Adapting IEEE 1584-2002Arc Flash Study Results to a Post IEEE 1584-2018 Risk Assessment

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This presentation is a based on a paper presented at the IEEE 2020 Electrical Safety Workshop in March 2020.

CONSIDERATIONS FOR ADAPTING IEEE 1584-2002 ARC FLASH STUDY RESULTS TO A POST IEEE 1584-2018 RISK ASSESSMENT

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The method outlined in this presentation was solely created by M. E. Valdes and is not a product of the ABB company nor is it endorsed or promoted by ABB in any way. The method is not intended to replace a well performed arc flash study by qualified personnel using the latest applicable standards and generally accepted practices.

The method is solely intended to provide an estimating tool that may be useful in the process of risk analyses associated with evaluating if PPE has a high enough arc rating, under certain identified limited conditions, to exceed the incident energy that may be calculated by an Arc Flash study performed using IEEE 1584-2018 under the same identified limited conditions.

Old AF study… New AF science…

PPE was selected with an IEEE 1584-2002 AF study

PPE good enough for my task now that IEEE 1548-2018 has established a new science?

Am in conformance with the legal requirements?

- **Is ignoring IEEE 1584-2018 the right thing to do from a "risk Assessment and control perspective?**
- **Does the worker have adequate PPE for the potential severity of an AF event based on the "new" science?**

A Paradigm Shift

Assistant Secretary David Michaels
letter to the OSHA staff
July 19, 2010

"Ensuring that American workplaces are safe will require a paradigm shift, …

with **employers going beyond simply attempting to meet OSHA standards**, …

to **implementing risk-based workplace injury and illness prevention** programs."

Is that, really, the right question?

Is this a legal matter? **Perhaps**

Is it a safety matter? **Definitely**

Primarily it is a "**Risk Analysis**" question!

“Risk” in 70E…Risk Management, Needs:

1. Communication & consultation
2. Establishing risk assessment context & objectives
3. Risk assessment
4. Risk treatment
5. Recording/reporting risk assessment results & treatment decisions
6. Monitoring & reviewing risks

“Risk” in 70E…Risk Assessment, Part of risk management involving:

1. Identifying sources of risk
2. Analyzing risk sources to estimate risk level
3. Evaluating risk → determine if risk treatment is required

“Risk” in 70E… Risk Analysis, must be:

1. Integral to organizational processes & decisions
2. Systematic, structured, & timely
3. Use best available information
4. Accounts for human & cultural factors
5. Dynamic, iterative & responsive to change
6. Facilitates continual organization improvement

Why bother asking?

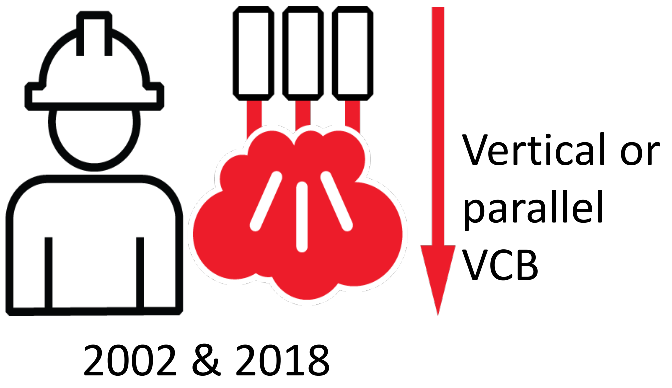
IEEE 1584 2018 is very different from 2002 version

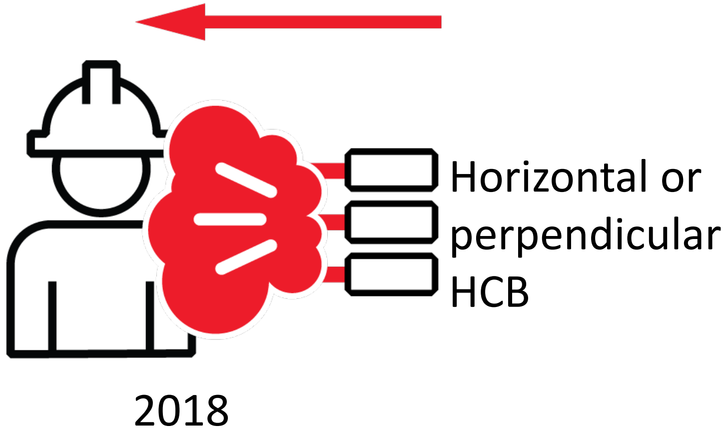
2002 version was good, the 2018 version is better

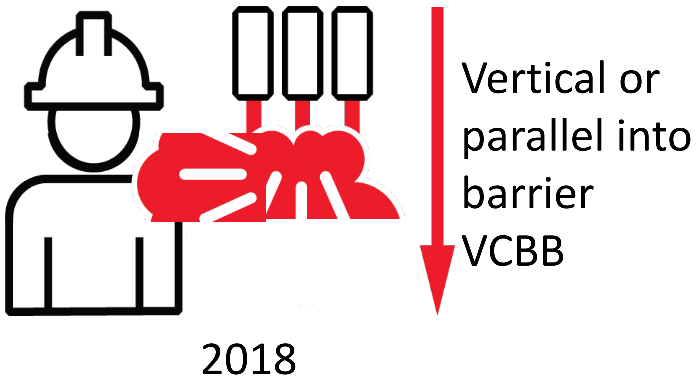
Inputs for the calculations are different…

Electrode orientation & arc environment were not considered before

Parameter	2002 model	2018 model
Voltage (Voc)	208 - 600 V & 1kV - 13.8 kV	208 V - 15 kV
Frequency	50 - 60 Hz	50 - 60 Hz
Current @ LV (Ibf)	700A - 106kA	≤ 600 V→ 500 A - 106 kA
Current @ MV (Ibf)	700A-63kA	> 600 V→ 200 A - 65 kA
Gap (G) @ LV	10 - 40 mm	≤ 600 V→ 6.35 - 76.2 mm
Gap (G) @ MV	13 - 152 mm	> 600 V→ 19.05 - 254 mm
Working Distance (D)	Typically 15-36 Inches	≥ 12 inches
System grounding	Used	Ignored
Enclosure	Assumed per voltage & gap	variable, 49" maximum for any 1 dimension
Electrode configurations	VCB, VOA (vertical only)	VCB, VOA + VCBB, HCB & HOA







Why bother asking?

And gap is now a variable

Is the arc pointing at the worker or not?

Is the arc constrained or free?

Is it an itty-bitty arc, or a great big long one?

Are the differences important ? Do we care?

Parameter	2002 model	2018 model
Voltage (Voc)	208 - 600 V & 1kV - 13.8 kV	208 V - 15 kV
Frequency	50 - 60 Hz	50 - 60 Hz
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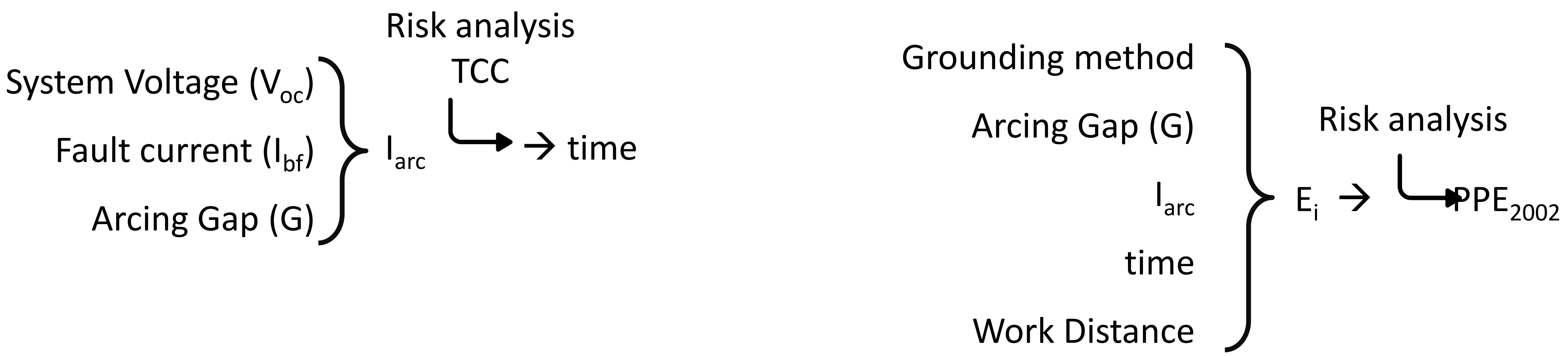
Relationships are not simple

Equations are complex, no need to go there for this analysis if one can make some assumptions!

$$I_{arc\_Voc} = 10^{(k_1+k_2 lg I_{bf}+k_3 lg G)}(k_4 I_{bf}^6 + k_5 I_{bf}^5 + k_6 I_{bf}^4 + k_7 I_{bf}^3 + k_8 I_{bf}^2 + k_9 I_{bf} + k_{10})\ )$$

$$E_{Voc} = \frac{12.552}{50} T \times 10^{\left(k_1+k_2 lg G+\frac{k_3 I_{arc_{Voc}}}{k_4 I_{bf}^7+k_5 I_{bf}^6+k_6 I_{bf}^5+k_7 I_{bf}^4+k_8 I_{bf}^3+k_9 I_{bf}^2+k_{10} I_{bf}}+k_{11} lg I_{bf}+k_{12} lg D+k_{13} lg I_{arc_{VOC}}+lg\frac{1}{CF}\right)}$$

2002 study (VCB)



Only 1 electrode description VCB, box is always standard… There is open as well but ignoring in this situation

In 2018 electrode description became a big factor!

Grounding method no longer a factor

Gap & box size also factors but will those change?

2002 study (VCB)

System Voltage (V_{oc})
Fault current (I_{bf})
Arcing Gap (G)
HCB, VCB or VCBB

Risk analysis
TCC
I_{arc} → time

System Voltage (Voc)
Fault current (Ibf)
Arcing Gap (G)
I_{arc}
time
Work Distance
HCB, VCB or VCBB
Box size

Risk analysis
E_i → PPE_{2018}

VCB, VCBB or HCB impact I_{arc} & E_i directly, & I_{arc} impacts time which also impacts E_i !

Electrode orientation is now “a” big factor!

Gap & box size also factors but will those change? Larger box will lower E_i

Gap and electrode orientation → I_{arc}

Gap probably will not change unless it's recognized the gap needs to be larger than previously used. If a larger gap is needed it's a more complex problem.

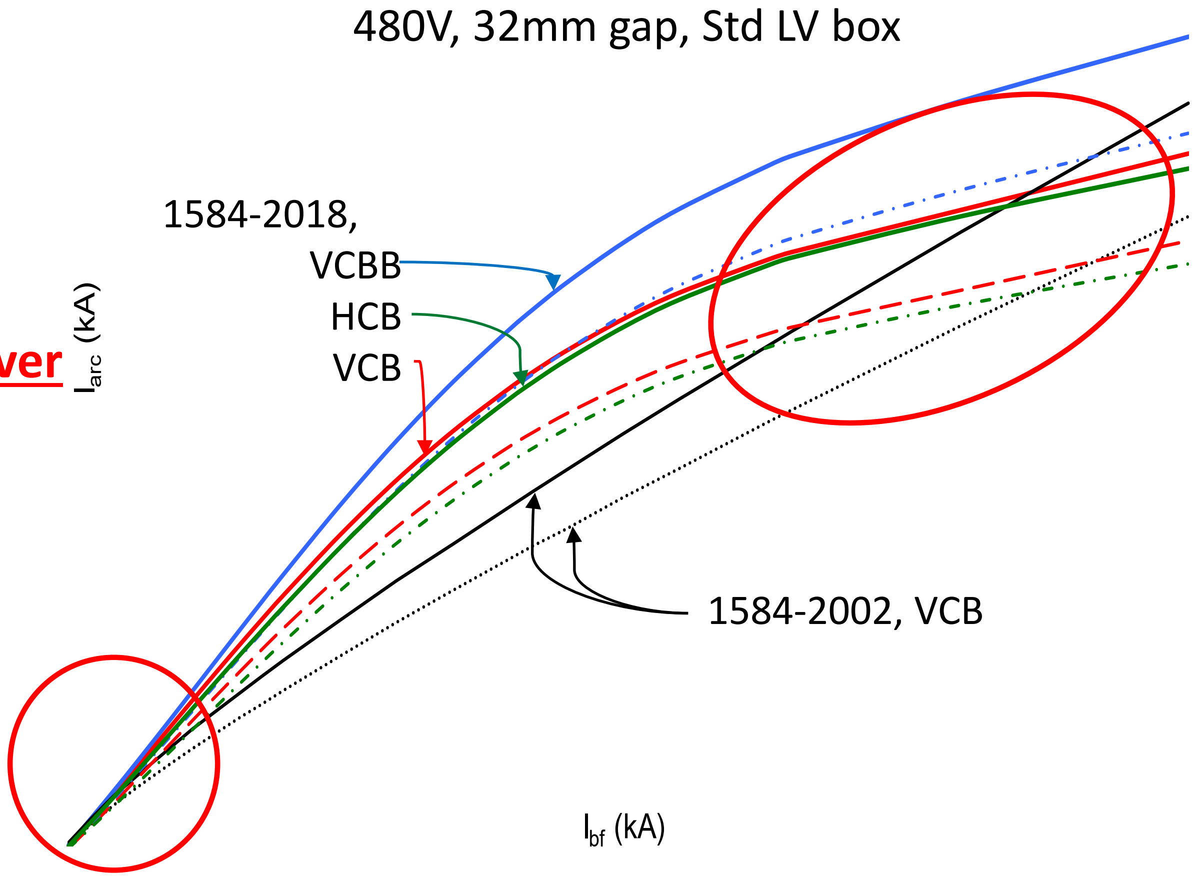
If the gap is smaller than what was used in calculation then analysis is conservative, for this purpose it can be ignored.

In a 2018 Arc Flash study, if not sure about "gap" use a larger gap…

Impact of gap on arcing current!

Over an important region the 2018 I_{arc} is > the 2002 I_{arc}!!!

Higher I_{arc} → equal or faster speed protection … **never slower**!



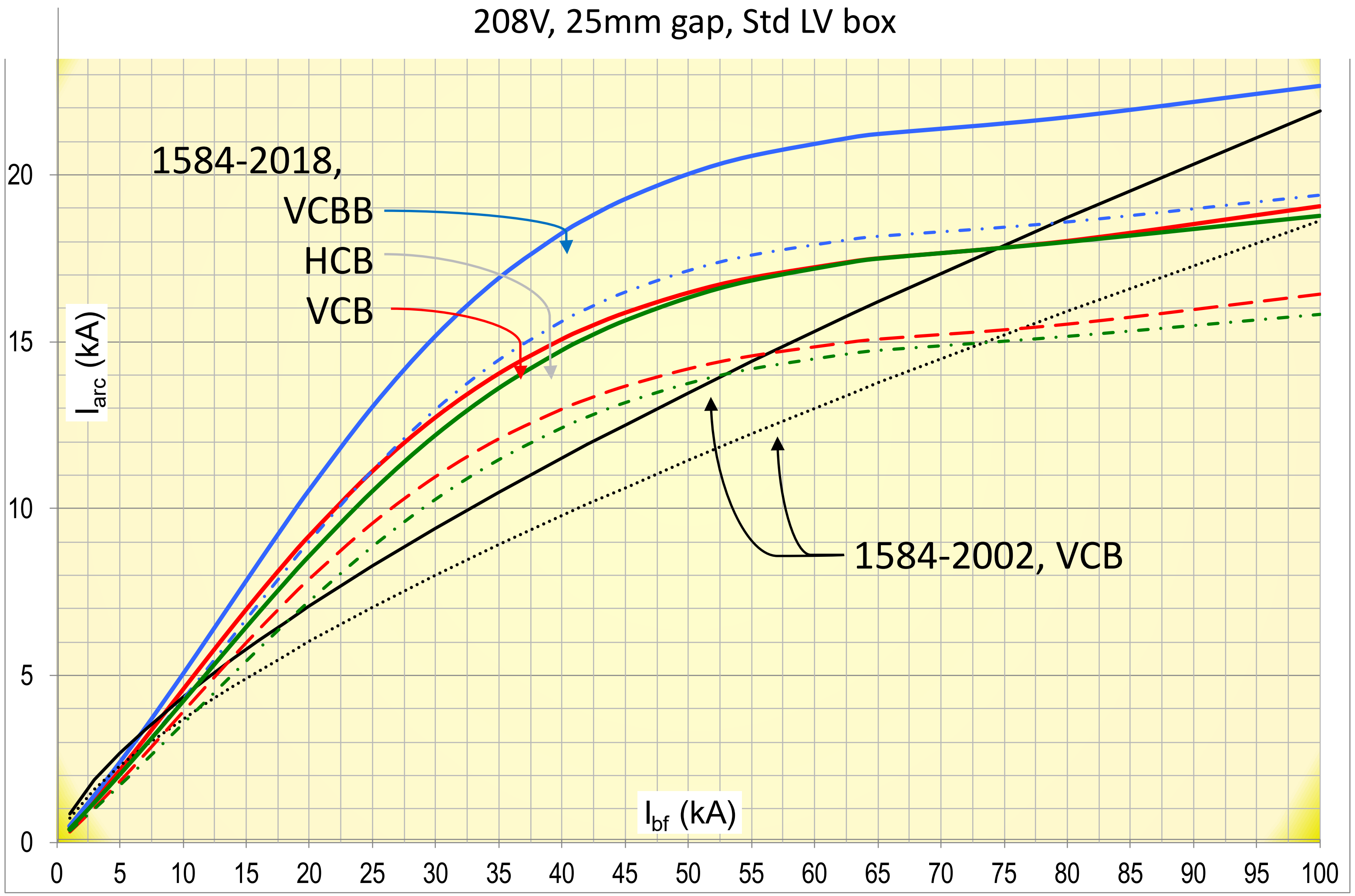
208V, similar to 480V except arcing current really flattens out

Similar relationships at 208V. Its also similar at 600V

Flattening of the arcing current… at some point more I_{bf} drives little more arcing current

What happens at 200kA I_{bf} ???

Arcing current can be much lower than traditionally calculated fault currents, specially at very high values of fault current and in lower voltage systems!



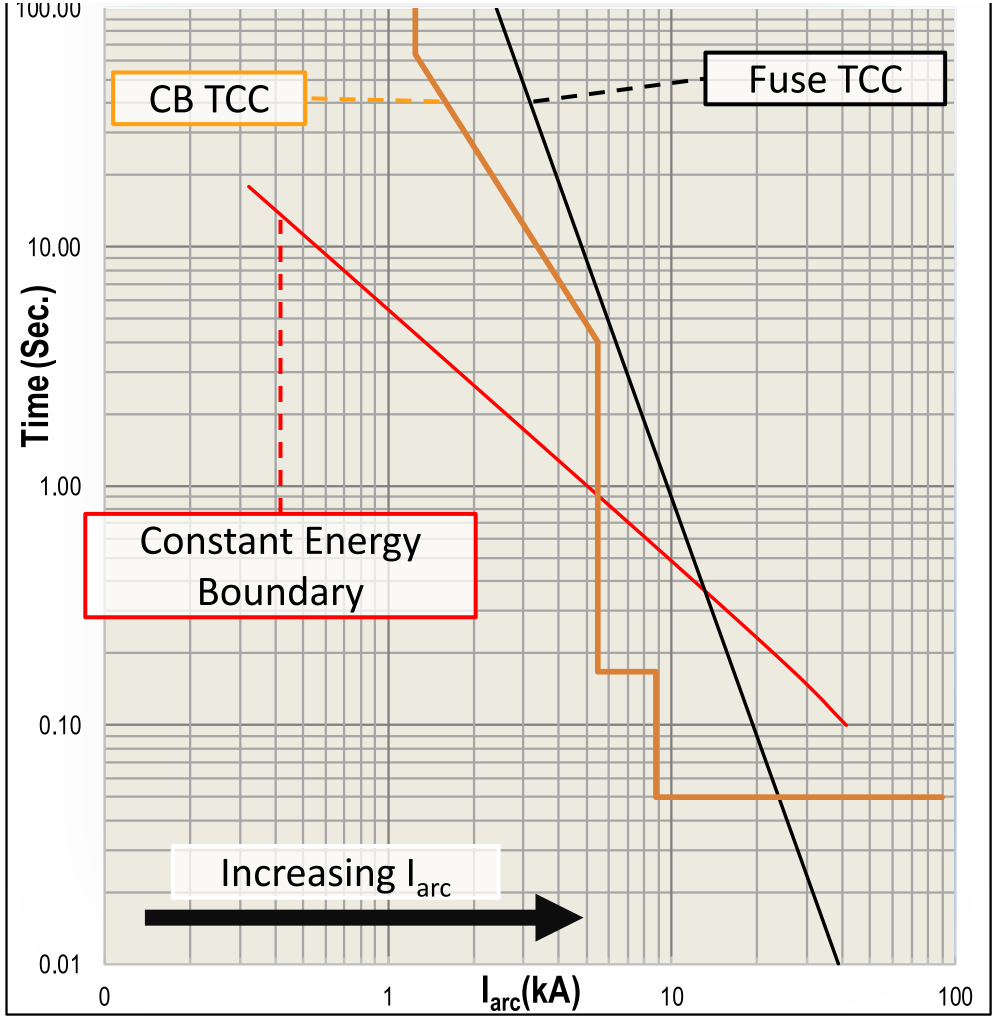
Important point

For a useful range of I_{bf} , same V_{oc} & gap, for all VCB/HCB/VCBB; I_{arc} will be higher in a 2018 study

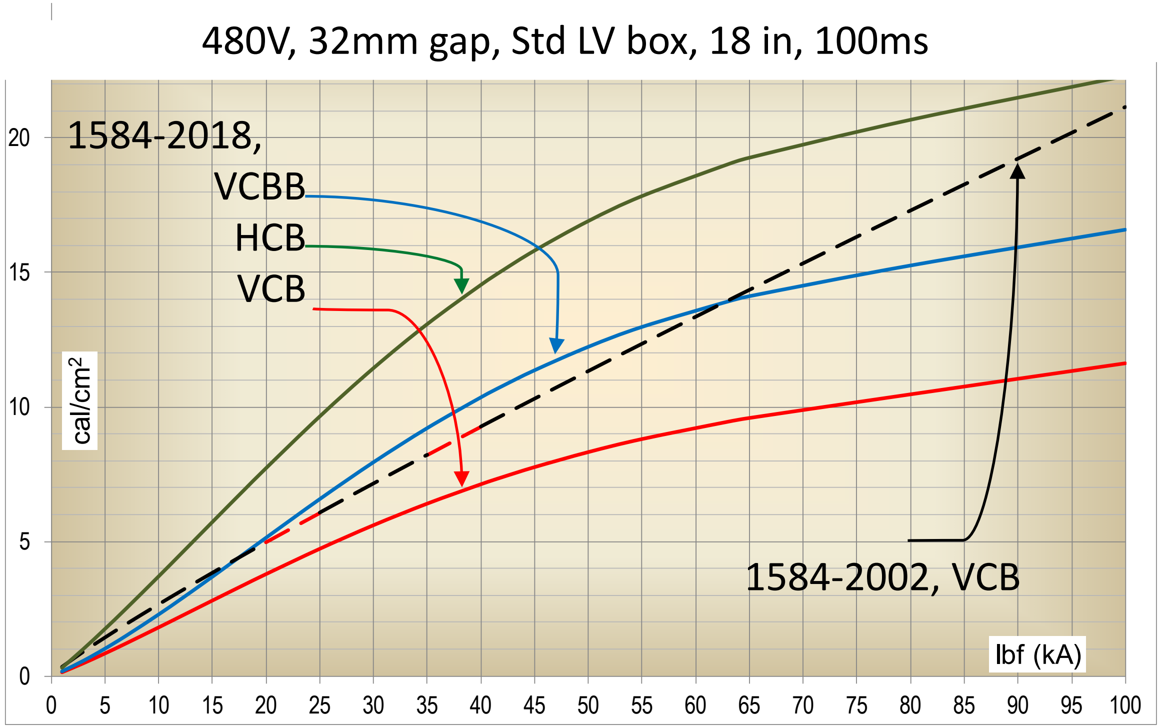
- Protection will be equal or faster over that range of I_{bf} Never slower!

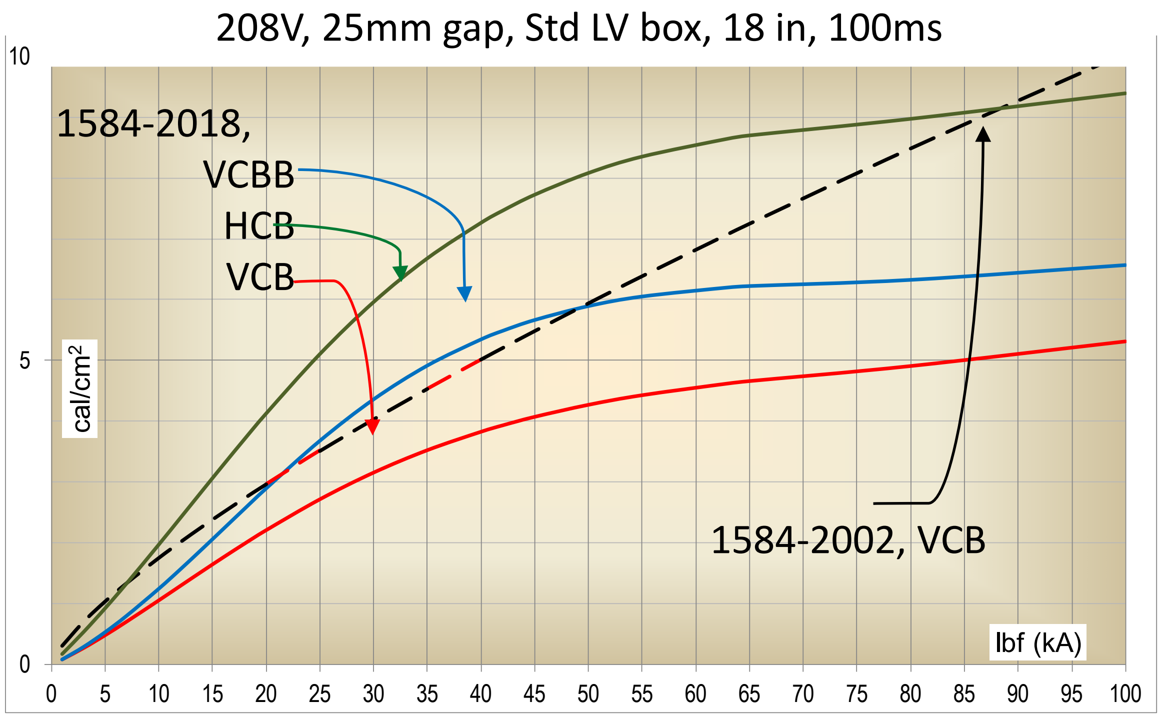
Fuse curve's & CB's TOC portion of curves are steeper than constant energy boundaries…

If I_{arc} increases the protection will never be slower!



E_i… not so clear



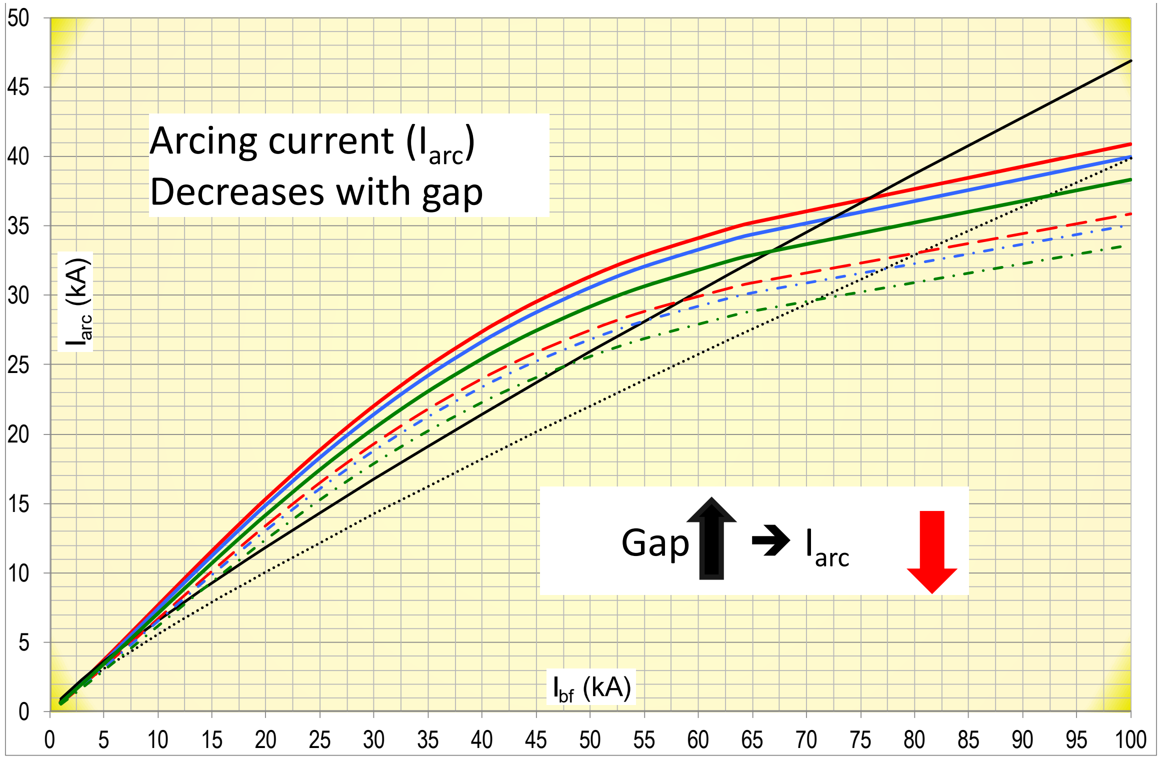


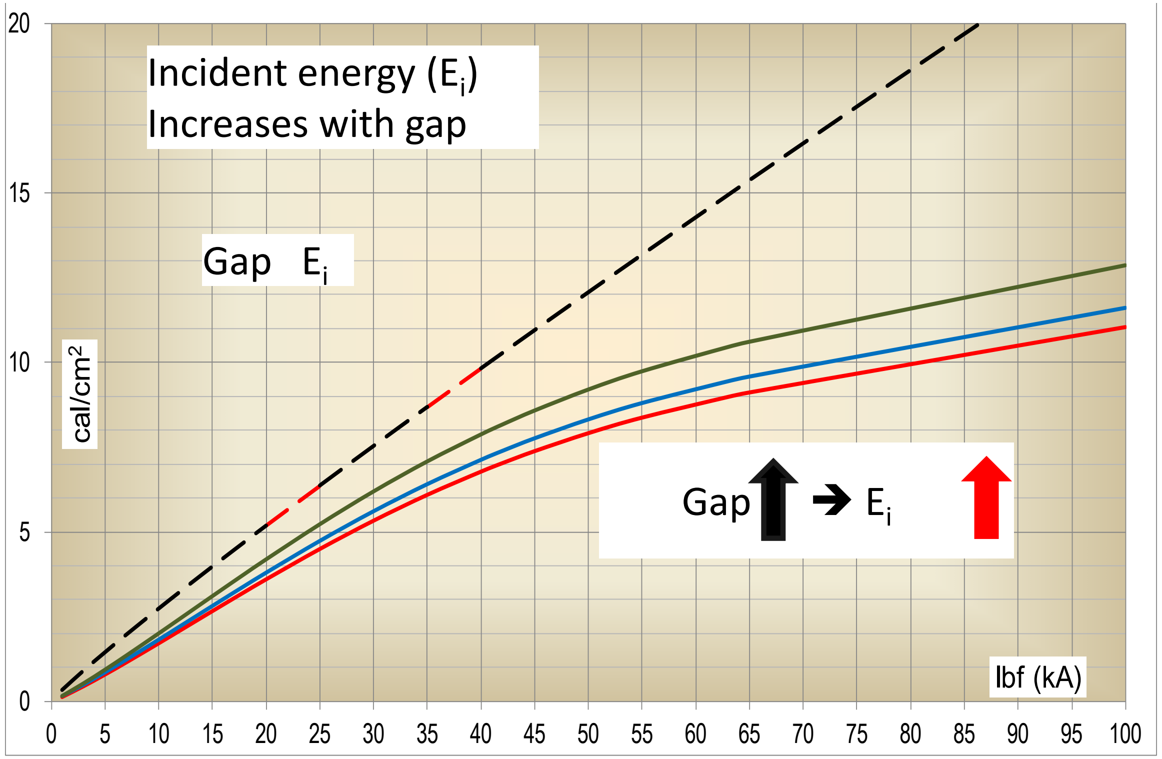
For VCBB & VCB, all else equal, the 2002 study may be adequate or even conservative over a wide range of situations, but not always

HCB, on the other hand… but there are more variables in the new equations

But above assumes time is equal! If the 2002 vs 2018 time are different….

Gap, 25, 32 & 51mm (1, 1.25 & 2 inches), VCB, 480V



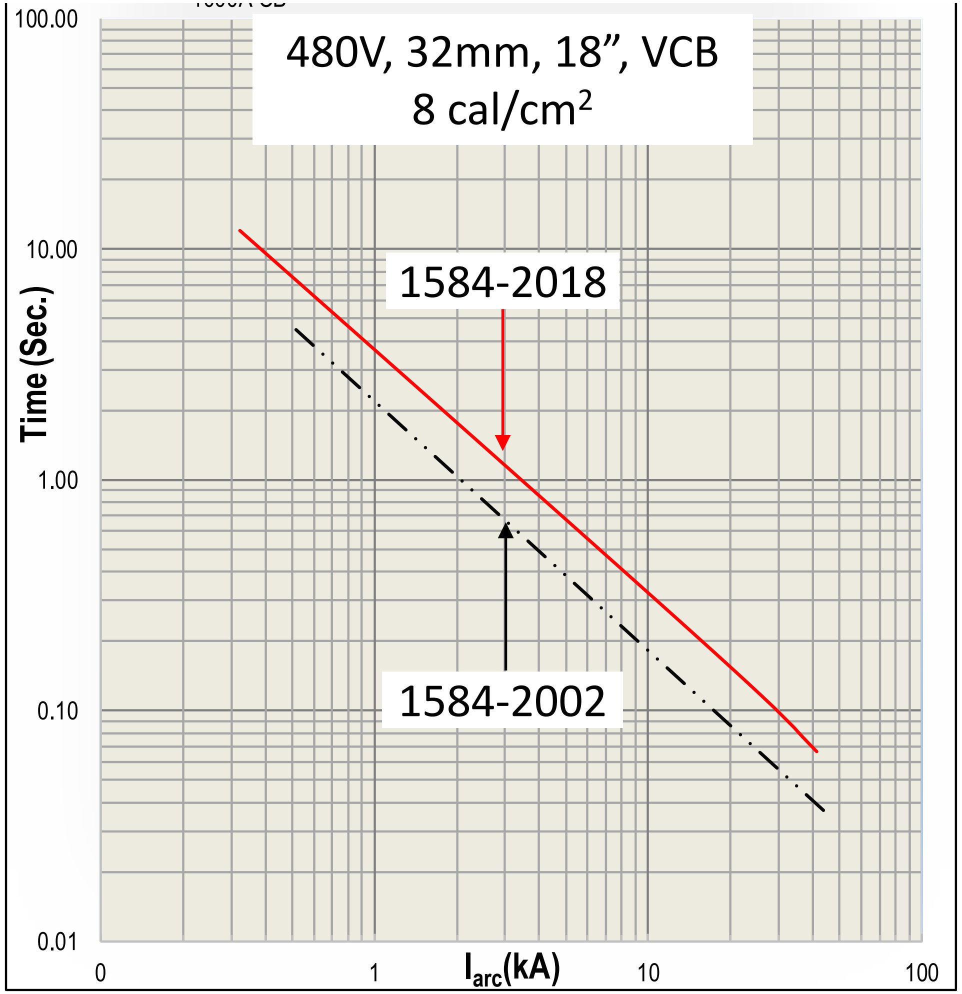


Lower I_{arc} is harder to detect, may cause protection to slow

Regardless the decreasing I_{arc}, E_i increases because the arc is longer

Effects may be small, but they may add up…specially if protection slows

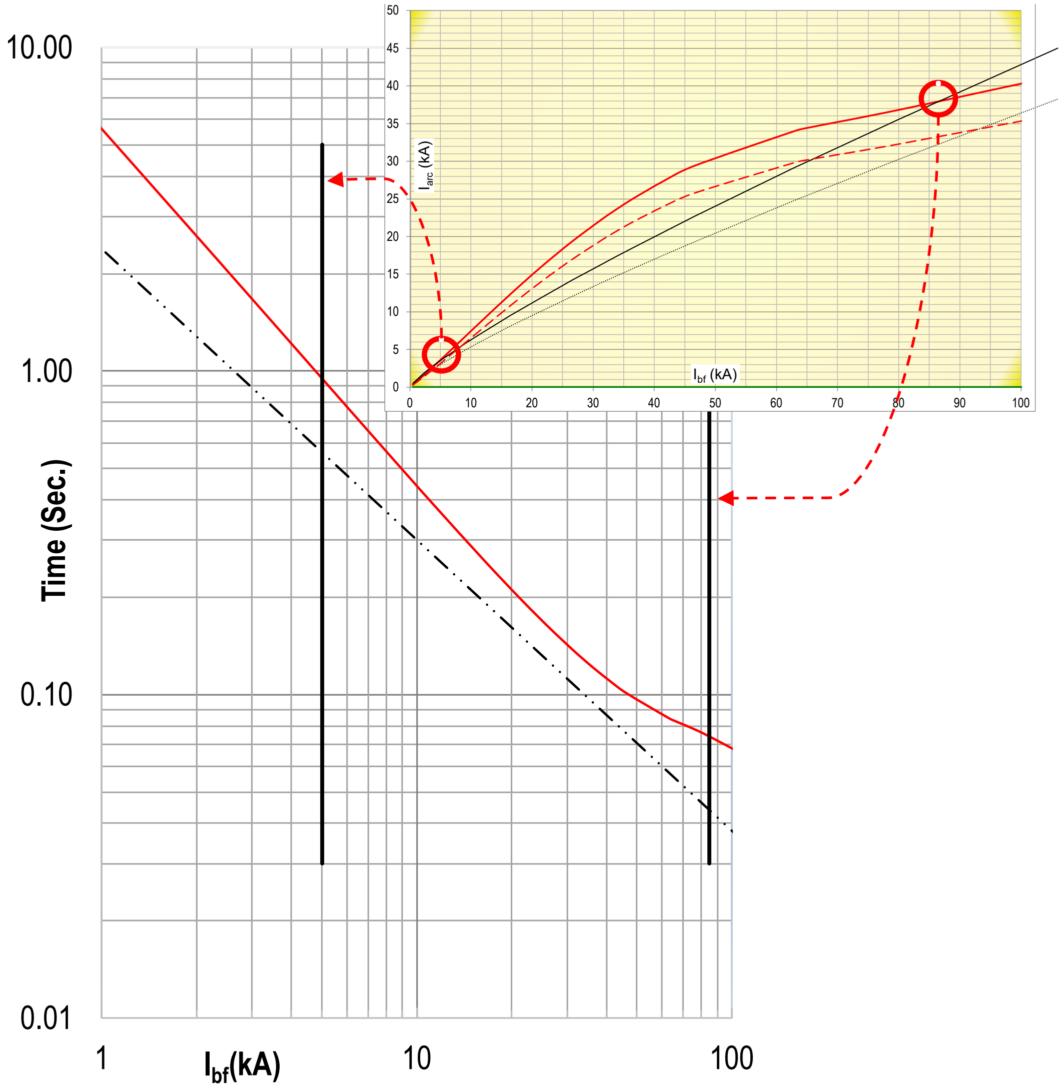
Constant Energy Boundary, A tool



- For any one value of I_{arc}, curve shows the time needed to produce a specific value of E_i.
- Notice, for same target E_i, 2018 allows more time at the same value of I_{arc}
- But… the AF study may tell you I_{arc} for a 2018 based AF study, we do not know what it would be for a 2018 calculation
- But we know that for a certain range of I_{bF} the 2018 I_{arc} will be higher… hence the OCPD will be equal speed or faster!

Transpose to I_{bf}

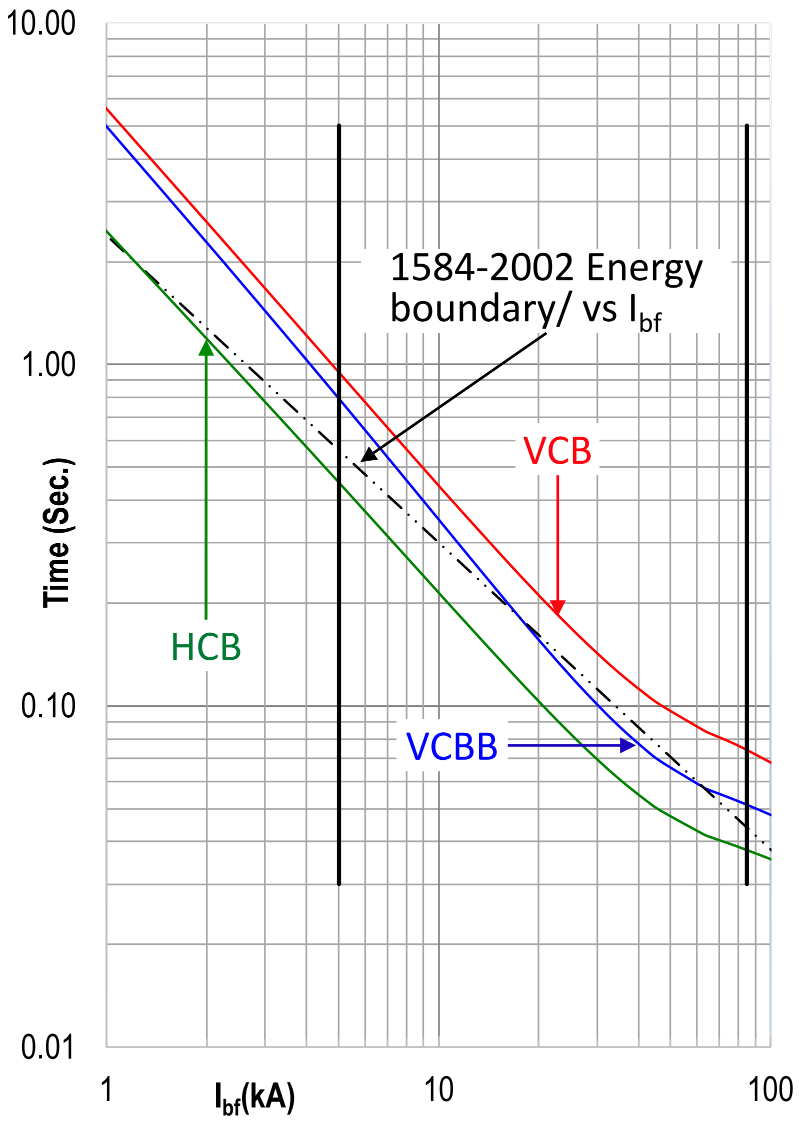
- Since we do not need OCPD clearing time we do not need actual I_{arc}.
- Plotting at I_{bf} allows the two lines to be compared to each other.
- The vertical lines bound the range of I_{bf} where we know the 2018 I_{arc} will be larger that the 2002 I_{arc}.
- If the gap, working distance & voltage are the same & I_{bf} is the same between 5kA to 85kA… the E_i will be less for VCB with the same OCPD.



VCB, VCBB & HCB

- 2018 VCB is always easier… but for VCBB it depends on the exact I_{bf}
- And for HCB it is always worse!!
- But this assumes the E_i target performance is the same for 2002 & 2018 studies…

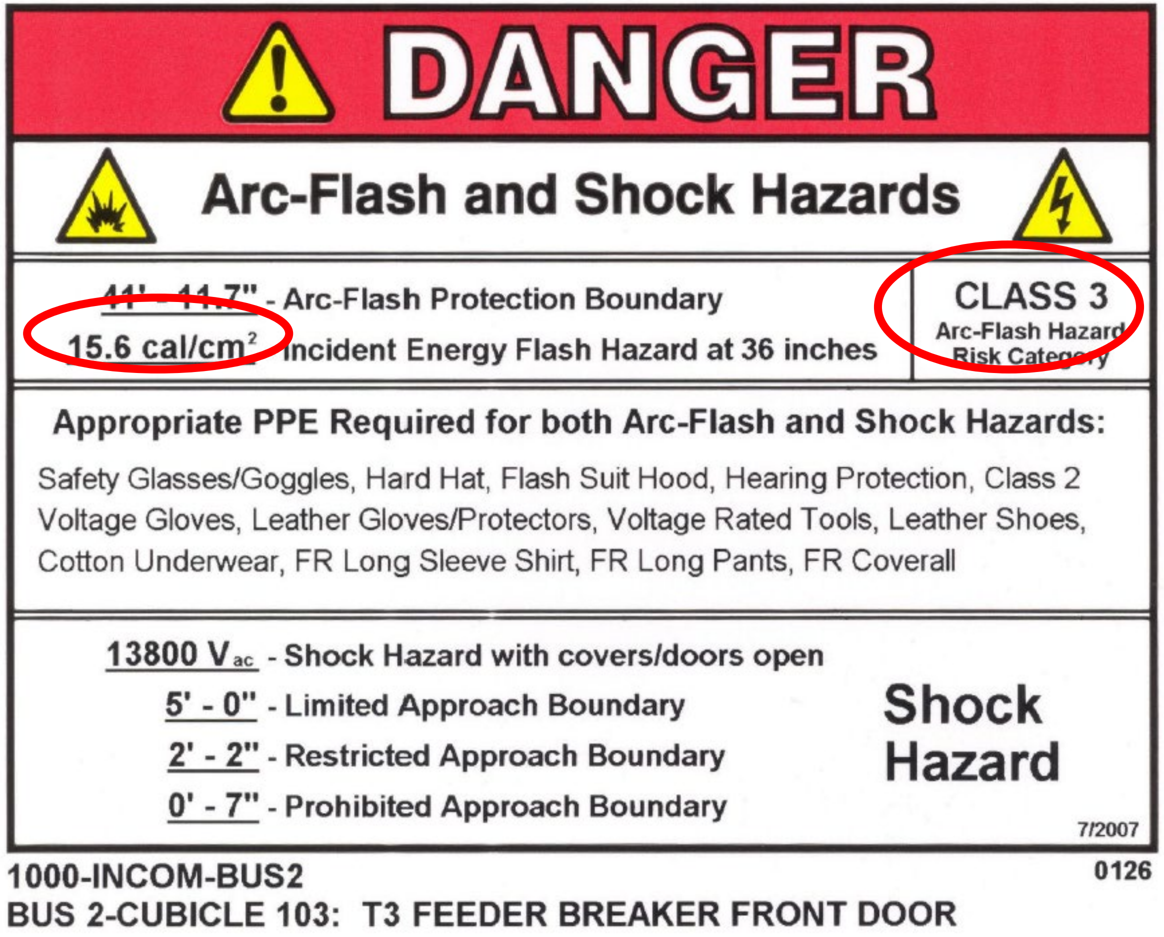
Chances are that the 2002 PPE decision selected a PPE higher than the actual exposure because PPE choices are limited by choice & availability... there is a margin



One more consideration

12-MCC-01	0.480	12-G2		Other	32	16.213	9.449	0.033	0	0.033	16.3	18	1	#0
12-MCC-02	0.480	12-A4		Other	32	16.693	*8.229	0.048	0	0.048	18.5	18	1.3	#0
12-MCC-02	0.480	12-MCC-02-MAIN		Other	32	16.693	9.682	0.027	0	0.027	14	18	0.8	#0
12-MCC-03	0.480	12-B4		Other	32	16.707	*8.235	0.048	0	0.048	18.5	18	1.2	#0
12-MCC-04	0.480	12-B3		Other	32	16.169	9.428	0.31	0	0.31	73.1	18	9.5	#3
13-PDL-MCC-01	0.480	13-PDL-MCC-01-D6		Other	32	11.957	7.332	0.019	0	0.019	9.3	18	0.5	#0
13-PDL-MCC-01	0.480	13-PDL-MCC-01E11		Other	32	12.107	7.409	0.022	0	0.022	10.3	18	0.5	#0
13-PDL-MCC-01	0.480	14B-C2		Other	32	10.208	6.427	0.49	0	0.49	85	18	11.8	#3
13-PDL-MCC-02	0.480	13-PDL-MCC-02-C8		Other	32	11.126	6.905	0.022	0	0.022	9.9	18	0.5	#0
13-PDL-MCC-02	0.480	14B-C1		Other	32	10.535	*5.609	2	0	2	187.9	18	38	#4
14-MCC-01	0.480	14B-C3		Other	32	11.201	*5.902	1.684	0	1.684	164	18	31.1	#4

- Generally a PPE level selected or recommended is > than the Ei calculated.
- Table above: 9.5 → 25, 11.8 → 25, 38 → 40, 31.1 → 40
- Can the margin absorb the extra energy the new exposure may cause?

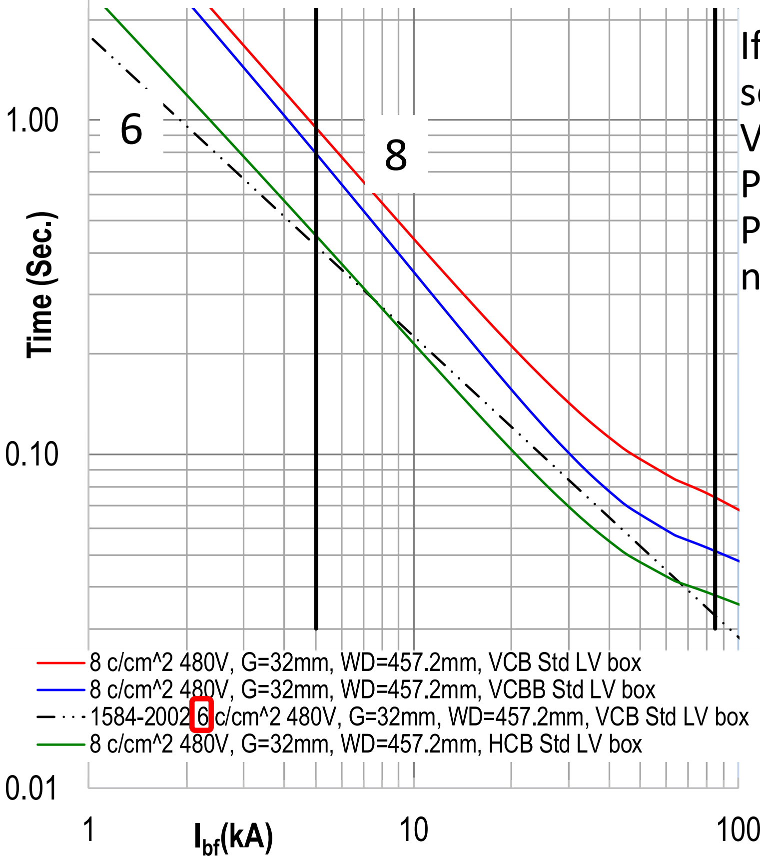


15.6 calories calculated; 25 calorie PPE identified…

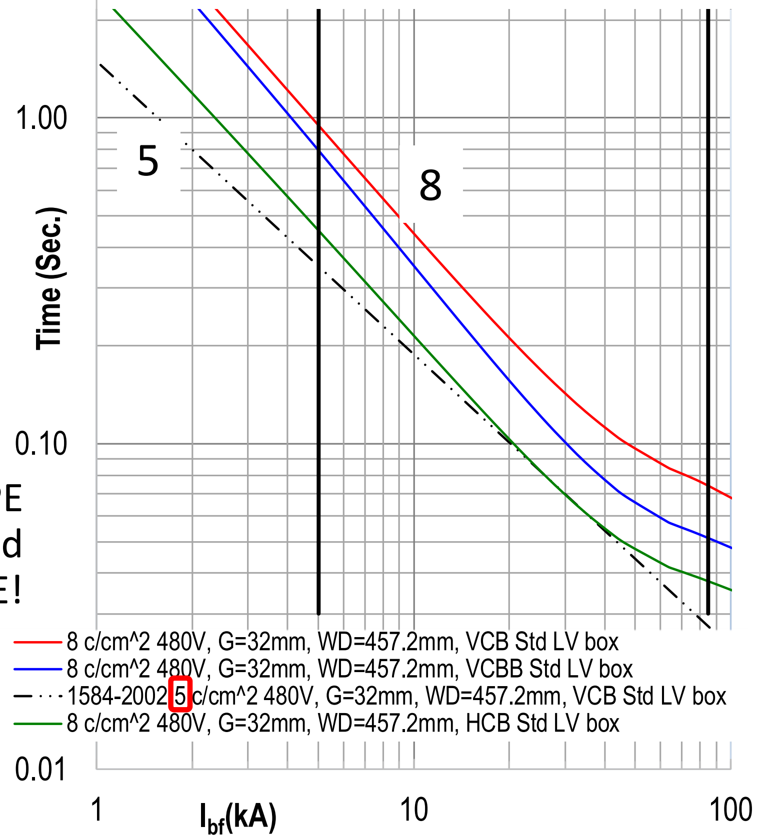
An almost 10 calorie margin, enough to accommodate the new calculations?

Improperly identified as HRC here!

With the right graph any situation can be analyzed



If E_i calculated was 6 cal/cm^2 but 8 PPE was selected. A task that may now have VCB or VCBB exposure is still covered by the 8 cal/cm^2 PPE. For HCB, for some I_{bf} range, E_i may exceed PPE selected... A more exact calculation will be needed to make sure!



If E_i calculated was 5 cal/cm^2 & 8 call PPE was selected. HCB energy may not exceed selected PPE!

Without I_{arc} or understanding the OCPD the method allows determination if a new electrode exposure presents unacceptable risk using only the 2002 based study!.... But one needs a chart to represent the specific scenario!

Table format for multiple scenario

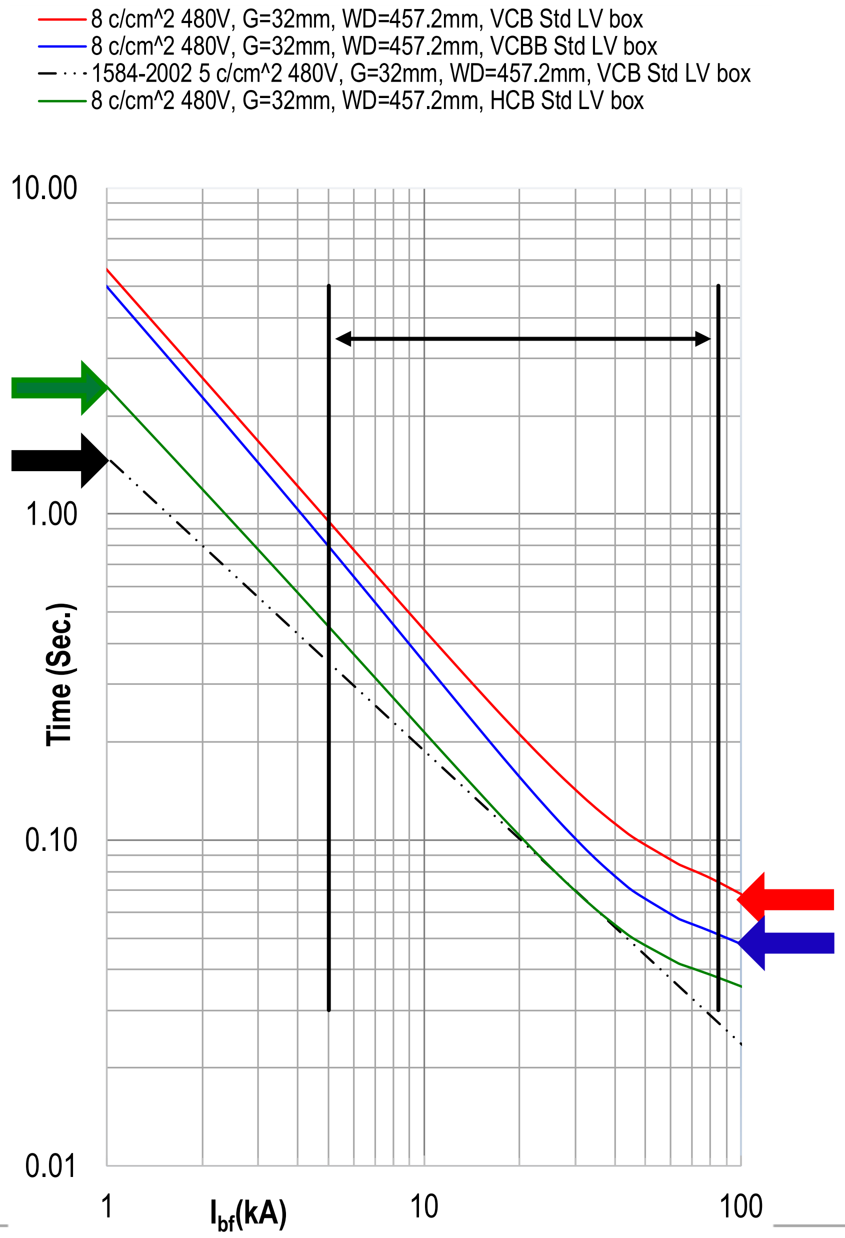
V_{oc} HRG	Gap G in mm	IEEE 1584-2018 Electrode Config.	$I_{a\text{-}1584\text{-}2018} \geq I_{a\text{-}1584\text{-}2002}$ I_{bf} from - to (kA)		1584-2018 8 cal/cm² VCB	1584-2018 8 cal/cm² VCBB	1584-2018 8 cal/cm² HCB	1584-2018 25 cal/cm² VCB	1584-2018 25 cal/cm² VCBB	1584-2018 25 cal/cm² HCB	1584-2018 40 cal/cm² VCB	1584-2018 40 cal/cm² VCBB	1584-2018 40 cal/cm² HCB
			I_{bf} range where 1584-2018 minimum I_a is > 1584-2002 minimum I_a		1584-2002 E_i calculated must be <= identified level for PPE selection to be sufficient; 1584-2018 calculated E_i over the range of I_{bf} identified								
208 V	13	VCB/HCB[1]	8	**68**[3]	12		6	37		20	59		32
		VCBB	6	88		8			27			42	
	25	VCB/HCB	11	72	9		5	40		17	50		27
		VCBB	7	106[2]		6			23			36	
	32	VCB/HCB	**12**[3]	78	9		5	29		15	47		24
		VCBB	7	106		6			21			34	
	40	VCB/HCB	**12**	94	8		4	25		13	41		21
		VCBB	7	106		6			18			29	
480 V	13	VCB/HCB	4	**69**	14		7	43		22	69		36
		VCBB	2	106		9			30			49	
	25	VCB/HCB	5	77	11		5	35		17	56		28
		VCBB	3	106		8			25			39	
	32	VCB/HCB	5	84	10		5	32		15	51		25
		VCBB	2	106		7			22			35	
	40	VCB/HCB	**6**	100	8		4	27		13	43		21
		VCBB	2	106		6			19			30	
600 V	13	VCB/HCB	6	**47**	17		8	52		27	84		43
		VCBB	3	61		12			38			60	
	25	VCB/HCB	**7**	56	13		6	42		21	67		33
		VCBB	3	77		9			30			47	
	32	VCB/HCB	**7**	64	12		6	38		18	60		29
		VCBB	3	90		8			27			42	
	40	VCB/HCB	6	74	10		5	33		15	52		25
		VCBB	3	106		7			23			36	

≥2.7kV 1584-2018 always yields lower I_{arc}

Notes: [1]VCB & HCB have similar I_a so they are grouped in this table.

[2]I_a not calculated for > 106 kA I_{bf}.

[3]**Bolded** numbers are the highest minimum & lowest maximum in the voltage range



I_{bf} range where 1584-2018 minimum I_a is > 1584-2002 minimum I_a					1584-2002 E_i calculated must be <= identified level for PPE selection to be sufficient 1584-2018 calculated E_i over the range of I_{bf} identified								
V_{oc} HRG	Gap G in mm	IEEE 1584-2018 Electrode Config.	$I_{a\text{-}1584\text{-}2018} \geq I_{a\text{-}1584\text{-}2002}$		1584-2018 8 cal/cm²			1584-2018 25 cal/cm²			1584-2018 40 cal/cm²		
			I_{bf} from - to (kA)		VCB	VCBB	HCB	VCB	VCBB	HCB	VCB	VCBB	HCB
208 V	13	VCB/HCB[1]	8	**68**[3]	12		6	37		20	59		32
		VCBB	6	88		8			27			42	
	25	VCB/HCB	11	72	9		5	40		17	50		27
		VCBB	7	106[2]		6			23			36	
	32	VCB/HCB	**12**[3]	78	9		5	29		15	47		24
		VCBB	7	106		6			21			34	
	40	VCB/HCB	**12**	94	8		4	25		13	41		21
		VCBB	7	106		6			18			29	
480 V	13	VCB/HCB	4	**69**	14		7	43		22	69		36
		VCBB	2	106		9			30			49	
	25	VCB/HCB	5	77	11		5	35		17	56		28
		VCBB	3	106		8			25			39	
	32	VCB/HCB	5	84	10		5	32		15	51		25
		VCBB	2	106		7			22			35	
	40	VCB/HCB	**6**	100	8		4	27		13	43		21
		VCBB	2	106		6			19			30	
600 V	13	VCB/HCB	6	**47**	17		8	52		27	84		43
		VCBB	3	61		12			38			60	
	25	VCB/HCB	**7**	56	13		6	42		21	67		33
		VCBB	3	77		9			30			47	
	32	VCB/HCB	**7**	64	12		6	38		18	60		29
		VCBB	3	90		8			27			42	
	40	VCB/HCB	6	74	10		5	33		15	52		25
		VCBB	3	106		7			23			36	

≥2.7kV 1584-2018 always yields lower I_{arc}

Notes: [1]VCB & HCB have similar I_a so they are grouped in this table.

[2]I_a not calculated for > 106 kA I_{bf}.

[3]**Bolded** numbers are the highest minimum & lowest maximum in the voltage range

HRG/ Floating Systems

Calories/cm² from 2002 study for HRG or ungrounded system. If PPE is = or higher rated than the arc rating identified at column top for identified conditions, then PPE should have higher arc rating than what a 2018 study would predict for the same identified conditions. Which include the same arcing gap, 18 inches working distance, standard box and electrode configuration of VCB in 2002 AF study and as identified in the column heading for the 2018 AF study.

Solidly Grounded Systems

Calories/cm[2] from 2002 study for solidly grounded system. If PPE is = or > rated than the arc rating identified at column top for identified conditions then PPE should have higher arc rating than what a 2018 study would predict for the same identified conditions. Which include the same arcing gap, 18 inches working distance, standard box & electrode configuration of VCB in 2002 AF study & as identified in the column heading for the 2018 AF study.

I_{bf} range where 1584-2018 minimum I_a is > 1584-2002 minimum I_a					1584-2002 E_i calculated must be <= identified level for PPE selection to be sufficient for 1584-2018 calculated E_i over the range of I_{bf} identified								
V_{oc} (Solidly Grounded)	Gap G in mm	IEEE 1584-2018 Electrode Config.	$I_{a\text{-}1584\text{-}2018} \geq I_{a\text{-}1584\text{-}2002}$		1584-2018 8 cal/cm²			1584-2018 25 cal/cm²			1584-2018 40 cal/cm²		
			I_{bf} from - to (kA)		VCB	VCBB	HCB	VCB	VCBB	HCB	VCB	VCBB	HCB
208/120 V	13	VCB/HCB (1)	8	**68** (3)	9		5	29		15	45		25
		VCBB	6	88		6			20			33	
	25	VCB/HCB	11	72	8		4	24		13	39		21
		VCBB	7	106 (2)		5.5			18			28	
	32	VCB/HCB	**12** (3)	78	7		3.5	23		12	36		19
		VCBB	7	106		5			16			26	
	40	VCB/HCB	**12**	94	6		3	19		10	31		16
		VCBB	7	106		4.5			14			23	
480/277 V	13	VCB/HCB	4	**69**	10		5.5	33		17	53		28
		VCBB	2	106		7			23			37	
	25	VCB/HCB	5	77	8		4	27		13	43		21
		VCBB	3	106		6			19			30	
	32	VCB/HCB	5	84	8		3.5	24		12	39		19
		VCBB	2	106		5.5			17			27	
	40	VCB/HCB	**6**	100	6.5		3	21		10	33		16
		VCBB	2	106		4.5			15			23	
600/347 V	13	VCB/HCB	6	**47**	13		6.5	40		21	64		33
		VCBB	3	61		9			29			47	
	25	VCB/HCB	**7**	56	10		5	32		16	51		25
		VCBB	3	77		7			23			37	
	32	VCB/HCB	**7**	64	9		4.5	29		14	46		22
		VCBB	3	90		6.5			21			33	
	40	VCB/HCB	6	74	8		3.5	25		12	40		19
		VCBB	3	106		5.5			18			28	

Notes

≥2.7kV 1584-2018 always yields lower I_a

1) VCB & HCB have similar I_a so they are grouped in this table.
2) I_a not calculated for > 106 kA I_{bf}.
3) Bolded numbers are the highest minimum & lowest maximum in the voltage range

Summary

- At LV, creating plots is not difficult for the Excel & math inclined… that is what interns are for! ☺
- Electrical system analysis software may be able to help, consult with your favorite vendor. Most software will plot constant E_i curve against I_{arc} but not I_{bf}
- Risk management principles would seem to dictate that old PPE selections should be questioned based on the new IEEE guide. Specially if HCB electrodes may be found.
- Doing the entire arc flash study over again by the time the task needs execution may be unreasonable
- Assessment with a few known variables is possible! Existing PPE practices may be good enough, sometimes, prioritize where more attention is needed!

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