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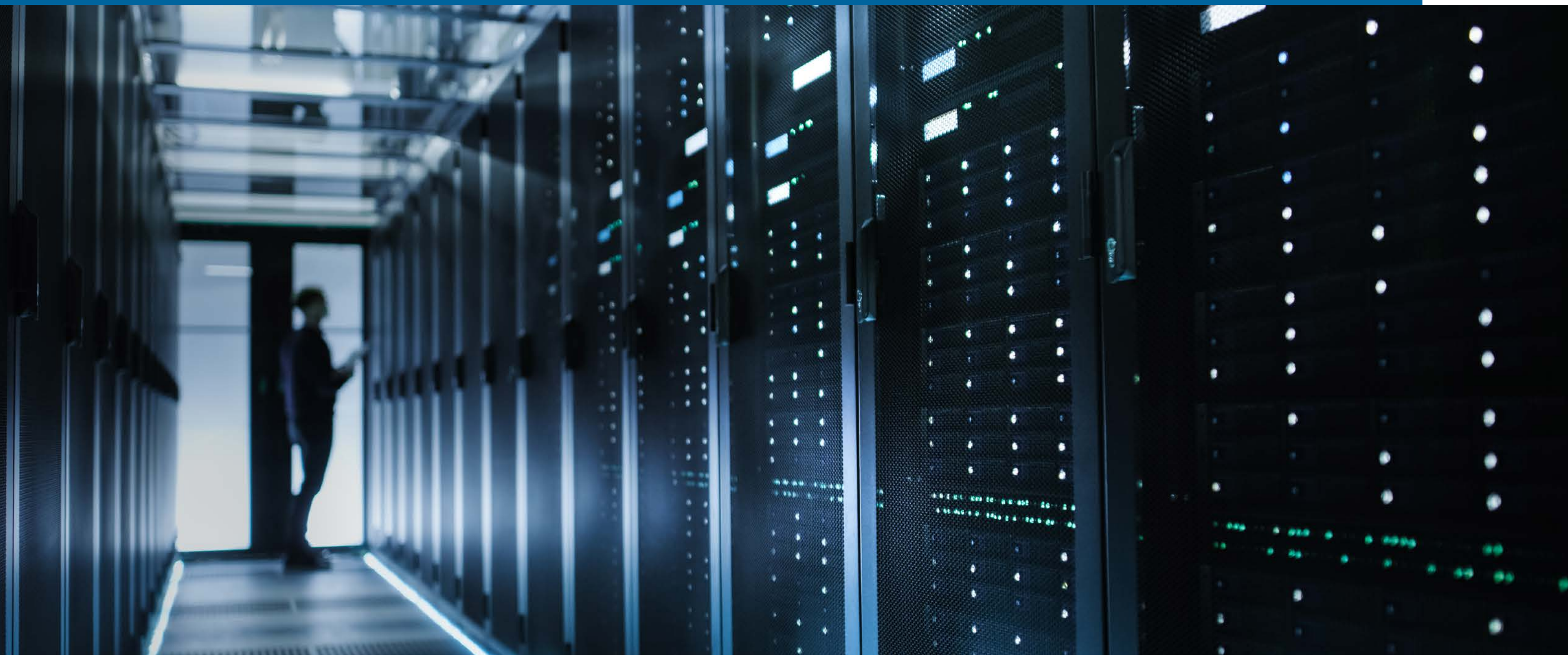
WHITE PAPER



How to Reduce the Risks of Arc Flash Incidents in the Data Center

Improving safety in the data center by utilizing electrical busway architecture, OCPDs, and arc flash hazard studies

ABSTRACT

Arc flashes are a dangerous on-the-job hazard in data centers. An arc flash occurs when electricity jumps, or arcs, between conductors. This can trigger an explosion that can kill or severely injure electricians and other workers, and cause major damage to a facility. However, data center owners can mitigate and significantly reduce the potential for arc flashes through a variety of methods. These include (1) better, safer design and engineering of power distribution architectures (2) use of Overcurrent Protection Devices (OCPDs) to stop fault currents (3) performing an arc flash hazard study in your facility, and (4) knowing the right Personal Protective Equipment (PPE) that workers must use when working on electrical equipment where an arc flash is possible.

INTRODUCTION

Arc flashes are one of the most dangerous on-the-job hazards that electrical workers face. An arc flash explosion can kill or severely injure workers, and cause massive damage in any facility that utilizes high amounts of electricity, especially in data centers.

An arc flash occurs when a high-amperage fault current jumps, or arcs, through the air to the ground, or from one conductor to another. This can result in an explosion of heat and light that instantly releases tremendous amounts of energy. Arc flash temperatures can exceed 35,000°F (19,400°C) – four times the temperature of the sun's surface – causing potentially fatal burns or skin damage to anyone in a close proximity.

An arc flash also triggers an arc blast, which vaporizes the conductors and sends out an explosion of molten metal, shrapnel, and expanding plasma. Debris from an arc blast can travel at speeds of 700 MPH, which can kill or severely injure anyone in the blast vicinity. Also, the arc blast produces a concussion noise of up to 1.6 decibels, which may result in hearing damage or loss to workers in the facility.

Arc flash accidents are often triggered by a worker touching a test probe to a live electrical surface, or by a dropped tool (i.e. electricity jumps from an open circuit to the metal blade of a screwdriver). Other causes include sparks between gaps in insulation, dust or corrosion on a conductor surface, or equipment failure due to improper installation or use of faulty or worn-out equipment.

The OSHA "general duty" clause (Title 29, Section 5, Duties (A)1, (A)2, and (B)) states that by law, an employer *"Shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."*

Data center owners have a responsibility to provide electricians and other employees with the safest work environment possible. To this end, you can mitigate and significantly reduce the dangers of arc flash accidents using several methods:

- Installing power distribution architectures using electrical busways, which are safer than panel-based legacy systems.
- Using Over-Current Protection Devices (OCPDs), such as sensitive fuses, to cut off fault currents when they occur.
- Performing an arc flash hazard study in your facility, to determine areas of high incident energy where an arc flash may occur.
- Following proper safety procedures when installing electrical busways and plug-in power distribution units.
- Following manufacturer's recommendations and NFPA 70E regulations for working on live electrical busways, and creating a safe work environment.
- Using the correct Personal Protective Equipment (PPE) when working with busways and other live electrical systems.

POWER DISTRIBUTION IN THE DATA CENTER

The demand for power in data centers is skyrocketing. Enterprise applications, the Internet of Things (IoT) revolution, and the massive daily increase in Internet traffic are placing higher demands on IT infrastructure, and on the data centers that support IT footprints. As power needs increase, capital and operating expenses for data centers increase as well. The costs of power, cooling, electrical equipment, and facility maintenance continue to grow exponentially.

To reduce operating costs, many data centers are adopting a more efficient three-phase power distribution architecture, allowing them to increase server efficiency and to operate more servers with less power.

Figure 1 shows the different types of power architectures and how they deliver power. The baseline is the 208V AC, 3-phase system, which many of today's data centers still have. Power enters the facility at 480V, is reduced to 208V by a Power Distribution Unit (PDU) transformer, and is distributed throughout the data center at 120V or 208V AC by a Cabinet Distribution Unit (CDU).

However, many data centers are now adopting a more efficient 415V AC, 3-phase power architecture. Incoming power at 480V is reduced to 415V by an autotransformer in the data center's Uninterruptible Power Supply (UPS) or PDUs, and further reduced to 240V by a CDU, which distributes power to servers.

Figure 2 shows the server efficiency of each type of power architecture. The green line on the graph shows that the 240V AC distribution voltage achieves 91.0% efficiency at 50% load in the data center. The IT servers in the facility run more efficiently using less power, which reduces the data center's power needs and power costs.

But with a higher voltage power architecture comes a higher level of incident energy, and a higher potential for fault currents and arc flashes. Data centers need to take additional steps to mitigate fault current risks, and prevent arc flash accidents from occurring.

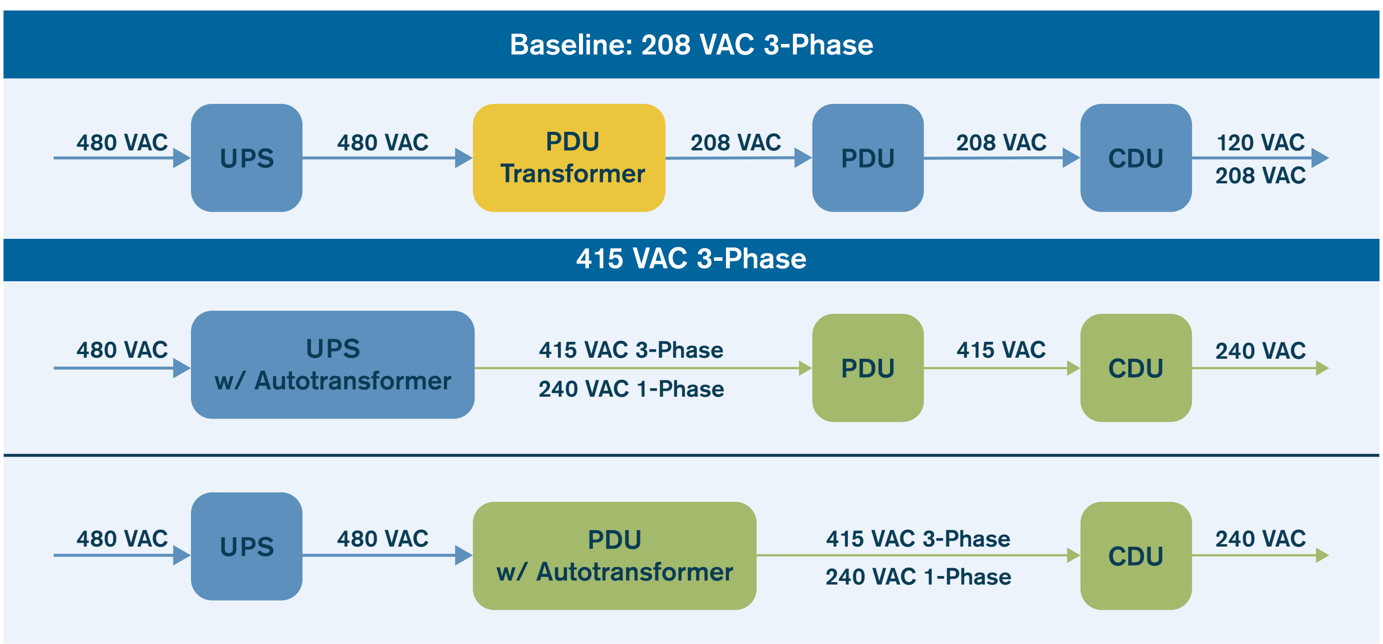


Figure 1

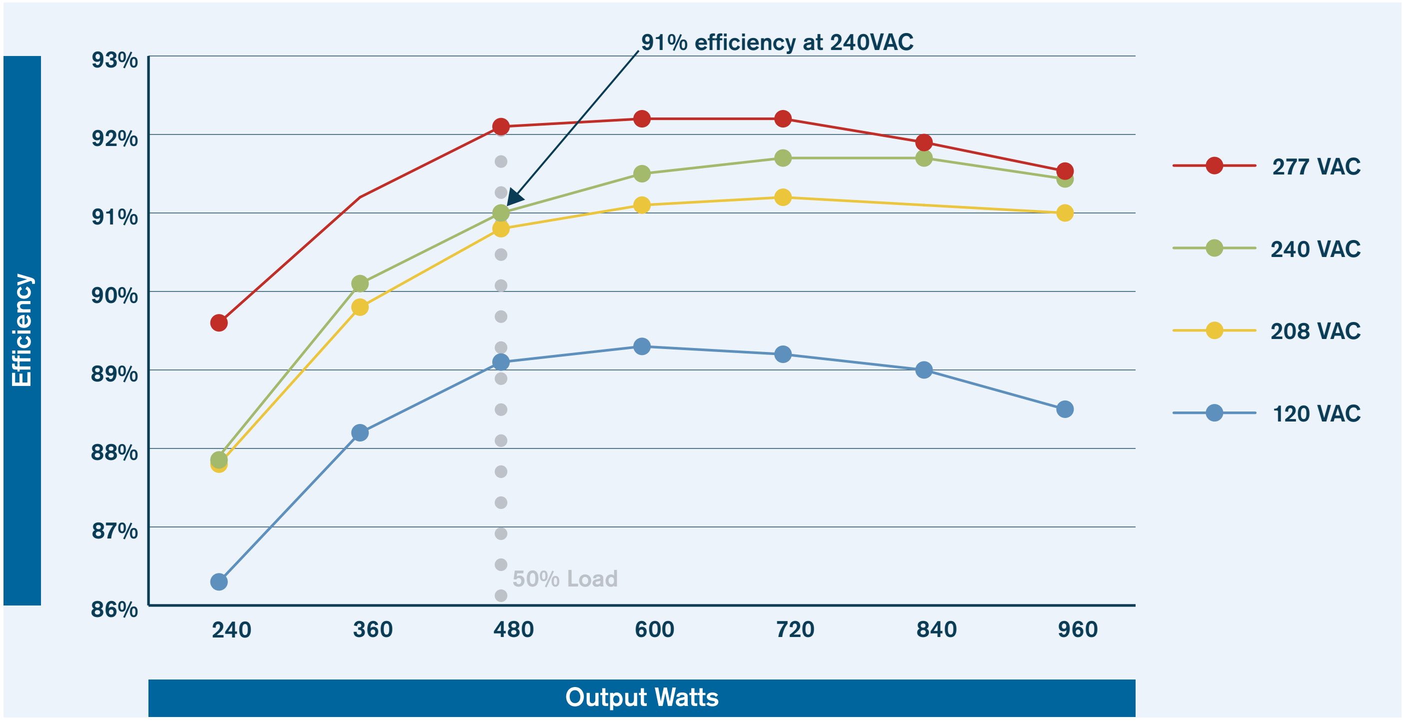


Figure 2

LEGACY SYSTEMS VS. ELECTRICAL BUSWAYS

The two types of power distribution architectures most common in data centers are legacy panel systems and electrical busway systems.

Legacy Panel Systems

With **legacy panel systems**, power from a UPS or PDU feeds into a power panel on the data center floor, located at the end of each row of server cabinets. The power panel is usually an electrical cabinet of circuit breakers called an RPP (Remote Power Panel). Individual circuits from the panel feed into individual cabinets, usually through cable connections that run under the raised floor of the data center room.

When electricians need to add or replace a circuit breaker in the RPP, they are usually required to do the work live, with exposed power conductors. (To power down all the circuits in the panel would also mean taking down all the server cabinets in that row.) There is always the danger that a worker will accidentally touch a live circuit, or drop a screwdriver or other metal tool, and create an arc between connectors, resulting in an arc flash explosion. This is why legacy systems have a higher danger of arc flashes.

Figure 3

Electrical Busway Systems

With a **busway system architecture**, electrical busways are suspended from the ceiling above rows of server cabinets. The busways are connected back to the central PDU by overhead cables, which run along the ceiling and are connected to the end feed unit at the end of each busway. Figure 4 shows a typical busway setup.

Each busway contains copper busbars, enclosed in an aluminum shell. During installation, the electrician inserts plug-in units into the access slot that runs along the bottom of the busways. Often, connecting drop cord cables are used to bring power from outlets in the plug-in units to the server cabinets below.

Electrical busway systems offer numerous safety advantages over legacy systems. Using busways eliminates the need for an exposed power panel, which also eliminates the common tasks requiring work on or near live parts. Busways are essentially maintenance free, with no exposed circuit breakers or backplanes. Also, the open channel of the busway limits exposure to exposed currents, and adding a closure strip into areas of the channel not occupied by plug-in units further limits this exposure. This significantly reduces arc and shock hazards, severely reduces risk, and improves safety.

All circuit breakers are located in the enclosed plug-in units, or upstream of the busway device. Plug-in units must be turned off when they are installed in a busway, and must be powered down before they are removed. The plug-in units feature local circuit disconnects that enable workers to turn off a unit before removing it, ensuring that the unit will not be removed while under load. Any maintenance work on the plug-in units is done when they are uninstalled from the busway. This makes adding or removing circuits much safer for electricians.

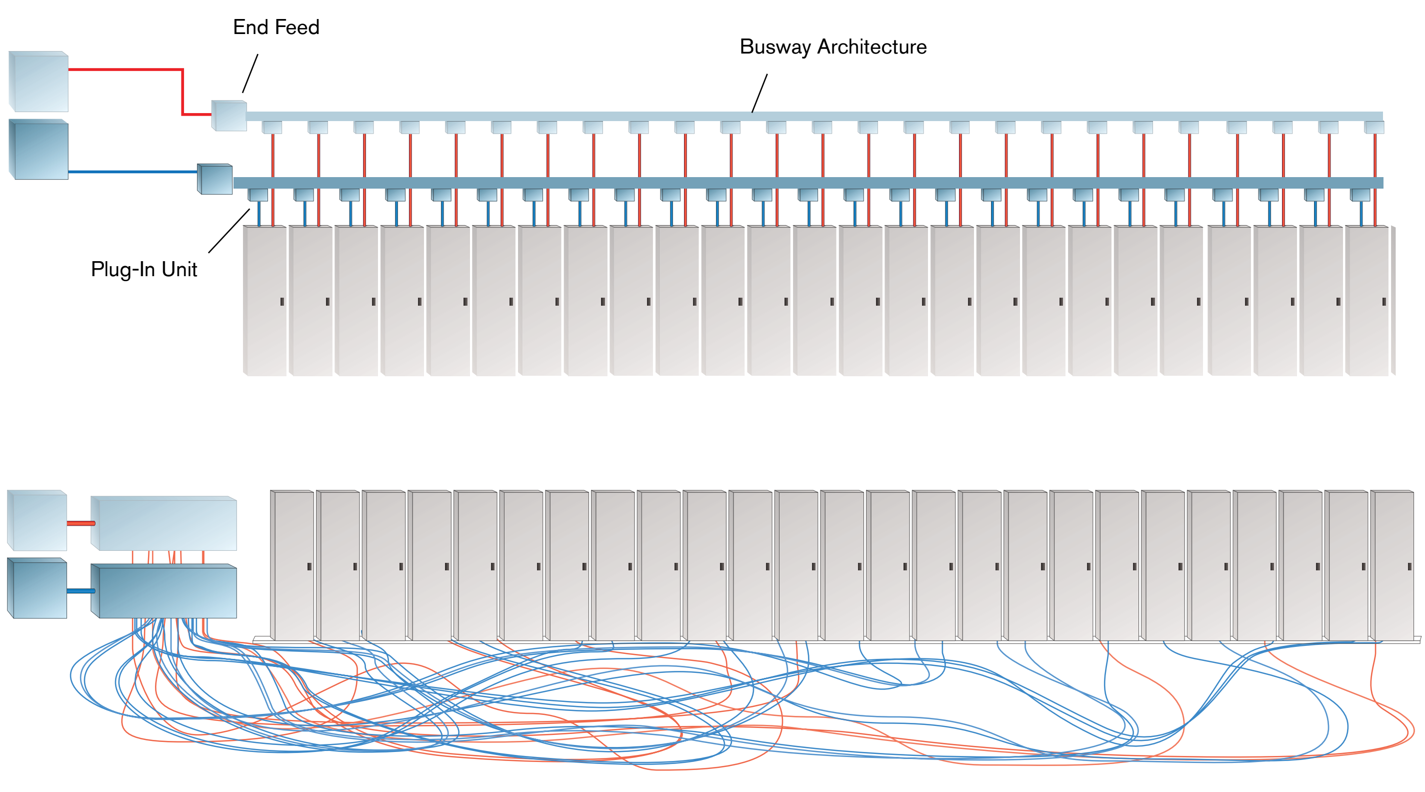


Figure 4

By mounting a busway from the ceiling, you can provide the necessary distance for a Limited Approach Shock Protection Boundary. In most cases, individuals can safely approach the busway area without fear of electric shock from a fault current. (See the NFPA 70E section for a discussion of limited and restricted approach boundaries.)

In addition to safety, a busway system offers greater flexibility in electrical architecture design for data centers. Placing the busway units above the cabinet rows allows you to easily access power as you add or remove server cabinets. It's easier for electricians to install new plug-in units in overhead busways than it is to run new cables under a raised floor. Using busways with plug-in units is not only safer, but faster and more convenient.

OCPD FUSES VS. CIRCUIT BREAKERS

The use of **overcurrent protection devices (OCPDs)** in power distribution architecture is an important safety measure to mitigate fault current dangers. The two main types of current-limiting devices used are (A) fuses and (B) circuit breakers.

(A)


(B)

Figure 5

As every electrician knows, fuses are a "one-use only" OCPD, containing a metal wire or strips of a certain material (i.e. silica) that melt when too much current flows through them, thus clearing (disconnecting) the current. The fuse must then be replaced. Circuit breakers are switches designed to automatically cut-off an electrical current when an overcurrent is detected.

Unfortunately, many companies choose to rely solely on circuit breakers to stop fault currents. In the event of a short circuit, current-limiting fuses have a faster clearing time, meaning they will cut off a fault current faster than a circuit breaker. The slower clearing time of a circuit breaker increases the amount of incident energy in a fault current, which can result in an arc flash.

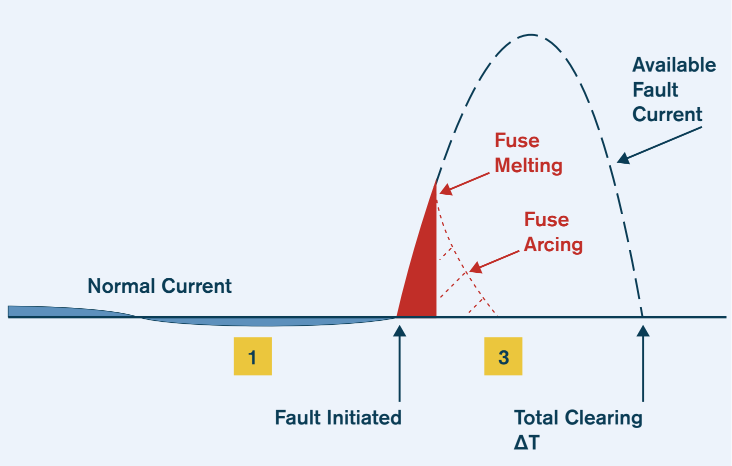


Figure 6

In Figure 6, the ΔT symbol represents the "**Clearing Time**," the time differential between when a fault current is initiated and when the fault is cleared, or stopped. As you can see, a fuse will clear a fault current much faster than a circuit breaker. In terms of actual time, a fuse clears a fault current in one-tenth of a second, about three times faster than a circuit breaker, which might take one full second to stop the fault current.

This time differential might seem small – after all, what's one-tenth of a second compared to one second? But fault currents move with such speed and force that a faster ΔT may mean the difference between a power outage and a life-threatening accident!

If a circuit breaker fails to cut off a fault current before it reaches an electrical panel or busway, the device could explode. This explosion could potentially kill or severely injure workers, and cause massive downtime.

A strategically-placed fuse will clear the fault current and prevent this accident from happening.

Also, when a fault current passes through an electric cable, it can cause the cable to violently jump and whip through the air with incredible force, potentially injuring anyone nearby. A fuse will quickly clear the fault, while a circuit breaker may not be fast enough to stop the overcurrent and prevent the cable from jumping.

Selective Coordination

Selective coordination is the practice of setting up OCPDs in a power distribution architecture so the OCPD closest to the fault current will trip first. This ensures that upstream OCPDs don't trip before downstream OCPDs, which can take down your entire power distribution system – and potentially the entire data center!

Figure 7 represents this concept. In the power distribution system at left, an upstream circuit breaker at the top of the architecture trips first. This cuts off power to the entire downstream system, resulting in unnecessary power loss and downtime for both the electrical and IT systems.

The power distribution system at right uses selective coordination. Upstream circuit breakers and downstream fuses with faster trip curves are strategically placed throughout the system. The downstream fuse that is closest to the fault cuts off the current, resulting in power loss to only one server cabinet instead of the entire row of cabinets.

(A "trip curve" is a measurement of the timing, voltage, and ampacity at which a fuse or circuit breaker will trip. Fuses have faster trip curves than circuit breakers, and will react faster to clear a fault. Also, some types of fuses have faster trip curves than other types of fuses. By strategically placing fuses with faster trip curves downstream in a power distribution architecture, you can isolate fault currents and ensure that any power outages resulting from a fault will not take down the entire system.)

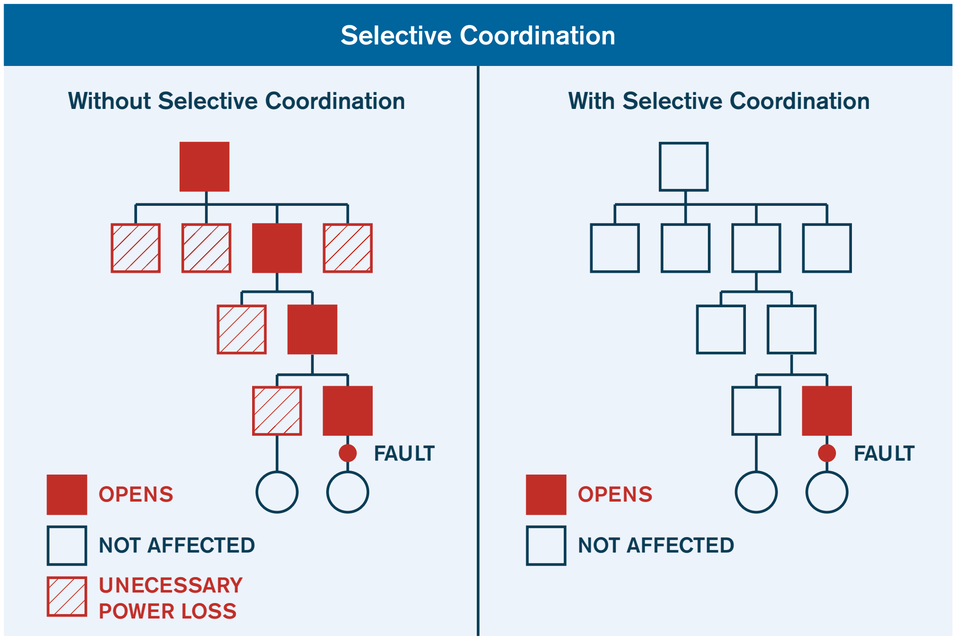


Figure 7

In an electrical busway system, for example, you can place fuses (1) in the end feed of a busway; (2) in the plug-in units that supply power from the busways to server cabinets; and (3) in the in-cabinet PDU strips that supply power to individual servers. With selective coordination, if a fault occurs, the fuse installed in the in-cabinet PDU strip will trip first. This means you will only lose power to the servers in that cabinet, instead of an entire row of cabinets (which would happen if the fuses in the busway end feed were to trip first).

PERFORMING AN ARC FLASH HAZARD STUDY

It is strongly recommended that you perform an arc flash hazard study in your facility at least once every two years, or if any major electrical equipment is added or removed. An arc flash hazard study has numerous advantages:

- It allows you to identify individual hazard areas in your power distribution system where an arc flash may occur. You can determine the potential power levels and severity of incident energy, and determine if your current OCPD devices (i.e. circuit breakers) will be strong enough to clear a fault current.
- After identifying hazard areas, you can take steps to fix them and mitigate the danger of arc flashes. This helps you to keep in compliance with OSHA, NFPA, and other safety regulations.
- It helps you to assess the health of your electrical system. You can identify and correct single points of failure that might take down your system.
- Many insurance companies now require arc flash hazard studies for mission critical facilities. Performing studies every two years and demonstrating that you have taken steps to prevent arc flash accidents may help lower your insurance rates.
- An arc flash hazard study may protect you from insurance or lawsuit liability if you can demonstrate after an accident that you took the necessary steps recommended by the study to mitigate your arc flash risks.

Ideally, an arc flash hazard study should be performed by a third-party consulting engineering firm. Different firms have different methods for arc flash hazard studies, but in general, they involve the following steps:

- **Data Collection:** Mechanical and electrical engineers inspect your facility and gather information on the components (i.e. transformers, UPSs, PDUs, CRAC/CRAH units, circuit breakers, fuses) of your power distribution and cooling systems.
- **Electrical System Modeling:** The engineers may use systems analysis tools (i.e. SKM PowerTools) to create a layout model of your system as part of their analysis.
- **Short Circuit Study:** The engineers will determine the potential fault currents at every piece of electrical equipment in the facility, and compare fault currents to the Interrupting Ratings of OCPD devices. (See next section for an explanation.)
- **Coordination Study:** The engineers will help you develop a selective coordination plan for strategic placement of circuit breakers and fuses.
- **Arc Flash Analysis:** The engineers will measure the incident energy, or arc flash potential, of every single piece of equipment in your facility, in cal/cm^2. This helps you to identify the required level of PPE that workers must wear for electrical maintenance work, according to that incident energy level (See the “NFPA 70E Standards” section for more information).

At the end of the arc flash study, the consulting engineers will give you a written report with recommendations on how to implement corrections in your facility in order to mitigate the risks of arc flashes. They will also provide you with OSHA-compliant “WARNING” and “DANGER” labels to attach to your electrical equipment.

Interrupting Ratings vs. Fault Current Levels

The **Interrupting Rating (IR)** is the maximum short-circuit current that an OCPD can safely interrupt under standard conditions. According to NEC 110.9 and OSHA §1910.303(b)(4), OCPDs such as circuit breakers and fuses must have an Ampere Interrupting Rating (AIR) equal to or greater than the available short-circuit current at their lineside terminals.

As part of an arc flash hazard study, engineers will compare fault current levels to the Interrupting Ratings of OCPD devices. For example, if the potential fault current for a certain power distribution area is 20,000 Amps, and a circuit breaker in this system has an AIR of 14,000 Amps, the circuit breaker is considered "over-duty." This means the circuit breaker doesn't have the structural integrity to withstand a 20,000 Amp fault current, and might actually explode if a current of that energy level passes through it. This is a code violation, and needs to be corrected immediately!

The engineers will also look at the Short Circuit Current Ratings (SCCRs) of your electrical equipment (i.e. busways, plug-in units), and compare them to fault current levels. For example, an electrical busway may have an SCCR of 35,000 Amps, which means it wouldn't be able to withstand a potential fault current of 50,000 Amps. However, in this case, you can mitigate the fault current danger by placing a fuse with a 60,000 AIR rating in the end feed of the busway.

SAFETY PROCEDURES FOR BUSWAY AND PLUG-IN INSTALLATIONS

Here are some safety procedures that may apply to busway and plug-in unit installations:

1. When installing busways, make sure that a ground connection is established before any phases are engaged.
2. The breaker (or switch) of a plug-in unit must be in the 'OFF' position before the unit can be installed or removed from a busway. The plug-in unit must be "powered down," and cannot be installed or removed while the unit is under load.
3. Be sure to follow manufacturer's recommendations when installing busways and plug-in units. For example, in some busway systems, when installing a plug-in unit, the top of the unit enclosure should be flush with the bottom of the busway. A plug-in unit typically includes a metal tab called a 'grounding tab,' which connects with grounding phases inside the busway. This provides an essential 'path to ground' in case of a fault current.

UL 857 STANDARDS FOR INSERTION OF PLUG-IN UNITS ON AN ENERGIZED BUSWAY

UL857 offers safety standards for busway systems, and specifically for systems with plug-in units that can be installed in or removed from an energized busway. In this section, we provide a brief overview of the UL857 standards.

In particular, UL857: Standard for Safety, Busways Sections 7.4.8 and 5.4.1 specify that in order to be designated for live insertion, a plug-in unit must be designed to minimize the chance of improper installation, and the unit must make the ground connection sufficiently in advance of any phase connections.

Under this standard, sections 7.4.8 and 5.4.1 state the following:

5.4.1 A plug-in busway and, with regard to Clause 7.4.8, a plug-in fitting intended for use with a busway that:

a) Involves a possible short-circuit condition during the installation or removal of the plug-in fitting or
b) Does not establish grounding continuity 3.2 mm (1/8 in) before contacting a live part shall be marked with the word "DANGER" and the following or equivalent wording: "Risk of electric shock or burn. Turn off power to busway before installing, removing, or working on this equipment." The wording shall be located on the front of the plug-in fitting so that it will

Figure 8

be readily visible during any attempt to install or remove the fitting.

7.4.8 A plug-in busway and plug-in fitting intended for use with a busway shall be:

a) Constructed to reduce the risk of insertion or removal of the contact members of the intended plug-in fitting in such a way as to result in a short-circuit condition, such as a live part contacting a grounded metal part or
b) Marked as specified in Clause 5.4.1.

To help ensure safety during installation or removal:

a) No load shall be present on the plug-in unit
b)The plug-in units circuit breakers or fused disconnects must be in the 'OFF' position
c) Installer must be qualified to do the installation or removal

Whatever electrical busway system you use, your electricians should follow local codes and other safety standards such as NFPA 70E: Standard for Electrical Safety in the Workplace. These codes and standards provide onsite safety practices and guidelines for all electrical installations, including busway systems. Employer(s) must interpret their local code and other safety standards such as NFPA 70E to decide how the standard applies to their electrical installation.

When approaching energized work, you should perform an arc flash hazard study to understand the hazards specific to your electrical system. This analysis will help you understand incident energy, arc flash/shock boundaries and personal protective equipment. Having a thorough understanding of hazards and being trained about equipment and the required PPE is essential for energized work.

NFPA 70E STANDARDS

The National Fire Protection Agency (NFPA) 70E – Standard for Electrical Safety in the Workplace covers electrical installations and practices for safeguarding electrical workers in the United States. NPFA 70E includes tables and other tools that you can use to determine Approach Boundaries and PPE clothing required. However, an arc flash study is still the best method to determine Shock Protection Boundaries in your own facility, and the necessary PPE clothing for electrical installation or maintenance.

NFPA includes standards for Shock Protection Boundaries, including Limited and Restricted Approach Boundaries. A **limited approach boundary** is the distance from an exposed live part in which a shock hazard exists. A **qualified person** who has received hands-on training in the construction and operation of the equipment, and who is able to recognize and avoid common hazards, is allowed to enter this boundary area. An **unqualified person** with general safety training may also enter this area only if they are escorted by a qualified person, and informed first of the hazards present.

The installation or removal of a plug-in unit would be an example of a task that would fall within the limited approach boundary regulations. The need to de-energize the load on the plug-in unit before removing it is an example of a common hazard.

A **restricted approach boundary** is the distance from an exposed live part in which there is an increased risk of shock due to electrical arc combined with inadvertent movement. Only a qualified person may enter this area, and perform the work involved. Examples of this kind of activity would include opening the lid of a plug-in unit (the unit should be removed from the busway before work is done), or taking a voltage or current reading (should only be done using appropriate voltage-rated gloves and tools).

An **arc flash approach boundary** (a.k.a. a flash protection boundary) is the approach distance from an exposed live part; inside this boundary area, a worker could receive second-degree burns if an arc flash occurs. Also within this boundary, the concussion of an arcing event could cause an individual to be 'pushed' with violent force by an arc blast.

Personal Protective Equipment (PPE) Requirements

NFPA 70E discourages electrical workers from working on or near a live part, and emphasizes that this should only be done if the required work isn't feasible otherwise. Employers must provide appropriate **Personal Protective Equipment (PPE)**, and employees must use PPE when performing these tasks.

PPE selection can be done using one of two methods according to the NFPA 70E: the **incident energy analysis method** or the PPE category method. The incident energy analysis method is highly recommended. The analysis results contain specific information on the system of interest including arc flash boundaries, incident energy and its corresponding PPE.

(**NOTE:** "Incident energy analysis" is a major component of arc flash hazard studies. Although different wording is used, the NFPA 70E standards are essentially recommending that all facilities perform an arc flash hazard study as a criterion for determining PPE usage.)

The standard measurement for PPE ratings is calories per square centimeter (cal/cm^2), based on the amount of incident energy that protective clothing can sustain. Cal ratings are achieved by combining PPE layers, as specified by the clothing manufacturer. (See NFPA 70E, Article 130.5 for more information.)

The second method for selecting PPE is the PPE category method. NFPA 70E, Article 130.5 provides the following table, which lists the required PPE based on incident energy exposures. The worker is required to wear PPE that has an arc rating equal to or greater than the estimated incident energy.

TABLE 130.5 (G): Selection of Arc-Rated Clothing and Other PPE When the Incident Energy Analysis Method Is Used (2018)*

Incident energy exposures equal to 1.2 cal/cm^2 up to 12 cal/cm^2	Incident energy exposures greater than 12 cal/cm^2
Arc-rated clothing with an arc rating equal to or greater than the estimated incident energy Long-sleeve shirt and pants or coverall or arc flash suit (SR) Arc-rated face shield and arc-rated balaclava or arc flash suit hood (SR) Arc-rated outerwear (e.g., jacket, parka, rainwear, hard hat liner) (AN) Heavy-duty leather gloves, arc-rated gloves, or rubber insulating gloves with leather protectors (SR) Hard hat Safety glasses or safety goggles (SR) Hearing protection Leather footwear	Arc-rated clothing with an arc rating equal to or greater than the estimated incident energy Long-sleeve shirt and pants or coverall or arc flash suit (SR) Arc-rated arc flash suit hood Arc-rated outerwear (e.g., jacket, parka, rainwear, hard hat liner) (AN) Arc-rated gloves or rubber insulating gloves with leather protectors (SR) Hard hat Safety glasses or safety goggles (SR) Hearing protection Leather footwear

SR: Selection of one in group is required.
AN: As needed.

***Please note that to use this table, your electrical system must first meet the requirements of NFPA 70E Table 130.7(C)(15)(A)(b), Arc Flash Hazard PPE Categories for Alternating Current (ac) Systems.**

Your electricians may be tempted to use NFPA 70E Table 130.5(G) as an easy, quick-reference guide for determining necessary PPE for electrical work. But once again, it is strongly recommended that electricians should only use this table in conjunction with the results of an arc flash study.

It's possible for electricians to overestimate the amount of PPE required for electrical tasks, if they only use the PPE category method, and don't have any idea of the actual incident energy levels in their facility. For example, an electrician may estimate the incident energy exposure for a certain task at 14 cal/cm², which requires them to wear an arc flash hazard suit (a.k.a. the "moon suit"). In fact, the incident energy level for that facility area may only be 3 cal/cm², which means they could perform the task wearing only a hard hat, safety goggles, and arc-rated leather gloves.

CONCLUSION

The dangers of arc flashes can never be completely eliminated, especially in data centers and other high power environments. But these dangers can be controlled, if you understand where the potential hazards are, and take steps to mitigate them. An arc flash hazard study will help you identify levels of incident energy in your facility. You can then reduce the potential for arc flash accidents by re-engineering your power distribution system with electrical busways, and installing OCPD fuses to clear fault currents. Requiring your employees to follow NFPA 70E safety standards and local electrical codes will further reduce the potential for arc flash accidents.

By creating and promoting your data center as a safe work environment, you let your employees know that safety matters. This instills confidence and inspires your employees to participate in that culture of safety, not only reducing the potential for arc flash accidents, but for other on-the-job accidents as well.

ABOUT STARLINE

Universal Electric Corporation (UEC), the manufacturer of Starline, is a global leader in power distribution equipment. For more than 25 years, Starline Track Busway has provided data centers with the most flexible, reliable, and customizable overhead power distribution systems on the market today. Other Starline products include the Critical Power Monitor (CPM), which works in conjunction with Starline Track Busway to improve energy efficiency; Plug-In Raceway, the flexible, wall-mounted power distribution system; and DC Solutions, the revolutionary 380V direct current alternative for data centers.