EFCOG Best Practice - #232-2019

Low Voltage 208Y/120V & 240VAC Arc Sustainability

Facility: DOE Complex

Best Practice Title: Low Voltage 208Y/120V & 240VAC Arc Sustainability

Point of Contact:

Jennifer L Martin (509) 554-9337 Jennifer_L_Martin@rl.gov

Alberto (Tico) Machado (803) 557-6342 Alberto.machado@srs.gov

Gregory Christiansen (208)526-5380 Gregrory.Christensen@inl.gov

John Whipple (208) 526-9858 John.whipple@inl.gov

Lloyd Gordon (505) 660-7161 Lbgordon@lanl.gov

Brief Description of Best Practice: Revisions to NFPA 70E and IEEE standard 1584 "IEEE Guide for Performing Arc-Flash Hazard Calculations" were evaluated for their potential impact on arc flash studies and risk assessments. This best practice provides guidance for identifying arc flash hazards for low voltage systems.

Why the best practice was developed: The IEEE 1584-2018 revision removed the 125kVA transformer threshold for arc flash hazards. This removal was based on testing of low voltage three-phase systems that demonstrated that although unlikely, it may be possible to sustain an arc flash briefly under certain conditions.

What are the benefits of the Best Practice: Provides guidance regarding arc flash evaluation to the engineering organizations throughout the DOE Complex.

What problems/issues were associated with the Best Practice: N/A (New best practice.)

How the success of the Best Practice was measured: N/A (New best practice.)

Description of process experience using the Best Practice: N/A (New best practice.)

INTRODUCTION

This best practice provides guidance for arc flash risk assessments of low voltage systems. Revisions to NFPA 70E and IEEE standard 1584 "IEEE Guide for Performing Arc-Flash Hazard Calculations" were evaluated and have the potential to impact arc flash studies and risk assessments. Other studies (see references) regarding low voltage arc flash testing were also considered in the development of this guidance.

Studies indicate that it is unlikely that an arc flash can be sustained on 208Y/120V and 240V 3-phase systems unless certain conditions are present. Low voltage arcs tend not to sustain for more than one-half cycle for electrodes having an arc gap of 0.5 inches or greater. In typical parallel bus arrangements, the magnetic forces propel the arcs and hot gases away from the source, making it more likely that the arcs will self-extinguish. Smaller bus spacings are expected to produce a more sustainable arc. Determining when and where an arc flash potential is likely requires a review of the configuration and the application of engineering judgement. Threshold values are based on available research and theoretical data and should not be considered as absolute; rather used as guidance when applying effective hazard analysis to a particular task. The small number of recorded injury cases typically involved a small enclosure supplied by a relatively large transformer. Studies also indicate that single-phase (single winding) systems will self-extinguish and not present an arc flash hazard.

BACKGROUND AND DISCUSSION

NFPA 70E-2009 Exception No.1 to Section 130.3 was removed starting with NFPA 70E-2012. This exception is in the IEEE 1584-2002 first edition albeit in a somewhat modified form.

The 2002 Edition "125 kVA transformer exception" stated:

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

After 16 years, IEEE 1584-2018 was published to reflect the results of new testing. Testing demonstrated that although not very common, it may be possible to sustain arcs briefly at lower levels of short circuit current resulting in a greater incident energy. Based on the results of additional testing, the 125 kVA exception was deleted from the standard.

The 2018 Edition New language states:

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

Table 1 utilizes IEEE 1584-2002 methods and illustrates the relationship of the transformer size and clearing time on the results of calculations. In comparison, Table 2 utilizes IEEE 1584-2018 methods and is provided for comparison. Note that the Table 2 results are less conservative than the Table 1 results.

Note also that the results from both Table 1 and Table 2 assume that the arcs are sustainable. At certain clearing times, KVA sizes, and configurations, while it is unlikely, it is theoretically possible to produce an arc flash event (>1.2 Cal/cm^2 at the working distance) on low voltage equipment.

Studies using various electrode configurations have been performed which includes the following-:

- Vertical Electrodes, Metal Box (VCB)
- Vertical Electrodes terminating in an insulating barrier, Metal Box Enclosure (VCBB)
- Horizontal Electrodes, Metal Box Enclosure (HCB)
- Vertical Electrodes, Open Air (VOA)
- Horizontal Electrodes, Open Air (HOA)

Table 1. Arc Flash Potential Calculations (IEEE 1584-2002)

Total Incident Energy (cal/cm^2) 208Y/120V Transformer Secondary					
Transformer size (KVA)	**Arc Flash Duration Cycles (1/60 second)**				
	1	6	10	20	30
112.5	0.20	1.22	2.03	4.07	6.10
75	0.15	0.90	1.50	3.0	4.50
45	0.10	0.62	1.03	2.07	3.10
30	0.08	0.46	0.77	1.53	2.30

Explanatory note: Table 1 calculation is based on an infinite bus on the primary of the transformer and a transformer %Z of ~4%. The IEEE 1584-2002 calculation method for panel boards was utilized with typical gap (25 mm) and working distance (18") parameters.

Table 2. Arc Flash Calculations (IEEE 1584-2018)

Total Incident Energy (cal/cm^2) 208Y/120V Transformer Secondary					
Transformer size (KVA)	**Arc Flash Duration Cycles (1/60 second)**				
	1	6	10	20	30
112.5	0.13	0.79	1.32	2.64	3.96
75	0.08	0.5	0.83	1.66	2.49
45	0.05	0.28	0.46	0.92	1.38
30	0.03	0.17	0.29	0.58	0.87

Explanatory note: Table 2 calculation is based on an infinite bus on the primary of the transformer and a transformer %Z of ~4%. The IEEE 1584-2018 calculation method for panel boards was utilized with typical gap (25 mm), working distance (18”), VCB bus configuration, and box dimensions of 12”W x 14”H x 10”D.

Studies indicate that it is unlikely that an arc flash can be sustained for 208Y/120V and 240VAC systems unless certain conditions are present. The conditions necessary to sustain an arc flash event appear to be rare and unusual. At 208Y/120V or 240VAC, arcs tend not to sustain for more than one-half cycle for an arc gap greater than 0.5 inches. At a one-half-inch arc gap, faults cleared within 10 cycles. Some tests were arranged so that the three phases were pointing at each other, which is a severe test condition. Arcs are more likely to self-sustain because the magnetic fields force the arcs towards the center of this arrangement. In a typical parallel bus arrangement, the magnetic forces propel the arcs and hot gases away from the source, making it more likely that the arcs will self-extinguish. Smaller bus spacings are expected to produce a more sustainable arc.

In the study “Effect of Insulating Barriers in Arc Flash Testing” IEEE Transactions On Industry Applications, Vol. 44, No. 5, September/October 2008, the authors conducted arcing fault tests at 208 and 250 V with arcing gaps of 12.7, 32, and 50.8 mm. With no barrier, at 208 V, arcing could not be sustained at 10 kA or less, even with the shortest (12.7 mm) gap. With an insulating barrier, the shorter arc lengths and stabilizing effect make it easier for arcing to be sustained, and it was found possible to produce self-sustaining arcs at 208 V. With a gap of 12.7 mm, sustained arcing was obtained at 4.5, 10, and 22 kA.

“An Investigation of Low Voltage Arc Flash Exposure” IEEE Paper No. ESW2013-30 evaluated the arc flash risks faced by utility workers operating equipment energized at 240V or less involving meter enclosures, meter installations, meter maintenance, and the connection of conductors in energized transformers and power pedestals. The investigation included tests conducted at an installation located immediately adjacent to a substation to achieve fault currents near 12,000 amps, which is more than that expected for the daily activities performed by utility linemen on voltages 240V and below. It concluded that the low voltage arc flash energy level to which these workers are exposed is very low.

In another study “208V Arc Flash Testing: Network Protectors and Meters”, 1022218, Technical Update, September 2010, prepared by the Electric Power Research Institute (EPRI) and Pacific Gas and Electric (PG&E), the results found that 208V faults self-extinguished in all tests. Incident energies measured at a working distance of 18 inches (47.2 cm) were all less than 0.5 cal/cm2. In less than one cycle, 70% of faults self-cleared on network protectors, and all faults self-extinguished in less than 1.6 cycles in self-contained meters. The longest arcing lasted six cycles.

Another study “Electrical Injuries and Fatalities: Facts, Myths, and Unknowns”, IEEE Paper No. ESW2019-32, identified only one fatality during 34 years of reporting from multiple sources (OSHA, NIOSH, DOE, BLS, and DOD). There are not a lot of specific details available on this event but the authors of this study believe that this fatality involved contact with the secondary side of commercial 240V service equipment.

Determining the likelihood of arc flash potential on low voltage systems requires the application of engineering judgement. Threshold values are based on available research and theoretical data and should not be considered as absolute, but rather as guidance when applying effective hazard analysis to a particular task. The small number of recorded injury cases typically involved a confined enclosure supplied by a relatively large transformer. A deep base increases the risk as it confines and directs the energy. As a result of new research testing, the new IEEE standard employs correction factors for box size and depth, recognizing this can affect the incident energy levels. In many cases the faults created in testing have been of a low order and benign.

CONCLUSIONS AND RECOMMENDATIONS

Based on testing and an evaluation of the physics of arcs, arc flash events are most likely to sustain for three-phase equipment with:

- Small bus spacings, < 0.5 inch
- Narrow bus bars, or an arrangement where they are side by side (narrow edges together)
- Confined environment – e.g., configuration resembles a smaller deep meter base.
- Vertical electrodes terminating in an insulating "barrier", inside a metal box (VCCB) enclosure, at ≥ 4.5 kA.
- For VCB, HCB, VOA, and HOA configurations at ≥ 10 kA.

NOTE: The equipment arrangement more likely to sustain an arc at 208Y/120V or 240VAC is one that will maintain a short arc length AND confine the arc.

Other factors that may be considered in an arc flash risk assessment include:

- Enclosure size may impact the arc flash energy being expelled and reaching a worker. An enclosure size correction factor is used to adjust the incident energy for smaller and larger enclosures in IEEE 1584-2018. For equipment less than 600V, the standard defines "Shallow Enclosures" as ≤ eight inches in depth and "Typical Enclosures" > eight inches in depth. The depth of the enclosure is not considered unless the width and height are both less than 508 mm (20 in.) and the system voltage is less than 600V.
- There is no main protection for the system (i.e., upstream OCPD is remote from the equipment), short wire run from the transformer (high fault current), or a long wire run (low fault current) that delays operation of the overcurrent protection device

- Although laboratory testing shows horizontal electrodes may contribute to higher incident energy levels, similar geometries are not typical in low voltage systems.
- Longer clearing times (20-30 cycle range or greater). Arc duration has a linear effect on the incident energy.
  - The fault current is below the instantaneous setting of the upstream over current device causing an increase in clearing time and available incident energy. This condition is common on higher energy 208Y/120V systems when a lighting panel has no main breaker or the main breaker is located remote from the panel it protects. The increased impedance in the circuit wiring causes a decrease in fault current to below the instantaneous setting of the upstream breaker or fuses resulting in increased arc duration.

The existing 208Y/120V and 240V systems should be evaluated by engineering to assess the factors that may be of concern and determine if additional arc flash analysis is warranted. The engineer performing the analysis will need to exercise judgment for these conditions.

REFERENCES

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