UPS installation safety requirements

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Executive summary

In a 24/7 'Always On' business, reliability and resilience are always the top priorities for mission-critical facilities. But even above these, the biggest priority has to be maintaining safety and eliminating risk to people and equipment when dealing with the hazardous voltages within a data center.

This is why there are international and European regulations that businesses – and their data center facilities – must comply with. These distinct safety requirements of backfeed protection and fault currents have some commonalities, not least that they are both commonly misunderstood.

The primary purpose of backfeed protection in a UPS system is to prevent conducting hazardous voltages upstream when the supply has been removed from a UPS. Meanwhile, the IEC regulations in Amendment 1:2013 protect personnel and equipment from fault currents that could otherwise cause arcing or fires within the UPS.

This white paper looks at the major regulations and the differences between external and internal backfeed protection, as well as the IEC regulations on Amendment1:2013, their impact on the UPS and the benefits from protection built into the UPS.

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Backfeed protection

Legislation

Backfeed protection is required by IEC 62040-1:2008 Uninterruptible power systems (UPS) – Part 1: General and safety requirements for UPS. The standard is also a European Normative and sets a legal mandatory requirement to ensure the safety of service personnel in UPS installations. The standard allows for two alternative implementations of backfeed protection; installing an internal backfeed isolation device within the UPS, or installing an external input line isolation device, with only backfeed detection and control implemented within the UPS while having required warning labels in the associated switchgear as described in the safety standard.

When the incoming supply is lost, the backfeed protection device must isolate the output of any permanently connected UPS from the supply by means of separation within 15 seconds, to prevent conducting possibly hazardous voltages upstream. Note that the term "backfeeding" and the requirement in this context relate to personnel safety and hazardous voltage or energy, not to a reverse power flow as is sometimes mistakenly understood.

It is important to understand that a static switch comprising semiconductors and thyristors together with associated control and snubber circuits may not provide adequate isolation for safe maintenance of the upstream electrical network, even when it is working as expected. When the gate signals for static switch thyristors are off and it is not passing power through, the electrical circuits may leak some voltage and current upstream; enough to be hazardous for personnel. Therefore, backfeed protection is primarily for UPS systems under normal operating conditions, not just for fault scenarios as often believed.

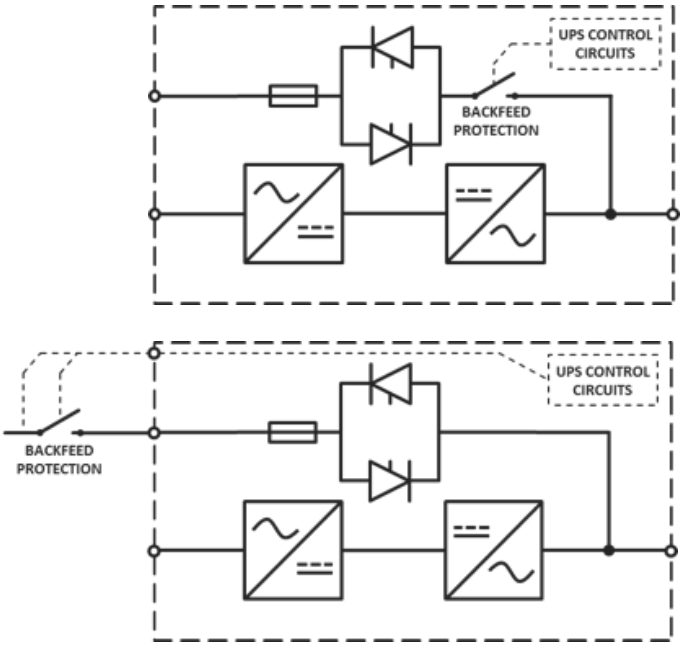

Figure 1: UPS with internal backfeed protection device in series with static bypass switch on left; principle of external input line isolation device implementation on the right.

If relying on an external device, the requirement relates to the installation rather than the product itself. In this case the responsibility for fulfilling the minimum legislation requirements lies with the electrical contractor or installation owner, who may not have adequate knowledge of the product-specific safety standard requirements for the UPS equipment and installation.

An externally connected backfeed protection device may be subjected to hazardous voltages from the UPS if it is operating in stored energy mode. To notify service personnel of this risk, the UPS product safety standard requires the user to fit warning labels on all switchgear access points and switching devices between the UPS and the external backfeed protection device.

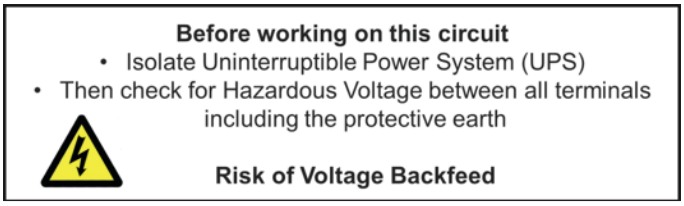

Figure 2: Warning label as described in IEC 62040-1:2008, to be used with external backfeed protection devices and when 4-pole switches are used upstream of a permanently connected UPS.

Some UPS models have internal backfeed protection as standard, but others do not. In some cases, the presence or otherwise of an internal device varies with different versions of a single UPS model from one supplier. Accordingly, care is essential in selecting the UPS product and verifying whether backfeed protection must be installed into the UPS supply.

For some UPS models, relying on external backfeed protection can impact the UPS supply configuration. It can compel the use of a dual feed, separate supply for the rectifier and bypass, instead of a single feed that may be acceptable in many cases while saving cost.

It is also worth mentioning that having the backfeed protection device external to the UPS will add "hidden cost" to a UPS system. The device will need the same or similar components as the UPS within the switchgear, to control its switching in response to mains power status. A motor operated circuit breaker or a contactor in series with overcurrent protection are typical ways to achieve this.

These can have a possible impact on type approval of the switchgear, with some additional cost involved. There will also be the costs associated with design, coordination, labor and materials when installing the external backfeed protection device and associated control wiring.

Using UPS products with a ready-installed and factory tested internal backfeed protection device ensures that safety requirements are fulfilled by the UPS supplier rather than relying on others to handle; this makes the solution easier for everyone.

Impact on fault tolerance

The primary purpose of backfeed protection in a UPS systems is to prevent conducting hazardous voltages upstream when the supply has been removed from a UPS, and the UPS is operating in stored energy mode. Since, in practice, the backfeed protection isolates the UPS system output from incoming supplies, and is in series with a static switch, it can also be used for another purpose; specifically, to isolate a faulty static switch from a system.

This secondary function for backfeed protection can help to increase system resiliency and is often a more widely discussed subject, when backfeed protection in UPS systems is considered. Nevertheless, it should be emphasized that backfeed protection is there for personnel safety and a mandatory requirement as explained previously.

The ability to isolate the faulty bypass circuit can keep the UPS system on-line and protect critical loads, even with a faulty static switch; eliminating a single point of failure from the system and increasing fault tolerance. Therefore, this secondary use of backfeed protection in UPSs, to reduce the impact of a faulty static switch, is highly welcome.

Backfeed protection in a single UPS system

Eaton offers three-phase UPS equipment that includes an internal backfeed protection device as standard, as shown in Figure 3. It includes an internal backfeed contactor (K5) that automatically protects against fault situations within the static switch.

If a static switch develops a fault that drives it into an unwanted conductive state, power will be fed between the UPS output and its supply; the power can be transferred in either direction, depending on voltage difference and phase shift between inverter and incoming supplies.

This unintended current flow can cause the UPS system to be overloaded, activating inverter current limits, and, for various reasons, to be tripped to bypass or even to shut down. Therefore, the fault can have a significant impact on system operation and reliability.

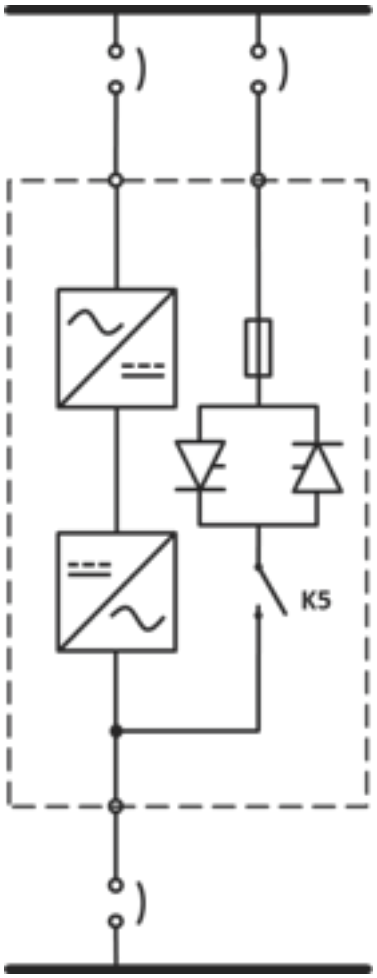

Figure 3: UPS with a static switch and internal back-feed protection (K5)

Backfeed detection circuitry and UPS firmware can detect this current in the bypass line when the UPS is not in bypass mode and the static bypass switch is not turned on. The internal backfeed contactor is then opened to isolate the fault and to prevent power flowing between the UPS output and supply, thus allowing the UPS to continue operation in dual-conversion mode even with a static switch failure.

An alarm will inform site personnel, or a remote monitoring station beyond the premises if used, of the defect in the unit to activate a sequence of planned corrective actions.

Backfeed protection in a parallel UPS system

UPSs are paralleled to gain higher availability or larger capacity in a UPS system. Figure 4 shows a parallel UPS system in a distributed bypass configuration with internal backfeed contactors K5.

A fault developing in one of the static switches would potentially allow the paralleled inverters to feed or draw current between system output and the mains. Accordingly, a failure in a single static bypass switch can eventually cause a critical failure in the system. However, the current flow caused by a faulty circuit can be detected and the internal backfeed contactor in the associated UPS module opened automatically, allowing the system to remain in double conversion operation to protect the loads.

The static bypass lines of the parallel system have redundancy, since a failure of one static bypass does not prevent the other bypass lines from operating. In a redundant parallel system, a static bypass failure does not affect the bypass capability of the system in any way; in capacity paralleled systems, however, the bypass capacity would be slightly reduced.

Some parallel UPS systems use centralized bypass topology, where the system bypass module (SBM) provides a common bypass line for all paralleled UPS units, as shown in Figure 4.

The SBM, like the UPS's internal bypass switch, comprises antiparallel-connected thyristors. Accordingly, the same safety hazards exist for service personnel and similar failure mechanisms may occur; therefore, backfeed protection is an equally important, and mandatory, requirement for centralized bypass systems.

In a parallel UPS system, internal backfeed protection means that each static switch in the distributed bypass system includes a backfeed contactor, so the configuration's redundancy is preserved. By contrast, having an external backfeed contactor often means installing only one contactor for multiple static switches, so a failure of one of the switches results in total loss of all the static bypass lines connected to the common backfeed contactor. Similar implementations are used in some modular UPS designs where one backfeed contactor is used for multiple or all static switches. The impact on systems redundancy and resilience can be far greater.

There is a view that a backfeed protection device itself may reduce system reliability, since it is a component and it can fail as well. This is very true, but there are many factors to consider. These include how the component typically fails, how it is used in the system and the possible implications.

If the backfeed contactor fails closed, and does not open on loss of supply, it would not impact UPS system operation until a static bypass switch failed; a second failure would be needed to impact the UPS system operation. The system would act almost like one that had no backfeed protection at all. In any case, this type of failure is rare.

Another, more typical, failure mode is for the backfeed contactor to open or not to close when it should. In practice this means that the bypass line is not available for use if needed. Systems with just one static bypass line lose all their bypass capacity; those with multiple static bypasses, each with their own backfeed contactors, lose some capacity.

Note that the UPS bypass line is available only when the mains bypass supply is available - and the bypass line availability cannot be higher than that of its supply. Clearly, the reliability of backfeed protective devices with associated control circuits is far higher than the mains supply's, and therefore has negligible impact on bypass line overall availability.

A UPS with backfeed protection and shorted static switch detection can isolate a faulty static bypass switch, which is a critical failure for a system at any time, and eliminate a single point of failure from the system. This benefit outweighs the marginal impact on bypass availability caused by backfeed protection, and improves overall system resiliency.

And finally, personal preference is not the deciding factor. Ensuring the safety of service personnel is a mandatory requirement for UPS equipment and installations. Safety must be designed in to UPS systems; the only question is how to implement the safety design to achieve the maximum additional benefits in the form of improved system level resiliency.

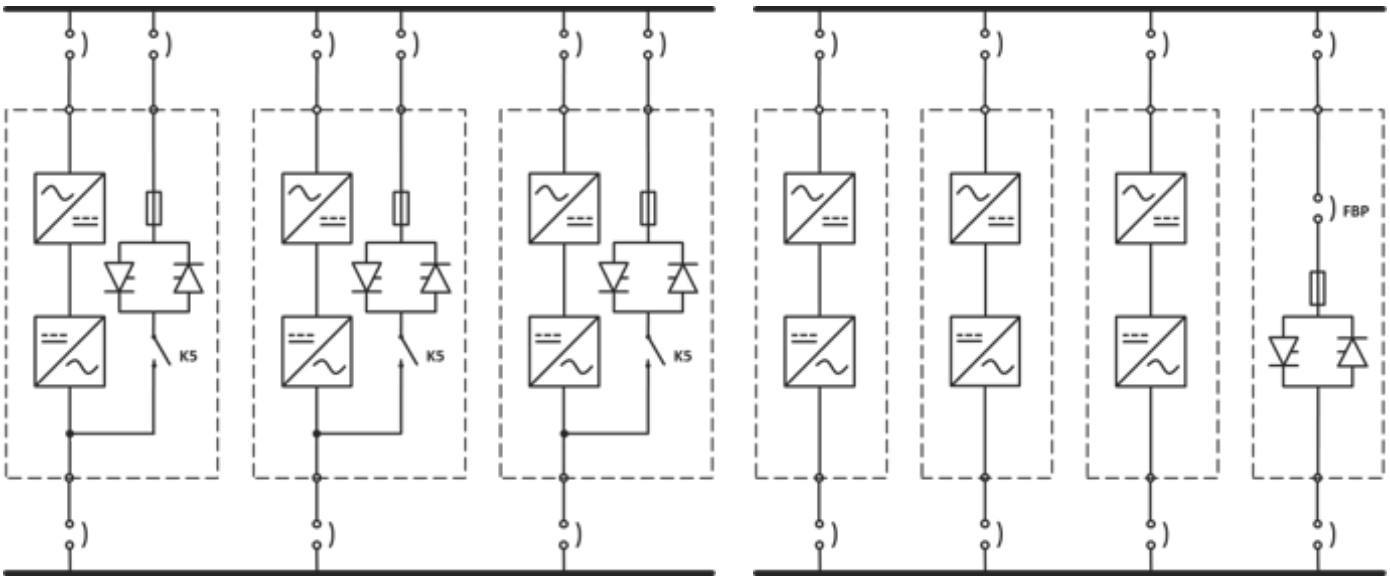

Figure 4: Parallel UPS system in distributed bypass configuration on the left and centralized bypass system on the right. Both examples have internal backfeed protection devices; contactors (K5) inside the UPS units and a motor operated air circuit breaker (FBP) as an isolator/switch (no trip unit) for large centralized bypass.

IEC 62040-1:2008 – Amendment1:2013

IEC 62040-1:2008 (EN 62040-1:2008-11) Uninterruptible power systems (UPS) – Part 1: General and safety requirements for UPS gives the mandatory safety-related requirements for UPS products and installations. Compliance with this standard is required for CE marking and is legally enforceable. The latest requirement, Amendment1:2013 to IEC 62040-1:2008, became mandatory on February 2016. This requires the UPS manufacturer to declare either:

- Rated short-time withstand current (I_{CW}):
  The r.m.s. value of short-time current, as declared by the UPS manufacturer, that can be carried without damage under specified conditions, defined in terms of current and time

  or

- Rated conditional short-circuit current (I_{CC}):
  The r.m.s. value of prospective short-circuit current, as declared by the UPS manufacturer, that can be withstood for the total operating time (clearing time) of the short-circuit protective device (SCPD) under specified conditions

In practice, a UPS supplier must state the maximum allowed fault current level at the UPS input terminals to maintain the safety of the UPS product and installation. The rating of any equipment selected must equal or exceed fault current levels found in the UPS installation and these declared values must not be exceeded under any conditions.

When the conditional short-circuit current I_{CC} rating is used, the fault current is reduced by a short circuit protective device (SCPD), typically a fuse, to a safe level for UPS internal circuits and components. The SCPD can be either an internal part of the UPS, or external in the UPS's upstream supply.

The requirements given in the standard only apply to the UPS's low impedance path, assuming that such a path exists. This low impedance path is either the UPS's internal bypass circuit, or for multiple UPSs, a large common bypass. It includes the static bypass switch circuit from the bypass input terminals to the UPS output terminals; it also extends to the UPS mechanical (maintenance) bypass circuit if this is an integral part of the UPS or sold as a UPS system component under the UPS product standard. When an external maintenance bypass is used as part of the low voltage switchgear assembly, it automatically falls into the switchgear product category and associated requirements.

The standard also requires that each bypass circuit must be independently safe at available fault current levels. Safety cannot be evaluated at system level assuming all circuits will share the fault current, since product and personnel safety must also be guaranteed during service activities and commissioning, or when part of the system has failed or is not in operation. In other words, having more UPS units or static switches in parallel does not reduce the requirements for individual static switches or UPS units.

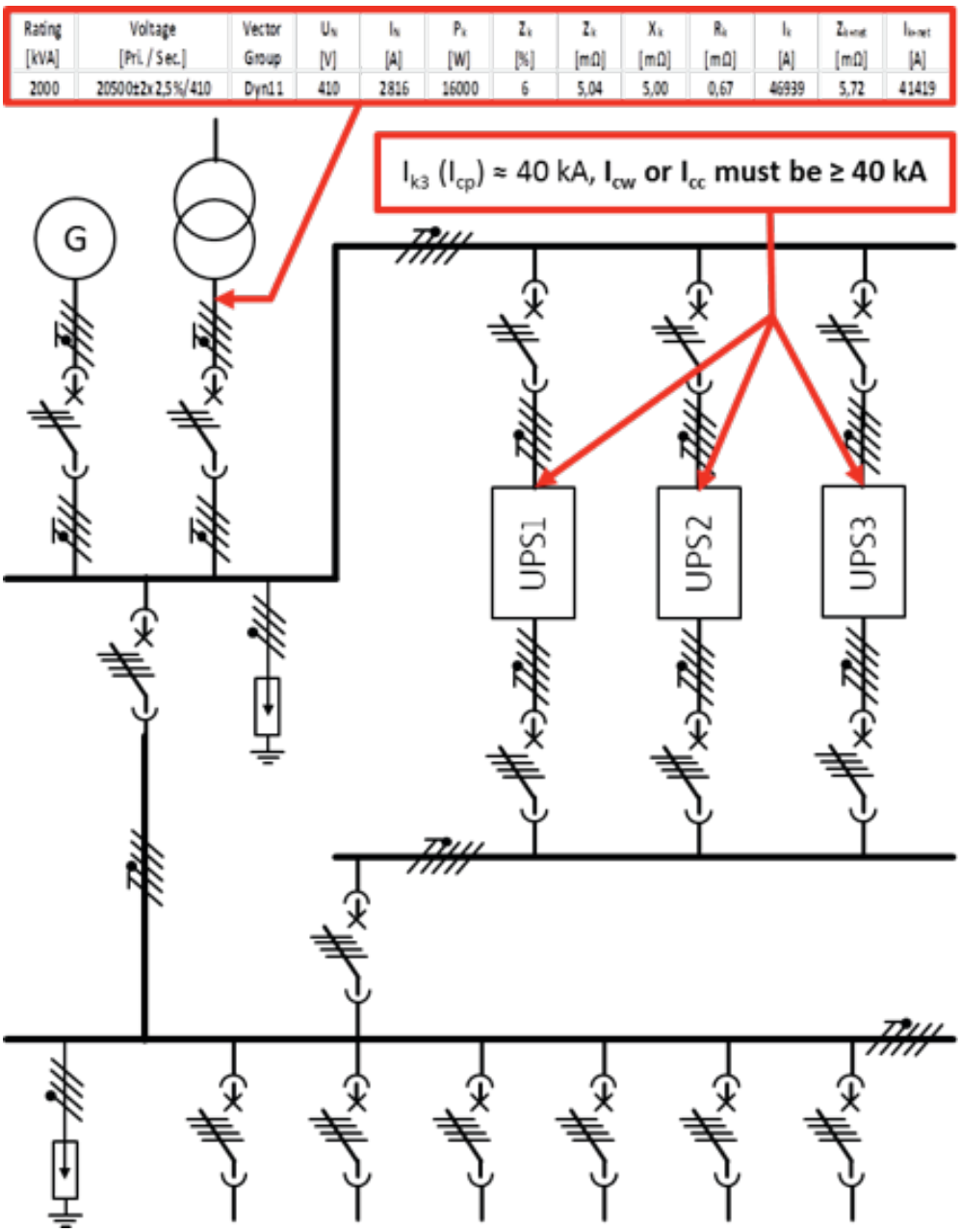

Figure 5: The withstand current rating of a UPS must match or exceed available fault current in the installation. In the above example the UPS withstand current requirement is based on the fault current available from the mains feed. If the generator is operated in parallel with the transformer, resulting in higher fault current levels, ratings must be selected to accommodate this condition and UPS compliance must be verified together with possible future changes in the installation.

Minimum requirements for the fault current levels are given in the standard, but these can be somewhat lower than typically seen in actual installations, especially within larger UPS units.
The UPS supplier can in any case declare higher figures than required; these may also be desirable from an application perspective.

Compliance with safety requirements for a UPS product must be verified by testing, conducted by a UPS supplier (manufacturer). Testing is mandatory with two exceptions; either the declared withstand current rating is ≤ 10 kA or the peak let-through current is limited by the SCPD to ≤ 17 kA.

Compliance is verified when, at the conclusion of the test, the following criteria are satisfied:

a) the UPS shall not have emitted flames, molten metal or burning particles, other than, e.g., metal particles normally emitted from a circuit breaker when it clears a fault

b) there shall have been no arcing from live parts to the UPS chassis or enclosure

c) components, e.g. busbar supports, used for mounting live parts, shall not have broken away from their initial position

d) any enclosure door shall not open rapidly (so causing injury), prevented only by its normal latch

e) no conductor shall have pulled out of its terminal connector and there shall be no damage to the conductor or conductor insulation

f) the UPS shall successfully pass the electric strength tests

When conditional I_{CC} rating is used, the UPS supplier shall test the product with the selected SCPD. It is the UPS supplier's sole responsibility to select the protective device and verify the design by testing as required. If external protective devices are used, the UPS supplier shall state the device type. Only the protective devices stated by a UPS supplier, and verified by testing if required, can be used.

If the UPS supplier relies on external short-circuit protective devices in the UPS supply switchgear, this requirement for UPS system safety falls onto the installation and becomes the responsibility of its designer, electrical contractor and owner. These individuals may not have sufficient knowledge of product-specific standards and requirements to ensure correct protective devices are used, and never replaced with a device giving less protection and having higher let-through energy.

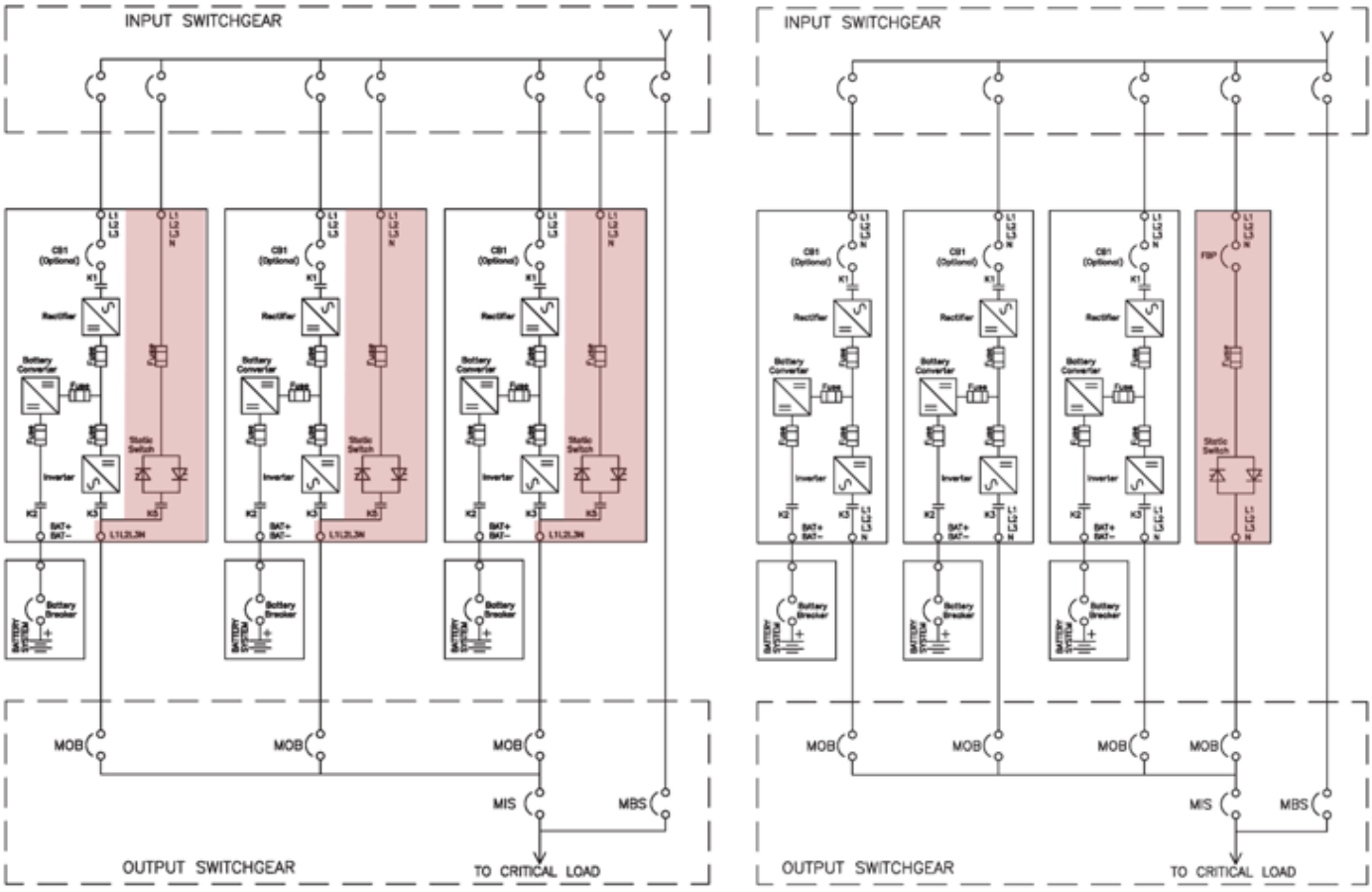

Figure 6: The withstand current rating of a UPS applies to a UPS static bypass circuit, either within the UPS or as a centralized system level bypass as highlighted above. It also applies to a mechanical bypass if this is an integral part of the UPS (system). Often, an external maintenance bypass is used; if so, it must follow LV switchgear requirements.

The UPS fault current rating must exceed the worst-case scenario on site, from day one onwards. For multiple feeds, possible parallel operation of supplies as well as future changes and upgrades to the upstream electrical infrastructure must be allowed for. Having multiple devices in parallel does not reduce the fault current requirements for each individual unit. UPS compliance must be re-assessed following any changes in installation that affect fault current levels. This is especially important if external SCPDs are used to protect the UPS. These must only be approved types and should not be replaced with other types in the future, for example when changes and upgrades are performed on the switchgear assembly.

As legal requirements, these must be fulfilled for a UPS installation, for both personnel and infrastructure safety. However, few people are aware of UPS product-specific safety requirements, creating a risk that these aspects may be neglected.

To reduce the risk of mistakes in safety related requirements, it can be beneficial to specify and use products which have internal SCPDs and have been laboratory tested with high fault current levels.

UPS products with internal SCPDs and up to 100 kA ratings are available on the market. These exceed the standard's minimum requirements, and allow their use in practically any installation without special requirements for feeders in supply panels on day one, or after future changes. This way the UPS supplier, as the expert on product technology, will protect himself by having a safe and verified design built into the product. He will be assured that the product and installation comply with all mandatory requirements.

Conclusions

There are two major, yet distinct, safety requirements for a UPS installation to protect equipment and personnel from faulty and dangerous electrical currents. Both are equally important but often equally misunderstood.

The first is backfeed protection, which is primarily a safety mechanism. It is mandatory, as specified by IEC standards, but it can also increase system resiliency. Beyond the legal and safety requirements that the UPS 'shall prevent hazardous voltage or hazardous energy from being present on the UPS input terminals after interruption of the input power', a UPS can detect backfeed current and open an internal backfeed connector while sounding an alarm, which enables the UPS to continue in dual conversion mode, significantly improving system operation and reliability. Backfeed protection can be applied to both distributed and centralized multiple UPS configurations, while maintaining the same levels of safety, system redundancy and availability.

The second is Amendment 1:2013, which requires a UPS supplier to state the maximum allowed fault current level to ensure that it does not emit flames, molten metal or burning particles or arc flash and to maintain the safety of the UPS and its installation. Some UPSs use external short-circuit protection, which passes the responsibility for system safety onto the designer, electrical contractor and owner.

Using UPS products with ready-installed and factory-tested internal protection device against backfeed and tested up to 100 kA fault currents, which is sufficient in practically any installation, ensures that safety requirements are fulfilled by the UPS supplier rather than relying on others to handle it; this makes the solution easier for everyone.

Overall, consultation with a well-established UPS supplier is highly recommended. This eliminates users' exposure to legislation transgressions arising from a lack of knowledge of all relevant requirements, while ensuring that they take advantage of every benefit offered by modern UPS technology; personnel and equipment enjoy the safety they are entitled to during normal operation, maintenance and fault conditions, while system resiliency and availability are maintained at maximum levels.

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