WHITE PAPER

Good practice for UPS protection

E-T-A®
ENGINEERING TECHNOLOGY

GOOD PRACTICE FOR UPS PROTECTION

Increased system availability and decreased energy consumption

When was the last time you experienced a power cut? Incidents with longer lasting power cuts, as on 4 November 2006, when the energy supply failed in half of Europe for several hours, are indeed extremely rare. Despite sluggish network expansion, the average interruption duration (SAIDI value) in Germany has decreased to less than 13 minutes in recent years.

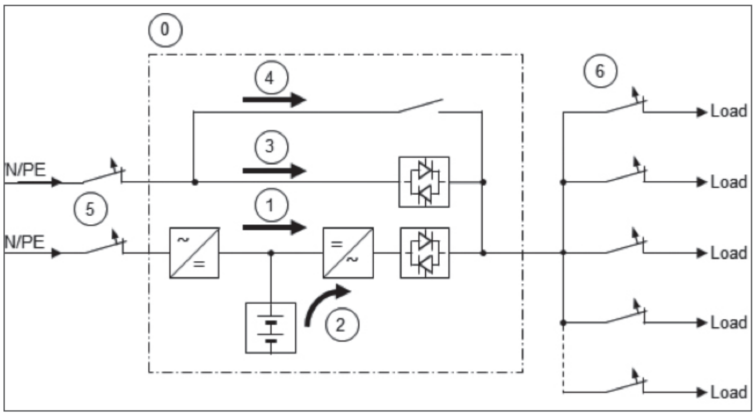
However, the short-time interruptions of less than 3 minutes are not included in this statistics. The incidents that can occur are described in the EN 50160 standard (»Merkmale der Spannung in öffentlichen Elektrizitätsversorgungsnetzen«, »Characteristics of voltage in public electricity supply networks«):

- Voltage breakdowns to 40 or 90 % Urated for less than 1 minutes: Between 10 and 100 per year
- Supply interruptions to < 1 % Urated for less than 3 mins: Between 10 and several 100 per year

Normally, this is no problem for the private user, but for manufacturing enterprises, whose processes must not be interrupted, even a short power cut can lead to high economic losses. Production processes come to a standstill, controllers perform a reset.

Companies, that particularly depend on stable or closely timed production processes rely on uninterruptible power supplies to be protected in the event of a power failure. Although UPS systems have been in use for many years, most users are ill-informed about the design in terms of overcurrent protection.
The UPS unit is designed to ensure availability, but users often complain about tripping fuses or completely shut down systems, because the corresponding fuse has not tripped.

In the event of a power cut, the simplest UPS systems (called "offline" or "line-interactive") ensure the power supply by switching on the backup system consisting of battery buffer and inverter. In general, this ensures the power supply during a mains failure, but short-term interruptions may occur in the switching moment. A permanent power supply is ensured with Online double conversion UPS. The energy is permanently supplied via the rectifier-battery-buffer-inverter path. In this case, too, a bypass path connects the mains either manually (e.g. during maintenance works on the battery) or automatically (in the event of an overload of the main path).



0 UPS unit
1 Mains mode
2 Battery mode
3 Electronic switching bypass
4 Manual bypass
5 Input side overcurrent protection
6 Output side overcurrent protection

***Fig. 1:** Topology of a typical Online double conversion UPS*

WHAT IS THE PROTECTION CONCEPT IN SUCH SYSTEMS?

Normally, blade fuses or high performance circuit breakers are used on the input side, while sub-distribution systems on the output side are often protected by miniature circuit breakers type B or C, just as in conventional distribution systems.

It is designed in such a way that the protection is as selective as possible, i.e. that in the event of an error, only the weaker protective element next to the error will trip. The stronger, upstream protective elements guarantee the switching capacity, i.e. they can reliably disconnect currents with high kA values.

Many UPS manufacturers indicate roughly in their data sheets, which protection is recommended.
What is the basis for these indications? Both the protection on the input and output side is determined based on the rated current of the UPS. A surplus is added on the input side for the inrush current, battery charging processes and short-term overloading, which must also be considered on the output side.

The rated current of the respective UPS unit is calculated based on its theoretical power:
The following applies to single-phase systems: $I_{rated} = \frac{S}{230\,V}$ (F. 1)
In case of three-phase systems, the current is divided between the phases: $I_{rated} = \frac{S}{3 \cdot 230\,V}$ (F. 2)

We use this to calculate the current to be continuously supplied in battery mode. For the actual power supply, the power factor cos(ϕ) must be multiplied. However, in terms of cut-in and short circuit currents, the theoretical power is decisive. In practice, a certain power reserve should remain when all loads are connected (usually 20 to 40 %).
Reserve surplus $r = 20 \ldots 40\%$

If loads are to be switched on during battery mode, the cut-in current must be added to the base load. This is accommodated by the fact, that most UPS units tolerate overload for a certain time. You can find the overload factor in the data sheet. As a rule of thumb, most UPS systems tolerate an overload of 150 % I_{rated} for a few 100 ms.

The minimum performance of UPS units is a comprehensive topic and only briefly mentioned here.
Most calculations of UPS manufacturers imply that the connected loads never reach their 100 % work load at the same time. They assume an average 2/3 continuous load.
Work load factor $a = \frac{2}{3}$
$I_{rated,\,USP} > (1+r) \cdot \left(\frac{I_{cut\text{-}in\,peak}}{1,5} + I_{base\,load} \cdot a\right)$ (F. 3)

In the event of a short circuit, the current is determined by the inverter technology and ranges between 180 to 300 % I_{rated}. If the short circuit continues for some time, the UPS unit will tolerate it for a few ms, but will then disconnect for self-protection. In case of such high overloads, severe voltage drops must be expected. To ensure the supply of the intact paths, the faulty path must be switched off within a few ms.

High-end online continuous transformers have a bypass path, that supports the overload or short circuit current, enabling significantly higher currents. Nevertheless, the overcurrent protection dimensioning should be done in battery mode, as the bypass switch as semi-conductor element is supported even by fast Thyristor fuses and upstream mains fuses. When fuses trip, they normally must be replaced by a service technician, affecting the sensitive UPS operation for the duration of the service. Moreover, the VDE 0100-430 specifies that "the equipment for protection against overcurrent must be capable to disconnect any current that occurs, including the prospective short-circuit current".
According to the VDE 0100, they must disconnect faulty paths in electrical systems before they can harm persons or damage production equipment. The following procedure applies:

WHAT MUST BE OBSERVED FOR THE COORDINATION OF THE OVERCURRENT PROTECTION ELEMENTS?

1. Loop impedance measurement

One action used to prove compliance with this requirement is measuring the loop impedance. This ensures that the line resistance up to the source is small enough to trip the protective element in the event of a short circuit.

$$Z_{conductor\ loop} \leq \frac{U_{conductor\ ground}}{I_{trip\ current}} \quad \text{(F. 4)}$$

Due to the special circumstances, this measurement must be extended for UPS units. It is hardly feasible in battery mode due to the control behaviour of the inverter and should therefore be carried out in bypass operation.

2. Ensured trip current

If a sufficiently small attenuation can be determined in the installation, check whether the maximum short circuit current flowing in battery mode is also sufficient to trip the overcurrent protection:

The above mentioned short circuit current of 180 to 300 % of the UPS rated current only applies to low resistive short circuits without further load paths. If you are not sure about the exact parameters of your system, you are on the safe side with a short-circuit current of 150 % I_{rated}.

$$I_{short\ circuit\ UPS} > I_{trip\ current} \quad \text{(F. 5)}$$

Rule of thumb: $I_{rated,\ USP} \cdot 1{,}5 > I_{trip\ current}$ (F. 6)

How high is the current that causes the circuit breaker to trip? It is important to know that the characteristics of every overcurrent protection device are subject to tolerances. When the holding current is exceeded (B = 3 x I_N; C = 5 x I_N), tripping is possible but not guaranteed. The minimum trip current (B = 5 x I_N; C = 10 x I_N) needed to safely trip the switch is about twice as high. For the design, the less favourable case with the higher trip current is normally implied. A good part of the system performance is used just to maintain this tolerance.

The trip current doesn't have to be considered in the EBU electronic circuit breaker design. The rated current of the UPS unit is adjusted at the circuit breaker instead. It will reliably trip at a 150 % overload of the UPS unit. Using electronic measurement enables a very low tolerance. The EBU reacts very fast in battery mode, because the voltage level is permanently measured. If the voltage is supported by a bypass instead, the EBU reacts more slowly in the event of an overload and tolerates the on-switching of loads with high cut-in currents.

3. Holding current limit

The fact that the holding current of the overcurrent protection device should not be exceeded is not a requirement for compliance with the safety standards, but it is necessary for undisturbed operation. Almost all modern electronic devices have integral switch mode power supplies for voltage supply and show a strong capacitive switch-on behaviour. The cut-in current can reach 10 to 40 times the nominal current. In case of doubt, the next higher variant of the overcurrent protection must be selected.

4. Trip time adherence

Another requirement of the VDE 0100 is the disconnection of faulty current paths within determined time periods.

		TN network	TT network
Distribution circuits		5 s	1 s
Final circuits	≤ 32 A	0.4 s	0.2 s
	> 32 A	5 s	1 s

According to the standard, i.e. that a forced disconnection of the UPS after 5 s in the frequently occurring final circuit ≤ 32 A is not sufficient. In practice, no system operator will rely on the forced disconnection, also switching off all faultless paths. With regard to the connected loads, the short circuit disconnection should be performed quickly: In the event of a severe short circuit, the voltage in the distribution system also breaks down. Loads can compensate the breakdown with internal buffers for a short time. However, the technical and product standards for interference immunity of typical loads indicate that the fault must be eliminated within 10 ... 20 ms to provide unimpaired operation as far as possible.
Both for the miniature circuit breakers and the EBU electronic breaking units, only the characteristic curve in the short-circuit range fulfils this requirement, because only in this range they react fast enough.

CONCLUSION:
In figure 2 on the left side, you can see a theoretically ideal overcurrent protection for UPS units. The characteristic curve lies between the source and the load, with a narrow tolerance area to keep the required power reserves for tripping to a minimum. The disconnection will be performed quickly after a few milliseconds. Miniature circuit breakers can also be designed in a way that their characteristic curve lies between source and load (figure 2, centre). However, due to the rigid nominal values and the relatively high tolerance, sufficient power reserves must be taken into account.

The characteristic curve of the EBU electronic breaking unit can be flexibly adjusted to the UPS unit and always lies to the left of the source when the rated current of the UPS is adjusted (figure 2, right side). The overload range can also be flexibly adjusted to the load. The tolerance is relatively low, i.e. that the next smaller UPS unit is often sufficient for tripping.

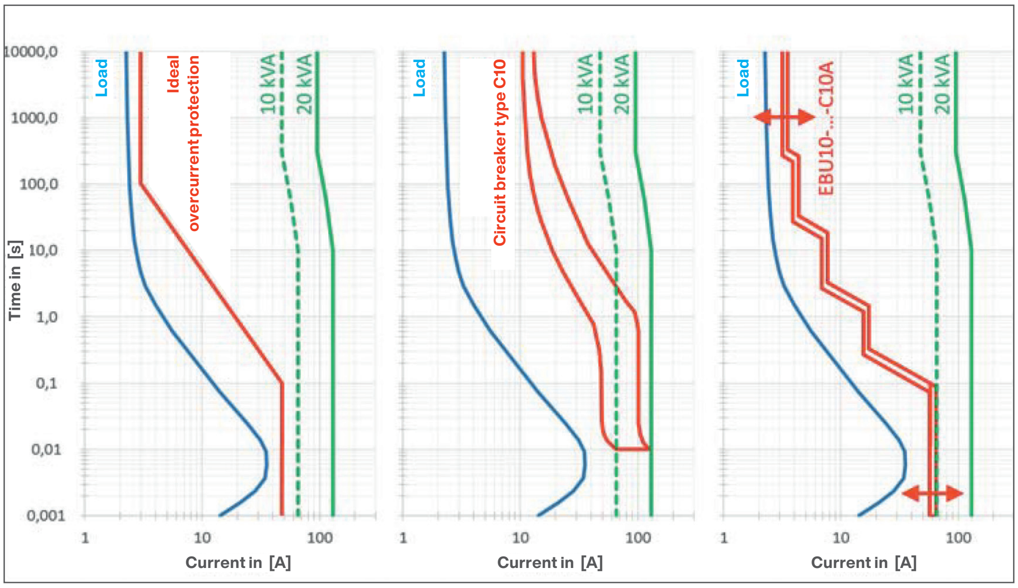


Fig. 2: *Left, centre, right: ideal protection, protection with miniature circuit breaker, protection with EBU-T*

Design example (see figure 2)

A sub-distribution with motors, switch mode power supplies and lights (base load: 12 A) is to be stabilised by a single-phase UPS unit. A 500 W switch mode power supply has the highest cut-in current of 36 A.
You can choose between UPS units with a minimum power of 10 or 20 kVA

to supply the loads.

The power required is to be calculated with F. 3 and F. 1 (selected: r = 30 %):

$$I_{rated,\ USP} > (1+r) \cdot \left(\frac{I_{cut\text{-}in\ peak}}{1{,}5} + I_{base\ load} \cdot a\right) = (1+0{,}3) \cdot \left(\frac{36A}{1{,}5} + 12A \cdot \frac{2}{3}\right) = 41{,}6A$$

$$S > 41{,}6A \cdot 230V = 9{,}6kVA$$

The unit with 10 kVA is sufficient to supply the loads.

Solution I: Protection by means of MCBs

F. 7 determines the holding current of the MCB:

$$I_{holding\ current} > I_{cut\text{-}in\ current,\ load} = 36A$$

A MCB with C10 characteristic is selected
(holding current = 50 A trip current = 100 A)
The rated current of the UPS for a 150 % short circuit is derived from F. 6:

$$I_{rated,\ USP} > \frac{I_{trip\ current}}{1{,}5} = \frac{100A}{1{,}5} = 66{,}7A$$

For a guaranteed tripping, the power must be increased:

$$> I_{rated,\ UPS} \cdot 230V = 66{,}7A - 230V = 15{,}3kVA$$

The unit with 10 kVA is sufficient to supply the loads.

Solution II: Protection by means of an Electronic Breaker Unit

Even if the C10 EBU version is selected, the holding current is higher than the cut-in current of the load. The tripping current does not have to be tested separately.
It is sufficient to set the rotary switch to the rated current of the UPS unit:

$$I_{rated} = \frac{S}{230V} = \frac{10kVA}{230V} = 43A$$

The $I_{N,Load}$ rotary switch can remain in OFF position or, if desired, can be set to the rated current of the load:

$$I_{N,Load} \geq \frac{500\ W}{230\ V} = 2{,}2\ A \Rightarrow \text{Selection: 3 A}$$

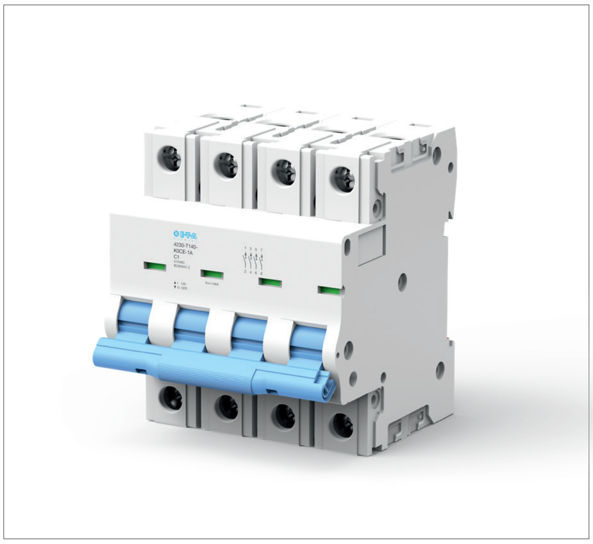
With an EBU, a 10 kVA power is sufficient
to reliably disconnect a short circuit in battery mode.

MCB

The trip characteristic of MCBs is determined by their overload and short-circuit behaviour. If an overcurrent flows through the bimetal, it will heat up and release the trip. A magnetic coil is connected in series to it, whose armature is accelerated by the magnetic field in the event of a short circuit and also causes a disconnection. Both elements are subject to tolerances. The thermal trip ranges between 1.05 ... 1.3 I_{rated}, the magnetic trip depends on the version, but according to the DIN EN 60898 lies within the threshold values:

B: 3 ... 5 x I_n

C: 5 ... 10 x I_n



4230-T, 4-pole miniature circuit breaker

EBU10-T Electronic Breaker Unit

Electronic overcurrent protection

The latest generation of electronic overcurrent protection is compatible with AC applications. The intelligent electronics of the EBU10-T circuit breaker detects a short circuit and causes the integral MCB with high switching capacity to trip within 10 ms. The characteristic curve of the EBU10-T depends on the rated current of the respective UPS unit, guaranteeing the tripping. The rated current can be adjusted via rotary switch.

The EBU10-T not only protects against short circuit, but also protects the path against overload: For this purpose, the rated current of the load can be set via another rotary switch. In the best case, the UPS power is distributed to all individual paths protected by the EBU10-T. The EBU10-T has an LED indicator for signalling the status and a signal contact designed as a changeover contact. Compared to MCBs, the electronic overcurrent protection has very low tolerances.

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