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White Paper

# Arc Flash Safety in 400V Data Centers

*Strategies for protecting employees from underappreciated yet potentially deadly hazards*

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## Executive summary

Tight budgets and rising interest in energy efficiency have many U.S. companies looking to switch from 120V power to 400V power in their data centers. However, while operating a data center at 400V significantly decreases energy waste, it also dramatically increases the magnitude and impact of arc flash events. Indeed, while arc flashes in a 120V data center generally produce minor, temporary wounds, comparable incidents in a 400V data center can easily result in permanently disabling and disfiguring injuries or even death.

This white paper discusses the potentially lethal hazards associated with arc flash events in a 400V data center, and then describes steps that businesses can take to reduce the frequency, severity and harmfulness of such incidents.

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## The rise of the 400V data center

In the U.S., utilities typically deliver power at 480V. Most U.S. data centers, however, operate at 120V/208V. As a result, they must use a series of mechanisms to “transform” or “step down” power from the 480V at which it’s received to the 120V at which it’s consumed by servers and other infrastructure devices. Unfortunately, a small amount of energy gets lost as waste during each of those steps.

One way to reduce such waste is to operate the data center at 400V, as organizations in most countries around the world already do. In a 400V data center, fewer voltage transformations occur along the power chain, resulting in reduced energy loss.

Not surprisingly, then, many U.S. data centers are taking a close look at increasing their operating voltage from 120V to 400V. As they do so, however, it is important that they examine the potential safety implications of such a move, including the heightened risks associated with arc flash incidents.

In a 120V/208V circuit, arcs tend to self-extinguish, so arc flash incidents are rarely capable of causing life-threatening or permanently-disabling injuries. In a 400V circuit, by contrast, an accidental short circuit can initiate an arc that does not self-extinguish. As a result, 400V circuit arc flash events routinely ignite powerful explosions marked by searing heat, toxic fumes, blinding light, deafening noise and devastating pressure waves. Without proper protection, workers exposed to such blasts can suffer third-degree burns, collapsed lungs, loss of vision, ruptured eardrums, puncture wounds and even death.

Eaton, for its part, provides mandatory arc flash training for all of its service personnel. Technicians are required to use “lockout/tag out” procedures (which ensure that equipment is not unexpectedly re-energized while technicians are working on it) and wear appropriate protective gear, including suits, helmets with face guards, safety glasses, safety shoes and protective gloves.

## Preventing arc flash events in a 400V environment

No company should begin powering their data center at 400V before making careful preparations aimed at protecting their employees. The remainder of this white paper discusses six essential safety steps that data center managers should consider taking.

### 1. Perform a hazard analysis

Proper arc flash safety is impossible without accurate measurements of the potential energy release associated with arc flash events. An arc flash hazard analysis can help you calculate those incident energy values, while also identifying arc flash risks along the power chain and strategies for mitigating them.

Data center managers who lack direct and extensive experience with performing arc flash analyses within 400V environments should be certain to include a qualified power systems engineer in the arc flash hazard analysis process.

### 2. Select appropriate personal protective equipment

Technicians in a 400V data center should never come within range of a potential arc flash incident unless they are wearing appropriate personal protective equipment (PPE), such as flame-resistant clothing, eye protection and gloves. For example, if live bus work is exposed, personnel should remain at least 10 feet away unless they are wearing appropriate PPE. The specific type of PPE worn depends on the calculated incident energy values. PPE shields wearers from the heat and light produced by arc flash explosions, and to a lesser extent from shrapnel and noise as well.

PPE is available in varying degrees of strength offering varying degrees of protection. Electrical engineers and fire safety professionals have developed two standards to help organizations determine how much protection their employees require:

- **IEEE 1584-2002:** Created by the Institute of Electrical and Electronics Engineers (IEEE), one of the world's most respected technical professional associations, IEEE 1584-2002 offers guidance on measuring the incident energy associated with arc flash events, as well as recommendations on how much PPE workers require based on those measurements. For more information, visit http://ieee.org and search for "1584-2002".
- **NFPA 70E:** Produced by the National Fire Protection Association, a non-profit organization dedicated to fire, electrical, building and life safety, NFPA 70E defines thresholds for appropriate PPE based on the severity of potential arc flash hazards. For more information, visit www.nfpa.org and search for "NFPA 70E".

Drawing on these two standards as well as the data collected during an arc flash hazard analysis, organizations can accurately calculate their Hazard Risk Category, which will in turn tell them what kind of PPE their employees should wear when working in arc flash danger zones. Data center managers should also ensure that any vendors or third-party service providers who perform maintenance procedures on their server infrastructure wear appropriate PPE at all times.

Though arc flash safety standards like IEEE 1584-2002 are extremely helpful tools, it is worth noting that they contain an important gap at present: single-phase-to-ground faults. Though IEEE 1584-2002 provides energy calculations for three-phase arcing faults, it offers no guidance on single-phase-to-ground faults, which are much more common in servers and other information and communications technology equipment that operate on single-phase power. Instead, the standard assumes that ground faults will ether self-extinguish or escalate into a three-phase fault. In truth, however, the additional energy released by single-phase ground faults before they become three-phase faults can be substantial. This is because ground faults tend to be lower current faults that require more time for upstream protective devices to clear, while higher current three-phase faults are cleared quickly. Since present IEEE 1584-2002 guidelines fail to take that additional energy into account, they may significantly underestimate the amount of protection that exposed workers require. Eaton and other leading companies have contributed substantial funding to a new joint NFPA/IEEE work effort aimed at updating the 2002 standard to include, among other things, single-phase arc flash testing.

## 3. Conduct employee safety training

While providing appropriate PPE is a vital part of safeguarding technicians from arc flash hazards, thorough safety training should also be part of every company's strategy for mitigating arc flash dangers. When delivered by experienced and knowledgeable instructors, arc flash safety training can also help data center managers calculate potential short circuit currents, Hazard Risk Categories and safe boundary distances based on the IEEE 1584-2002 and NFPA 70E standards. Organizations should also ensure that any vendors or third-party service providers working in their data center have received thorough safety training as well.

## 4. Leverage parallel redundant architectures

Many organizations currently use parallel redundant power chain architectures in their data centers. At their most thorough, such schemes provide multiple, independent power paths all the way from utility mains to electrical load, so that if one path becomes unavailable due to a component failure or routine maintenance, the others can keep critical applications up and running.

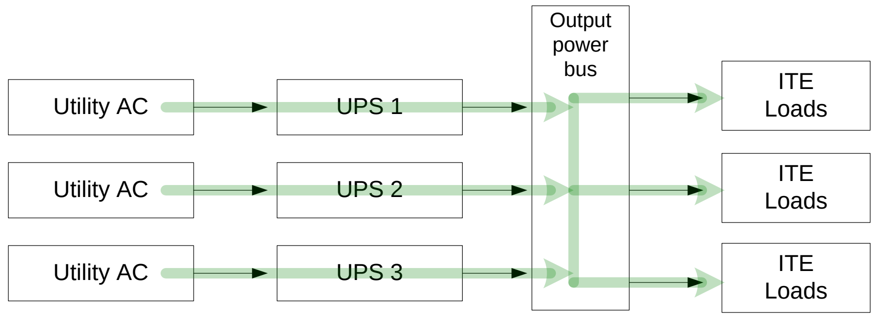


***Figure 1.*** *Creating multiple power paths all the way from utility mains to UPSs to IT equipment (ITE) can improve both reliability and safety.*

However, companies can temporarily use parallel redundant power architectures to promote safety rather than reliability, by manually de-energizing a power path before repairing or administering the IT equipment it supports. Though such a move briefly increases the risk of downtime, it also reduces the risk of arc flash-related injuries. For most businesses in most situations, that's a tradeoff worth making.

## 5. Use circuit breakers with fuses

Generally speaking, organizations typically take an either/or position when selecting overcurrent protection technologies in a data center power system: should fuses *or* circuit breakers be used? Though data center managers should consider a range of factors before making their choice, the use of both circuit breakers and fuses provide significant advantages with respect to arc flash safety due to the faster fault clearing time they provide during all possible faults that occur in a data center.

Current limiting fuses provide better arc flash incident energy reduction than circuit breakers for very high current faults such as a three-phase fault. The opposite is true for low level faults, such as ground faults. By combining both technologies, a data center is using the best arc reduction technology regardless of the type of arc fault that might occur.

## 6. Deploy arc flash safety products

Beyond wearing appropriate PPE, there are four main ways to lessen arc flash hazards: reduce arc flash durations, reduce arc flash currents, reduce the frequency of arc flash incidents and place protective physical barriers between arc flashes and data center personnel. With the help of safety products from Eaton and other manufacturers, data center managers can cost-effectively take advantage of all four strategies.

**Reduce arc flash durations**
The shorter an arc flash event lasts, the less energy it releases and hence the less danger it poses to nearby personnel. Organizations can use a variety of tools to interrupt arc flashes quickly, including these:

*Feeder protective devices with arc flash reduction maintenance system settings:* During a fault, data center operators always prefer protective devices closest to the fault to trip before upstream devices, as that minimizes the number of servers impacted by the interruption of electrical power. Consequently, most companies select products with intentional delays in upstream protective devices that give downstream devices time to trip first. Unfortunately, however, such products also give arc flashes time to reach potentially deadly energy levels if the fault occurs between two protective devices, as current will flow longer than needed while the upstream device waits for the fault to be cleared by the downstream device. Since the downstream device does not see the fault, there is no reason to wait before clearing the fault by the upstream device. Feeder protective devices with maintenance system settings enable technicians to temporarily disable intentional delays along the power chain while they work with live electrical equipment, so as to shorten arc flash incidents and limit the energy they release.

Be sure, however, to look for arc flash reduction maintenance systems that operate even faster than the circuit breaker's normal instantaneous clearing time. Such products include dedicated high-speed analog tripping circuitry that bypasses the circuit breaker trip unit. Modern electronic trip units use microprocessors to calculate currents and decide when to trip. The time delays introduced by executing this program code (not to mention boot-up time if the breaker is closed into a fault and the microprocessor is initially powered up), are eliminated by the analog bypass circuit.

*Zone selective interlocking:* Though it doesn't provide as much arc flash incident energy reduction as a true analog bypass arc flash reduction maintenance system, zone selective interlocking (ZSI) offers the advantage of automatic operation. No maintenance switch must be activated. ZSI systems accomplish this by interconnecting "inhibit" signals between upstream main and downstream feeder breakers. Should a fault occur downstream of a feeder breaker, the feeder breaker sends an inhibit signal to the upstream main telling the main to wait and allow the feeder to clear the fault, if the feeder breaker sees the fault. The upstream main breaker maintains its time delays and remains closed during the fault. However, should a fault occur *between* the upstream main and the downstream feeder, the downstream feeder does not have any fault current flowing through it, so it does not send an inhibit signal to the upstream main. Consequently, the upstream main bypasses internal time delays and trips instantaneously. This reduces the arc flash incident energy released for faults that occur within electrical equipment between circuit breakers.

Note that some manufacturers offer "maintenance systems" that manually disable the ZSI inhibit signal, essentially telling the upstream breaker to trip instantaneously during a fault. This does not provide improved arc flash reduction performance over a ZSI system, however, since a fault occurring between the main and feeder would trip the main instantaneously anyway. A better approach is to specify both ZSI and a true arc flash reduction maintenance system that utilizes the bypass analog circuit, which can trip the breaker faster than the instantaneous clearing time of the breaker.

*Bus differential schemes:* These are coordinated zones of protection within an electrical system. When a fault occurs within a given zone of protection (i.e. between the main and feeder breakers), protective devices trip instantaneously, limiting arc flash durations while also confining arc flash damage to specific portions of your infrastructure. Bus differential systems are typically faster and more sensitive than ZSI systems, but require additional current transformers and relaying equipment. This tends to make bus differential systems more difficult to implement and more expensive than ZSI systems.

**Reduce arc flash currents**

Just as a shorter arc flash is less dangerous, the same is true (on a circuit breaker protected system[1]) of an arc carrying a smaller amount of current. Among the many ways companies can reduce arc flash currents are these:

*Current limiting reactors:* Typically deployed in series with the three-phase conductors feeding the load, current limiting reactors restrict current under fault conditions. For example, low-voltage motor control centers can be supplied with three single-phase reactors that limit available short circuit current, resulting in a reduction of available arcing current during faults.

*High-resistance grounding systems:* During ground faults, high-resistance grounding (HRG) systems provide a path for ground current via a resistance that limits current magnitude. That dramatically reduces the magnitude of line-to-ground faults and limits the scale of arc flash events. While HRG can be used on systems that service only three-phase loads, the US National Electrical Code prohibits using HRG on distribution systems providing loads that are connected line-to-neutral, as are most servers. This limits the practicality of an HRG system to the portion of a data center that powers cooling plants and other large three-phase loads.

**Reduce frequency of arc flash incidents**

Several technologies, including the following, can help data center managers decrease the likelihood of arc flash events happening at all:

[1] As discussed earlier, reducing current levels on systems protected by current limiting fuses can actually increase incident energy released during a fault.

*Predictive maintenance systems:* Deteriorating insulation is the leading cause of arc-producing electrical failures. Identifying and repairing compromised insulation before it fails can help avert arc flash explosions. Predictive maintenance systems provide early warning of insulation failure in medium-voltage switchgear, substations, generators, transformers and motors.

*Remote monitoring, control and diagnostics software:* With the help of power management systems, technicians can perform many administrative tasks remotely, rather than expose themselves to potential arc flash events. Power management applications also equip companies to remotely de-energize electrical equipment before data center personnel approach it.

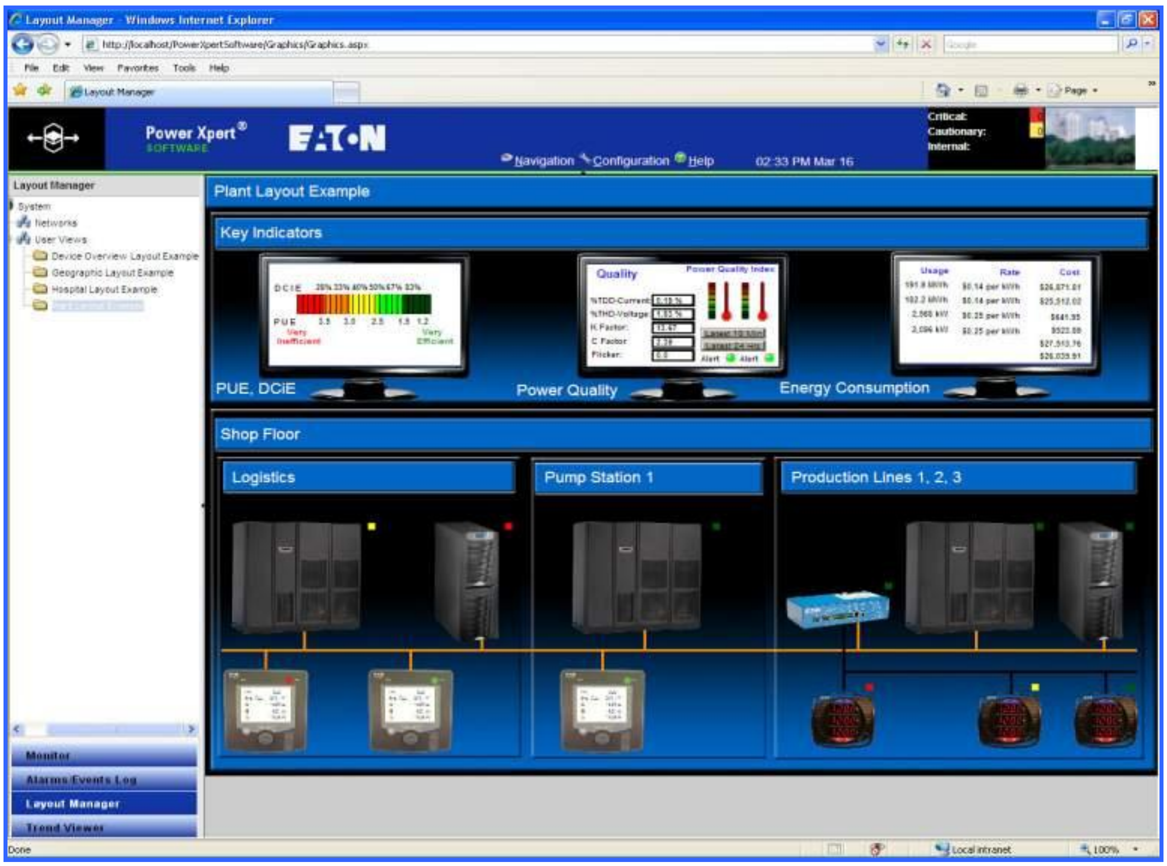


***Figure 2:*** *Power management software enables data center personnel to perform many tasks remotely rather than expose themselves to arc flash dangers.*

**Erect protective physical barriers**
When all else fails, protective safety barriers offer vulnerable data center employees a critical last line of defense from the explosive power of arc flash incidents. Among the many varieties of such barriers are these:

- *Arc-resistant switchgear:* Properly-designed switchgear utilizes sealed joints, top mounted pressure relief vents, reinforced hinges and “through-the-door racking” to contain harmful gases and reduce injuries during arc flash explosions.

- *Infrared windows:* These allow technicians to complete thermal inspections of electrical switchgear without opening cabinets or doors. Leveraging their infrared thermography technology, operators can safely and quickly assess potential equipment problems without first de-energizing electrical circuits.

Also, always keep equipment doors and access covers closed and fastened during normal operation, to keep arc flash energy contained.

## Conclusion

Long common elsewhere in the world, 400V data centers are slowly gaining popularity in the U.S., at least partly because they eliminate 480V to 120V transformers and thus offer superior energy efficiency. Yet operating a data center at 400V poses arc flash risks far more severe than those found in a 120V data center. To protect their employees from disabling and even lethal injuries, organizations contemplating a move to 400V must carefully study the potential hazards and supply their people and facilities with appropriate PPE, circuit protective devices and training. By doing so, they will position themselves to enjoy all of the power-saving benefits 400V operation offers without needlessly endangering lives.

For more information about arc flash hazards safety, visit www.arcflashsafetysolutions.com.

## About Eaton

Eaton is a diversified power management company providing energy-efficient solutions that help our customers effectively manage electrical, hydraulic and mechanical power. With 2012 sales of $16.3 billion, Eaton is a global technology leader in electrical products, systems and services for power quality, distribution and control, power transmission, lighting and wiring products; hydraulics components, systems and services for industrial and mobile equipment; aerospace fuel, hydraulics and pneumatic systems for commercial and military use; and truck and automotive drivetrain and powertrain systems for performance, fuel economy and safety. Eaton acquired Cooper Industries plc in 2012. Eaton has approximately 103,000 employees and sells products to customers in more than 175 countries. For more information, visit www.eaton.com.

## About the author

After receiving a BSEE from the University of Kentucky and his MSEE from the University of Pittsburgh, Dave Loucks has been serving the electrical industry for 34 years. He is a veteran with Eaton for 19 years and currently holds a position of Manager, Power Solutions and Advanced Systems. Dave has eight patents with three additional pending and is a senior member of the IEEE. Besides being certified as an Energy Manager by the Association of Energy Engineers, he is also a registered professional engineer in the Commonwealth of Pennsylvania. In addition, he is currently pursuing a Ph.D in electrical engineering at the University of Pittsburgh.