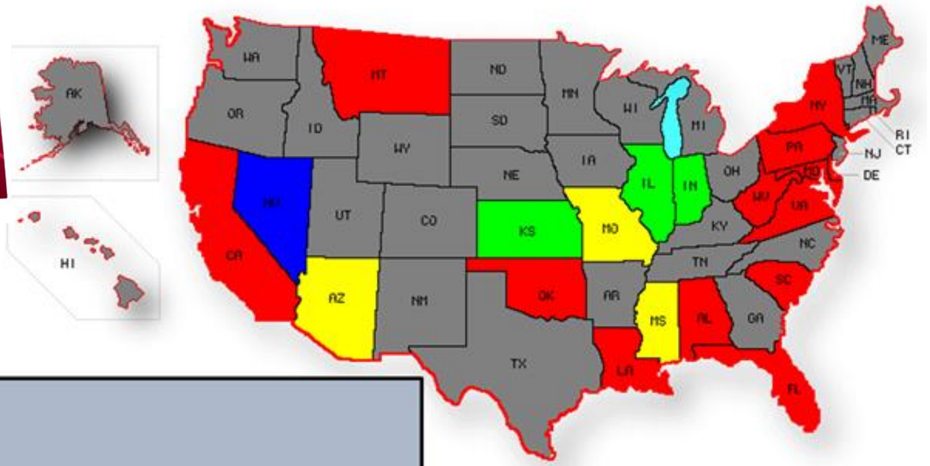


2020 NEC® Update Process Underway - 5 **
2017 NEC® Update Process Underway - 7
Current Update Process Completed - 35
(See NEC® in Effect Map for Updated Edition)
County/Municipality NEC® regulation only - 3

State	Current Edition Of The NEC In Effect (Effective Date)	2017 NEC UPDATE Status (Effective Date)
California	2014 (1/1/2017)	1/1/2020
Maryland	2014 (1/1/2015)	Update process underway (1/1/2020)
South Carolina	2014 (7/1/2016)	Update process underway (1/1/2020 projected)
New York	2014 (4/6/2016 with 6-month grace period ending 10/3/2016)	Update process underway (3/2020)
Florida	2014 (12/31/2017)	Update process underway (12/31/2020)



NEC® in Effect
10/1/2019



2017 NEC® - 30
2014 NEC® - 13
2011 NEC® - 1
2008 NEC® - 3
County/Municipality NEC® regulation only - 3

Source: diymaps.net (c)

*Source: http://www.nfpa.org/NEC/NEC-adoption-and-use/NEC-adoption-maps
**IEEE Twin Cities PES/IAS October 2019 Technical Event by Chad Kurdi. P.E., IEEE Member: https://events.vtools.ieee.org/m/200513

Summary

- Understanding the New IEEE 1584-2018 Guide, NFPA 70E, and OSHA
  - IEEE 1584-2018 Inputs: Working Distance, Electrode Gap, Electrode Orientations, and Size Information
  - Multiple and Varying Arcing Currents with IEEE 1584-2018
- Review Fuse Clearing Time Problems and the 2020 / 2017 NEC 240.67 Article
  - Case #1: Varying Cable Lengths
  - Case #2, Parts I-III: Varying Transformer Sizes
- 15kV and Below Solutions for New and Retrofit Applications
  - Review Arc Energy Reduction Solutions per 2020 / 2017 NEC 240.67 and 240.87
  - CEU (Continuing Education Unit) Exercises:
    - 240.67 (B)(2)
    - 240.67 (B)(3) and 240.87(B)(4)
- Understand the Present / Pending Enforcement Maps of the 2020 / 2017 NEC

MIPSYCON Safety/Security Session Q&A

If you have questions, please contact me further

IEEE Advancing Technology for Humanity

Booth #311

Speaker

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- Founder and Chair, IEEE Twin Cities PES/IAS http://sites.ieee.org/tc-pesias/

ABB

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EasyPower® Power made easy.

Understanding IEEE 1584-2018 and the 2017 NEC Article 240.67, Arc Energy Reduction for Fuses*:
https://www.easypower.com/resources/article/understanding-ieee-1584-2018-and-the-2017-nec-article-240.67

Nebraska IEEE Section

Sep. 12th, 2019 @ 5:30-7:30pm, IEEE Nebraska:
https://events.vtools.ieee.org/m/202678

Minnesota Power Systems Conference

Nov. 12th, 2019 @ 1pm, MIPSYCON-Safety/Security:
https://ccaps.umn.edu/minnesota-power-systems-conference

***Superceding "Understanding NEC 240.67 2017, Arc Energy Reduction for Fuses":**
https://www.easypower.com/resources/article/nec-240.67-2017-arc-energy-reduction-for-fuses

IACET: International Association of Continuing Education & Training

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