Infrastructure with Intelligence
White paper

Power Distribution + UPS

Smart tricks to improve power supply reliability

The possible "outages" that might have been forgotten Uninterruptible Power Supplies and Power Distribution

Different power source behavior and effect on the power distribution

Janne Paananen
Technology Manager, Critical Power Solutions, Eaton
Martijn Imming
Business Development Manager Data Centers, Eaton

Executive summary

In today's 24/7, 'Always On' business environment, reliability and resilience are always the top priorities for mission-critical facilities. However, these objectives can be threatened by practical aspects of daily use and operation in such facilities. Accordingly, Eaton has prepared a set of three White Papers which together provide a complete insight into data center power distribution systems; they draw on the Company's proven experience in these areas, offering design guidance and practical tips that may not be available in textbooks, yet can significantly improve system reliability, power availability and uptime.

Data center power distribution (PD) systems in their entirety extend from the available power sources – typically incoming transformer, generator and Uninterruptible Power Supply (UPS) - out through the switchgear and circuit breakers to the supported ICT, cooling and associated loads.

It is essential to appreciate issues not only related to each item of power equipment, but also to show how these items interact with one another. This needs special attention as the nature of these interactions can vary as the data center load changes.

These interactions can cause issues that are not allowed for when considering either PD or UPS systems alone. These issues create risks for safety and reliability.

Safety issues, particularly arc flash mitigation but also 3/4 pole switching, earthing and backfeed considerations, can be as critical to facility uptime as power system resilience, so these are also covered. Additionally, problems arising from poor maintenance as well as operation or design are included. What could happen if the wrong equipment is used, or insufficient attention is given to potential dangers? Diagnostics and communications techniques are discussed, as are applicable norms, as these provide guidelines for good design as well as setting out legal requirements.

The first two papers covered power distribution and UPSs respectively, while this paper focuses on aspects of the complete power distribution and UPS installation. Overall, the three papers provide knowledge to improve reliability and safety, while preventing unnecessary outages.

Staying up to date in a dynamic environment

Most critical application managers find themselves continuously engaged in optimally balancing reliability against investment. There are also frequent changes in focus as new topics arise; examples include earthquake resilience, environmental sulfur pollution, EMI, heat dissipation, switching responsibility and persons involved. New Application Notes will be available from Eaton to address these topics and others as they appear.

EATON
Powering Business Worldwide

Contents

Different power source behavior and effect on the power distribution 3
- Overcurrent protection 3
- Protection coordination and selectivity 3
- Prospective fault current 3
- Transformer short-circuit current 3
- Generator short-circuit current 4

Impact of UPS in power system 4
- UPS basic operation 4
- UPS reaction to a short-circuit in downstream distribution 4
- Inverter feeding a short-circuit 4
- Single and three phase faults and impact of a transformer 7
- Clearing a fault with a UPS static bypass 7
- Protecting static bypass semiconductors 8
- Selectivity with downstream protection 8
- Load Distribution Breakers 8
- Scalability and modular UPS designs 9
- I^2t – behind the figures 10
- Pre-arcing (melting) I^2t 10
- Total clearing (let-thru) I^2t 10
- I^2t values of different fuse types 10

Conclusions 11

Different power source behavior and effect on the power distribution

This chapter describes the factors that must be taken into account when designing a power distribution system that uses multiple power sources such as a transformer, generator and especially a UPS, either in bypass or inverter mode. Their behaviors need to be recognized and accommodated throughout the entire power supply system's protection strategy.

Failure to consider the different behaviors of these power sources can cause unexpected load losses. For example, voltage dips, caused by short circuits or other events, with a duration exceeding the load's tolerance, could also cause unwanted load losses due to slow-acting protection. A holistic power supply system's protection strategy is required.

Overcurrent protection

A power distribution system in general should be designed around the system-voltage and system-current. When looking at system currents there are three situations to be considered:

- Nominal current;
- Overcurrent;
- Short-circuit current.

Nominal current is the current that can flow through the system throughout its live time. The whole system is dimensioned around the nominal current value.

Overcurrent refers to a current slightly above the nominal current value; enough to push the system over its thermal limit and cause overheating and possible fire hazard as well as deterioration of component parts.

A short circuit occurs when conductors make direct contact (a short-circuit) and cause a maximum possible current to be drawn from the source feeding the system. Excessive duration of over-current and short-circuit are conditions that must be prevented by means of protection in the system.

Protection coordination and selectivity

Protection in the low voltage system can be achieved with built-in protection relays on the breakers, or with fuses. These protections must be chosen and set correctly to ensure selectivity with other protective devices. For this purpose, various data is published for the protective devices by the suppliers.

Most commonly this data is a time-current-, pre-arcing- or tripping-curve indicating the correlation of time and current and operation time of protective device with various current levels. Other typically published data is the pre-arcing, or melting, energy values for a fuse element indicating required energy to start the melting of the fuse element, and also total clearing, or let-thru, energy values indicating the total amount energy passed through the fuse element.

The pre-arcing and total clearing energy values are often referred as I^2t values, using A^2s as a unit. Most typically these can be found in fuse data sheets inside tables listing the "nominal values" for various current ratings of a same fuse.

When the fuses are same type and designed according same standard, such as *IEC 60269-1 Low voltage fuses – Part 1: General requirements*, those should have similar characteristics and are intercomparable. In this case using I^2t datasheet values to compare protective devices with each other for coordination purposes, as sometimes a practice is, can be a useful approach. Having ratio 1,6:1 or more between fuse pre-arcing I^2t values typically results in selectivity.

It must be recognized that the nominal values in datasheets are declared with a specific fault current level, or operation time, and circuit conditions, and are not comparable between different fuses having different time-current characteristics. This is especially valid looking at general purpose fuses, like; gG/gL, and other types like aM, aR and gR. These other types of fuses are used to protect against specific problems in electrical distribution or equipment, and are designed to have different and specific time-current characteristics.

Coordination of different types of devices must be done at the explicit estimated fault current level occurring in the installation in case of a fault. The time-current curves of various devices can help to do this and allow comparison of device clearing or tripping times at various current levels for various fault cases.

With current limiting, by very fast tripping times or current limiting fuses, the total let-thru energy of downstream protective device, at given fault current level and system voltage, may be compared against the pre-arcing values of upstream protection at same current level or time. This can further help to estimate if upstream fuses are in risk to clear or deteriorate.

Prospective fault current

During a short circuit situation, the power feeders will be feeding a maximum current into the short-circuit. This current is not infinite, due to the internal impedance of the sources and conductors. Power supplies in a mission-critical facility power chain consist of a power transformer, a backup generator and a UPS. Each of these sources have their own characteristics and provide different short circuit currents. Although transformer and generator supplies might have the same nominal rating, their short circuit values differ enormously as shown below.

Transformer short-circuit current

Power transformers are standardized within IEC regions; the international standard *IEC 60076-1:2011 Power transformers - Part 1: General* suggests preferred values based on the R10 series: 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100, and multiples of 10n. For example, the preferred transformer sizes from 500kVA to 4000kVA are: 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000 kVA, however special transformers are available on request.

These standard transformers have the following average values related to their nominal power. The list in Table 1 below indicates ratings at a secondary full load voltage of 400 VAC 50 Hz.

Nominal power of the transformer. (4% and 6%) **S [kVA]**	Nominal current on secondary side **In [A]**	Maximum short circuit current **Ik [kA]**	Nominal current on primary side, 10 kV **In [A]**	Nominal current on primary side, 20 kV **In [A]**
100	145	4	6	3
160	231	6	9	5
250	361	9	14	7
315	455	11	18	9
400	578	14	23	12
500	723	18	29	14
630	910	15	36	18
800	1156	19	46	23
1000	1445	24	58	29
1250	1806	30	72	36
1600	2312	39	92	46
2000	2890	48	116	58
2500	3613	60	145	72
3150	4552	76	182	91
4000	5780	96	231	116

Table 1. Power transformers – nominal currents and short-circuit current

Generator short-circuit current

While transformers are standardized by IEC recommendations, diesel emergency generators have many more parameters, often optimized for the diesel engine driving them. Diesel emergency generators have average values as shown in Table 2 below, related to their nominal power rating at a secondary full load voltage of 400 VAC, 50 Hz. The maximum available short circuit current in the generator will be 10 x I_n for the first 100 ms; this then collapses to about nominal current. This calculation has been simplified by only looking at sub-transient reactance, not at the possible addition of the DC component for the first few cycles.

Nominal power **S [kVA]**	Nominal current **In [A]**	Maximum short circuit current **Ik [kA] (100ms)**
630	910	9,1
800	1156	11,6
1000	1445	14,5
1250	1806	18,1
1600	2312	23,1
2000	2890	28,9
2500	3613	36,1
3150	4552	45,5
4000	5780	57,8

Table 2. Example short circuit currents from low voltage emergency (back-up) generators

Impact of UPS in power system

When a UPS is used in a power distribution system, two additional fault current paths and a new source is introduced, with their own behavior that need to be considered in the protection design of a mission critical system.

The behavior and capabilities of the UPS under a short circuit differs from other power distribution components and neglecting the UPS in a selectivity study can turn a fault in any load branch into a SPoF (single-point-of-failure), resulting unnecessary load loss or outage of operation for extended period.

UPS basic operation

UPS units can operate in normal, stored energy or bypass mode. Path of energy through a UPS into load in normal mode depends on UPS topology. In a double conversion topology, the inverter is feeding the load in normal mode, and UPS draws power form mains supply with a rectifier to support the load. With newer so called multimode UPS units, the UPS can also operate in energy saving mode and support the load through static bypass, when conditions allow, to reduce losses and save energy.

In stored energy mode that is more typically called battery mode, as name suggests, the inverter draws power from local energy storage, typically a battery, and feeds the load. UPS operates in this mode when the mains supply is not available for use.

In bypass mode the load is fed through the UPS's static bypass switch. Typically UPS static bypass is used under fault conditions, when for a reason or another the inverter(s) is not capable to produce or maintain proper voltage at system output, or doesn't have sufficient capacity to support the load due to overload condition or reduction in inverter capacity.

The UPS's main function is to provide clean energy and uninterrupted power to the load. Whenever the inverter cannot provide clean energy and proper voltage levels, the UPS will transfer the load to the static bypass feed, if available.

UPS reaction to a short-circuit in downstream distribution

In the case of a short circuit on the UPS output side, the load impedance goes to practically zero. Under these circumstances the UPS output voltage collapses, since the inverter cannot provide infinite current to maintain a proper voltage at system output. Trying to secure continuous power for the load, the UPS will transfer immediately to static bypass if available. This functionality, or a transfer sequence, is sometimes referred as "emergency transfer to bypass".

The reason for this behavior is to "assume worst", and to maximize the fault clearing energy to clear a fault in UPS system output as quickly as possible, thus minimizing the impact for the load or other loads branches. The bypass feed can provide considerably more current to clear a fault, compared to an inverter current limit. Once the fault is cleared, transfer back to normal mode happens automatically. In the bypass mode the fault current is limited by line impedance and UPS static switch capabilities only.

The exact behavior and transfer times are UPS vendor and model specific, differences do exist. Some UPS vendors may prefer, by default, to "wish for the best" and use inverter as a primary choice to clear a fault. If eventually the inverter cannot clear a fault and restore normal voltage to output, the UPS will transfer to bypass after a few hundred milliseconds. This, anyhow, may have caused too long interruption in system output voltage, already impacting the loads.

For the purpose of selectivity, understanding the UPS system behavior under a downstream short-circuit condition is important. Therefore this shall be verified from the UPS supplier.

Whenever the UPS bypass feed is not available, and fault occurs at UPS system output, UPS will use inverter(s) to clear the fault. In this case inverters will feed as much current as they can, limited by their current limit, until the fault has cleared and system voltage restored. If the inverter cannot clear the fault, it will shut down after a timer has expired. In this case UPS system is turned off and power to the load is interrupted.

The value of inverter current limit, and duration, varies by UPS models and vendors, and shall be verified from UPS supplier or published data.

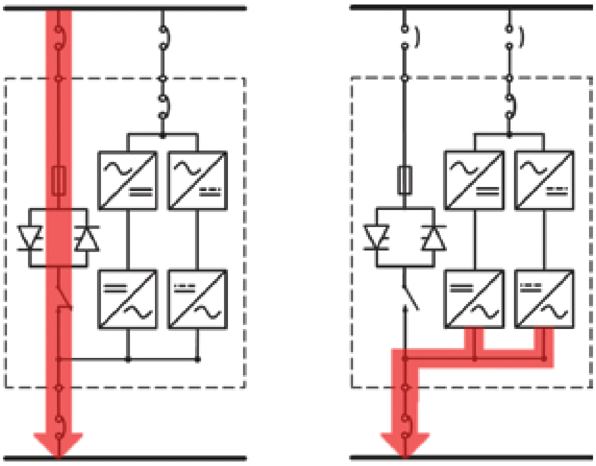


Figure 1. UPS behavior under downstream short-circuit condition with mains available (left) and without mains (right).

Inverter feeding a short-circuit

A UPS inverter has current limiting function to protect its own semiconductor components from too high current to prevent damaging the components. Both, the amplitude of current, and duration of current are limited. When an inverter feed a fault with a current limit, it is acting as a current source.

While an inverter supports the load, it will drive as much current as required, to maintain the proper voltage level at the UPS output. The amount of current required is defined by load impedance. If the load impedance is too low, a current limit is activated. For instance due to excessive overload or a short-circuit, this could cause a required current to exceed designed safe level for inverter. As a result, current is limited to maximum defined value and UPS can no longer provide regulated sinusoidal voltage in the output.

The current waveform during current limiting situation is typically close to a square wave. The r.m.s. value of the current is typically from 2 to 3 times of hardware nominal current. Maximum amplitude and time the inverter feeds a short-circuit varies by vendors and UPS models. UPS product standard limits the duration to maximum 5 seconds, but this may exceed requirements coming from local regulations for low-voltage electrical installations. Eaton UPS units feed the short-circuit current by inverter for 300 or 400 milliseconds. This is in line with requirement for automatic disconnection of supply for circuits equal or below 32 A as defined in IEC 60364-4-41.

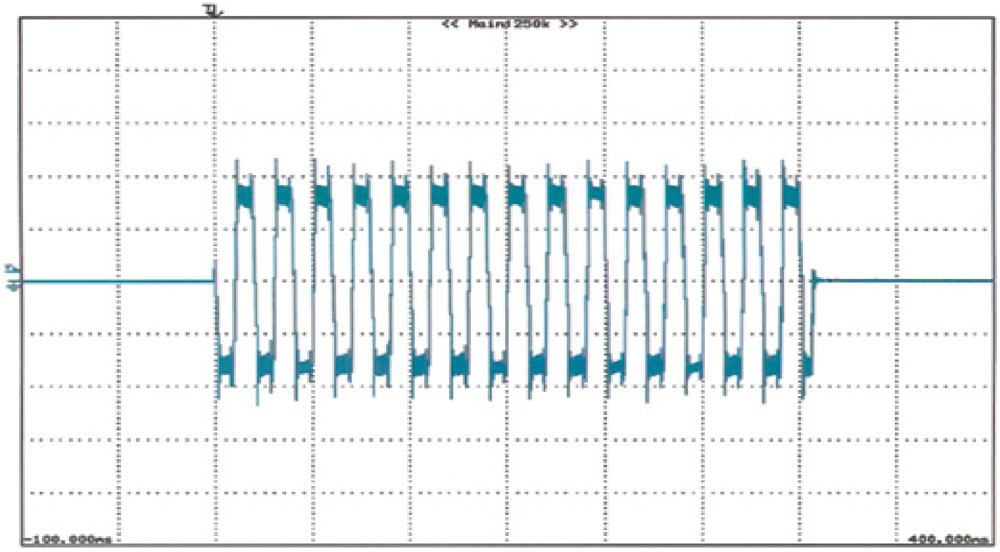


Figure 2. Measured short-circuit current waveform from Eaton UPS.

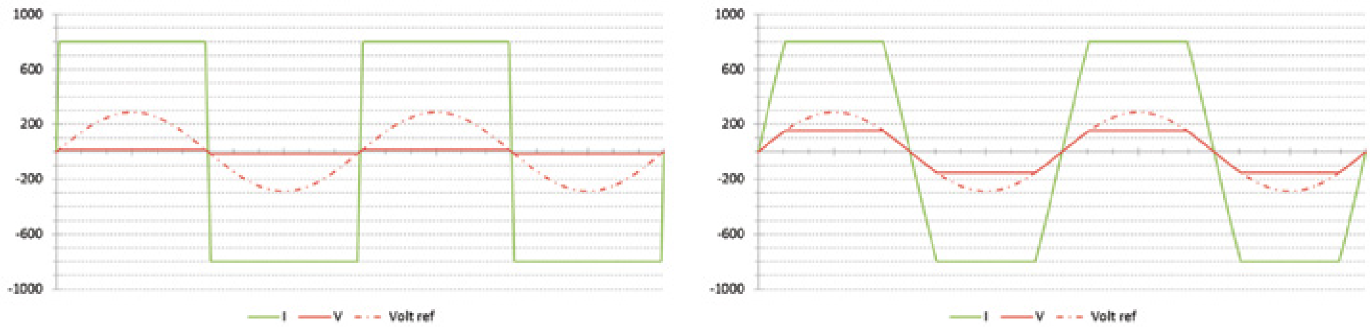


Figure 3. Theoretical inverter short-circuit current and voltage produced at UPS output. Green line is inverter current, solid red is output voltage and dotted red line is inverter voltage reference. Short-circuit current is limited to 800 A and fault impedance on left is 19 mΩ and 190 mΩ on the right.

Once the fault is cleared, the voltage in system output and power for the load will be restored. If the protective device cannot be cleared with short-circuit current available from inverter, UPS will shut down once the timer has expired. The supply to a fault is disconnected by a UPS and requirement for automatic disconnection of supply is fulfilled.

The impedance of a fault doesn't typically impact the amount of short-circuit current fed by a UPS inverter. Inverter will feed all the current it can to produce the reference voltage at system output. As long as inverter cannot provide normal voltage in output, by feeding the current, it will limit the current to a defined value. With typical fault impedances, short-circuit current from UPS inverter is approximately same regardless of length of cables in distribution etc.

In case of long fault circuits and high impedances, higher voltage is created at UPS end. As a result the short-circuit current edges are getting sloped and r.m.s value of the current is slightly reduced while limited peak current remains at same level.

When the fault circuit impedance is high enough for a UPS to produce normal sinusoidal voltage, and the peak current fed through circuit impedance creates voltage equal to the peak value of UPS voltage reference, the current doesn't actually reach the inverter current limit and is also sinusoidal, having r.m.s. value 71% of fault current peak value. From a UPS point of view, this is no-longer a short-circuit condition, but a considered to be a high overload.

If the resulted fault current peak value drawn by the fault is limited to lower than maximum value of a UPS, this is due to circuit impedance of a fault, not because of UPS capabilities.

With traditional power distribution components, such as a transformer, the internal short-circuit impedance is added together with distribution side impedances and total resulting circuit impedance defines the fault current in the circuit. Therefore increasing the size of a transformer, thus lowering the source impedance, will reduce overall fault circuit impedance and increase the fault current.

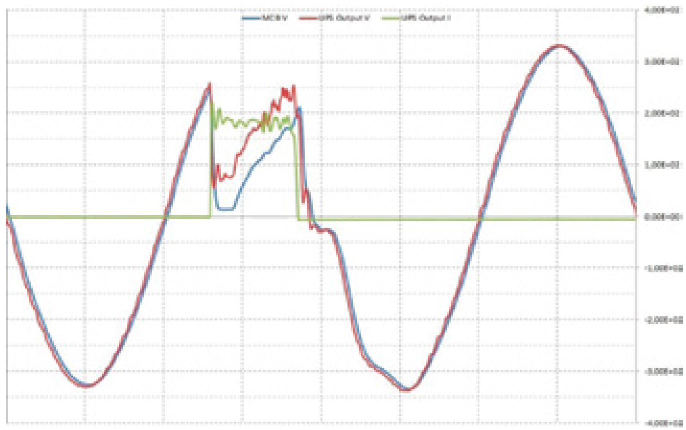


Figure 4. Measurements of a MCB during a short-circuit, fed by a 50 kW UPS through 50 m long cable. Green line is current, red is voltage in UPS terminals and blue is voltage across MCB.

This approach doesn't anyhow apply with an UPS, that is a controlled voltage source and acting as a current source during a short-circuit condition.

A UPS will produce and regulate sinusoidal voltage in its output, and feed the required amount of current to do it, thus limiting the peak value of the current to protect internal components. When the fault current is limited by a circuit impedance and doesn't reach the current limit value of the inverter, resulting short-circuit current is below the maximum inverter fault current capacity. Therefore adding more inverter fault current capacity doesn't result any higher fault current, since the voltage feeding the fault and the circuit impedance, thus fault current, would remain the same even when more inverters would be added.

If the resulting fault current through the circuit is too low to trip the protective device, or it doesn't trip it fast enough, the fault circuit impedance shall be reduced. This can be done by shortening the distances for fault current and length of cables or by increasing the cross section of conductors.

To estimate if enough fault current is available to trip a protective device in specific load branch, following question shall be answered:

- How much current, and how long is needed to trip load branch protective device?
- Does UPS inverter have high enough short-circuit current to deliver this?
- Does the circuit impedance allow such a current to be fed from inverter with nominal voltage?

Example: Load has 7 circuits per phase, and each is fed by a 10 A C-curve miniature circuit breaker. Estimated load is maximum 80 % and power factor varies from 0,7 to 0,95. Instantaneous tripping is wanted for fast disconnection of a fault and to minimize voltage interruption for healthy load circuits:

- Design load:
  $I_{Load} = 7 \times 0,80 \times 10$ A = 56 A,
  $S_{Load} = 3 \times 0,231$ kV $\times$ 56 A = 38,8 kVA,
  $P_{Load\ max} =$ 38,8 kVA $\times$ 0,95 = 36,9 kW
- Defined magnetic release for a C-curve device is:
  $5 - 10 \times I_n$
  and short-circuit current requirement $I_{K\ min}$ min is therefore:
  $I_{K\ min} = 10 \times 10$ A = 100 A
  and peak value of required fault current is:
  $I_{K\ pk} = \sqrt{2} \times 100$ A = 141 A
- Select a UPS with high enough capacity and short-circuit current;
  ≥ 39 kVA, ≥ 37 kW and >141 A
- Maximum fault circuit impedance is:

$$Z_{K\ max} \approx \frac{V_{ref\text{-}pk}}{I_{ref\text{-}pk}} \approx \frac{\sqrt{2} \times 231\ \text{V}}{141\ \text{A}} = 2,31\ \Omega$$

In previous example the inverter current limit was chosen according the peak value of required sinusoidal fault current to guarantee fast operation of MCB. This can be the case with circuit breakers when a magnetic release, an instantaneous trip. For thermal tripping evaluation, the r.m.s. value of the inverter short-circuit current is to be used.

Short-circuit current fed by a UPS inverter is rather low, 2 to 3 times UPS nominal current. The theoretical value for fault circuit impedance, that would reduce current even lower, is therefore rather high, and would also create considerable voltage drop in the cable by the load in the circuit.

In case of long load distribution branches, the conductor sizes may need to be increased to reduce voltage drop, and to achieve necessary fault current levels for the protective devices to operate within the required time. Oversizing the cables, however, doesn't mean that rating of protective device must be higher as well. These can be selected and set according actual load rather than being maximized for selected conductor size. This would require a reconsidering of the tripping time and could lead to even bigger conductor size requirements.

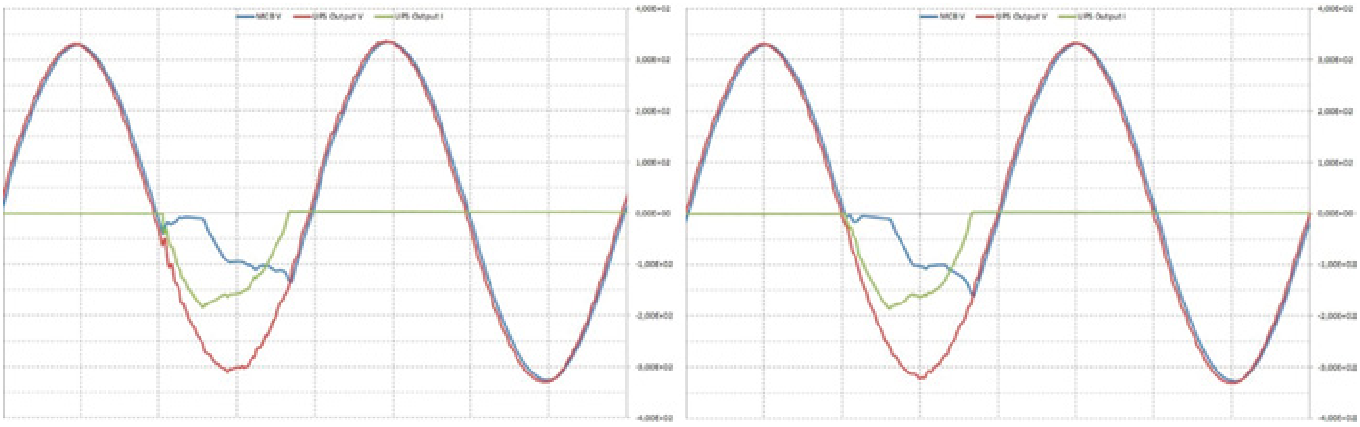


Figure 5. Measured tripping current of MCB through a high impedance. Test on the left is done with a 50 kW UPS, test on the right with a 100 kW UPS. Increase of inverter capacity doesn't impact fault current when limited by a circuit impedance. Green line is current, red is voltage in UPS terminals and blue is voltage across MCB.

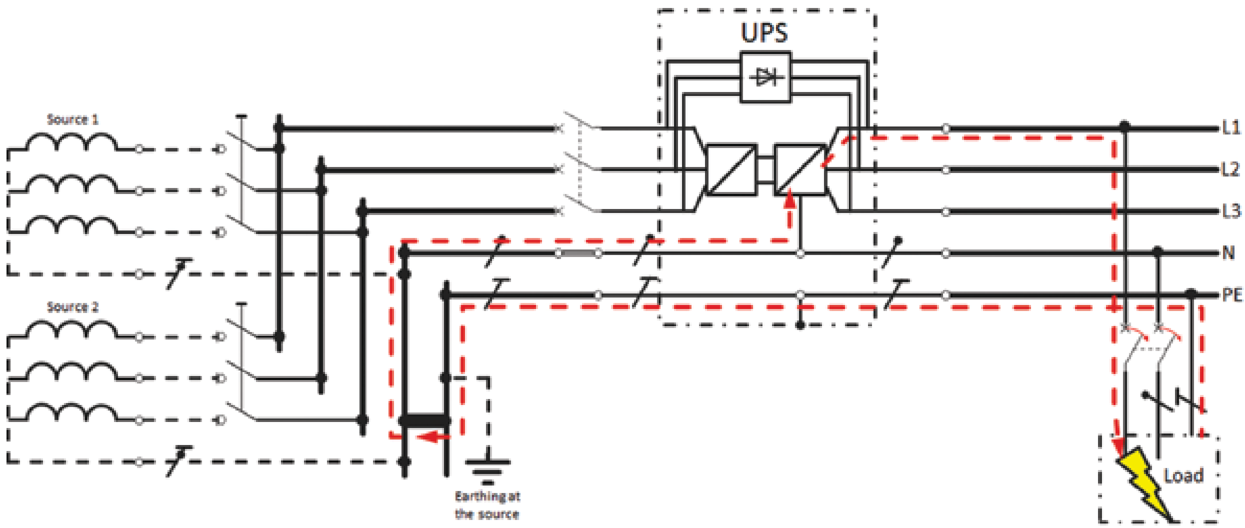


Figure 6. Path of an earth fault current when fed by a UPS inverter in stored energy mode.

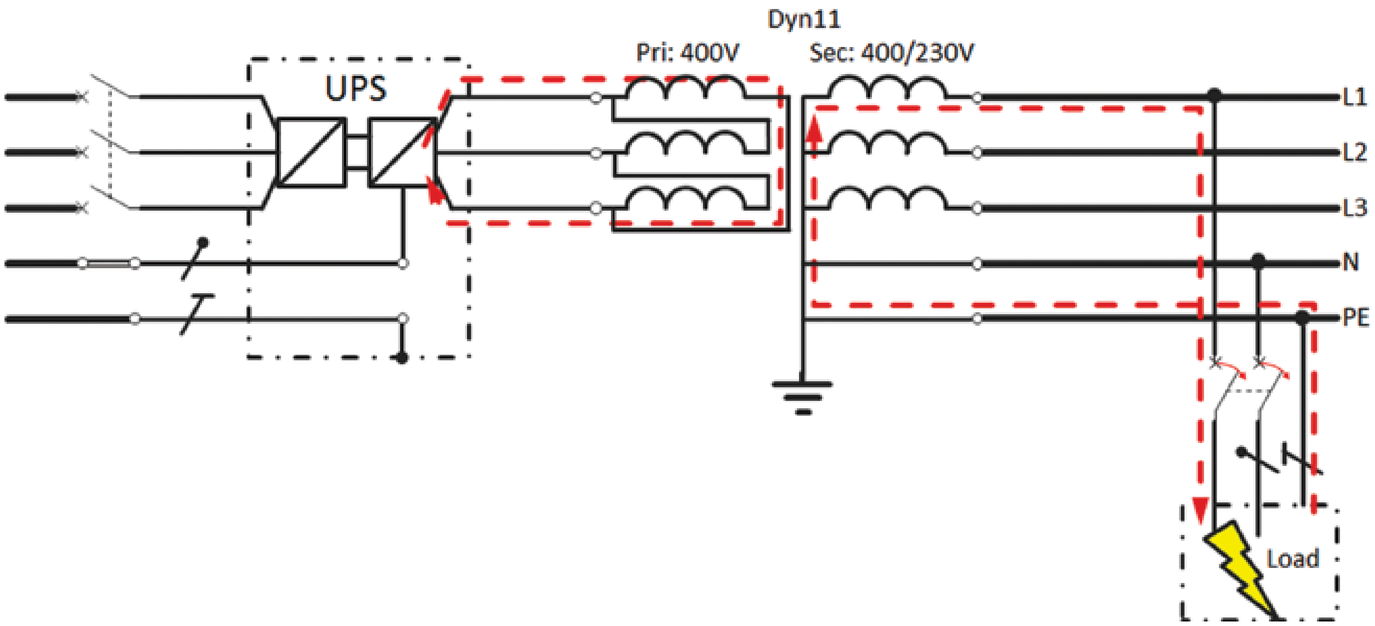


Figure 7. Short circuit current on primary and secondary side of UPS system output side distribution transformer. Secondary side single phase fault is creating phase-to-phase current on primary side with a delta-star connection.

Single and three phase faults and impact of a transformer

A modern UPS that doesn't have a transformer in its inverter output typically feeds about the same amount of short-circuit current for a single phase, three phase or two phase fault.

If the UPS has an output transformer, then the short-circuit current at secondary side of transformer also depends on transformer winding ratios, vector group and naturally on inverter short-circuit current.

- The winding ratio is: $\frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{400\ V}{231\ V} = 1{,}73$
- The current ratio is: $\frac{I_2}{I_1} = \frac{N_1}{N_2} = 1{,}73$ and
- The secondary current is: $I_2 = \frac{N_1}{N_2} \times I_2 = 1{,}73 \times 100\ A = 173\ A$

Above is a rather simple case, but also quite typical case in 400 V environment. Delta-star, or delta-wye, connection group is very commonly used. With more complex connection groups things can get a bit trickier to calculate, but the principle is always same: The inverter acts as a current source and the current ratio between downstream transformer primary and secondary depends on winding ratio and connection group.

Clearing a fault with a UPS static bypass

Whenever the static bypass is available for use, the UPS will transfer to bypass to clear a downstream fault if the fault has such a magnitude that it will cause the UPS output voltage to collapse and initiate an emergency transfer to bypass.

The common data sheet figure for a UPS static bypass maximum current is ~10 x I_n for one cycle. This is considerably more than the 2 to 3 times nominal current available from inverter. Therefore it can be beneficial to use the static bypass, whenever available, to clear downstream faults to achieve fastest possible disconnection times for protective devices.

The exact capabilities of a static bypass often exceed the typical 10 x I_n figure declared in the UPS data sheets. The exact maximum current that can be fed through the bypass circuit depends on used components, mainly semiconductors and fuses if any. For detailed analysis and fault coordination purposes, it is recommended to consult UPS supplier to get detailed information about used components and true product capabilities.

Large three phase UPS's are often connected to supplies with tens of kiloamperes of prospective fault current available. For a power semiconductor devices, such as used in a UPS static bypass switch, managing these current levels is extremely challenging if not impossible. If too much current flows through the thyristor, and its maximum capabilities are exceeded, a catastrophic failure can occur, resulting in arcing and other undesired consequences inside a UPS unit. These can impose a high risk for equipment, installation and personnel if in near vicinity. Therefore adequate protection against those conditions shall be in place or maximum fault current levels shall not exceed specified values for semiconductors.

Specific requirements are given in UPS product safety standard to ensure safety of product during such events. These requirements are detailed in *IEC 62040:1-2008 Amendment1:2013* that became mandatory to follow in February 2016. Every UPS supplier shall declare the maximum allowed prospective fault current level in UPS bypass input terminals, practically defining the maximum short-circuit current level of the installation where a product can be used. See a separate white paper about Amendment1: 2013 for further details.

In parallel UPS system with multiple static switches, also the switching time and simultaneous turn-on of static switches has importance with high fault current levels. If one or some the static switches turn-on faster, they will carry all the fault current in beginning that could clear the protective devices, creating and event of cascading failures when system transfers to bypass with a downstream fault.

By using a distributed control architecture and not relying on communication to initiate an emergency transfer to bypass, the simultaneous operation of static switches can be better guaranteed. In this method, each UPS monitors the critical output voltage independently. If output voltage suddenly goes out of limits, a UPS will initiate an emergency transfer to bypass based on voltage signal and turn on the static bypass switch. Same time it will send a command for other UPS's to transfer to bypass as well, but other units have made same conclusion by themselves based on common output voltage that they all monitor. This method to initiate the transfer will eliminate the delays of communication lines in case of time critical events.

When the system output voltage is within normal limits, and a normal transfer sequence to bypass is initiated through communications, due to overload or a user command, there's no excessive overcurrents in the system and minor delays between turn-on of static switches are not critical.

Protecting static bypass semiconductors

The power semiconductors used in a UPS static bypass circuit are commonly thyristors, also known as silicon controlled rectifiers (SCR). These devices have limited capability to feed current, since losses occur as function of current, internal resistance and on-state voltage. These losses heat up the semiconductor and must be conducted away from the device. In case of extreme current levels, the heating occurs very fast and cannot be managed properly resulting a device failure. Commonly three values are used to specify the surge current capability of a thyristor.

- I^2t , amount of maximum pass through energy for a sub-cycle transient, < 8,33 … 10 ms, to be used for a selection of a protective fuses
- I_{TSM} , maximum peak value of one half cycle sinusoidal surge current (8,33 … 10 ms)
- $I_{T(OV)}$, a curve or table defining surge overload on-state current vs time

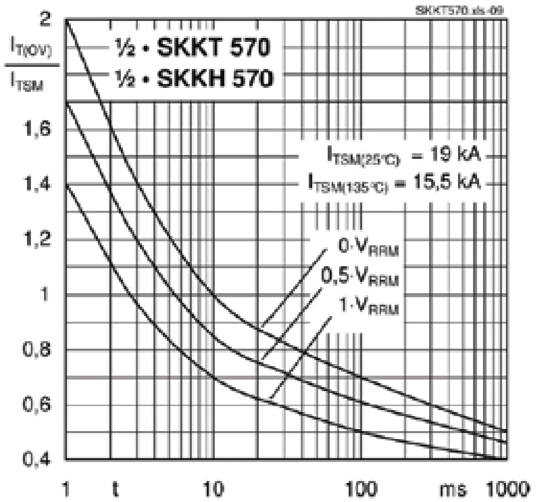


Figure 8. Semikron thyristor-module $I_{T(OV)}$ characteristics.

If short-circuit protective devices are used to protect the UPS bypass circuit and thyristors against excessive overcurrents, these shall be selected by a UPS supplier and is their responsibility. If these devices are not within a UPS unit itself, the UPS supplier must specify the devices, that are allowed to be used in the installation to comply with requirements of IEC 62040-1:2008 Amendment1:2013.

The protection shall limit the let-thru energy of sub-cycle transients below the thyristor I^2t value and have a tripping or clearing curve below semiconductor surge overload current curve. This is to ensure that conditions like downstream short-circuits or inrush current for large transformers do not cause damage for the semiconductors. If the UPS product capabilities are exceeded, the current is then interrupted in safe and controlled manner by protective devices, that are designed to fail safely.

Purpose of the protective devices in this context is not thermal protection of bypass circuit, this is achieved with UPS bypass feeder in the input switchgear. In case of external short-circuit protective devices, sometimes short-circuit and thermal protection is achieved with same device.

Selectivity with downstream protection

The short-circuit protective devices used to protect the UPS static bypass, in context of IEC 62040-1:2008 Amendment1:2013, are not to protect the electrical installation. Those are to protect only the UPS unit. Especially when internal devices within a UPS unit are used. Therefore those do not need to be considered as part of electrical installation, and coordinated with other protective devices in electrical system.

In case of a short-circuit downstream a UPS, it is preferable for a UPS bypass feeder to trip before UPS internal fuses clear. This way the system can be restored to normal condition faster since no part replacement is required in a UPS. But it is also preferred in same situation, that a single load branch circuit protection acts faster than UPS internal fuses, and the impact of a fault is limited to only one load branch, instead of clearing static bypass fuses and losing power to all load branches.

A fault coordination with UPS internal protective devices is done to achieve reliable power distribution for critical loads and the exact requirements are driven by an application where UPS is used. But the primary purpose of UPS internal devices is to protect the UPS and the protection of electrical installation is done with the protective elements in electrical distribution.

If a short-circuit would occur in main busbar of UPS output switchgear, then surely all the loads are impacted anyhow, and clearing UPS internal fuses may not be the biggest concern after the event and therefore could be considered to be acceptable. One has to define and choose the point in downstream distribution where selectivity is required with UPS internal devices. To achieve wanted level of reliability in a specific application. This can have a big impact on required fault current level and duration the UPS static bypass needs to manage, and a high impact on system cost.

Load Distribution Breakers

Load distribution breakers are used to deliver power to the load and to protect the load circuit against over- and short-circuit currents. Often downstream a UPS one can find a main load breaker and multiple branches for load distribution, each protected by its own breaker. With larger UPS units and systems, UPS output switchgear typically has multiple load breakers feeding overhead busbars, local distribution boards or PDUs with smaller circuit breakers. Any short circuit or overload related problem should be contained within the affected branches and not influence others. This can be achieved by using protections on the outgoing branches that are selective with the upstream protective devices.

The required tripping time of a load branch circuit breaker, or a fuse, depends on application and the impact of voltage disturbances to other loads. The general requirements for automatic disconnection of a supply may not be fast enough from application point of view in mission critical systems or with sensitive loads.

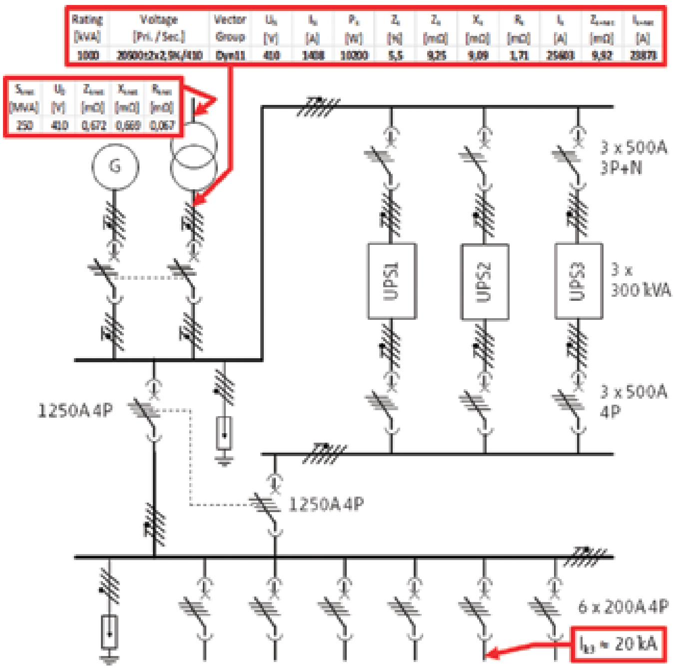


Figure 9. Example of power distribution with a centralized UPS system and load distribution from UPS output switchgear.

To estimate the selectivity between load distribution breakers and UPS system static bypass, some basic questions need to be answered:

- What is the estimated fault current in a load branch (point for coordination)?
- How long does it take to trip or clear a load branch protective device?
- Can UPS system feed the current long enough to be selective?

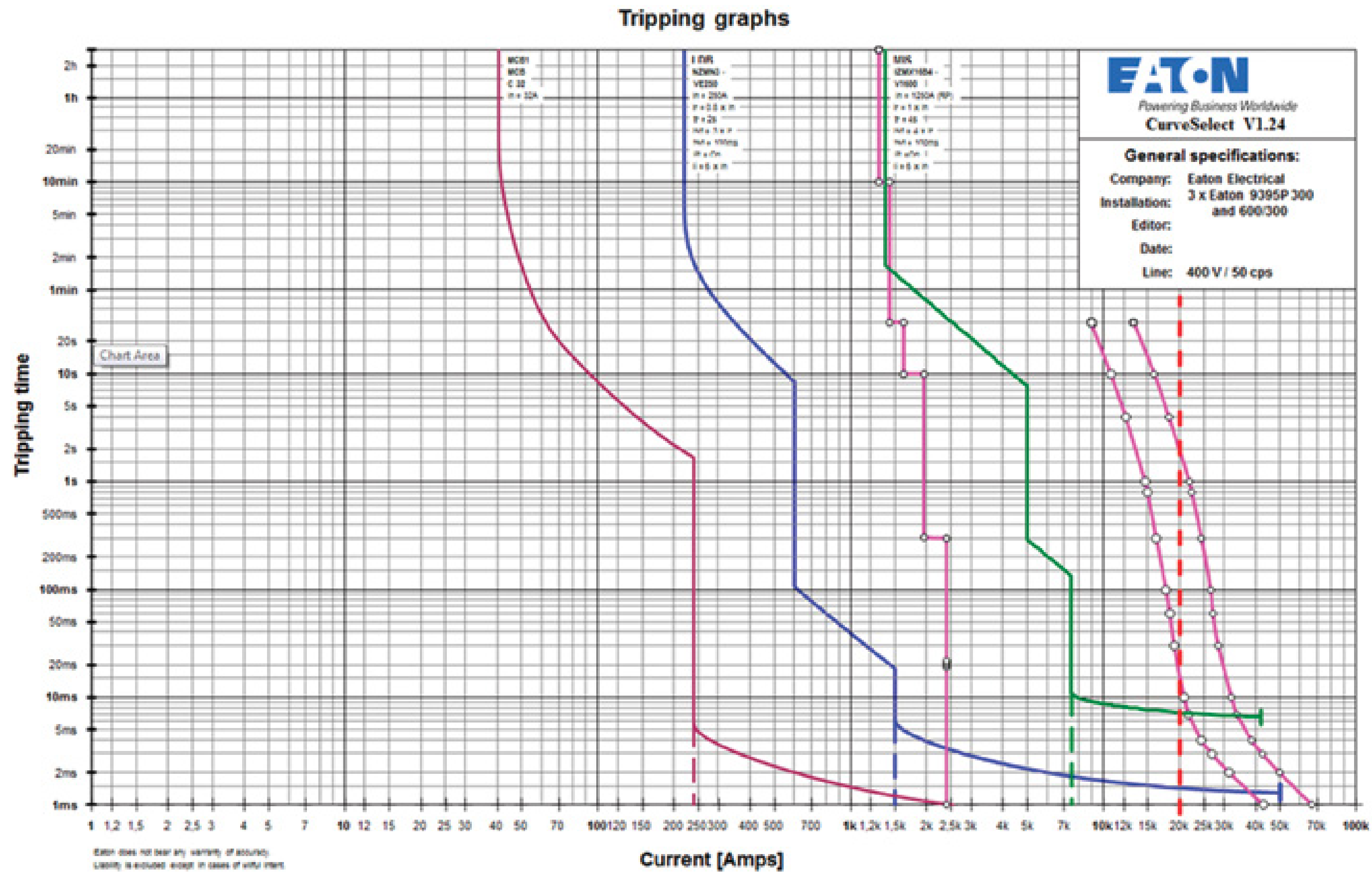


Figure 10. Example of time-current curves in a distribution with a UPS system. From left to right; 32 A C-curve MCB (red), 200 A MCCB (blue), UPS system inverter time-current curve (1st cyan), 1250 A ACB (green), 3 x 300 kVA static bypass time-current curve (2nd cyan) and 3 x 600 kVA static bypass time-current curve (3rd cyan). Dotted red line represents estimated fault current in a load branch.

For this, basic understanding needs to exist on prospective fault current in the installation, and used components in electrical distribution. The prospective fault current at low-voltage system input depends on supply transformer and also on the medium voltage network. Often common practice figures are used for the medium voltage side when actual figures are not know. Also if the site is equipped with a back-up generator, fault currents shall be estimated with it as well. When transformer and low-voltage generator are used in parallel, the fault current levels can increase considerably.

To estimate a fault current level in a load branch, distribution components in the fault current path shall be taken into account as closely as possible. Every cable, busbar, breaker, UPS and other equipment have a reducing impact to actual fault current in a load branch due to added impedance of fault current circuit.

The estimated fault current in a load branch, or other point of installation under consideration, is then compared to time-current curves of protective devices of that specific circuit. The tripping time gives the duration for the fault current that UPS system static bypass must be able to feed to be selective.

With below example of time-current curves relating to power distribution one-line drawing in Figure 10, the UPS system inverters can easily trip a 32 A miniature circuit breaker protecting individual loads. Inverters can also trip instantly the common 200 A molded case circuit breaker feeding a group of loads.

By comparing the dotted red line, that is the estimated fault current in a load branch, with second cyan line, that is the system level time-current curve for 3 x 300 kVA UPS, one can see that pre-arcing of UPS system bypass fuses may be faster than preferred with a worst case short-circuit. 3rd cyan line is also system level time-current curve for 3 x 300 kVA UPS, but this system has 600 kVA static switches instead. Using UPS units with a bigger static bypass allows to feed more fault current as can be seen from graphs, and pre-arcing takes much longer than downstream protective devices to trip, thus selectivity is achieved even in worst case “bolted short-circuit” conditions.

Scalability and modular UPS designs

Many modular UPS products in the market have one static bypass switch in each power module, making the bypass and inverter capacity tied. If more bypass capacity is needed, also more inverter capacity needs to be added.

On the other hand, some of the UPS products in the market have a separate static bypass in a UPS frame, that is common for all power modules within a UPS. This way the static bypass is rated for maximum load of a UPS frame, and inverter capacity can be chose according actual load. This allows to better match the UPS with installation, since the bypass circuit sizing can be matched for fault current requirements, and inverter capacity to match load demand. When inverter and bypass capacity can be mixed and matched with actual needs, not only on thermal rating, but also for fault scenarios. This can bring great benefits on designing selective and reliable power distribution with a UPS system, even if the load and power distribution grow gradually.

With scalable systems, where some of the UPS capacity is installed on day one and remaining as the load grows, the challenges for selectivity are obvious. Typically the main transformer is chosen and installed according final design load, even the day one load and UPS capacity will be less. Since the transformer, a source, is full sized, also the fault current levels in installation are according full design configuration. The UPS system shall be selective with downstream distribution also on day one and therefore having reduced bypass capacity, and reduced fault current feeding capabilities, can be troublesome from selectivity point of view.

One way to tackle this is to use a larger centralized bypass for all UPS units, that will carry all the fault current and is sized according final load. Another possibility is to use a UPS design that allows to size the bypass line independently from inverter capacity, and to match the bypass design with fault current requirements. This allows to match the bypass and inverter capacity with day one requirements and to easier achieve to have a scalable and selective design with a distributed bypass configuration and without unnecessary extra costs.

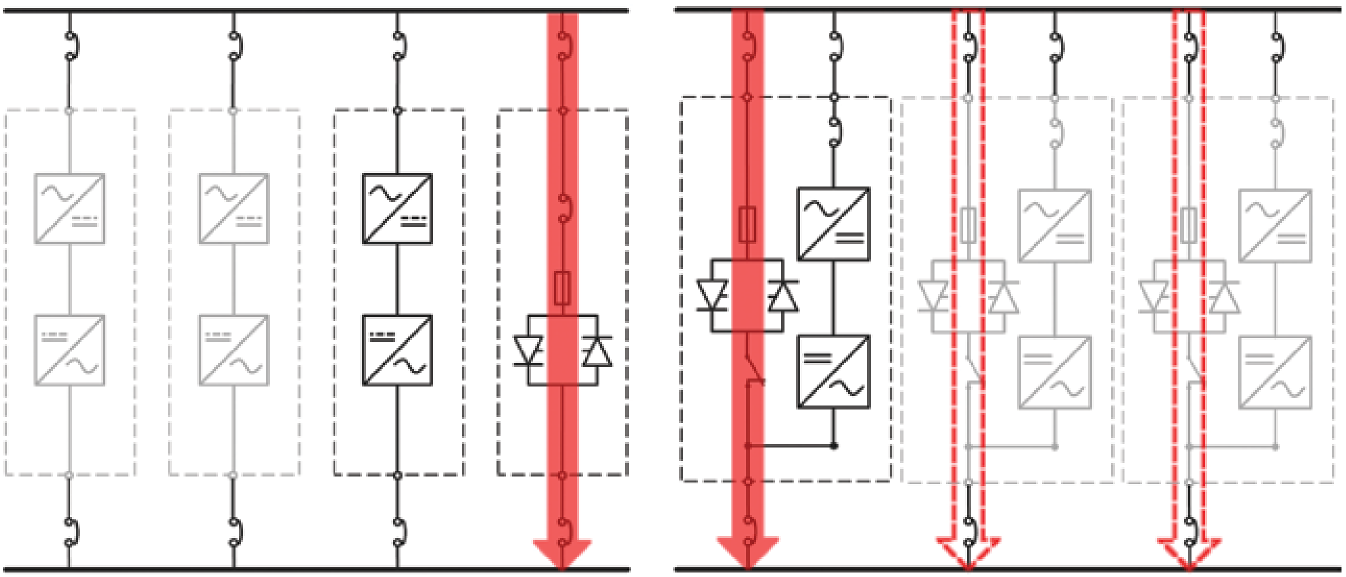
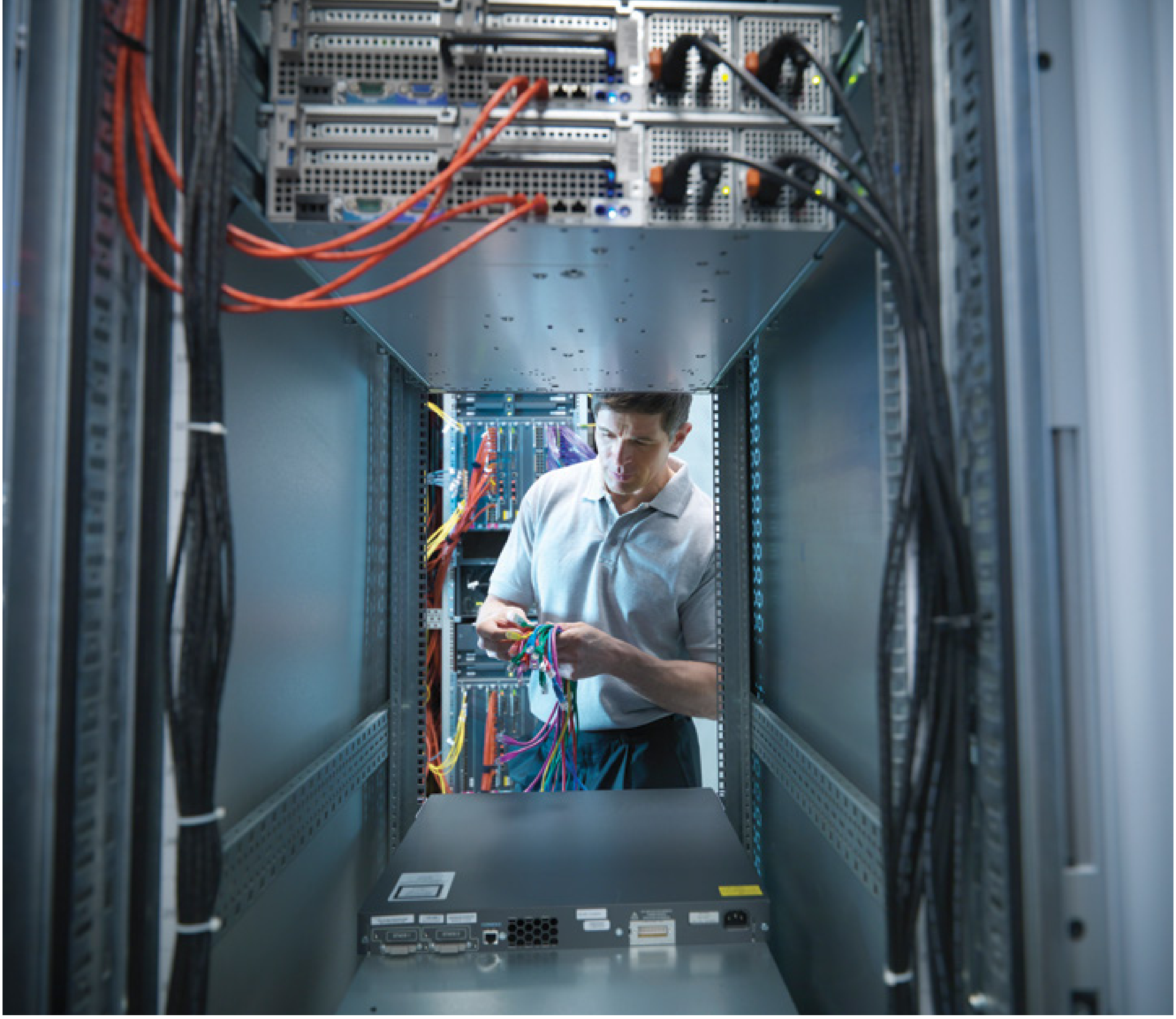


Figure 11.Fault current path through scalable UPS system with centralized bypass (left) and distributed bypass (right).

The same principles apply to a single UPS unit, when built together from multiple power modules. It can either have a static switch in each power module, and also scaling bypass capacity as modules are added and removed. Or a modular UPS can have a single static switch sized for full UPS frame rating, and the bypass capacity is not impacted by amount of inverter capacity within a UPS.

Eaton UPSs' unique capability to mix and match the power module (inverter) capacity and static bypass capacity means they can be tailored to meet both load rating and fault clearing requirements, in an optimal way for both functionality and cost. This allows configuration of reliable scalable systems that can have full bypass capacity to manage fault currents as both centralized and distributed bypass implementations. Additionally, the UPS static bypass can be easily upgraded to better accommodate and match the requirements for higher fault currents and proper selectivity in the installation.



Conclusions

In these Papers we have seen how mission-critical power systems require feeds from the utility mains, a standby generator and a UPS to ensure power quality and availability at all times. The discussion has shown the importance of allowing for the ways in which these power supply components interact with one another, as well as with the switchgear equipment along the power distribution system paths and branches to the critical load elements.

The interaction between the UPS and PD system can cause issues that are not allowed for when considering either PD or UPS systems alone. These issues create risks for safety and reliability.

This interaction is complicated by the fact that it changes according to the operating mode of the UPS – normal, battery or bypass. In all cases, behavior during nominal current, overcurrent and short-circuit current conditions must be considered. Available short-circuit current also depends on how the system is used.

The importance of making correct choices between 3- and 4-pole switching is highlighted, as they have consequences for safety and regulatory compliance. Guidelines have been given to offer the best balance between compliance, safety and economy. Further opportunities for economy are given in the form of breaker sizing tips.

Selectivity is another key topic; the paper has shown how to build selectivity into the system, isolating a faulty branch quickly while leaving fault-free areas energized. Selectivity studies should consider Ik max and min levels as well as the effects of open arcs and pre-arcing in fuses. Possible solutions for when selectivity is hard or impossible to achieve are also offered.

Power distribution system uptime and sometimes safety are also influenced by two further factors; maintenance-induced errors, and modular systems that are scaled over time to meet growth in demand for capacity. Key interlocking and hardware interfacing have been covered as protection strategies against operator error, while the pros and cons of different modular configurations have also been reviewed.

Overall, striking the right balance between availability, safety and cost in a power distribution system, especially where UPSs are involved, is a complex calculation – and one liable to continued change as the critical load grows. With these considerations in mind, the advantages of consulting with knowledgeable experts from companies such as Eaton, backed by a long-established international reputation and an extensive selection of UPS and switchgear components of proven interoperability, are clear.

Eaton
EMEA Headquarters
Route de la Longeraie 7
1110 Morges, Switzerland
Eaton.eu

Powering Business Worldwide

Publication No. WP000000EN
June 2017