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Thought Leadership White Paper

The Not-So-Shocking Truths About UPS Safety

A candid Q&A about reducing the risks associated with servicing data center UPSs

Bob Lauricella
Environmental Health and Safety Manager
Eaton

Zachary Greenhaw
EHS Analyst
Eaton

Executive summary

When working with data center and commercial facility electrical systems, shocks of 100mA to more than 2,000mA are possible – definitely in the realm of serious harm to humans and property. Energized electrical equipment also presents the risk of arc flash caused by electrical faults that produce powerful explosions.

When dealing with commercial and industrial electrical systems, such as uninterruptible power systems (UPSs) and their batteries, data center and facilities managers need to be aware of these risks, especially since some repair and maintenance procedures require working with a unit that is still energized.

There are ways to minimize the risks to employees, equipment and the field technician performing the service. This paper answers some common questions about UPS maintenance, how to reduce the risks associated with servicing UPSs and batteries, and how to qualify a UPS service provider.

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Introduction

Get an electrical shock at 1mA and you'll feel a mild tingling sensation.
At 5mA, you'll feel the shock, but it probably won't seem painful or disturbing.

A shock in the 6mA to 16mA range is painful and can cause injury from involuntary muscle contractions.

A shock in the 17mA to 99mA range is enough to trigger respiratory arrest and loss of muscle control, including losing the ability to let go. Fatal consequences are possible.

When working with data center and commercial facility power systems, shocks of 100mA to more than 2,000mA are possible. We don't have to detail the consequences to the human body of taking an electrical shock of that magnitude. It's not good.

Energized electrical equipment also presents the risk of arc flash – the energy release that occurs during an electrical fault when current flows through the air between two live conductors, causing a short circuit. In a residential setting, arc flashes usually produce little more than a brief flash of light before extinguishing themselves harmlessly. In a commercial or industrial setting, however, voltages and current are much higher, so arc flashes routinely produce powerful explosions marked by searing heat, toxic fumes, blinding light, deafening noise, flying shrapnel, and massive pressure waves.

According to Electrical Safety Foundation International (ESFI), 2,000 workers are admitted to burn centers each year for treatment of severe arc flash burns.

When dealing with commercial and industrial electrical systems, such as UPSs and their batteries, the safest place to be is away. But this equipment requires preventive and restorative maintenance, which usually requires technicians to be working near the unit, even inside it, and sometimes when it's still energized.

Fortunately, there are ways to minimize the risk to your employees, the equipment and the field technician performing the service. This paper answers some common questions about UPS maintenance and how to reduce the risks associated with servicing UPSs and their batteries.

A candid conversation about UPS service and safety

What types of services do UPSs need?

UPSs protect and power the equipment that runs essential business systems, industrial and medical processes, and communications networks – the very pulse of the organization. Unplanned outages can quickly add up to hundreds of thousands of dollars in lost revenue – or even lost lives. Generally, if a UPS protects the equipment, it's because downtime is not an option.

Preventive maintenance dramatically improves the performance, availability and service life of this critical equipment. It should be intuitive that the better you take care of any equipment, the better it will perform and the less likely it will experience problems.

UPSs that receive no preventive maintenance have a 400 percent greater chance of load loss, compared to properly maintained UPSs. Analysis of millions of operating hours for thousands of UPSs has shown that mean time between failures (MTBF) for UPSs that receive preventive maintenance twice a year is more than 20 times better than for UPSs that receive no preventive maintenance. Increase the frequency of preventive maintenance to quarterly, even monthly, and UPS reliability and service life just keep getting better. Prevention pays off.

Don't forget batteries in preventive maintenance plans. According to the Institute of Electrical and Electronics Engineers (IEEE): "Proper maintenance will prolong the life of a battery and will help enable the battery to satisfy its design requirements. A good battery maintenance program will serve as a valuable aid in maximizing battery life, preventing avoidable failures, and reducing premature replacement."

Repair service addresses the reality that even the best-made components eventually wear out and need to be replaced. Capacitors, circuit boards, fans, batteries and power supplies are all consumable parts that you can expect to periodically replace in a UPS. A well-designed UPS configuration simplifies this process to minimize mean time to repair (MTTR) and restore function as quickly as possible.

What actions are taken during a preventive maintenance visit?

The field technician will perform a variety of checks and inspections, both visual and with diagnostic tools. For example, infrared thermography identifies loose connections, which show up hotter than good connections. Visual inspection of connection points shows evidence of soot marks or degradation that could signal a short circuit or bad connection. Computer analysis of the error log and alarm history can point to impending problems, such as a loss of insulating value on a cable.

Following industry guidelines, a customer engineer may conduct the following preventive maintenance activities:

For the UPS:

- Measure and record input AC voltages and currents on all three phases.
- Measure and record delta voltage at the static switch.
- Measure and record rectifier output DC voltage and adjust if needed.
- Measure and record AC voltages and currents on all three phases.
- Test static switch for “no break” transfer.
- Test all alarms for proper operation.
- Measure and record all DC power supply voltages, and adjust if needed.
- Test all indicator lamps and report any that are not operating.
- Inspect all ground connections and wire insulation for electrical safety.
- Vacuum its interior.
- Inspect air filters and replace if needed.
- Inspect input and output conductors and tighten to manufacturer specifications.
- Document each inspection done along with actions taken or recommendations made.

For UPS batteries:

- Check the appearance, safety, cleanliness and temperature of the battery room.
- Make sure ventilation equipment is deployed per the manufacturer specifications.
- Test each battery with a 100-ampere load applied for 10 seconds.
- Measure and record the cell voltage and specific gravity of each battery cell.
- Re-torque cell connections and micro-ohm to manufacturer specifications.
- Measure internal impedance of all cells to manufacturer specifications.
- Check for corrosion on battery terminals and advise whether teardown is needed.
- Check batteries for cell leaks or cracks and repair or replace as necessary.
- Check battery cables and clean, repair or replace as needed.
- Check the integrity of rack mounting, tighten as required, and notify of any structural damage.
- Inspect the charger and inverter.
- Check grounds, connections, wire insulation and electrical safety, and repair as needed.
- Calibrate ammeters and voltmeters to manufacturer specifications.
- Calibrate charger DC output current to manufacturer specifications, float and equalize voltage.
- Calibrate inverter AC output current to manufacturer specifications, float and equalize voltage.
- Calibrate timers, alarm relays and indicator lamps to manufacturer specifications.

This is just a sampling. IEEE Std 450-2010 outlines even more comprehensive guidelines for monthly, quarterly and annual maintenance.

Who performs this service? Can we do it ourselves?

> *You may hear an electrician talk about the "dead front" in a UPS. It's the unfortunate nickname for the galvanized steel plate behind the attractive black faceplate of a data center UPS.*
>
> *When you remove that handsome, black front panel, this dead front is what separates people from the electricity. If that plate is removed, the UPS had better be fully shut down, with no chance of it being energized by a secondary source.*

The more complicated the equipment becomes, the more important it is to have experts perform the maintenance to keep it running smoothly. Without the right safety training, and without expensive (and often complex and proprietary) diagnostic, analysis and connectivity tools, UPS owners can perform only very limited service themselves. For example, a technician might be able to scroll through the alarm history and see voltage fluctuations, but not gain clarity into why these events are happening or know what to do about it.

Some self-sufficiency is possible with interactive learning programs. For example, Eaton sells a DVD that trains users to do some basic maintenance on their Power Xpert™ 9395 UPS and some other models. Such training is like learning to change the oil and rotate the tires, but not to deal with the dreaded check engine light. The inner workings of modern UPSs are more complex than a standard electrician is prepared to handle.

Furthermore, because large UPSs carry dangerous electrical voltages, all types of service to these units presents the potential for personal harm and property damage to anyone without extensive safety training.

Even powering down the unit is complex. Consider that UPSs and their surrounding electrical infrastructures are designed to prevent the power from going off, so even if the main power source is switched off and the UPS itself is turned off, the equipment could still be getting power from other sources, such as battery, generator or secondary utility feed. Consider also that some procedures, such as infrared thermography and measurements of voltage, currency, resistance, and capacitance, must be done with the unit fully operational.

Do you want anyone other than a highly trained UPS service engineer to be tackling that risk, when it's so easy to take advantage of that expertise through service contracts?

UPSs under warranty or extended service contracts after the warranty period receive recommended preventive maintenance and repair services from authorized, trained field technicians as needed. For smaller single-phase UPSs, manufacturers typically have authorized and trained independent contractors to provide this service. For the larger three-phase UPSs, you can expect the field technician to be factory-trained and certified by the manufacturer.

In rare instances, UPSs are in such remote locations that the only practical solution is for the manufacturer to train the customer's employees to service the UPS themselves. In that case, it must be configured such that everything in the UPS cabinet can be completely de-energized. More on that later.

What will the service vendor's field technicians do to work safely on my UPS?

Field technicians follow risk reduction and mitigation strategies set forth by the Occupational Safety and Health Administration (OSHA) and the National Fire Protection Association (NFPA), which have written standards and regulations that build on one another to help protect workers from electrical hazards in the workplace.

Wear protective gear. Even when working with a de-energized unit, the field technician should be wearing non-conductive safety glasses, safety clothing designed to withstand heat up to 8 cal/cm², and leather safety boots. Working with an energized unit requires either Level 2 (bodywear rated to 8 cal/cm²) or Level 4 (protection rated to 40 cal/cm²), depending on calculations. At Level 4, the field technician will also wear a 40-cal/cm² arc flash protection hood, hearing protection and two sets of gloves. Anything that exceeds 40 cal/cm² requires an escalation in safety level, because the energy associated with a possible blast is extremely dangerous.

Personal protective equipment requires increased supervision and its effectiveness may be limited. For instance, an EH hardhat with tinted face shield protects the face but does not offer side impact protection. Nitrile gloves provide chemical resistance but do not protect against punctures and abrasion. Defects or excessive wear can inhibit the effectiveness of any gear. Gloves should be inspected daily and regularly re-certified. Hardhats should be replaced every five years.

Furthermore, employees may wear incorrect personal protective equipment (PPE) for the task at hand. Wearing Level 2 PPE for a task with an energy level associated with Level 4 can result in a catastrophe. This is why proper training on safety gear and a culture of excellent safety are extremely important.

NFPA standards for PPE are set forth in Table 130.7(C)(16) of the NFPA 70 national electrical code safety standard: *Protective Clothing and Personal Protective Equipment*.

Keep appropriate distance from the unit. Only employees with work justification should enter arc flash/shock protection boundaries. Shock protection boundaries are listed in NFPA 70 Table 140.4(C)(a): *Approach Boundaries to Energized Electrical Conductors or Circuit Parts for Shock Protection for Alternating Current Systems*, and Table 130.4(C)(a): *Approach Boundaries to Energized Electrical Conductors or Circuit Parts for Shock Protection for Direct Current Systems*.

Eaton uses a conservative general rule of 10’ for the arc flash boundary. Annex D of the NFPA 70E standard provides a calculation to determine exact boundaries. Annex D of the NFPA 70E standard provides a calculation to determine exact boundaries. Eaton has a conservative rule of 10’ for the arc flash boundary and only qualified persons with the necessary skills, training, tools and personal protective equipment (PPE) should be within 4’ of an energized unit.

Figure 1. Establish safety zones and protocols for qualified and unqualified personnel.

Have appropriate training and certification. Field technicians must have training and knowledge to perform their jobs effeciently while maintaining a safe work enviroment, as per OSHA requirements, specifically:

- OSHA Part 1910, *Occupational Safety and Health Standards*
- OSHA Part 1926, *Safety and Health Regulations for Construction*

This training should be comprehensive, covering principles of electrical hazards such as arc flash, procedures for incident reporting, personal protective equipment, driving safety, back safety and ergonomics, hazard recognition and communication, and waste handling. This training should be validated and/or refreshed periodically, at least annually.

What can we do to minimize the risk?

Prepare ahead and keep good records. Keep single-line diagrams up-to-date, so there's a reliable record of the data center's or facility's electrical system. Hold pre-job meetings and brief employees on their roles and safe work practices.

Implement an employee training program to ensure data center personnel understand arc flash dangers and how to avoid them. Be sure every existing and new employee receives this training.

Configure each UPS with a maintenance bypass. The last thing any data center manager would want to hear is, "Sorry, but I'm going to have to turn off your data center while I work on the UPS." A maintenance bypass provides an alternate power path that bypasses the UPS circuitry altogether. A field technician can then safely service or replace a UPS without interrupting power to loads and without danger of electrical shock.

Smaller UPSs, in the range of 2 to 30kVA, might have an *internal maintenance bypass* located on or inside the UPS cabinet. When a field technician switches to maintenance bypass operation, almost all of the UPS cabinet is de-energized. The portion of the UPS cabinet that's still powered—where the maintenance bypass resides—is shielded behind metal baffling or a metal wall. The engineer has safe access to the most frequently serviced components and can do fairly extensive work without undue risk.

For larger UPSs, loads are generally so critical that an *external maintenance bypass* is used, usually in a wall-mounted cabinet. Because the bypass path is physically separate, the entire UPS cabinet can be completely de-energized, and field technicians can work in confidence.

A maintenance bypass is not required, but it is *strongly recommended* on every hardwired UPS, even when the UPS has been configured for redundancy. It is a relatively simple device that provides a strong benefit for most any application from 2kVA and up—powerful insurance for a modest additional cost. It is the safest way for field technicians to work on the unit, the safest configuration for your employees, and the safest way to protect the equipment and the load.

Implement arc flash reduction strategies. Every arc flash mitigation program should begin with a hazard analysis—usually performed with help from a qualified power systems engineer—to calculate the amount of energy an arc flash could release at various points along the power chain.

IT and facilities managers can dramatically mitigate arc flash likelihood and severity by:

- Reducing the amount of available fault current
- Decreasing the time required to clear faults
- Anticipating and eliminating the conditions that cause faults
- Redirecting the blast force of an arc flash through the use of arc-resistant switchgear

Post signage on equipment warning of arc flash danger. The NFPA 70E standard requires employers to post signage notifying employees of potential arc flash dangers. Organizations that overlook this directive dramatically increase their chances of paying serious fines and losing lawsuits after arc flash incidents.

The arc flash hazard risk category cannot accurately be determined until the energy potential is evaluated in context. The parameters of a potential arc flash event—how much force/fire are likely and how long it will last—are functions of how much power is being connected in the unit and how quickly the interruption device (such as fuse, breaker or the UPS itself) will activate. Since this risk rating can vary for each aisle of a power setup, manufacturers should not apply arc flash labels to equipment as it ships out. Onsite evaluation is available as a service once the equipment is installed.

To ensure data center employees are always aware of potential arc flash hazards, companies should mark arc flash hazard zones on the floor so workers not wearing PPE can clearly see how far they must keep away from electrical equipment to avoid potential injury.

Select a service vendor with a strong safety record. Whether you choose to get your UPS service from the manufacturer or a third-party vendor, choose a provider with a proven track record of safe performance. To reduce liability and injury risk, ask to see records that show a solid safety record in terms of protecting field technicians and customers' employees and property in the RFP process.

How can we assess the safety practices of a service vendor?

UPS service vendors must be able to show you several tangible measures of their safety performance and commitment as evidenced in safety practices and reportable incidents.

Recordable incident rate. Incidence rates can be used to show the relative level of injuries and illnesses among different industries, firms or operations within a single firm. Because a common base and a specific period of time are involved, these rates can help determine both problem areas and progress in preventing work-related safety incidents.

Experience modification rate. In workers' compensation experience ratings, the actual payroll and loss data of the individual employer are analyzed over a period of time. Usually, the latest available three years of data are compared to similarly grouped risks to calculate the experience modification.

In general, an employer with better-than-average loss experience receives a credit, while an employer with worse-than-average experience carries a debit rating. The experience rating is generated by taking the average loss experience and modifying it based on the individual's own loss experience.

Training and safety protocols. Eliminating safety incidents is a matter of recognizing and evaluating the risks, then implementing the correct controls to prevent or mitigate them. Review the service provider's procedures related to insurance, employment checks, safety programs, OSHA/EPA citations in the previous three years, management systems (such as ISO 14001 and OHSAS 18001), and initial and refresher training for field technicians.

At a minimum, training programs should include instruction in the following areas:

- OSHA 10/30 general industry/construction requirements
- NFPA 70E arc flash safety protocols
- Electrical safe work practices, including proper use of personal protective gear
- Lockout-tagout (LOTO) safety procedures to ensure that electrical gear is properly shut off and not started up again until the maintenance or service work has been completed
- First aid and cardio-pulmonary resuscitation (CPR)

Closing thoughts

The risks associated with high-energy voltages are serious, but there are many ways to prevent incidents or reduce their effects. Prevention is foremost; mitigation is the second line of defense. To put it in other terms, if you have activated your car's air bag, you're already having a bad day. It's much better to have good visibility, tires and brakes so you can avoid the incident in the first place.

For more information on arc flash safety, please refer to Eaton's white papers, What You Need to Know About Arc Flashes and Arc Flash Safety in 400V Data Centers. The NFPA National Electrical Code is also available online.

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.

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About the authors

Bob Lauricella is the Sub-Regional Environmental Health and Safety Manager for the Southeast Region of the US. He has a Bachelor's of Science degree in Mechanical Engineering from Michigan Technological University and has been working with Eaton for the past 6 years. He can be reached at BobLauricella@Eaton.com

Zach Greenhaw is EHS Analyst for Eaton's UPS Field Service organization in Eaton's Power Quality Division in Raleigh, North Carolina. He has a degree in Environmental & Occupation Management from Methodist University and has been working in the EHS field for nearly 5 years. He can be reached at ZacharyGreenhaw@Eaton.com