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Arc Flash Safety eGuide

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Protection, Arc Flash Mitigation Using Internal VFIs In Liquid Substation Transformers

White Paper:
Arc Flash Safety In 400V Data Centers

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Understanding electrical distribution equipment and its associated risks can help reduce incident energy levels and save lives.

By Bruce W. Young, PE, Bala Consulting Engineers Inc., King of Prussia, PA.

Anyone involved with electrical distribution systems—either as a design engineer, commissioning agent, or contractor—for more than five years probably has been directly involved in an arc flash incident or has heard of one.

According to [NFPA 70E: Standard for Electrical Safety in the Workplace](#), arc flash is a “dangerous condition associated with the release of energy caused by an electrical arc.” It is measured in terms of arc flash incident energy, which is used to determine the appropriate level of personal protective equipment (PPE), and in terms of an arc flash protection boundary.

An arc flash is the result of an electric current passing through air as the result of conductor failure, equipment failure, or the accidental connection between voltage sources such as dropping a tool across

buses in distribution equipment. The flash is immediate but the resultant release of energy can cause severe injury, and possibly death. There is a potential for a tremendous amount of heat to be released, which can result in overpressures, as well as flying debris. The energy released can cause temperatures exceeding 35,000° F, which can vaporize steel, copper, and aluminum. Inhaling these vaporized metals could be fatal. Injuries or fatalities could occur if personnel are in the area in front of an arc flash, which could send projectiles such as parts of metal buses away from the blast. Also, molten metal can cause significant burns, and the sudden air pressure

increase can knock personnel off their feet.

Each year, more than 2,000 people are treated in burn centers for injuries from arc flash incidents. Many injuries caused by arc flash incidents can be prevented. Not working on or around energized equipment may be the simplest way to avoid injury. Scheduling maintenance outages may seem like a bother, but will easily offset the loss of production, unscheduled outages, and equipment damage that may occur with an arc flash incident.

Arc flash hazard analysis

Sometimes working on live electrical equipment may be necessary. Appropriate PPE is required when working on or around energized electrical equipment. An arc flash hazard analysis is required by NFPA 70E. This determines the arc flash boundary, the incident energy at the working distance, and the level of PPE that must be used within the arc flash boundary.

Procedures for performing an arc flash hazard analysis can be found in [IEEE 1584: Guide for Performing Arc Flash Calculations](#). Some of the factors that determine the amount of incident energy include:

! WARNING	
Arc Flash and Shock Hazard	
Appropriate PPE Required	
105 inches	Flash Hazard Boundary
22 cal/cm ²	Flash Hazard at 18 inches
Category 3	Cotton Underwear + FR Shirt & Pant + FR Coverall
480 VAC	Shock Hazard when cover is removed
00	Glove Class
42 inches	Limited Approach
12 inches	Restricted Approach
1 inches	Prohibited Approach
Bus: ESWBD B SIDE Prot: ESWBD G2 BKR	

This arc flash label indicates that the breaker settings used in Figure 1 result in conditions that require personnel to wear Category 3 PPE within the flash boundary. Courtesy: *Bala Consulting Engineers Inc.*

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- **The available fault current at the circuit:** This is the amount of current that could flow into the circuit in the event of a fault. This is calculated in the short-circuit analysis. Factors that determine fault current are the available fault current of the power source (typically available from the local power utility), the impedance of the transformers that supply the circuit, length and type of conductors in the circuit, and motor contribution. At first, it may seem counterintuitive, but higher fault currents may actually reduce the flash hazard because they will decrease the overcurrent device clearing time, which reduces the flash hazard.

- **The operating characteristics of the overcurrent protective devices in the circuit:** These vary with the type of device used. These characteristics are determined by simple fixed settings on thermal magnetic breakers, fuse melting curves, and multiple pickup settings on relays and solid-state breakers. Settings for adjustable devices are determined in a coordination study.

- **Equipment labeling requirements:** For distribution equipment that has a main overcurrent protective device, two labels may be required: one label for the energy level

at the line side of the device and another on the load side of the device. Energy levels at the line side and load side may be significantly different. This differential should be identified to provide maintenance personnel with information regarding potential arc flash hazards. Even with the main breaker opened, the line side of the main is still energized.

Equipment labeling

After the arc flash hazard analysis is completed, warning labels are printed and affixed to the electrical equipment. The labels should include the level of PPE required, the flash hazard boundary, the flash hazard, the shock hazard, and approach distances.

After the study is completed and



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the labels are installed, work on this equipment or routine maintenance will likely be required at some point. Work that may be required could be thermal scans to check for equipment hot spots, racking out a breaker for routine maintenance, or installing a new circuit breaker to serve new loads.

Regardless of the work to be done, personnel must follow the appropriate safety procedures. Observe the label to determine the proper PPE

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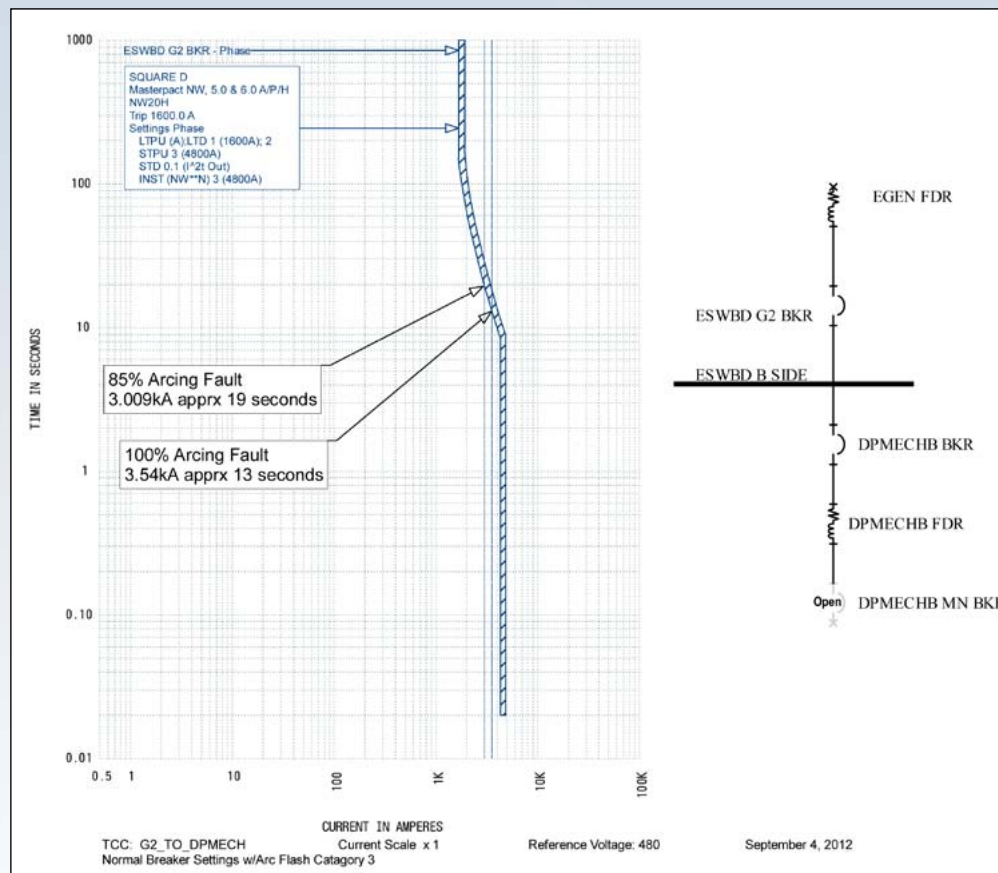


Figure 1: This graph shows breaker settings and the corresponding time-current curve for selective coordination requirements. Courtesy: *Bala Consulting Engineers Inc.*

level, gear up, and carefully proceed to perform the necessary work. PPE may be as simple as safety glasses, gloves, and untreated cotton—or it could include a full face shield and protective suit. For minor or simple

maintenance tasks, the temptation may be to proceed without proper PPE to save a few minutes. But even with the most careful work, accidents can happen, and the potential for serious, life-threatening injuries still

⚠ WARNING

Arc Flash and Shock Hazard

Appropriate PPE Required

<p>15 inches Flash Hazard Boundary</p> <p>0.86 cal/cm² Flash Hazard at 18 inches</p> <p>Category 0 Untreated Cotton</p> <p>480 VAC Shock Hazard when cover is removed</p> <p>00 Glove Class</p> <p>42 inches Limited Approach</p> <p>12 inches Restricted Approach</p> <p>1 inches Prohibited Approach</p>	<p>Bus: ESWBD B SIDE Prot: ESWBD G2 BKR</p>
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This arc flash label indicates that the breaker settings used in Figure 2 result in conditions that reduce the boundary hazard and lower the PPE requirement to Category 0. Courtesy: *Bala Consulting Engineers Inc.*

exists. Therefore, it is critical that personnel working on electrical distribution equipment be trained in proper procedures, and that they wear the appropriate PPE.

Reducing incident energy levels at a location where electrical work is to be performed reduces the level of PPE required when working on energized circuits at that location. However, energy incident level reduction does not eliminate PPE requirements.

Figure 1 shows a time-current curve (TCC) for a 1,600 A, 480 V, solid-state trip-unit circuit breaker with adjustable long time pick-up, long time delay (LTD), short time pick-up

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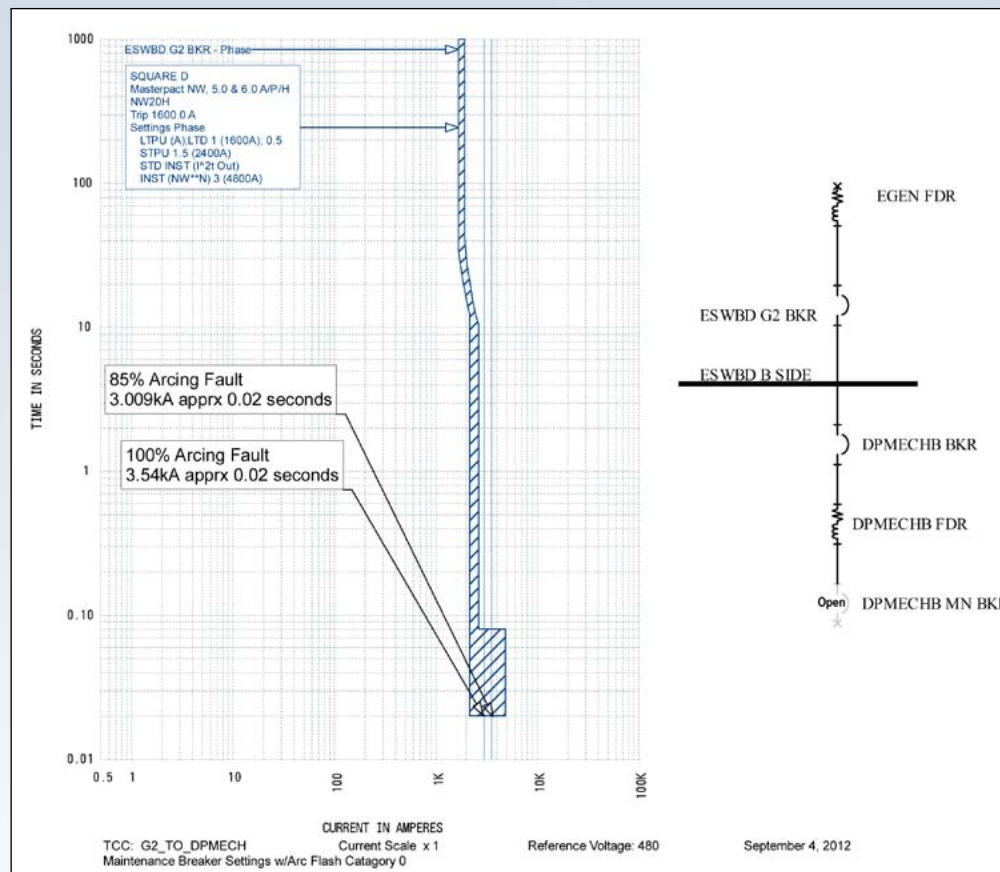


Figure 2: This graph shows breaker settings and the corresponding time-current curve for reducing the arc flash hazard. Courtesy: *Bala Consulting Engineers Inc.*

(STPU), short time delay (STD), and instantaneous settings. These settings allow the breaker's operating characteristics to be adjusted. The settings in Figure 1 were selected to achieve selective coordination with

upstream and downstream overcurrent protective devices to isolate the potential fault as close to the fault as possible. With these settings, the 85% arcing fault level of 3,009 A will last approximately 19 sec, and the

100% arcing fault level of 3,540 A will last approximately 13 sec. Using the maximum arcing exposure time of 2 sec as recommended in IEEE 1584 results in an arc flash hazard of 22 Cal/cm² and requires Category 3 PPE as indicated on the warning label (see inset). Energy levels above 1.2 Cal/cm² can cause a temperature rise that will result in second-degree burns on exposed human skin.

When energized maintenance is required for this equipment or downstream equipment, the energy level and required PPE may be reduced by setting the LTD to 0.5, the STPU to 1.5, and the STD to instantaneous, with the resulting TCC shown in Figure 2 and its corresponding warning label shown in the inset. These settings reduce the arcing fault durations (the 85% and 100% fault levels) to 0.02 sec. This means the breaker will clear the fault more quickly. The flash boundary is reduced from 105 in. to 15 in., and the flash hazard has been reduced from 22 Cal/cm² to 0.86 Cal/cm². Note that some breaker designs may not allow adjusting these points while energized.

Reducing incident energy

After the maintenance has been performed, the original settings can be restored. Please note that adjusting

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the trip characteristics of an energized breaker may also cause a nuisance trip to occur. Before performing this work, the facility staff should be made aware of this possibility and informed that a temporary power outage could ensue. If this happens, the breaker could be immediately reset so the outage would be no longer than a few sec, but for critical facilities, such as hospitals and data centers, even this temporary outage could be detrimental to the facility operation.

Many manufacturers offer maintenance switches that can decrease the time an arcing fault is allowed to exist, thereby reducing the incident energy exposure. This function is usually enabled with a keyed switch, often located out of the hazard boundary. Some manufacturers offer an arc fault detection circuit, which typically uses a photoelectric sensor to differentiate between an overload, a fault, and an arc flash. Others offer zone-selective interlocking between the levels of the overcurrent protective devices. Using this feature can reduce clearing time if a fault occurs, thereby reducing the incident energy and the level of required PPE.

Another method to reduce exposure during device operation is with

a remote operating station located outside the flash hazard boundary area. The station allows personnel to operate the device without having to wear PPE. Remote operating stations typically provide positive feedback—usually an indicating lamp—that verifies the open or closed status of the device.

For many critical facilities such as data centers, dual power paths to the equipment are provided. This allows the electrical distribution equipment to be de-energized while maintaining operation. Dual paths require additional distribution equipment—almost a mirror image of all the distribution components. This increases initial installation costs, but when properly designed and installed, complete isolation of any component in the electrical distribution system is possible. Dual paths give personnel the ability to perform maintenance and testing on de-energized equipment.

Understanding arc flash and its potential hazards, calculating risk mitigation, knowing the importance of labeling, and the proper use of PPE can maintain the effective use of electrical distribution equipment through equipment maintenance and upgrades—and ultimately save lives.

Learning from experience

Being an electrical engineer for more than 25 years, I'm aware of at least 15 arc flash incidents and have been directly involved in three. The following is an account of my experience with one of those incidents.

Our design-build team was adding a new distribution section onto an existing service entrance switchboard that supports a critical infrastructure distribution system. Installing the new section required the switchboard to be de-energized. Shutdown arrangements were made, the method-of-procedure (MOP) was in place, and the new section was on-site and ready to be connected. Work was to begin at 1 a.m. on a Sunday and to be completed by 6 a.m.—more than enough time (we thought) to accomplish our task.

As 1 a.m. approached, we had portable generators running, flashlights in hand, all the equipment was powered down, and we were ready to begin. The first step in the MOP was to trip the main disconnect using the ground fault test relay. We pressed the trip button; nothing happened. Because the equipment was more than 20 years old and probably had not been tested in some time, the consensus was that the ground fault relay prob-

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ably had a blown fuse and could be repaired after the main was opened.

Because there was a limited amount of time to perform the work, the decision was made to manually open the main. The main was a bolted pressure-fused disconnect, so the electrician tripped the “open” lever. Nothing happened. He recharged the trip spring, tried to open it again, but the switch did not open, but we did detect some movement. He tried again, but it still did not open. Looking back, we should have stopped here, delayed the project, and called in a service technician for the equipment. But, there was a lot of pressure to finish the work and delaying the project was not an option.

A few access panels were removed to allow switch inspection. The trip spring was recharged and we tried to open the switch again, but still with no success. The operating mechanism did move a small amount, so the decision was made to keep trying. As we kept trying, the operating mechanism moved a little each time, so we thought the switch would open with just a few more tries. We left the panels off for easy inspection. We tried a few more times and there was a large flash, with lots of smoke and noise. Luck-

ily, no one was injured, but we were a bit shaken.

Upon further examination, we determined that because the switch had not been operated in several years, the lubricant on the operating linkage had deteriorated. Cycling the switch, along with the deterioration of the lubricant, had resulted in a mechanical failure of the linkage, and a piece of the linkage had fallen across the load side bus causing the arc flash. Although no one was injured, the flash damaged the main switchboard, which necessitated using a portable generator while the switchboard was being repaired.

About the author

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Integrating maintenance requirements into the design of an electrical system is an important first step to provide workplace safety.

By Kenneth Mastrullo, MES Consulting Services Inc., Weymouth, Mass.

Safety-related maintenance requirements for electrical equipment are outlined in Chapter 2 of [NFPA 70E: Standard for Electrical Safety in the Workplace](#), but they are often overlooked to the detriment of both worker safety and a company's reputation. Using the concepts and strategies in Chapter 2 can enhance the company's worker safety, productivity, and positive image.

Integrating maintenance requirements into the design of an electrical system is an important first step to provide workplace safety. There are two elements that comprise maintenance tasks at a facility: technical expertise and safety considerations. Chapter 2 provides a great foundation to understand the fundamentals of what every company requires to operate and maintain the electrical system in a safe manner after it has been commissioned. Lack of proper maintenance could not only affect the operation of production at a facility,

it could have a catastrophic effect for workers.

In difficult economic times it is common to eliminate or decrease the frequency intervals of preventive maintenance for electrical systems. However, lack of adequate maintenance often results in the failure of overcurrent protection devices to operate within the prescribed range for opening. An elongated opening time, which can be measured in a few tenths of a second, can have a significant difference in the arc flash exposure to a worker. The idea is that the calculations assume a certain opening time, if the device fails to operate in that time, then the arc flash study/values are incorrect, and the worker may not have the proper personal protective equipment



(PPE). If the worker is not protected for the magnitude of the exposure, it could result in a significant injury or death.

An example of what can happen when electrical equipment is not properly maintained occurred in 2010. In this case the electrical equipment was installed in the 1970s and was never maintained, calibrated, or exercised. When the arc flash occurred, the main breaker in the switchboard did not trip. The circuit eventually opened at a fuse located on the primary side of the site transformer. This is an example of the difference in magnitudes that could result in an actual event compared to what could be anticipated using the NFPA 70E tables or arc flash calculations. The difference in actual and anticipated tripping time of the overcurrent protection device due to failure to maintain equipment resulted in an exposure to the worker of 15 Cal/cm². A typical protective worker strategy for this installation would be Category 2 in accordance with Table 130.7(C)(15)(a) of NFPA 70E. This would require 8 Cal/cm² outer layer arc rated clothing with 100% cotton underlayers.

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Understanding the regulatory framework

Both the safety and the efficiency of electrical equipment maintenance and modifications can be greatly enhanced if equipment systems were designed to facilitate the use of safe work practices under both [Occupational Safety and Health Administration](#) (OSHA) regulations and NFPA 70E during maintenance and modifications. That is why an understanding of the regulatory framework and the interplay between OSHA's electrical safety regulations, NFPA 70 (National Electrical Code, NEC), and NFPA 70E should be basic to design, installation, and maintenance of electrical equipment.

OSHA regulations are federal and are the law nationwide. Historically, OSHA's electrical safety regulations have drawn heavily on the NEC and NFPA 70E, but there are important distinctions. Compliance with the NEC and 70E does not always equate to compliance with the OSHA regulations.

When designing electrical systems, there are two different considerations: installation, and maintenance and modifications after the equipment is commissioned.

With regard to installations of electrical equipment, there is a long and successful history of equipment that permits a safe installation for persons and property if performed in accordance with the overlapping OSHA regulations that cover installations. U.S. electrical product specifications are developed in correlation with the NEC, which has led to this success. OSHA's electrical construction regulations (29 CFR 1926, Subpart K) apply to new electrical installations. This could be classified as any addition, enhancement, or upgrade to an electrical system. Examples could include a new electrical system, adding a feeder or branch circuit to an existing power panel, or adding components in an existing control panel.

As to maintenance and modifications of already installed electrical equipment, it must be emphasized that all OSHA regulations are based on the task that the worker performs, rather than the worker's job title or the classification of the company he/she works for. Overlapping but different regulations apply to the construction industry (29 CFR 1926) versus general industry (29 CFR 1910). Determining whether OSHA's construction or general industry regulations apply is not always as simple as it sounds. For example, when a maintenance



Figure 2: This remote port can be used for equipment programming. This permits the equipment to be programmed by the worker without wearing electrical PPE and without specialized electrical safety training. Courtesy: MES Consulting Services

worker employed at an existing facility adds a feeder or branch circuit for a new piece of electrical equipment, the task would be classified as a construction activity and would be covered under the requirements of OSHA's construction regulations (because it's an installation). Another example: When the employee of a construction company is changing defective lighting ballast on an existing fixture, it would fall under the general industry standard (because it is maintenance).

Most of the electrical safety-related work training that is currently given to workers is based on NFPA 70E, rather than the applicable OSHA

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electrical regulations. The energized work wording in NFPA 70E differs from OSHA's general industry electrical regulations, creating some misinterpretations of whether the job task is permitted to be performed live at a worksite.

It is critical to remember that any place where OSHA regulations set a more stringent rule than NFPA, the OSHA regulations must take precedence. As federal regulations, they have the force of law.

For example, [Section 29 CFR 1926.416\(a\)](#) of the OSHA electrical construction regulations says:

No employer shall permit an employee to work in such proximity to any part of an electric power circuit that the employee could contact the electric power circuit in the course of work, unless the employee is protected against electric shock by de-energizing the circuit and grounding it or by guarding it effectively by insulation or other means.

This regulation does not contain any exception, for example, for infeasibility to perform a task. Note that this regulation was promulgated in the 1980s, before arc flash was recognized as a hazard in the industry.

Of course, from a practical aspect, you would have to de-energize the equipment to attempt to install what would "[guard] it effectively." If that were the case, you could perform the task while the equipment is de-energized.

Some design criteria involve the use of a technique called "finger safe." The finger safe concept is used with the intent of protecting a worker from electrical shock by enclosing/isolating exposed parts. However, it may not protect the worker from all recognized electrical hazards in a piece of electrical equipment. There are two issues with this concept. When the equipment cover is removed or the equipment door is open, it would not comply with the listing requirements of the product. Additionally, finger safe design would not protect the worker from an arc flash or arc blast.

Functional and operational considerations

Designing an electrical system for a facility requires several considerations in order to make the electrical system functional, address the operations of the facility from a production and safety standpoint, and make it cost-effective. This includes how the electrical equipment

is maintained, operated, and modified. Another important consideration would be continuity of electrical power service. This could include the facility's tolerance to power shut-downs and interruptions in service, and frequency of modifications to the electrical system to support company operations.

Continuity of service: A primary concern of many facilities is providing an uninterrupted source of electrical power to the entire facility. The designer should solicit input from the operations and maintenance groups to understand the critical functions that must be protected from scheduled and/or unscheduled power outages. Under the OSHA general industry rules, infeasibility is not justified based on economic considerations such as production schedules, interrupting a manufacturing process, or data processing operations. The feeders and branch circuits of a facility's electrical system may require additional design steps to maintain continuity of service and provide worker safety.

Maintenance: Workers that maintain electrical systems encounter electrical exposures on a daily basis in the course of their work. A review of their assigned work tasks could

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lead to enhanced design to eliminate or minimize the worker's exposure. The properly designed electrical system could provide increased safety with a minimum amount of interruption to the operation of the facility.

If a company performs infrared testing on electrical equipment as part of a preventive maintenance program, specifying and installing site window(s) on the equipment to perform the infrared task is a cost-effective design consideration. This site window would remove the hazard to the worker. This would also reduce maintenance time for removing covers and wearing electrical PPE. If installing site windows is not a practical solution, specifying hinged covers on electrical panelboards versus bolted covers is another consideration. The worker would still require the electrical PPE to open the cover, but it would reduce the potential exposure to an arc flash.

Modifications and additions

Modifications and additions to electrical systems and equipment are a major obstacle to the operation of a facility. Taking a proactive approach to consider the operation of the facility and taking steps to design the electrical hazards out of the work task could result in actual cost sav-

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ings for operations and increased safety for the worker.

Some facilities have production equipment that requires the equipment's computer program to be modified to accommodate production processes. To reprogram or modify a program requires opening the control panel door, exposing the worker to electrical hazards. A resolution to this hazard is to relocate the computer port to the exterior of the control panel. This would permit the equipment to be programmed by the worker without wearing electrical PPE and without specialized electrical safety training, thus eliminating the worker's exposure to a hazard.

Another design technique to facilitate maintenance, repair, and electrical installation is to install an overprotection protective device adjacent to or upstream of the power or control panel. This changes the design specification from a main circuit breaker type panel to a main lug only panel. This provides the capability for the

worker to disconnect power to the power or control panel, providing a safe environment to make modifications or install new circuitry or components. It also is cost effective and facilitates a lockout/tagout procedure. An installation technique that provides both safety and efficiency is to incorporate the use of wireways with electrical power and control panel installations. This design concept provides numerous benefits to the facility for both efficiency and safety. Figure 3 shows a typical design that could be used. The basic design would be to install the power or control panels as shown. The wireway would be installed above the panelboard at a distance not to exceed 24 in. Conduit nipples would be installed between the power or control panels to facilitate installing the conductors into the electrical panel. These conduits would be of an adequate size to accommodate the installation of the number and size of the wires to the power panel. Limiting the length of the conduit nipples to 24 in. between the wireway and the panel(s) would permit the installation of a large number

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of conductors without having to derate them. This is permitted in section 310.15(B)(3)(a)(2) of the 2011 NEC. The space above the wireway would be used to run the individual feeder or branch circuit cables or conductors and conduit to feed substation equipment.

The most significant benefit of using wireways is after the electrical system has been commissioned and energized. When an additional feeder or branch circuit has to be installed, the worker can remove the wireway cover and ensure that there is adequate clearance to enter the conduit or cable in the top of the wireway with the equipment energized. The worker can then install the cable or conduit, and pull in the wire from the equipment to the wireway, leaving the conductors long enough to be installed and terminated in the panel. The worker can then schedule an outage and make the final terminations of the conductors. This would minimize the disruption to the continuity of service for the facility.

This design technique could also be used for data centers. If the installation has a raised floor, the wireway would be located in the plenum space below the raised floor. Many data installations are designed with

an ample amount of spare circuit capacity in the power distribution units (PDU). If the majority of the circuits in the PDUs are 120 V/20-amp circuits, it provides an opportunity to proactively prewire the PDU. The strategy would be to install the spare branch circuit wiring from the PDUs to the wireway. The conductors would be marked in the wireway and designated as a spare circuit on the panel directory. The ends of the conductors in the wireway would be made electrically safe.

When an additional circuit is required in the data center, the worker would remove the cover, ensure that there is adequate clearance to enter the conduit or cable in the wireway, and install the branch circuit to the substation equipment. The worker would then determine spare circuit number in the PDU that would be used. The applicable circuit breaker could be locked out and verified, de-energizing the circuit in the wireway. The conductors in the wireway could then be re-energized. The entire task can be performed with no interruption to the operation and electrical power in the data center. It also prevents the worker from being exposed to electrical hazards.

Electrical product design

U.S. electrical product specifications are developed in correlation with the NEC. While this can permit a safe electrical installation, it may not address worker safety issues when equipment has to be accessed or maintained after it is commissioned. While product standards are designed to provide guarding from electrical shock, in most cases they may not provide adequate safety from arc flash and arc blast. Once a cover or panel trim is removed, the equipment is not in compliance with the product standards and the worker could be exposed to electrical hazard.

Electrical distribution equipment could be designed to isolate sections of the equipment in order to permit work on them without exposure to electrical hazards. Consider, for example, an electrical power panelboard. Typically, the main circuit breaker is unguarded and is located in the same compartment as the branch circuit breakers and wiring. If a listed and labeled design were approved so that the panel cover could be removed and be classified as de-energized with the main breaker in the panelboard locked out, it would permit modifications and additions to the electrical panel in accordance with OSHA regulations. This would

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be an exceptional benefit for the residential market.

OSHA enforcement regulations forbid compliance officers from approving products or installations. They have to conduct inspections and review products in accordance with their listing and labeling. In the case of a residential panelboard, if there is electrical power on the line side of the main circuit breaker and the main breaker is in the off position, the panelboard is still classified as the worker could be exposed to live parts. Under the listing and labeling criteria, the employer would have to demonstrate that the equipment would be listed and labeled with live power inside and the cover removed. The manufacturers require all trims and covers be installed when there is power above 50 V present. The trims and covers act as guarding from live parts.

The past 20 years have seen a marked evolution in the electrical industry's awareness of electrical safety issues and increased requirements for electrical safety-related work practices. Building inherently safe design into electrical products for maintenance and modification as well as installation purposes is the next step.



The Eaton drawout molded case breaker panelboard and switchboard were engineered with safety in mind. A mechanism system doesn't allow for the breaker to be inserted or removed while it is energized. Optional molded case breakers with the Eaton Arc Flash Reduction Maintenance System means reduced levels of incident arc flash energy, allowing for reduced level of personal protective equipment or PPE.

Engineers can design the hazard out of work tasks by specifying electrical products that have enhanced safety features. Specifying products that address both design requirements and operation of the facility—and incorporate improved installation techniques—is a strategy that will not only increase worker safety, but also increase productivity and profits.

About the author

Kenneth Mastrullo is president of MES Consulting Services. His many years in the electrical construction industry include: 7 years in OSHA's New England Regional Office (Region I Electrical Technical Expert), 6 years in the NFPA (Secretary, NFPA 70E Electrical Workplace Safety), and 11 years as a facilities engineer.

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Protection, Arc Flash Mitigation Using Internal VFIs In Liquid Substation Transformers

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White Paper: Arc Flash Safety In 400V Data Centers

From our previous discussions about the Cooper HDC liquid transformer with internal, under-liquid VFI's, expanding the use of the VFI takes this concept a step further, and makes a great way to mitigate arc flash hazards on the secondary.

By Joe Guentert, Owner and Sole Proprietor, Power Distribution Systems

David Durocher of [Eaton](#) (assisted by Warren Hopper of [Weyerhaeuser](#) and Dave Shipp of Eaton), published an article in June 2011 describing a fairly unusual case of secondary unit substations without secondary main breakers (which was common 30 to 40 years ago under NEC's "Six-Handle Rule"), and how overcurrent relaying could be applied on the secondary bus to trip a protector on the primary side of the transformer. The result was that very effective and sensitive protection could be provided for both secondary faults and internal winding faults, even without having a secondary main breaker.

I love this protection concept (works just as well - maybe even better - if

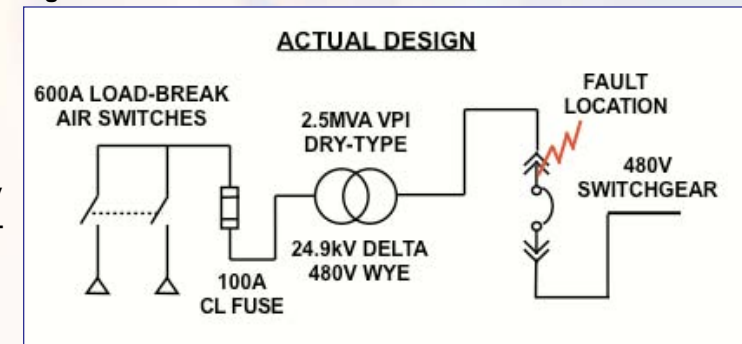
you DO have a secondary main breaker). I've been doing essentially the same thing in most data center projects for about 10 years now, having employed this scheme on approximately one-hundred 5-MVA data center substations that had large fault duties on 600-V secondary buses.

David's article described VPI dry-type transformers in unit substation configurations, in which a compact VCP-TL linear actuator breaker with an isolating switch in the same section were added on the transformer primary to provide good isolation and excellent protection, replacing the primary load interrupter switches and CL fuses. An elegant, smart, simple, and very safe scheme, I think. I'm happy to see that Eaton thought well enough of the approach to develop into a standard product offering called "MSB." I believe that this product can literally save lives, and prevent serious injuries and major equipment damage at large data centers and other facilities.

From our previous discussions about the Cooper HDC liquid transformer with internal, under-liquid VFI's, expanding the use of the VFI takes this concept a step further, and makes a great way to mitigate arc flash hazards on the secondary.

Here's an example (Figure 1), based upon a real data center project de-

Figure 1



sign I saw earlier this year, that used 2.5 mVA 115 C rise VPI dry-type substation transformers, 24.9 kV primary, close-coupled to 480 V secondary switchgear, with solidly-grounded 480 Y/277 V secondary windings. The design used two interlocked 600-amp primary air switches, with a set of 100E current-limiting fuses to protect the transformer against primary

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and secondary faults, with upstream 27 kV metalclad switchgear feeding transformer primary loops. Let's say that the transformer is energized, and operators wish to rack the 4,000-amp secondary main breaker, and that as they do so, one of the drawout finger clusters on the line side of the breaker misaligns, and creates a line-to-ground fault. (This can and DOES happen - not frequently, but often enough to be of concern, and always with EXTREMELY serious consequences. It's everyone's worst nightmare, because there is no way to shut it down until after a lot of equipment has been destroyed, or personnel injured. Generally, it also happens to be the very location of the greatest arc-flash hazard in the entire data center.)

The time-current curves below show the result. The 100E primary fuses provide virtually NO protection against this condition. The fuses would not clear this fault until after the transformer had been destroyed. The arcing secondary ground fault would burn for more than 4 min (about 250 sec, in fact, unless another phase became involved), and

in this case, the arc-flash hazard boundary on the secondary makes the secondary switchgear bus "unapproachable". No PPE presently available would adequately protect operators from personal injury from this

fault, and the 100E fuses are the only protectors anywhere in the system that could possibly clear this fault.

If these were instead the Cooper HDC liquid transformers with an internal VFI we've been discussing, the VFI would clear this same fault within about 3 sec on its normal curve (Red curve on Figure 2).

Now, consider an overcurrent relay with a selectable Maintenance Mode settings group on the secondary, supplied from current transformers slipped over the transformer's secondary bushings, and connected to trip the primary VFI (the very same concept as described in the Dave Durocher article). With the Maintenance Mode settings group activated by a selector switch, this same fault would be cleared in 0.080 sec (Green curve on Figure 2), and the arc flash hazard would be reduced by more than 99.9% from the hazard level of the 100E fuses. All in all, it's the same great result described in Dave Durocher's article, except that the liquid transformer option allows the VFI to be located entirely inside the transformer tank, where it adds

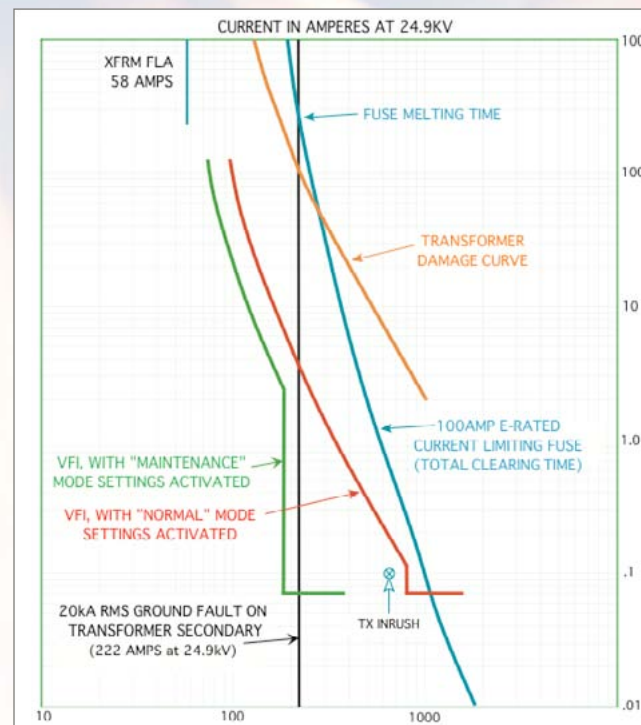


Figure 2: (You could write a Standard Operating Procedure requiring de-energizing the transformer prior to racking secondary breakers, or maybe, employ a motorized remote racking mechanism. But, even with that, the secondary switchgear and transformer would still be very badly damaged, and operating personnel would still be in unsafe proximity to the arc flash when re-energizing the transformer).

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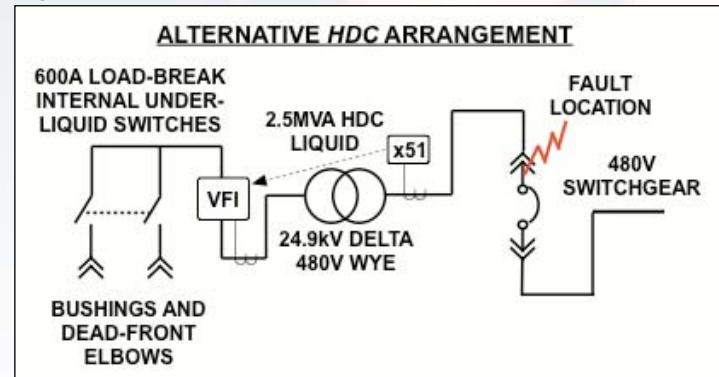
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not much cost, and adds zero extra footprint.

The VPI dry-type design example used in Dave's article requires the addition of an external, floor-standing primary breaker and an isolating switch, requiring additional floor space, and some additional cost, per unit substation. It's a perfect solution for a dry-type or cast-coil transformer, but the same approach becomes much simpler, more compact and much less expensive in a liquid transformer having a primary VFI in the tank - and the VFI is available in transformers with primary voltages up through 35 kV.

Figure 3



About the author

Joe Guentert is owner and sole proprietor of Power Distribution Systems, located in Charlotte, NC. He is a 1969 graduate of the University of Notre Dame (dual majors of Electrical Engineering and Business Management). He had an 18-year career with General Electric Company, with various assignments around the U.S., and worked five years as a vice president of IEM, Inc, Fremont, CA.

He founded Power Distribution Systems in 1994 in San Ramon, CA. Since that time, the company has focused entirely on mission-critical electrical power systems, with the

vast majority of projects being large data centers. The company specializes in medium voltage power distribution, primary substations, MV and LV switchgear, and the integration of protective systems, control and monitoring systems within data centers.

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Strategies for protecting employees from underappreciated yet potentially deadly hazards

By Dave G. Loucks, Manager, Power Solutions and Advanced Systems, Eaton

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.

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

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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://iee.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 either 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

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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.

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

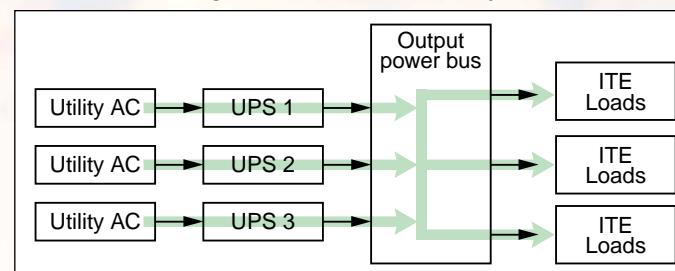


Figure 1. Creating multiple power paths all the way from utility mains to UPSs to IT equipment (ITE) can improve both reliability and safety.

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

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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 acti-

vated. 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

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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 system¹) 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:

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.

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

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

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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 equip-

ment 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.arclashesolutions.com



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

About Eaton

Eaton is a diversified power management company providing energy-efficient solutions that help our customers effectively manage electrical, hydraulic and mechanical power. A global technology leader, Eaton acquired Cooper industries PLC in November 2012. The 2012 revenue of the combined companies was \$21.8 billion on a pro forma basis. Eaton has approximately 102,000 employees and sells products to cus-

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tomers 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.

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