Mitigating Electrical Risk While Swapping Energized Equipment

White Paper 13
Version 2

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Executive summary

Mission-critical applications require continuity of power while inserting or removing modules in low-voltage electrical equipment, such as UPSs and PDUs. This type of work poses a potential risk to workers and requires electrical safe work practices. There are ultimately three parties with their own contributions to protecting workers. This paper describes these three parties, their contributions for electrical safe work, and explains the conditions for energized swapping. In addition to electrical safe work practices, recommended electrical equipment design attributes are also described that help reduce the risk of injury.

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Introduction

Mission-critical applications such as data centers, hospitals, airports, and military require continuity of power, which is also referred as availability. One means of improving availability of power is to keep the electrical equipment energized while inserting or removing modules. This practice is commonly known as "hot swap" and it can help ensure the continuity of power for capacity expansion (scalability) and also reduce mean time to recover (MTTR) if there is an issue. Note that for simplification, we will use the term "**energized swapping**" to mean "hot swap – swapping modules in energized low-voltage equipment" for the remainder of this paper.

However, without an appropriate risk assessment, this energized swapping activity poses electrical hazards to workers such as shock and arc flash. A shock hazard exists when the operator approaches energized electric conductors or circuit parts. The workers may inadvertently touch the part (i.e. due to disturbances, stumbling, or when in close proximity to de-energized parts they're working on but touch the energized conductors next to it).

An arc flash happens when a fault occurs between two live conductors or conductor to ground. Sources of an arc flash can be foreign elements such as tools or dust/debris, defect or worn-down insulation material, poor design, poor installation, etc. Arc flash can be measured based on incident energy released through the air in the form of heat, sound, light, and explosive pressure, all of which can cause harm. Some specific injuries can include burns, blindness, electric shock, hearing loss, and fractures. For more information on arc flash, see White Paper 194, *Arc Flash Considerations for Data Center IT Space*.

In order to protect the workers from electrical hazards, a risk assessment is necessary. An assessment identifies hazards, assesses risks, and implements risk controls according to ISO 45001 hierarchy of controls. This hierarchy is shown below, with examples for each risk reduction method related to electrical hazards.

1. **Elimination** – Disconnect and remove all power (a state in which the circuit has been disconnected from energized parts, locked/tagged in accordance with established standards, and tested to verify the absence of voltage.)
2. **Substitution** – Use a fully-redundant system (2N) to allow maintenance shutdown of one of two systems.
3. **Engineering controls** – Design attributes that reduce risk. For example, touch-compliant connectors, compartmentalization, mechanical interlocks, protective devices (e.g. fuse).
4. **Awareness and warnings** – Temporary signs, personnel barricades, and hazard labels.
5. **Administrative controls** – Job planning, training, creating a safety culture.
6. **Personal protective equipment (PPE)** – Arc rated clothing, face shields, safety glasses, electrically rated gloves, hearing protection.

Items 1–3 above are considered more effective as they are usually applied at the source and less likely to be affected by human error. Items 4-6 are less effective as they are usually not applied at the source and are more likely to be affected by human error. Note that PPE, which is often the first thought related to safety, is the last item on the list of six risk control methods – meaning it is the least effective and least preferred. See White Paper, *Safe Electrical Work Practices* for more information on each item.

The concept of electrical safety is founded on the ability to recognize the hazards associated with electrical energy and then take the necessary precautions to mitigate those hazards. There are three parties including **employer**, **employee** and **vendor** who have a role in electrical safety. Each party has their own contributions that must be fulfilled to help protect the workers according to the **hierarchy of risk controls** (as shown in **Table 1**). Excluding items 1 and 2, this hierarchy provides a multi-layer protection scheme for energized swapping activity, with each party contributing to risk reduction. The definitions and contributions of each party including employee will be discussed in detail in next section.

Table 1

Multi-layer protection for protecting workers from electrical hazards

	Hierarchy of risk controls	Contributions from each party		
		Employer	Employee	Vendor
Most effective	1. Elimination	Enforce policy of not allowing any form of energized work	Adhering to employer's policy of no energized work.	
	2. Substitution	Specify system redundancy (e.g. 2N) so as to maintain operation during maintenance on redundant system	Work on redundant systems that have been shut down	Reduce voltage to safer levels e.g. SELV (safety extra low voltage)
	3. Engineering controls	Specify the engineering controls via their decision for using a particular vendor's equipment Specify and use the recommended installation, breakers, etc.	Refrain from disabling the engineering controls	Design equipment Adhering to touch compliance, incident energy reduction, and 3rd party verification. See section "Recommended electrical design attributes"
	4. Awareness and warnings	Read and adhere to all warnings and recommendations from vendors	Read and adhere to all warnings and recommendations from vendors Adhere to work practices	Warn about risks that cannot be guarded against or designed out
	5. Administrative controls	Provide job planning, training, create a safety culture Provide training, process, and equipment required for a lockout tagout	Complete lockout tagout training and adhere to its procedures	Inform that only trained personnel may perform the task.
Least effective	6. Personal protective equipment (PPE)	Provide arc-rated clothing, face shields, safety glasses, electrically rated gloves, hearing protection, etc.	Use PPE when required	Inform that PPE should be used

This hierarchy of risk controls uses similar logic to James Reason's "Swiss cheese model of accident causation". An analogy that suggests that multiple layers of "things" (in this case risk controls) reduce the risk of an accident. As illustrated in **Figure 1**, if the holes are vulnerabilities, adding multiple slices (i.e. risk controls) reduces the likelihood of all the holes lining up for hazards to cause an accident.

Furthermore, there are some standards and regulations[1] that have also issued rules to enforce better and safer work practices. There are four main groups of standards in most developed countries (including Canada, China, European Union, and U.S.) related to electrical hazards. Although there are differences among regions or even within the same country, all these standards basically describe the person responsible for safety, system installation, worker protection, and risk quantification. The three parties need to fulfill their contributions to ensure they are compliant with those standards and regulations in their regions.

[1] Examples of standards and regulations: International Electrotechnical Commission (IEC) in European Union, National Fire Protection Association (NFPA), and Occupational Safety and Health Administration (OSHA) in the U.S.

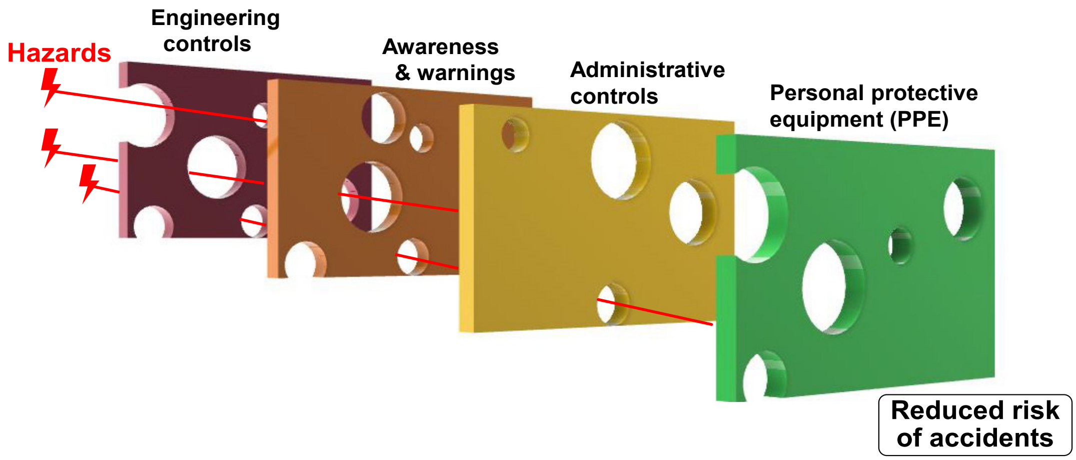

Figure 1

Swiss cheese model of accident causation

This paper describes the three parties and explains their contributions specifically to help protect the workers from harm, and also lists the vendor's contributions that help employers and employees to more easily fulfill their contributions. This paper provides three objectives to help achieve energized swapping capability while complying with the standards and regulations. In addition to electrical safe work practices, recommended electrical equipment design attributes are also described that help reduce the risk of injury while keeping the continuity of power.

The three parties and their contributions

In this section we define the three parties including **employer**, **employee** and **vendor**, and explain their contributions for electrical safety. With this information, mitigation of electrical hazards is facilitated, and each party can fulfill their contributions to help ensure they are compliant with the standards and regulations.

Employer and their contributions

The employer is the entity which has the fiduciary responsibility to those under its charge. It involves those who have installed, own, and are using the electrical equipment.

The employer that allows employee to swap noncompliant[2] equipment on energized systems will violate regulations, which could result in fines and/or lawsuits. In other words, the **employer is held liable for violations**. In order to comply with regulations and standards, the employer needs to fulfill their contributions *before* allowing the employee to perform energized work. Some examples of employer's contributions are listed below:

- Perform a risk analysis – Identify potential hazards, estimate the likelihood of occurrence of injury or damage to health, and the potential severity of an injury, resulting in the identification and implementation of proper risk controls. In another words, assess the degree to which a worker may be exposed to potential electrical hazards. For example, the employer or the employer's qualified designee are required to identify PPE needed for the job based on a properly executed risk analysis because only they know the full extent of potential hazards for work to be done.

[2] Noncompliant equipment is that which requires shutdown to perform work.

- "Establish, document, and implement the safety-related work practices and procedures required by the standard." According to NFPA 70E.[3]
- "Provide employee with training in the employer's safety-related work practices." Furthermore, the employer shall document that each employee has received the training according to NFPA 70E.

Employee and their contributions

The employee could be one of the following persons or individuals:

- **The qualified person** – One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.
- **Individual(s)** – Those are involved with the installation, operation, programming, configuration, maintenance, servicing, troubleshooting, or decommissioning of equipment.
- **The unqualified person** – One who inadvertently is in proximity to a hazard.

The employee has the following contributions:

- "Shall comply with the safety-related work practices and procedures provided by the employer." According to NFPA 70E.
- Report any objections to the work due to safety concerns according to the standard EN50110-1.

Vendor and their contributions

The vendor is a manufacturer or an original equipment manufacturer (OEM) and those within the chain of distribution of electrical equipment.

Vendors also have certain contributions to help mitigate electrical hazards. For example, the vendor should design electrical equipment which, when used as intended, helps avoid shock and arc flash hazards during energized swapping. **Simply adding the words "hot swappable" to a brochure or manual may provide a false sense of security but does nothing to protect workers from harm.** Some examples of vendor's contributions are listed below:

- Evaluate the probability and severity of potential risks – The vendor needs to evaluate the likelihood of a risk (e.g. arc) and its severity if it did occur. For example, failure mode and effects analysis (FMEA) is a common methodology used to evaluate the risk probability and severity. A vendor can also use a 3rd party, such as Underwriters Laboratories (UL), TÜV Rheinland, etc. to verify the results by witnessing the tests.
- Provide employers the data required to perform a risk analysis – Each vendor needs to provide the necessary data (i.e. inform about risks and guide awareness) to assist the employer performing the risk analysis for the workers.
- Provide user instructions for energized swapping activity – The employer can use this information to train the employee.

With this understanding for three parties and their contributions, we now explain the conditions which allow for energized swapping in low-voltage electrical equipment.

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[3] U.S. standards and regulations relevant to arc flash are among the highest standard of safety today and are therefore referenced from this point forward in this paper. Schneider Electric has applied this highest standard globally in order to secure equally safe working conditions for everyone, everywhere.

Conditions for energized swapping

To comply with regulations, answering the following two questions before allowing the workers to do energized swapping, will assess the degree to which the workers may be exposed to potential electrical hazards.

Question 1 Can you justify the need to perform the work energized?
Question 2 Do you know what happens if an arc flash event were to occur?

In the U.S., Question 1 is regulated by NFPA 70E clause 110.3: "*Energized electrical conductors and circuit parts operating at voltages equal to or greater than 50 volts shall be put into an electrically safe work condition* ***[deenergized, locked out]***[4] *before an employee performs work if any of the following conditions exist:*

(1) The employee is within the limited approach boundary. ***[increased risk of shock]***
(2) The employee interacts with equipment where conductors or circuit parts are not exposed but an increased likelihood of injury from an exposure to an arc flash hazard exists. ***[increased risk of arc flash]***"

Either of these conditions trigger the need to de-energize unless the application can meet specific energized work exceptions that appear in 110.4(A) or 110.4(B).

> 110.4(A) permits energized work *"…where the employer can demonstrate that de-energizing introduces additional hazards or increased risk"*. Examples of additional hazards or increased risk include interruption of life-support equipment.
>
> 110.4(B) permits energized work *"…where the employer can demonstrate that the task to be performed is infeasible in a de-energized state due to equipment design or operational limitations."* Examples include performing diagnostics, testing, or troubleshooting.

In the majority of cases the answer to **Question 1** is NO for a system feeding a data center. It can be extremely difficult for an employer to demonstrate that deenergizing the equipment would introduce additional hazards or that it is infeasible.

While the rules above apply to the U.S., the rest of world follows IEC standard IEC 60364 which restricts energized work to enforce safer work practices. Specifically IEC 60364-4-41 clause 4.1 states, "*Hazardous-live-parts shall not be accessible and accessible-conductive-parts shall not be hazardous live* ***[deenergized, locked out]*** *either under normal conditions (operation in intended use and absence of a fault); or under single-fault conditions.*"

Furthermore, clause 4.5 states, "*Technical committees shall specify measures to protect against electric burns in their standards. An electric burn can be caused where a current of sufficient density and duration flows through the human body or livestock. Arcs can also cause burns. The effects can be severe even if only a small part of the body is involved.*" ***[measures are required]***

Properly answering **Question 2** is not easy. The knowledge associated with arc flash phenomena has increased dramatically over the past 25 years, but quantifying it is still complex. Methods exist to calculate energy release and support decision making. However, these methods produce estimates that may not reflect all real-life scenarios. **Question 2** can only be answered definitively through verification tests of multiple potential failure scenarios. We discuss this more later.

[4] Text has been edited for clarity. [ ] is text added for clarity.

Based on these answers, it is nearly impossible for a vendor to claim energized swapping yet still have the application comply with these rules. However, a closer look at NFPA 70E 110.3, shows that the worker must turn off the equipment (i.e. "electrically safe work condition") *"if any of the following conditions exist"*. If neither of these conditions is triggered, then the worker could perform the task. In other words, if the equipment meets both conditions below, **energized swapping is allowed**:

1. **If the worker is not within the limited approach boundary** – The limited approach boundary is an approach limit from an exposed energized part within which a shock hazard exists. However, if the equipment's energized parts are not exposed, but instead are suitably guarded, isolated, or insulated, then the limited approach boundary is not crossed.
2. **If the worker does not increase the likelihood of exposure to an arc flash hazard** – An arc flash hazard is caused by a release of energy from an electric arc. Where an arc flash hazard exists, the arc flash boundary defines the approach limit from an arc source at which incident energy equals 1.2 cal/cm². According to the "Stoll skin burn injury model"[5], the onset of a second degree burn on unprotected skin is likely to occur at an exposure of 1.2 cal/cm² for one second. If the task results in a worst-case energy release of less than 1.2 cal/cm² at the working distance, the worker is not inside the arc flash boundary.

Even if a vendor was able to design equipment that met the two conditions above, how would that vendor prove it? The answer lies in the interaction between the standards and regulations listed in **Appendix Table A1**. For historical reasons the protection of workers from electrical hazards is not handled by a single code or standard. For example, a UPS is approved for the U.S. market in accordance with UL1778 standard and is witness tested by UL for same; similarly a UPS is approved for the rest of world market in accordance with IEC 62040 standard and is witness tested by a 3rd party certification body such as TÜV Rheinland.

The drawback with these standards and regulations is that they do not require products to be evaluated for arc flash. Instead, they evaluate creepage, clearance, resistance to fire, ground continuity and mechanical robustness in the aim to reduce the risk of an arc to an acceptable minimum. But they do not evaluate what happens if an arc flash really did occur. In another words, the arc flash testing is not mandatory, and each vendor could have different interpretations of these standards. Decades ago, this was accepted as "good enough" in the industry. Through the last decade, OSHA has focused on fatal accidents in the electric industry. They observed that shock and arc flash were common root causes. OSHA together with NFPA have issued new rules to enforce better and safer work practices.

One remarkable consequence of this historical background is the paradox that **Question 2**: *"Do you know what happens if an arc flash event were to occur?"* can't be validated because:

- UL and TÜV Rheinland are accredited laboratories that validate compliance against standards. But they can't validate an energized swapping activity, only things that are measurable. Also, UL can't validate against NFPA or OSHA standards while TÜV Rheinland can't validate against IEC standards.
- NFPA & OSHA can't certify that a product complies with something. Furthermore, they do not have means to enforce their regulations before an incident

[5] https://ewh.ieee.org/r3/nashville/events/2018/IEEE-MCPQG%20NFPA%2070E%20&%20OSHA%20Presentation%202018-08-07.pdf page 17.

occurs, so their standards can only be used as a reference for a manufacturer's self-declaration.

How to unlock this paradox? UL / TÜV Rheinland can't "validate" in this case, but they can apply due diligence to check a vendor's test plan and to witness the tests conducted to "verify[6]" that the vendor's self-declaration is fulfilling. In the case of energized swapping, a vendor self-declares that their equipment complies with NFPA 70E article 110.3 because:

- "**No risk of touch**" is verified by UL, TÜV Rheinland, etc. for compliance based on the product standards. For example, the product standards of an UPS are UL1778 and/or IEC62040.
- "**No increased risk of arc flash**" is proven in witness testing under UL, TÜV Rheinland, etc. and verified by UL, TÜV Rheinland, etc. UL uses test protocol UL RP 2986 while TÜV Rheinland uses IEC TR 61641.

Based on the discussion above, vendors should meet the following **three objectives** to help protect workers when swapping modules in energized low-voltage equipment, while fulfilling their contributions (two self-declarations above):

1. **Help ensure touch compliance through the entire swapping sequence**
2. **Help reduce potential arc flash incident energy to under 1.2 cal/cm²**
3. **Document and verify (with 3rd party accredited laboratory) that 1 & 2 are met**

The following section provides some recommended electrical design attributes to achieve these three objectives.

Recommended electrical design attributes

Before we move to discuss design attributes, we need to talk about a prerequisite for energized swapping capability – modular design. In another words, modular design makes energized swapping possible. Furthermore, compared with traditional standalone design, modular design not only achieves product-level fault tolerance (through redundant modules), but also has other benefits such as ability to scale and grow (pay as you grow), simpler process of duplication through greater production of volume for few issues, more automation and less mutual work during manufacturing, etc. For more information on benefits of modular design see White Paper 76, *Modular Systems: The Evolution of Reliability*.

Note that in this section, we choose a specific type of low-voltage equipment (a modular UPS in this case shown in **Figure 2**) to discuss electrical design attributes. Therefore, these design attributes are not meant to be a prescriptive solution for all low-voltage equipment.

[6] Verification is testing that your product meets the specifications / requirements you have written. Validation tests how well you addressed the business needs that caused you to write those requirements. It is also sometimes called acceptance or business testing.

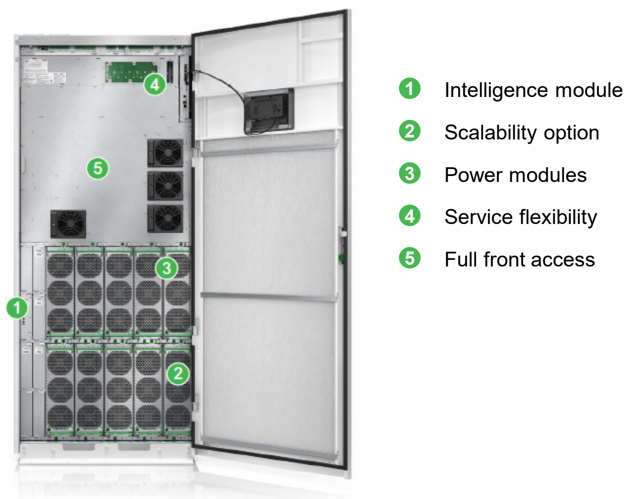


Figure 2

An example of a 3-phase UPS with modular design

In order to achieve power continuity and help reduce MTTR, the power modules shown in Figure 2 can be upscaled or replaced when the UPS is energized. In order to offer these benefits while meeting the three objectives above, the following electrical design attributes are recommended.

- Touch-compliant design
- Compartmentalization
- Mechanical interlocks
- Protective devices
- FMEA analysis
- 3rd party verification
- Hazard labels

Each design attribute is discussed in detail in the following subsections.

Touch-compliant design

First, let's recall the touch-compliant design for a lightbulb socket (as shown in Figure 3). The old E27 bulb socket is touch-compliant only when a bulb is inserted. If certified today, this design would be challenged by a number of questions:

- How do we know that power is turned off during the replacement? After all, the bulb doesn't glow, and we don't know for sure if the light switch is on or off.
- What could happen if a new bulb is not immediately inserted? What if someone wants to move the lamp (without bulb) and accidentally inserts their finger in the socket?
- Can it be assumed that the person replacing the bulb understands the risk? The problem with E27 is that it is not so obvious that a danger exists when the plug is left unattended without a bulb inserted.

It's clear that the E27 design can't provide a satisfactory answer to these questions (in fact it would not be approved today). The modern equivalent GU10 provides the following answers to the above questions accordingly:

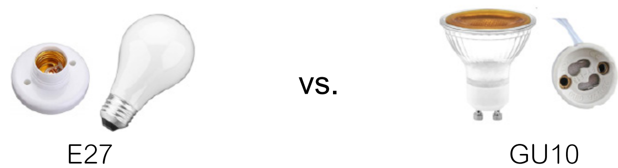
- GU10 design accepts that it is not certain whether power is on or not. There is no immediate danger. It is recommended to turn off, merely as a precaution should there be a mechanical fault on the socket.

- If a bulb is not immediately inserted in GU10, it does not represent an immediate danger. If there is a mechanical fault, it is not in itself a danger. If someone put their finger into the socket, it is not in itself a danger. For an accident to occur even with power on, the connector must be simultaneously defective and touched. In other words, the GU10 is said to be “first fault tolerant”.
- Those with minimal knowledge about electricity would know that they should not use tools to manipulate the connector or put a screwdriver into the holes.

In summary the GU10 design is much safer than E27. Even without the bulb, it is “first fault tolerant”, so accidents can occur only as a result of neglect or misuse.

Figure 3

Touch-compliant design innovation for light bulb socket



The same concept should be applied to ensure first fault tolerance through all stages of energized swapping design. For example, even with the module removed, a design should be first fault tolerant against the risk of touch, exactly like the GU10 socket example. We now describe three examples of how the concept of first fault tolerant design applies to UPS systems.

1. Add insulation between human and energized components. Figure 4 shows an example of a connector that meets this criteria.

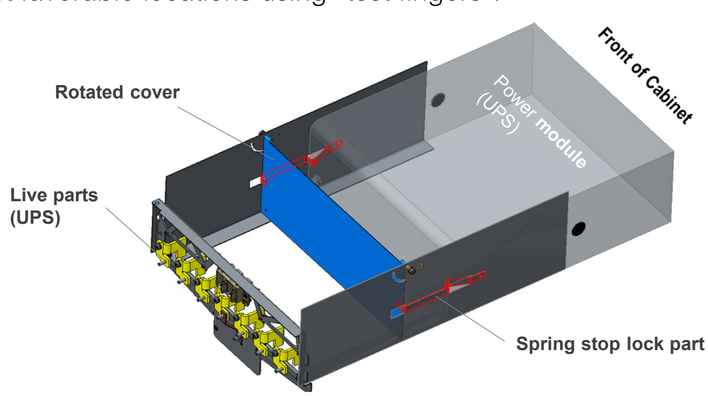
Figure 4

An example of connector selection that is “first fault tolerant” against the risk of touch

2. Replace exposed busbars with insulated cables. The exposed busbars can be kept in a separate compartment while the connections between a power module and input section uses insulated cables. Compartmentalization can not only achieve touch-compliance but also helps mitigate arc flash risk, discussed in the next subsection.
3. Shield the live terminals with a metal panel when the power modules are not installed or withdrawn. Figure 5 shows an example of this touch-compliant design with a self-locked metal panel. The shield must meet the creepage and clearance distance requirements and be tested with defined force in the least favorable locations using “test fingers”.

Figure 5

An example of metal shield against the risk of touch



Compartmentalization

Compartmentalization is a design attribute to segregate exposed energized components away from swap area. This adds an extra layer of insulation to help avoid touch hazards during energized swapping activities.

Furthermore, different energy levels can be segregated in separate compartments so that an arc occurring on one location can't spread to areas with high energy content (likelihood of an arc occurrence) and make matters worse or uncontrolled (severity of an arc if it did occur). The methodology is to help reduce potential arc flash incident energy to under 1.2 cal/cm² in order to comply with NFPA 70E. High incident energy levels are typically present at the input/output terminals inside any product. So, it is vital that the input/output terminals are in a compartment separated from the swap section for power modules.

Figure 6 shows an example of a 3-phase UPS with compartmentalization, where the exposed landing terminals and bypass section with high energy content are segregated behind a cover in the upper compartment of the unit (solid green line) while the swap area (power module compartment) with low energy content is in the lower section of the unit (dotted green line). While swapping the power modules, the segregation helps ensure that workers can't touch any exposed live connectors or conductors, while helping to reduce the likelihood and severity of an arc.

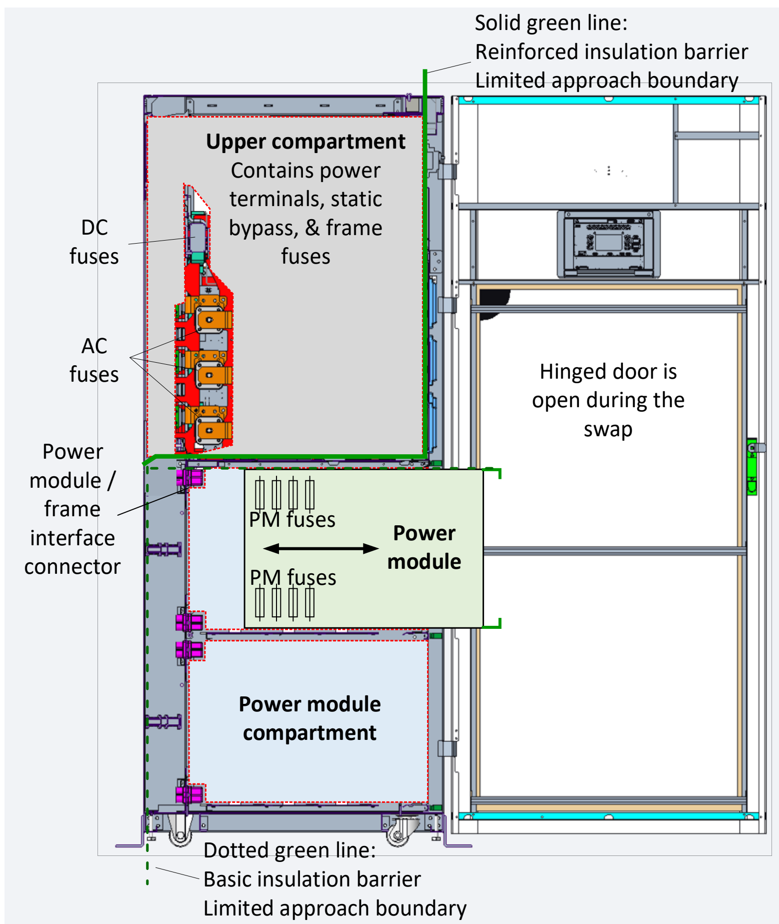


Figure 6

An example of compartment design to segregate energy levels

Mechanical interlocks

Mechanical interlocking is a widely used design attribute to achieve safe electrical work. In order to help reduce the likelihood of an arc flash, the power modules are designed with mechanical interlocks and relays to achieve a zero-current condition (as shown in Figure 7). This design attribute can help ensure the modules are inserted and withdrawn when they are in the "OFF" state. This zero-current condition eliminates the possibility of triggering an arc.

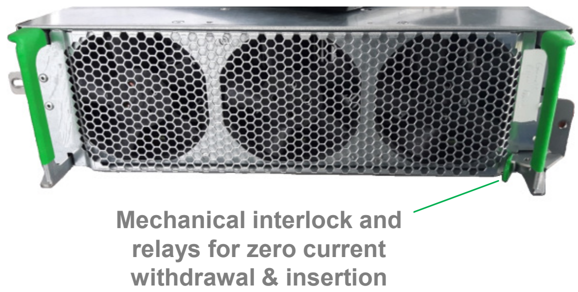


Figure 7

An example of a power module designed with mechanical interlock and relays to achieve zero-current condition

Protective devices

Time to stop the accident is another strategy to help mitigate arc flash incident energy. Adopt protective devices such as breakers and fuses within the modules and upstream is a design attribute which is vital to minimize the time before an arc is interrupted. The methodology is to use protective devices to clear faults or ensure enough time to react. The lower the fault current is, the longer the opening time required, which can increase the incident energy. The severity of a potential arc flash depends on fault current and opening time of protective devices. Figure 8 shows some examples:

- A fast semiconductor fuse can clear a fault in around 2-10ms. But they need a rather large current for fast clearance.
- For smaller current, breakers can clear a fault in 50ms.
- For very small current, there is enough time (2 seconds) to react and escape.

In the example provided, the power module is equipped with fuses. The fuses ensure that any significant arc can't be produced inside the power module. The power module itself does not expose a worker to an increased risk of injury from arc flash. The vendor needs to specify the correct size of fuses or circuit breakers. A witness test is also required by a 3rd party.

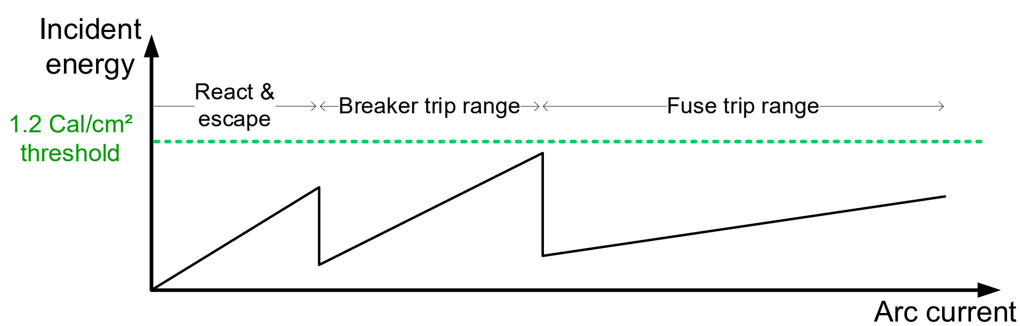


Figure 8

Examples of protective devices with different opening times

FMEA analysis

FMEA is an analytical risk analysis methodology that focuses on the design of the product to reduce the risk of product failure and improve product quality. Thus, it can be used to assess arc flash risk during the product design and development phase. Table 2 contains a summary of 5 common swapping steps that must be assessed with a risk analysis methodology for an arc risk.

For example, in order to get a UL verification with this example, the test is done per UL RP 2986 to ensure the incident energy is less than 1.2 cal/cm^2 for the person performing the energized swapping, which is discussed in detail in next subsection.

Table 2

An example of FMEA risk analysis considerations for energized swapping risk (could include but not limited to):

Activities during energized swapping	Cause
Arc fault in terminal compartment during the swap (with compartment cover closed)	• Breakdown of insulation barriers (i.e. due to wear or water) • Foreign elements shifting position • Lose strands or poor installation cabling
Arc fault at insertion	• Foreign elements
Arc inside the module	• Faulty module • Defect component • Contaminated • Transport damage
Arc fault at extraction	• Mechanical interlock failure
Arc fault with module fully extracted from frame	• Frame side connector damage

3rd party verification

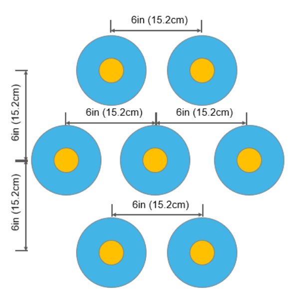
Verification tests help confirm that the vendor's self-declarations are correct. In this section, we describe two 3rd party verifications including UL and TÜV Rheinland.

UL verification

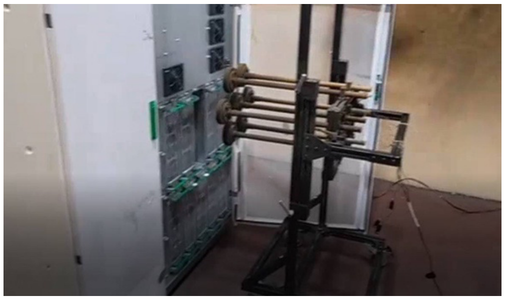
The incident energy of an arc flash can be measured based on UL RP 2986. Arc flash testing ensures the incident energy is less than 1.2 cal/cm². Calorimeters are used to measure incident arc energy. Calorimeter plates are placed in front of the unit at head/chest distance from the modules (as shown in Figure 9).

Figure 9

An example of arc flash incident energy test verified by UL



Arrangement of slug calorimeters

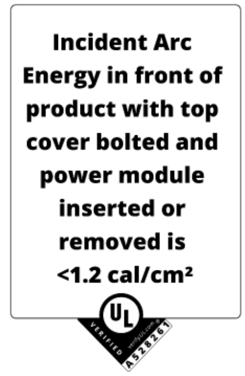


Placement of calorimeter plates

Upon witnessing the tests to verify that the vendor's self-declarations are correct and their contributions are fulfilled for energized swapping activity, the UL issues the vendor an official verified certification which the vendors can apply it to their products and use it in promotional materials (as shown in Figure 10).

Figure 10

An example of verified certification from a 3rd party accredited lab



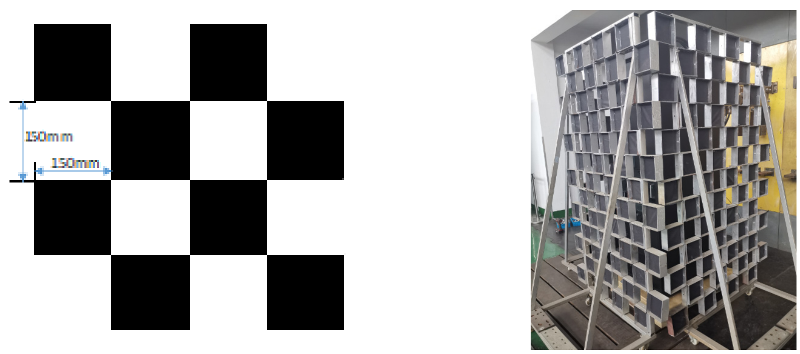
TÜV Rheinland verification

There are two steps for this verification. The first step verifies the worst-case arc flash incident energy is less than 1.2 cal/cm^2 through theoretical calculations according to IEEE 1584-2008 standard.

The second step tests worst-case arc flash incident energy based on FMEA with cheese cloth indicators placed around the UPS, according to IEC TR 61641 (as shown in Figure 11).

Figure 11

An example of arc flash incident energy test verified by TÜV Rheinland



Arrangement of cheese cloth indicators Placement of indicators

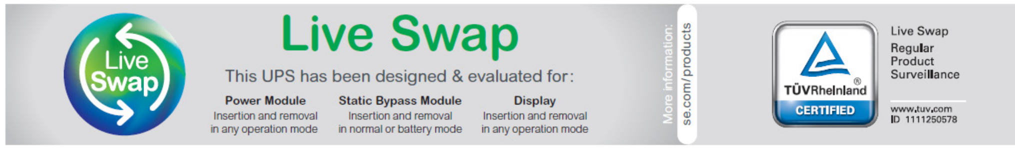
According to IEC TR61641, the UPS must fulfill the following criteria to verify arc flash testing:

1. "Correctly secured doors and covers do not open and remain effectively in place and provide a minimum level of protection in accordance with the requirements of IP1X of IEC 60529. Deformations are accepted. Some breakage of a limited number of fastenings and hinges is acceptable. The ASSEMBLY does not need to comply with its IP code after the test;"
2. "No parts of the ASSEMBLY are ejected which have a mass of more than 60g except those which are dislodged and fall between the ASSEMBLY and the indicators;"
3. "Arcing does not cause holes to develop in the external parts of the enclosure below 2 m, at the sides declared to be accessible as a result of burning;"
4. "The indicators do not ignite (indicators ignited as a result of paint or stickers burning are excluded from this assessment);"
5. "The protective circuit for accessible part of the enclosure is still effective in accordance with IEC 61439-2."

Upon witnessing the tests to verify that the vendor's self-declarations are correct and their contributions are fulfilled for energized swapping activity, TÜV Rheinland issues the vendor an official verified certification which the vendors can apply to their products and use it in promotional materials (as shown in **Figure 12**).

Figure 12

An example of an arc flash incident energy test, verified by TÜV Rheinland

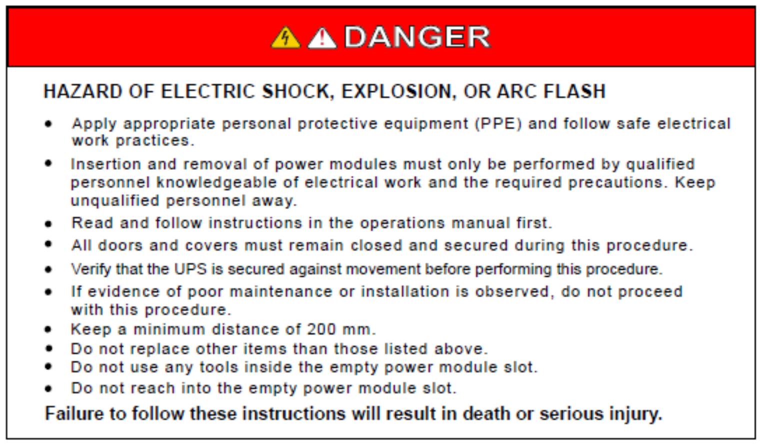


Hazard labels

According to ISO 45001 hierarchy of risk controls, **awareness and warnings** can help identify and mitigate electric hazards. Applying a hazard label to a product can make workers aware of risks and risk controls. **Figure 13** shows an example of a hazard label for swapping energized equipment.

Figure 13

An example of a hazard label



DANGER

HAZARD OF ELECTRIC SHOCK, EXPLOSION, OR ARC FLASH

- Apply appropriate personal protective equipment (PPE) and follow safe electrical work practices.
- Insertion and removal of power modules must only be performed by qualified personnel knowledgeable of electrical work and the required precautions. Keep unqualified personnel away.
- Read and follow instructions in the operations manual first.
- All doors and covers must remain closed and secured during this procedure.
- Verify that the UPS is secured against movement before performing this procedure.
- If evidence of poor maintenance or installation is observed, do not proceed with this procedure.
- Keep a minimum distance of 200 mm.
- Do not replace other items than those listed above.
- Do not use any tools inside the empty power module slot.
- Do not reach into the empty power module slot.

Failure to follow these instructions will result in death or serious injury.

Conclusion

This paper defines three parties including employer, employee and vendor, and lists their contributions to help protect the workers from electrical hazards according to risk assessment (hierarchy of risk controls) from ISO 45001. This paper provides three objectives to help ensure the contributions of vendor are fulfilled for the purpose of complying with standards and regulations for energized swapping activities.

These three objectives include:

1. Help ensure touch compliance through the entire swapping sequence
2. Help reduce potential arc flash incident energy to under 1.2 cal/cm^2
3. Document and verify (with 3rd party accredited laboratory) that 1 & 2 are met

Several electrical design attributes based on a specific type of low-voltage equipment (a modular UPS) are recommended in this paper to help the vendor achieve the above three objectives for their equipment with energized swapping capability.

About the authors

Claus Andersen is a system architect in the 3 Phase UPS systems product development. He has been with the company since 2003 and is re-appointed Edison in systems engineering for the 2nd time. His primary assignments are in the early phases of new product development, with conceptual studies, impact assessments, and consolidating business needs and validation requirements together with other project stakeholders. He has 5 granted patents. His educational background is a master's degree in Electro-Mechanical systems design from Aalborg University.

Paul Lin is the Research Director and Edison Expert at Schneider Electric's Energy Management Research Center. He is responsible for data center design and operation research and consults with clients on risk assessment and design practices to optimize the availability and sustainability of their data center environment. He is a recognized expert, and a frequent speaker and panelist at data center industry events. Before joining Schneider Electric, Paul worked as an R&D Project Leader in LG Electronics for several years. He is also a registered professional engineer and holds over 10 patents. Paul holds both a Bachelor's and Master's of Science degree in mechanical engineering from Jilin University. He also holds a certificate in Transforming Schneider Leadership Programme from INSEAD.

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Appendix

Table A1 briefly describes missions and requirements of different standards and regulations on electrical hazard safety in the U.S. and the rest of world.

Table A1

Distinctions on electrical safety requirements between different standards and regulations in the U.S. and the rest of world

Standards and regulations		Requirements on electrical hazard safety
NEC[7]	Code	Based on web: "The NEC is an extensive collection of definitive guidelines for the safe and secure installation of electrical equipment and electrical wiring in the United States." It is a part of National Fire Code series published by NFPA[8] and can be regarded as a "uniform code" or a set of "guidelines", so, it is not a federal law. Based on NEC article 110.16, all equipment that may be worked on while energized must be identified and marked with an arc-flash warning label.
NFPA 70E[9]	Standard	NFPA 70E is a standard for electrical safety in the workplace. It is one of NEC family of documents. It was originally developed at OSHA's request, NFPA 70E helps companies and employees avoid workplace injuries and fatalities due to shock, electrocution, arc flash, and arc blast, and assists in complying with OSHA 1910 Subpart S and OSHA 1926 Subpart K.
OSHA	Regulation	Based on the U.S. government website: "The OSHA assures safe and healthful working conditions by setting and enforcing standards, and by providing training, outreach, education and assistance." Based on OSHA 29, the employer is responsible for the protection of employees and contractors who perform work on electrical equipment in their facilities. OSHA also categorizes work into General Industry Standard (1910.333) and Construction Standard (1926.416). General Industry Standard allows only three exceptions to work on live exposed live electrical parts while Construction Standard prohibits work on live exposed parts with no exceptions[10].
UL	Certificate	Based on the UL website: "The UL is a nonprofit organization and fosters safe living and working conditions for people everywhere through the application of science to solve safety, security and sustainability challenges." It is the largest, oldest and most recognized laboratory listed by OSHA to certify a product for authority for safety requirements through testing, inspection, audit, certification, validation, verification, advisory and training business.
IEEE	Standard	Based on the IEEE website: "The IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity." IEEE 1584 has provided incident energy calculation methods and provides reference methods for test.
IEC	Standard	Based on the IEC website: "The IEC is a global, not-for-profit membership organization, whose work underpins quality infrastructure and international trade in electrical and electronic goods. Our work facilitates technical innovation, affordable infrastructure development, efficient and sustainable energy access, smart urbanization and transportation systems, climate change mitigation, and increases the safety of people and the environment." IEC TC64 is an IEC technical committee. The task is to develop and maintain up-to-date standards, in order to ensure: - the protection of persons and livestock against electrical shock - the design, verification, and implementation of low-voltage electrical installations.
TÜV Rheinland	Certificate	Based on the TÜV Rheinland website: TÜV Rheinland is one of the world's leading testing service providers. TÜV Rheinland operates a global network of approved labs, testing and education centers. As an independent third party, TÜV Rheinland tests technical systems, products and services, supports projects and tests processes for companies and organizations.

[7] https://www.electriciancareersguide.com/what-is-the-national-electrical-code/

[8] The NFPA is a global self-funded nonprofit organization, established in 1896, devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards. The NFPA delivers information and knowledge through more than 300 consensus codes and standards, research, training, education, outreach and advocacy.

[9] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70E

[10] https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=interpretations&p_id=21569