EC&M®

EXECUTIVE SUMMARY

How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

Marcelo E. Valdes, P.E., Application & Standards Engineering Manager, Marketing, ABB

DECEMBER 7, 2021

KEY TAKEAWAYS

- Arc flash incident energy determines the appropriate PPE for workers, but quantifying arc flashes is complex.
- Arc flash calculations require a two-step process.
- Constant energy boundaries are a tool for evaluating situations associated with arc flash over a range of fault current and range of OCPD response for a specific set of arc flash parameters and selected PPE.
- Another approach to determine required PPE is to adapt the findings from IEEE 1584-2002 arc flash studies.
- The NFPA 70E table is an official method for estimating arc flash PPE categories, but it is not always conservative, particularly for low arcing current.
- Canada's Workplace Electrical Safety Standard CSA Z462 is a better alternative to NFPA 70E tables.
- The constant energy line is another way to determine the correct level of PPE.

in partnership with

ABB

How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

OVERVIEW

Different approaches exist for determining the correct amount of PPE to protect workers from arc flash. In the absence of an arc flash study, workers may turn to NFPA 70E tables 130.7 (c) (15) (a). The table, however, may be difficult to apply to a specific task or situation and may be very conservative, or not conservative enough. Graphical approaches like energy boundary graphs can be useful because they incorporate fault current variance and do not require the need to know the exact performance of an overcurrent protective device at a specific value of arcing current.

CONTEXT

Marcelo Valdes discussed different approaches for estimating arc flash PPE requirements.

KEY TAKEAWAYS

Arc flash incident energy determines the appropriate PPE for workers, but quantifying arc flashes is complex.

Wearing too much PPE is undesirable. It can make workers inefficient and uncomfortable. However, if something goes wrong, like an arc flash incident, wearing inadequate PPE can be extremely dangerous. Arc flash describes an electrical explosion which is chaotic and hard to predict. Although arc flash studies may look exact, in reality they are simply approximations, hopefully conservative, of what might happen.

Marcelo Valdes made several observations about quantifying arc flash incident energy:

- **All methods used to estimate risks to human life must account for potential error.** As a result, they should be conservative. A key question is whether the inputs used in arc flash studies are correct. Were they estimated conservatively or do they represent the most likely value?
- **To estimate risk, it is important to analyze probability and severity.** A risk assessment considers the probability of an event. Arc flash studies, however, only address severity. If the arc flash numbers are high enough, and the probability of an event is not negligible, then PPE is needed per the expected severity.
- **Electrical system studies aren't an exact science.** Short circuit studies and almost all electrical system studies are biased conservatively—impedances are estimated low, while sources and short circuit currents tend to be estimated high. Short circuit studies ensure that all equipment ratings are high enough to handle potential worst case short circuit currents. If a high short circuit current event occurs, there could be serious consequences should equipment not be adequately rated.
- **Arc flash studies include many estimated variables which can impact the results in one direction or another.** Arcing currents are lower than the bolted fault current. Depending on the voltage, they can be significantly lower. Generally speaking, it is advisable to consider a range of potential results for arc flash based on a range of potential inputs.

Arc flash calculations require a two-step process.

First, the arcing current (I_a) must be calculated and then the incident energy (E_i) must be found. Many of the values and inputs used for these calculations are never known exactly. If an error is conservative or within a margin that other factors account for, it's okay.

The IEEE 1584-2018 model is conservative with respect to E_i, but Valdes believes it may not be conservative with respect to low I_a. IEEE 1584-2018 may not truly account for how low I_a can be, because it ignores factors excluded from the original test data. Some variance in Ia can have a significant impact on E_i.

How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

Figure 1: Calculating Arc Flash

First, arcing current (I_a)

- Voltage V: Usually well known within a narrow range
- Bolted fault current (I_{bf}): Estimated high, particularly in LV & may vary significantly, typically downward, due to expected or known & unexpected or unknown topology changes
- Arcing Gap (G): Can be measured, but usually is not, often guessed at. Guessing large is more conservative, drives lower I_a & higher E_i
- Electrode orientation (V or H): Seems obvious if you see the conductors, but it's the direction power comes from that is important & one needs to see it relative to the task to be sure.
- Box or no box (CB or OA): Box size does not impact I_a, but impacts E_i per the model… but very large boxes may be like OA if the arc is unconstrained which leads to potentially lower than expected I_a
- Defines "average" I_a & "minimum" I_a. Minimum I_a doesn't consider minimum I_{bf}, maximum gap or voltage regulation… **minimum may not be minimum**

Second, Incident Energy (E_i)

- I_a from step 1: 2 values, an average & a minimum
- Protection time (t): Derived from the expected response of the protection to the I_a that flows through it, or from the response of the protection mechanism used to mitigate the AF event. High I_a may cause the protection to be a lot faster, & low I_a the opposite
- Working distance (D): How far the worker's chest is from conductor terminals. Usually comes form values in IEEE 1584 guide but may vary for multiple reasons.
- Size of the box (correction factor): Small & deep is more conservative but has relatively low effect.
- V & G are also used

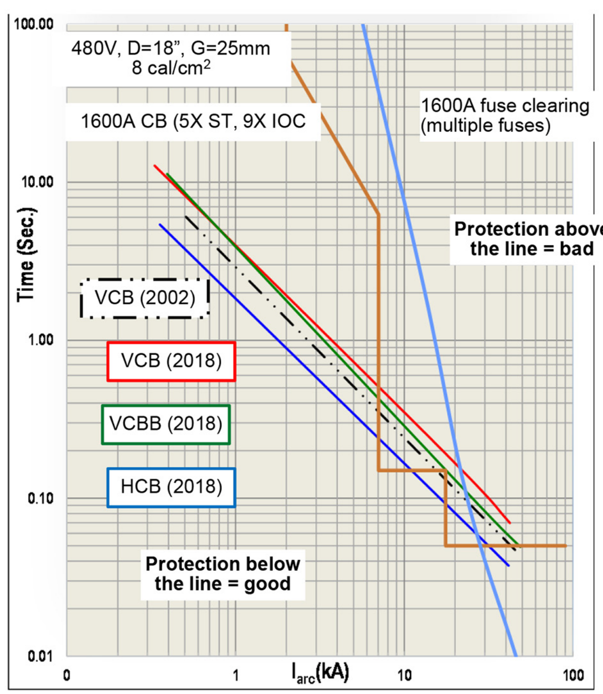
Constant energy boundaries are a tool for evaluating situations associated with arc flash over a range of fault current and range of OCPD response for a specific set of arc flash parameters and selected PPE.

A constant energy boundary (CEB) shows graphically how a protection system performs against a specific PPE performance target and range of arcing current. The CEB in Figure 2 shows 480V, 18" D, 25mm G, in a standard box up to 100kA I_{bf}.

If I_{bf} is not a well-known variable, then I_a is even less so. Both the circuit breaker and fuse are "steeper" than the CEB. As a result, low I_a can result in higher energy than high I_a. This is counterintuitive. At high I_a, both the circuit breaker and fuse may be good enough. Fuse size matters whether it's current limiting or not, and circuit breaker size, type, and settings matter.

Figure 2: A Constant Energy Boundary Example

8 cal/cm² Constant Energy Boundary, 480V, D=18", G=25mm



How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

Another approach to determine required PPE is to adapt the findings from IEEE 1584-2002 arc flash studies.

With an IEEE 1584-2002 arc flash study, it is possible to identify what PPE will do at arcing currents determined from the 2002 equations. What is unclear, however, is whether the changes in IEEE 1584-2018 will result in more or less PPE being required.

However, it is possible to compare the CEBs drawn against bolted fault current instead of arcing current because the fault current has not changed. Using the highest value of energy that was calculated in the original 2002 arc flash study plot a CEB(I_{bf}) for that level of energy, plot your selected or available PPE based on the new IEEE 1584-2018 method, and compare it based on the bolted fault current. This eliminates the need to calculate the exact arcing current or look at the OCPD TCC. What allows this comparison to be valid is that the arcing current in a LV 2028 arc flash study will always be higher than an equivalent 2001 study for a significant and useful I_{bf} range. Hence, you know the protection will be the same speed or faster, never slower.

The NFPA 70E table is an official method for estimating arc flash PPE categories, but it is not always conservative, particularly for low arcing current.

NFPA 70E takes a task-based approach to hazard risk analysis which has two steps:

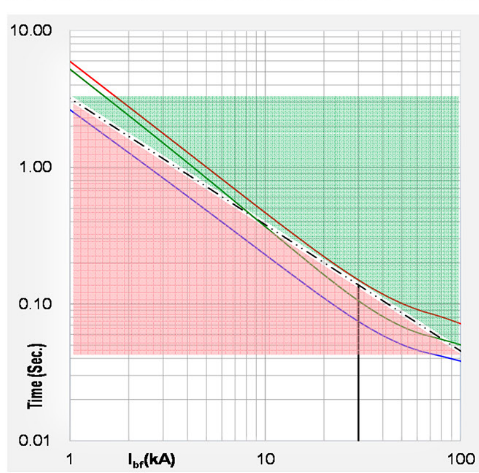
1. **Does the task require PPE?** This is determined using Table 130(5): Estimate of the likelihood of occurrence of an arc flash incident for ac and dc systems.
2. **If so, what level of PPE is required?** This is determined using Table 130.7(C)(15)(a): Arc flash PPE categories for alternating current (ac) systems. Selection depends on voltage, short circuit current (I_{bf}) maximum, overcurrent protection device (OCPD) performance at a particular current, and the type of equipment. The most important thing about incident energy mitigation is what the OCPD does at the arcing current. However, nothing in this table helps to understand arcing current.

Figure 3: Leveraging IEEE 1584-2002 Arc Flash Study Results

If you have an IEEE 1584-2002 study but not a 2018 study….

- 2002 study → 8 cal/cm² PPE & per this chart 2018 study with same inputs "may" be good enough for VCB or VCBB, but not HCB…But "may be" is not good enough…
- IEEE 1584-2018 I_{arc} often higher than IEEE 1584-2002 I_{arc}, → the protection will be = speed, or faster, not slower…
- For Ibf where the new I_{arc} is higher, if the protection was good enough for 8 cal/cm² before, its good enough for 8 cal/cm² now… this chart shows that
- Margin between 2002 values & PPE selected, even better
- If the 2002 line is plotted at the highest E_i level calculated in the 2002 study and the 2018 lines are plotted at the available PPE level the margin between can be leveraged

8 cal/cm² Constant Energy Boundary, 480V, D=18", G=25mm



Graph vs. I_{bf} not drawn by normal system analysis software

How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

Valdes reviewed several other weaknesses in NFPA 70E tables:

- No changes account for the different I_{arc} and E_i in the new IEEE guide, although incident energy can be more than twice as high.
- The NFPA 70E tables require users to know I_{bf} and OCPD performance at I_{bf}. Both are hard to know without a coordination study. Knowing OCPD performance at Ibf is irrelevant and possibly even misleading.
- Equipment descriptions include OCPD type or size and have equipment descriptions that don't follow applicable standards. Switchgear, for example, doesn't have fused switches.
- There is no consideration of task or bus bar direction.
- Most table entries can result in higher energy if arcing current is low, or worse if the arcing current is low through the OCPD but not low at the arcing point, which may be the case with sources in parallel or significant motor contribution.

Rather than relying on NFPA 70E, a better approach may be to check with someone who understands arc flash calculations.

Figure 4: Shortcomings with NFPA 70E Table 130.7(C)(15)(a)

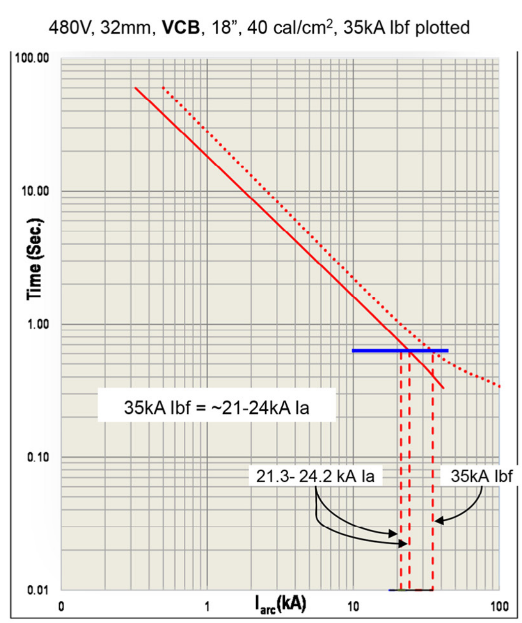
Focuses on a "maximum" I_{bf} and what the OCPD does at fault current.

- A user would need to know available fault current
- To determine what the OCPD does at the fault current you need the OCPD curve or a coordination study
- From the above you can determine clearing time at fault current **which has nothing to do with arc flash** but does tell you what PPE to wear based on this table?

Canada's Workplace Electrical Safety Standard CSA Z462 is a better alternative to NFPA 70E tables.

In 2021, CSA Z462 was updated with arc flash PPE categories for alternating current (ac) systems. The alternate table in the appendix is based on IEEE 1584-2018 analysis and on factors verifiable in the field without engineering studies. It includes circuit size and considerations for OCPD size, I_{bf} and I_{arc} variation, and possible error due to human factors.

> Any table method means you're dealing with a significant lack of detailed knowledge and you're addressing potential variability in the input parameters. By definition, you have to be conservative. Wearing too much PPE may be undesirable, but if you underestimate and have an event, the results could be unacceptable.
>
> *Marcelo Valdes, ABB*



How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

Figure 5: CSA Z462 Reduces Error Opportunities and Uses Relevant Information

CSA Z462:21, table V.1 Arc-flash PPE categories for alternating current (ac) systems

(1) Equipment	(2) Nominal voltage	(3) Upstream device at same voltage in separate compartment *	(4) Arc flash PPE category
Panelboard, Motor control centre (MCC), Disconnect switch, or Other equipment (rated ≤ 800 A) Minimum working distance: 46 cm	240 V (1ϕ)	Transformer:	
		≤ 15 kVA	N/A
		≤ 50 kVA (Z ≥ 1.8%), or ≤ 75 kVA (Z ≥ 3%)	2
		≤ 250 kVA	4
		Fuses:	
		≤ 150 A	N/A
		≤ 600 A	2
		≤ 800 A	4
		Circuit breaker with fixed or adjustable T/M or M trip unit:	
		≤ 80 A	N/A
		≤ 300 A	2
		≤ 800 A	4

Identifies source size, to establish an I_{bf} range

Possible settings identified that may be observed on site

Identifies equipment, type & size & important task factor

Identifies OCPD type & size to establish a response range to I_{arc}

Identifies V! Important for I_{arc} estimate

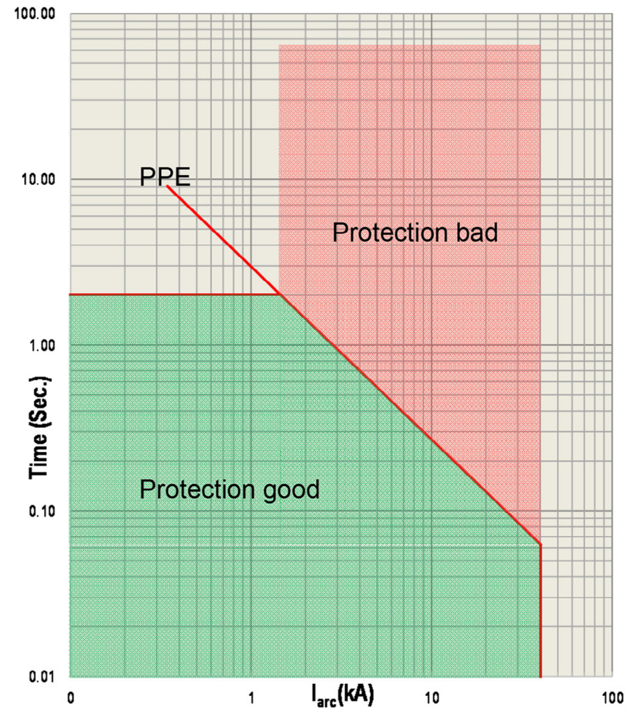
Panelboard, Motor control centre (MCC), Disconnect switch, or Other equipment (rated ≤ 800 A) Minimum working distance: 46 cm	208 V (3ϕ)	Transformer:		
		≤ 10 kVA	N/A	< 0.46 m
		≤ 45 kVA (3ϕ), or 3 x 10 kVA (1ϕ)	2	2.0 m
		≤ 150 kVA (3ϕ), or 3 x 25 kVA (1ϕ)	4	4.5 m
		Fuses:		
		≤ 60 A	N/A	< 0.46 m
		≤ 200 A	2	2.0 m
		≤ 800 A	4	4.5 m
		Circuit breaker with T/M or M trip unit:		
		Fixed or adjustable magnetic not set at lowest setting:		
		≤ 30 A	N/A	< 0.46 m
		≤ 90 A	2	2.0 m
		≤ 400 A	4	4.5 m
		Adjustable magnetic set at lowest setting:		
		≤ 225 A	2	2.0 m
		≤ 600 A	4	4.5 m

- **All information the worker may find at job site!**
- **This should reduce error opportunities.**
- **Also uses relevant information!**

The constant energy line is another way to determine the correct level of PPE.

With this graphical method, you determine what you need to know to select PPE, consider variance in the fault current, and use variables that you have access to.

Figure 6: Determining PPE with a Constant Energy Line



How to Estimate Arc Flash Incident Energy When You Do Not Have a Proper Arc Flash Study

BIOGRAPHY

Marcelo E. Valdes, P.E.
Application & Standards Eng. Manager, Marketing, ABB

After 41 years with GE, Mr. Valdes joined the ABB Electrical Products division in July 2018. Mr. Valdes has held positions in field engineering, equipment sales, application engineering, and product marketing. He is past chair of various IEEE PES and IAS chapters in Northern California as well as past chair of the 2014 IEEE Electrical Safety Workshop (IEEE-ESW). Mr. Valdes chaired the IEEE 1683-2014 working group "IEEE P1683 Guide for Specification and Selection of Low Voltage Motor Control Centers with Enhanced Safety Features" and is active in various other IEEE working groups, mostly in electrical safety and electrical systems protection. Mr. Valdes has received multiple recognitions from the IEEE for various contributions in the area of overcurrent protection and electrical safety. He received the IEEE *IAS Applications Magazine* "First Prize Article Award" for the 2014 article "Assessing Solutions to Electrical Hazards: An Analytical Tool to Reduce Hazards in Electrical Facilities." Mr. Valdes has authored or co-authored over 35 technical papers for IEEE and other engineering forums. Marcelo participates in CSA Z462, the Canadian Electrical Safety Standard, the NEC & NFPA70B NFPA's Electrical Maintenance Standard. Mr. Valdes holds 28 patents in the field of electrical distribution and control.

© 2021 Endeavor Business Media. All rights reserved.