

HIGH ENERGY ARCING FAULT (HEAF) RESEARCH

Needs and Objectives



U.S. Nuclear Regulatory Commission

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INTRODUCTION

This document is written for a diverse audience that may have different levels of understanding of electrical arcing fault. For those with limited knowledge of this hazard, the remainder of this section will provided background information of the hazard, data and current models used to characterize the hazard as it is applicable to the commercial nuclear power plants. Those with an intimate knowledge of this hazard could proceed to the “Research” section where the goals, objectives, and needs of the project are identified.

HAZARD

Infrequent events such as fires at a nuclear power plant can pose a significant risk to safe operations, if not adequately protected against. Licensees have robust fire protection programs designed to minimize the likelihood and consequences of fire. These programs provide reasonable assurance of adequate protection from known fire hazards. There remain a limited set of hazards or sequence of events contributing to a hazard that are unknown to designers and safety professionals. Because of these unknowns, safety margins are commonly incorporated into the design.

One such hazard comprises an electrical arcing fault involving components made of aluminum. While the electrical faults and subsequent fires are considered in existing fire protection programs, recent research has indicated that the presence of aluminum during the electrical fault can exacerbate the damage potential of the event. The extended damage capacity could exceed the protection provided by existing fire protection features for specific fire scenarios and increase plant risk estimated in fire probabilistic risk assessments (PRAs).

Electrical arcing fault

Several definitions of the *electrical arc hazard* exist with small differences dependent on the intended application. All involve an “arc” which is defined as a high-temperature luminous electrical discharge across a gap [1]. Thus, electrical arcs involve electrical current flowing across a gap that can ionize the surrounding air and create a conductive plasma. Temperatures near the plasma can reach 35,000°F (19,425°C) creating molten metal and superheated air. The increase in temperature results in a pressure increase. This pressure increase has the potential to cause mechanical damage to the electrical enclosure, as well as structures, systems, and components

located in the vicinity of the fault. Figure 1 provides a generic illustration of the byproducts of an electrical arc.

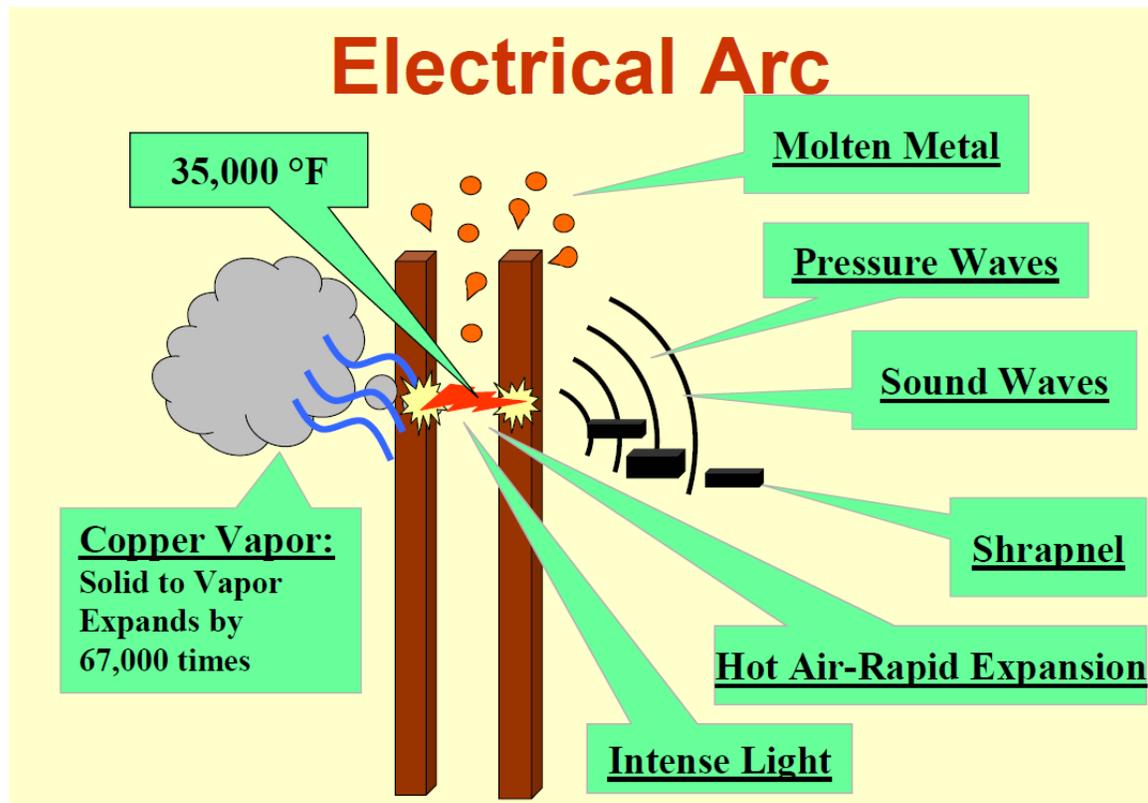


Figure 1. Illustration of electrical arc and its byproducts [2](Ref. UAW Electrical Safety in the Workplace)

Three terms are commonly used and in some cases incorrectly used interchangeably to define the electrical arc hazard, they are:

Arc Flash : rapid release of thermal energy from an electrical arc by the vaporization and ionization of materials [3]

Arc Blast : a rapid release of mechanical and acoustical energy caused by the rapid heating and vaporization of materials resulting from a sufficiently energetic arc flash. Arc blasts can cause overpressures and missile damage.

High Energy Arcing Fault (HEAF): a type of arc flash that persists for extended durations and have the potential to cause damage outside the equipment of origin.

Understanding of these definitions can lead to simple distinctions between them. For instance, all arc blasts are arc flashes, but not all arc flashes are arc blasts. Similarly all HEAFs are arc flashes, but not all arc flashes are HEAFs. HEAFs may or may not include arc blasts. The latter of the definitions (HEAF) describes an event that is the focus of this research initiative. A HEAF presents a unique hazard that has the potential to challenge the plants safe shutdown capability and for some plants represent a large contributor to overall plant risk from fire.

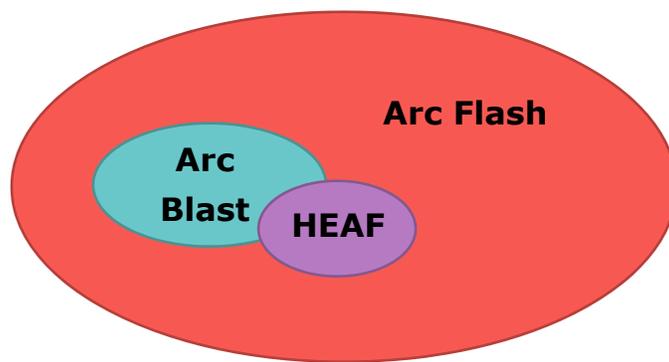


Figure 2. Illustration of relationship between terms (size doesn't represent frequency)

DATA

Operating Experience

U.S. commercial nuclear power plant operating experience has shown that in a limited number of cases electrical protection has not limited the duration of an electrical arc (arc flash vs. HEAF). Internationally, a report issued in 2013 documents 48 HEAF events from 12 member countries, representing approximately 10% of the fire events reported [4]. As a result of that international report, a U.S. lead international experimental program was conducted to better understand the hazard.

International Experimental Program

In 2017, the Organization for Economic Co-operation and Development (OECD) issued a report entitled, "Report on the Testing Phase (2014-2016) on the High Energy Arcing Fault Events (HEAF) Project," NEA/CSNI/R(2017)7 documenting the results of a HEAF testing program [5]. This program investigated the HEAF phenomena by performing 26 large scale tests and recording electrical, thermal, and pressure measurements during and after each test. Much of the testing confirmed the adequacy of existing regulatory requirements and guidance. However, two tests exhibited results that were distinctly different. In tests 23 and 26, much larger damage states were observed. Aluminum was present in both of the tests and is attributed to causing the larger damages states due to the exothermic involvement of aluminum during the electrical arcing phase. These results led the NRC staff to propose a potential safety issue as a Generic Issue (GI).

Generic Issue Program

A Generic Issue (GI) is a well-defined, discrete, technical safety or security issue for which the risk and/or safety significance can be adequately determined in a timely manner. Congressional and Commission direction resulted in the NRC staff creating the GI program. This program comprises five states; 1) identification, 2) acceptance, 3) screening, 4) safety/risk assessment, and 5) regulatory assessment. The proposed GI on HEAFs involving aluminum is currently in the 4th stage of the program. Given the limited HEAF testing involving aluminum components, an action plan with short and long term actions has identified testing as a key action to support the safety/risk assessment [6].

ARC FLASH MODELS

Evaluating arc flash hazard to personal safety

In 2007, the Department of Labor, Occupational Safety and Health Administration (OSHA) issued a final rule on electrical hazards in the work place. This revision to 29 CFR Part 1910, Occupational Safety and Hazard Standards," was a result of the determination that electrical hazards in the workplace pose a significant risk of injury or death to employees. Several codes and standards are available to support implementation of this rule and estimating the arc flash hazard, including:

- *NFPA 70E, Standard for Electrical Safety in the Workplace*
- *IEEE 1584, IEEE Guide for Performing Arc-Flash Hazard Calculations*
- *NEC, National Electrical Code (NFPA 70), and*
- *NEESC, National Electrical Safety Code (IEEE C2).*

The intent of these documents is to protect workers from electrical arcing hazards by estimating boundaries and appropriate personal protective equipment.

Incident Energy

Incident energy is the amount of thermal energy that could be absorbed by an object at a specified distance from an arc flash. Its units are cal/cm^2 [J/cm^2] and is as measure used by some standards to quantify the severity of the arc flash [7]. IEEE 1584 provides a set of equations for predicting the incident energy. The equations are empirically derived and developed through a regression analysis of that data. Parameters used for calculating the incident energy include: bolted fault current, gap between conductors, distance from an arc, equipment type and voltage class, and arcing time. In 1982, Ralph Lee presented a theoretically derived model to predict incident

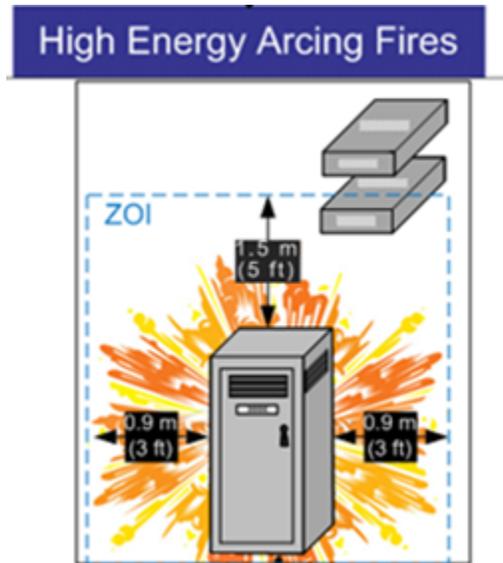
energy and distances from arc for curable and fatal burns [8]. The parameters of importance for the method of Lee include voltage, bolted fault current, distance, and arcing time.

HEAF FIRE DAMAGE MODELS

Current fire protection approaches of the HEAF hazard is provided by either deterministic or performance-based methods. Under deterministic protection, separation and compartmentalization are the prescriptive methods used to ensure one train of safety systems are available to safely shutdown and maintain the reactor in a safe shutdown state. However, when these requirements and associated guidance were developed, the potential impact of aluminum during a HEAF was not known. As such, while existing separation criteria provide some protection against HEAFs involving aluminum, the question of reasonable assurance of adequate protection has not been answered in detail.

Under a performance-based protection approach, fire probabilistic risk assessments (PRAs) are typically developed to quantify the potential for a challenging fire to result in damage to the reactor core. A methodology developed jointly between the NRC/RES and EPRI documents a process to quantify HEAFs. In this method, a specified geometry commonly referred to as a zone of influence (ZOI) is used to postulate damage and ignition of structures, systems, and components (SSCs) near the postulated HEAF source. Traditional fire modeling is then used to predict the fire growth and damage to systems and components important to safety. While this method provides a reasonable damage footprint based on plant experience, the test results involving aluminum question the adequacy of this method. In addition, this method is a one size fits all approach to quantify the hazard. Operating experience shows that not all HEAFs generate the same level of damage and variables such as arc voltage, arc current, arc path, equipment configuration, materials, and arc duration influence the damage potential of a HEAF. Therefore, a more refined

method to quantify the hazard could support a better estimation of plant risk.



RESEARCH

The NRC has a vested interest in determining the adequacy of existing models and understand the potential of HEAFs involving aluminum materials. Collaboration with international organizations has shown a sizable number of HEAF events; approximately 1 out of every 10 significant fire events involves a HEAF. As such, international collaboration and resources are being expended understand this hazard, either jointly or independently. As such, a follow-on experimental program is being planned to acquire more data to support model revision and risk assessment. The following identifies the goals, objectives, and informational needs to support an efficient, effective, and ultimately successful research program.

GOALS

The goal of the HEAF research program is to understand the extent of damage a HEAF event may cause to structures, systems, and components than could impact plant safety. This damage may be caused by thermal, electro-magnetic, and/or mechanical (particle dispersal / pressure) mechanisms. The results from this research are expected to be used to refine and improve a methodology by which damage is estimated. This goal is split into two parts:

1. *Refine the existing HEAF model [9]*
2. *Understand how the effects of aluminum change the refined HEAF model*

In order to achieve this goal, empirical data is needed. Testing will focus on initiating arc faults in low voltage (≤ 1000 Volts) and medium voltage (1kV to 100kV) electrical equipment to cause HEAF conditions representative of those experienced in the field. Thermal, electrical, and pressure measurements will be made during each test along with measurements of particle characteristics.

OBJECTIVES

In order to reach the stated goal the following objectives have been determined to be important.

- *Identification of realistic test conditions, based on:*
 - *typical nuclear power plant electrical distribution system design and protection*
 - *operating experience*
- *Optimize test parameter variants*
- *Development and application of measurement devices*
- *Collect measurement data to characterize HEAF environment*
- *Analyze data to determine extent of damage and understand extent of hazard*
- *Revise existing models*

NEEDS

Developing realistic methodologies is at the forefront of today's fire PRA refinements. To ensure realism in HEAF model refinements, testing needs to represent field conditions to the extent practical, yet be designed for general application.

Given the wide variation in electrical system design and power source characteristics, testing should be valid for a range of HEAF hazards that could be encountered in the plant. Testing performed at select conditions within that range will provide valuable data to support refinement to the HEAF model. As such, it is important to understand the maximum and nominal arcing energies that may be possible. This understanding will allow for variation of test parameters representative of power system characteristics, while ensuring an upper limit on realistic test conditions. Parameter variation will play a key role in understanding the external characteristics of the HEAF to subsequently be used to develop a refined HEAF model.

Parameters determined to be important include:

Electrical parameters

- *Arcing time (Primary parameter)*
 - *Electrical protection clearing times for primary and secondary protection*
- *Bolted fault current / Arcing fault current (Primary parameter)*
 - *Short circuit current at location of fault*
- *Equipment Voltage class*
 - *Phase-to-phase voltage of system*
- *System grounding configuration*
 - *solid, resistive, reactive, or ungrounded*

- *Arc initiation phase angle*
 - *DC offset impact on initial fault current*
 - *Protective devices*
 - *Induction instantaneous relays or DC filtering*
 - *Plunger and hinged-armature relays*

Physical parameters

- *Conductor gap distance*
 - *Spacing between phase conductors*
 - *Differences between aluminum and copper?*
 - *Bus bar insulation [type, thickness, population]*
- *Arc location / orientation*
 - *Credible arc locations*
 - *Vertical bus vs. horizontal bus*
- *Cabinet / Enclosure*
 - *Wall and partition thickness*
 - *Wall and partition material*
 - *Steel, aluminum, composite, etc.*
 - *Ventilation*
 - *configuration*
 - *size*

Specific Informational Needs

An understanding of the parameter range is needed. The following cases are intended to help identify that range. The cases are presented in a manner that mirrors the skeleton test matrix presented in the Draft OECD test plan [10]. A summary table of the cases are presented below. General questions follow the case specific.

Case	Voltage		Class		Equipment		
	Medium Voltage	Low Voltage	1E	Non-1E	Switchgear	Motor Control Center	Bus Duct
1a	X		X		X		
1b	X		X		X		
2a	X			X	X		
2b	X			X	X		
3a	X		X				X
3b	X		X				X
4a	X			X			X
4b	X			X			X
5a		X	X		X		
5b		X	X		X		
6a		X		X	X		
6b		X		X	X		
7a		X	X			X	
7b		X	X			X	
8a		X		X		X	
8b		X		X		X	

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9. *EPRI TR-1011989 and NUREG/CR-6850, EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities: Volume 2: Detailed Methodology, Electric Power Research Institute (EPRI), Palo Alto, CA, and U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research (RES), Rockville, MD, 2005.*
10. *High Energy Arcing Faults in Electrical Equipment – Phase 2, Draft Test Plan, NRC ADAMS Accession No. ML17201Q551, June 2017.*

Case 1a. Class 1E Medium voltage switchgear (4kV up to 15kV) - Maximum current

This case is to understand the maximum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____ kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____ / _____ kA (sym / asym)
Maximum Bolted Fault Current at Bus _____ / _____ kA (sym / asym) [I_{bf}]
Maximum Arcing fault current _____ / _____ kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____ (cycles / seconds)
Feeder breaker clearing time (Arcing Fault Current) _____ (cycles / seconds)
Feeder breaker clearing time (85% of Arcing Fault Current) _____ (cycles / seconds)
Arc duration w/ feeder breaker failed (stuck closed) _____ (cycles / seconds)

Case 1a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / location / style / size : _____

Manufacture / Model # _____ / _____

Case 1b. Class 1E Medium voltage switchgear (4kV up to 15kV) - Minimum current

This case is to understand the minimum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 1b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 2a. Non-Class 1E Medium voltage switchgear (4kV up to 15kV) - Maximum current

This case is to understand the maximum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 2a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other: _____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other: _____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 2b. Non-Class 1E Medium voltage switchgear (4kV up to 15kV) - Minimum current

This case is to understand the minimum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 2b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 3a. Class 1E Medium voltage bus duct (non-isophase) (4kV up to 15kV) - Maximum current

This case is to understand the maximum fault current on the Class 1E safety bus duct.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 3a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 3b. Class 1E Medium voltage bus duct (non-isophase) - Minimum current

This case is to understand the minimum fault current on the Class 1E safety bus duct.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 3b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 4a. Non-Class 1E Medium voltage bus duct (non-isophase) (4kV up to 15kV) - Maximum current

This case is to understand the maximum fault current on the Class 1E safety bus duct.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 4a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 4b. Non-Class 1E Medium voltage bus duct (non-isophase) - Minimum current

This case is to understand the minimum fault current on the Class 1E safety bus duct.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____ kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____ / _____ kA (sym / asym)

Maximum Bolted Fault Current at Bus _____ / _____ kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____ / _____ kA (sym / asym) [I_a]

From IEEE 1584

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Feeder breaker clearing time (Arcing Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____ (cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____ (cycles / seconds)

Case 4b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 5a. Class 1E low voltage switchgear (380V up to 1,000V) - Maximum current

This case is to understand the maximum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 5a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 5b. Class 1E low voltage switchgear (380V up to 1,000V) - Minimum current

This case is to understand the minimum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 5b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 6a. Non-Class 1E low voltage switchgear (380V up to 1,000V) - Maximum current

This case is to understand the maximum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 6a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 6b. Non-Class 1E low voltage switchgear (380V up to 1,000V) - Minimum current

This case is to understand the minimum fault current on the Class 1E Safety switchgear bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____ kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____ / _____ kA (sym / asym)

Maximum Bolted Fault Current at Bus _____ / _____ kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____ / _____ kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____ (cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____ (cycles / seconds)

Case 6b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 7a. Class 1E low voltage motor control center (380V up to 1,000V) - Maximum current

This case is to understand the maximum fault current on the Class 1E low voltage MCC safety bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____ kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____ / _____ kA (sym / asym)

Maximum Bolted Fault Current at Bus _____ / _____ kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____ / _____ kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____ (cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____ (cycles / seconds)

Case 7a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 7b. Class 1E low voltage switchgear (380V up to 1,000V) - Minimum current

This case is to understand the minimum fault current on the Class 1E low voltage MCC safety bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 7b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 8a. Non-Class 1E low voltage switchgear (380V up to 1,000V) - Maximum current

This case is to understand the maximum fault current on a Non-Class 1E low voltage MCC bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____/_____kA (sym / asym)

Maximum Bolted Fault Current at Bus _____/_____kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____/_____kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____(cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____(cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____(cycles / seconds)

Case 8a. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

Case 8b. Non-Class 1E low voltage motor control center (380V up to 1,000V) - Minimum current

This case is to understand the minimum fault current on the Class 1E Safety switchgear bus (Unit Connected Design, if applicable). This case is to understand the minimum fault current on the Non-Class 1E low voltage MCC bus.

Electrical

Unit connected design? Yes / No [See EPRI 3002011923 for definition]

Voltage: _____ kV (line-to-line)

AC Sources: _____

(Identify all sources used to estimate the current reported below: i.e., main generator, diesel generator(s), motors, etc.)

Grounding: _____

Connection Configuration: Delta or Wye

Current:

Maximum Available Fault Current at Bus _____ / _____ kA (sym / asym)

Maximum Bolted Fault Current at Bus _____ / _____ kA (sym / asym) [I_{bf}]

Maximum Arcing fault current _____ / _____ kA (sym / asym) [I_a]

From IEEE 1584

$$I_a = 10^{(0.0042 + 0.983 \log_{10} I_{bf})}$$

Duration:

Feeder breaker clearing time (Maximum Bolted Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (Arcing Fault Current) _____ (cycles / seconds)

Feeder breaker clearing time (85% of Arcing Fault Current) _____ (cycles / seconds)

Arc duration w/ feeder breaker failed (stuck closed) _____ (cycles / seconds)

Case 8b. (cont'd.)

Physical

Bus Bar Spacing

Minimum gap distances between phases _____(inches)

Or

Center to center spacing with bus bar diameter _____ spacing (inches)

_____ diameter (inches)

Bus Bar Material: Aluminum / Copper / Tin-Plated Copper Other:_____

Bus insulation? (Type / Material / Thickness) : _____

Bus Orientation : Vertical / Horizontal / Both

Enclosure

Material: Steel / Aluminum / Other:_____

Cladding thickness (external) : _____

Partition thickness (internal) : _____

Ventilation configuration / style / size : _____

Manufacture / Model # _____ / _____

General system design / construction

What alloy is used for the aluminum bus bar material (i.e., aluminum 6061)?

What alloy is used for aluminum bus duct construction?

Does the aluminum bus bar material differ for switchgear versus non-segregated buses in bus duct?

Are separation distances different between Aluminum and copper?
Applicable design standards.