PRODUCT TECHNICAL GUIDE

UPS and Critical Power Solutions

2024

When **energy** matters

socomec
Innovative Power Solutions

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Overview

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1. POWER QUALITY ISSUES AND SOLUTIONS

It goes without saying that in order for power to be used by the load, it must be present. A less obvious concept is that the power must have characteristics that make it ideal for use, e.g. it must fall within the tolerances permitted by the electric load or utility.

The concept of Power Quality (PQ) is, therefore, the set of limits which make energy useable and, consequently, the branch of study which defines assessment criteria and methods of measurement, in addition to analysing causes and proposing solutions.

The concept of PQ is not absolute, but always depends on the energy load. For example, in general terms, it can be stated that IT equipment has more stringent PQ requirements than a motor for industrial applications. Normally, PQ requirements and the measures for achieving them, depend on techno-economical considerations and compromises.

Loads, in addition to being sensitive to poor-quality power, are often also the cause of power quality issues. The diffusion of non-linear loads (typically electronic equipment) and the connection of large utilities on weak lines are just some of the many causes. Another cause is atmospheric phenomena.

The most common disturbances that adversely affect the operation of a component or an electrical utility are:

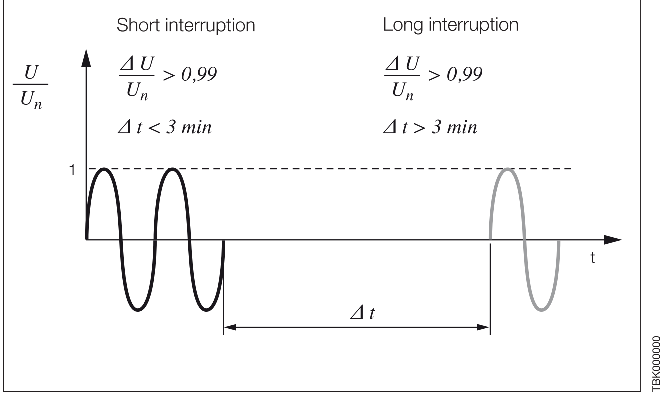
- power sags or outages due to network faults
- short voltage variations due to the connection of heavy loads or the presence of faults in the network
- distortion of currents and voltages due to non-linear loads present in the system or in the systems of other utilities, etc.
- flicker due to large intermittent loads
- asymmetry in the supply voltage system

1.1. Power interruptions and voltage dips

All elements in an electrical system are sensitive, in different ways, to power dips or interruptions.

Long interruptions are the result of permanent faults which occur in public distribution networks or within the user's system. The duration may vary from a few minutes to several hours in the most critical cases. By contrast, micro-interruptions are linked to faults which occur in the distributor's networks and normally last for less than a second.

1.1-1 Accidental power interruptions.



1.2. Voltage and current distortions

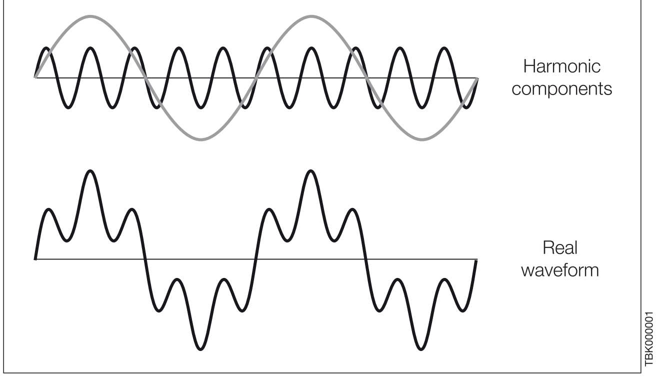
Waveform distortions are mainly caused by non-linear loads which, even if powered using sinusoidal voltages, draw highly distorted currents.

Typical non-linear loads include:

- devices which perform AC/DC and DC/AC conversions (present in all electronic power supplies, for example computers)
- fluorescent lamps
- electric soldering irons
- arc furnaces (also responsible for flicker)
- electrical drives

Any periodic waveform can be represented through Fourier series analysis by a fundamental sinewave and by sinusoidal components of varying amplitude and with multiple frequencies, known as harmonics (Figure 1.2-1).

1.2-1 Sinusoidal waveform distortion.



Harmonic currents circulating in the network cause voltage drops of the same order of magnitude and depending on the line impedance, with resulting voltage distortion.

This means that the magnitude of the disturbance caused at each point of the system (both the user and at the point of delivery) depends not only on the characteristics of the load, but also on the characteristics of the plant itself. All electrical components are affected by waveform distortion.

Harmonic distortion is also known as THD (total harmonic distortion).

The negative consequences of harmonics generally include thermal overloading and sometimes dielectric problems (which can occur in power-factor correction batteries, for example).

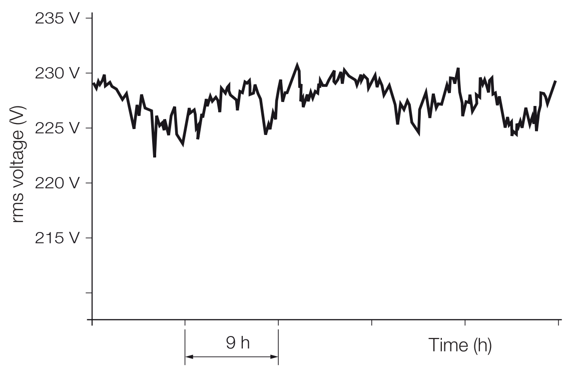
Harmonics typically increase the risk of overheating in system components or nuisance trips.

1.3. Flicker

The connection and disconnection of loads in an electrical system generate rapid and repetitive voltage variations. In particular, certain types of consumers such as arc furnaces and soldering irons draw current in an irregular and variable manner during their operating cycle, giving rise to *flicker*.

Loads which are most sensitive to voltage fluctuations are incandescent lamps, as the flicker produced by variations in light flow can cause irritation to those who use them.

1.3-1 Example of fluctuations of voltage RMS value



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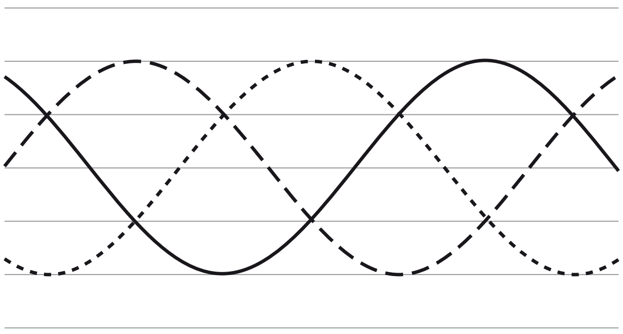
1.4. Voltage asymmetry

There are two main causes for asymmetry in the supply voltage system, with the first one being most prevalent:

- Presence of highly unbalanced loads supplied from the same line. This includes high-power single-phase loads which in certain cases may also be intermittent (e.g. high-power single-phase soldering irons). The severity of this phenomenon increases in proportion to the degree of load imbalance and the impedance of the power supply line (length, diameter). The worst affected loads are those located near to or downstream of the unbalanced load.
- Asymmetrical impedance of the power line. This problem is significant in the case of long backbone lines with no transpositions between the conductors along the route.

Asymmetrical voltage can create problems especially in rotating synchronous and asynchronous machines such as, for example, overheating windings, reduced starting torque and vibrations.

1.4-1 Three-phase symmetrical voltage



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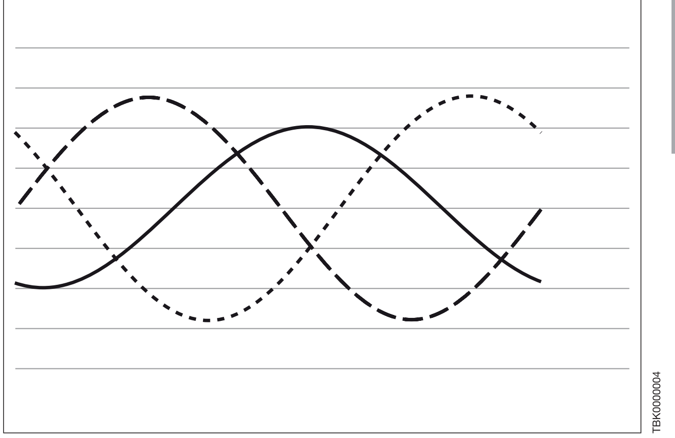
In general, even the nominal power of the transformers and the cable ratings are reduced in the case of significant asymmetry. In fact, the operating limit of these components is determined by the effective value of the total current which, in the case of imbalance, also consists of non-direct sequence currents. This fact must also be taken into account when adjusting the trip thresholds of protection devices which are sensitive to the total current.

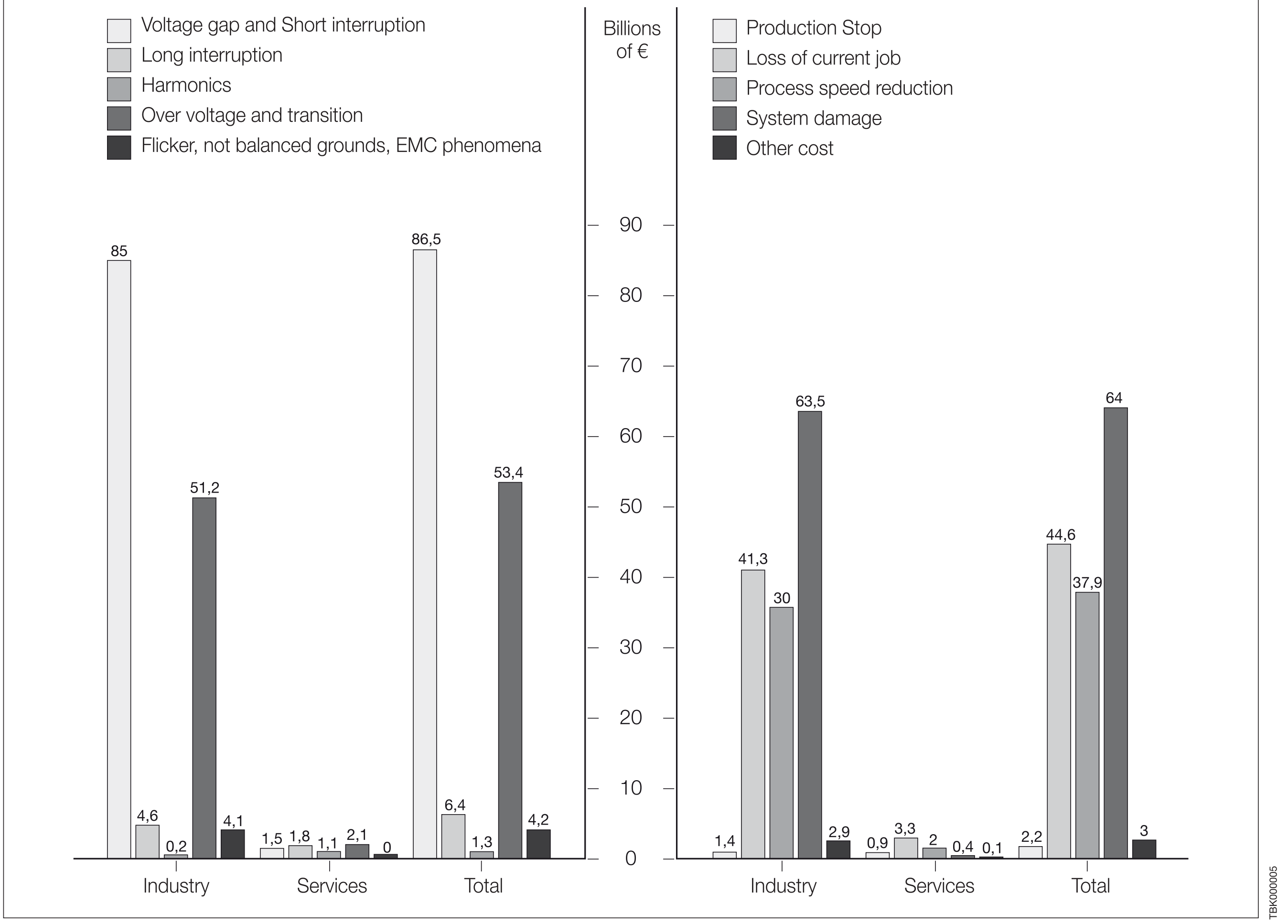
1.4-2 Three-phase asymmetrical voltage



1.5. Costs of poor-quality power

The following estimated costs of poor power quality are provided for indication purposes (source: LPQI).

1.5-1 Power quality costs in Europe (billions of €)



2. ELECTRICAL POWER AVAILABILITY

2.1. Definition

The general concept of availability (A) refers to the length of time that a system is able to perform its intended function.

Normally, availability is indicated as a value per unit or as a percentage of the system's total lifespan.

Electrical power availability refers to the length of time a load is supplied with high-quality power. More intuitively, it is the length of time the power distribution system performs its intended function without interruptions due to breakdown or [routine] maintenance. In information technology terms, this concept is known as 'uptime' and is the opposite of downtime, e.g. periods when a system is unavailable.

The mathematical definition of availability is:

$$A = \frac{MTBF}{MTBF + MTTR} = 1 - \frac{MTTR}{MTBF + MTTR} \cong 1 - \frac{MTTR}{MTBF}$$

All parameters involved are statistical and describe:

- MTBF: mean time between failure;
- MTTR: mean time to repair.

The approximation derives from the fact that, due to the intrinsic characteristics of standard-compliant power supply systems, MTTR is at least two orders of magnitude less than MTBF.

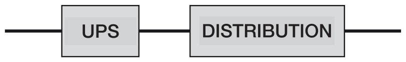
Availability is always less than 1 or at 100% and is always expressed in nines (99.99..%)

It is self-evident that the availability of an electrical power supply depends on the availability of its constituent components: distribution network, transformers, lines or cables, protection devices, UPS, generator sets, etc.

2.2. Availability of parallel or series systems

Below are three examples for comparing availability based on the different topologies. For simplicity, the availability value of both the source and the load are the same and are equal to 0.998.

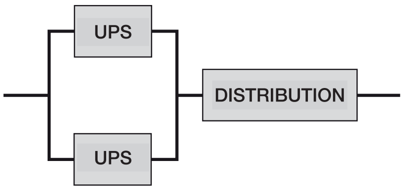
2.2-1 Single source with single distribution



$A_{tot} = A*A \cong 0.996004$

Statistical annual downtime: 35 hours.

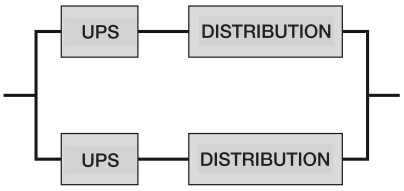
2.2-2 Double source with single distribution



$A_{tot} = A^2 (2-A) \cong 0.997996$

Statistical annual downtime: 17 hours.

2.2-3 Double source with double distribution



$A_{tot} = A^2 (2- A2) \cong 0.999984$

Statistical annual downtime: 8 minutes.

2.3. Importance of topology

Topology is fundamental. This is demonstrated not only by the previous example but by experience. Human error, fire and flooding are just some of the possible causes of physical damage to equipment. You can imagine the consequences of having two redundant UPS systems installed in the same equipment room or two distribution lines in the same channels or conduits: a vital and expensive redundancy system would be at serious risk due to physical causes.

In view of technical and economic considerations, it is advisable not only to ensure redundancy of the various systems, but also to physically separate them.

3. STATIC UNINTERRUPTIBLE POWER SUPPLY (UPS) SYSTEMS

3.1. Definition

Uninterruptible power systems, perhaps more commonly known as UPS, primarily consist of an energy storage system in various forms, on the basis of which an initial classification can be made, and a system for converting this into power.

In a static UPS, energy is stored in an electrochemical form in either special storage batteries or in kinetic form, using flywheels, and reconverted into the desired form using static electronic converters.

In dynamic UPS systems, energy storage is exclusively in kinetic form, and uses a rotary generator for reconversion.

3.2. Types

The standard EN 62040-3 was developed in response to the need to classify the various types of static UPS systems currently available on the market. It distinguishes between three major product families, according to the internal schemes adopted:

- VFD - passive standby;
- VI - line-interactive;
- VFI - double conversion.

3.2.1. Passive Standby

Utilities are normally powered by the mains supply. At the same time, the mains power supply also supplies the battery charger, which maintains the storage batteries at the maximum load level.

In the event of power loss, a solid-state or electromechanical commutator transfers the load to the inverter, which now activates, supported by the batteries. This mode of functioning continues until ordinary mains power conditions are restored or until the stored energy is exhausted.

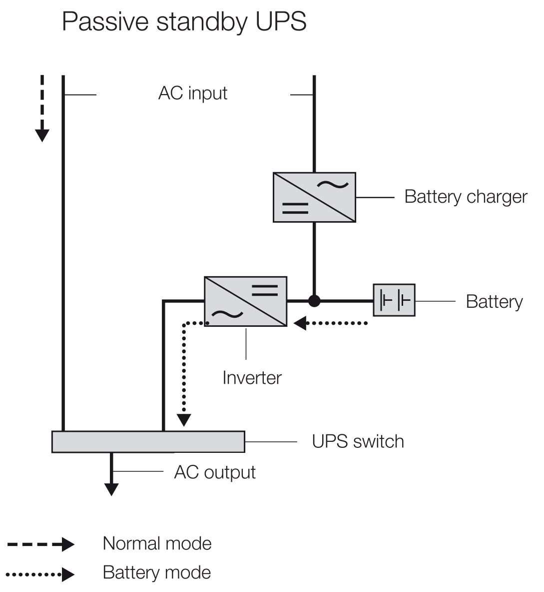
The merits of this solution are essentially in its simple design, which helps to contain the cost of the equipment.

Being the least expensive option, this type of UPS offers extremely limited performance, e.g:

- no decoupling between the upstream distribution system and the load;
- switching times of approximately 10 milliseconds, which are not always compatible with the loads needs;
- no system for regulating the output frequency;

Because of these disadvantages, UPS systems in this category are now used only for loads with low power ratings, typically up to 2kVA.

3.2-1 Operation of passive standby UPS



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3.2.2. Line-Interactive

This configuration is characterised by the presence of a reversible AC/DC converter which can function both as an inverter and as a battery charger. In ordinary conditions, the load is supplied by the mains power supply through a solid-state breaker, which allows isolation of the system when the inverter is activated, preventing power from being fed back to the mains power supply. The voltage supplied to the load is conditioned by an AVR autotransformer (Automatic Voltage Regulator). In contrast to a passive-standby system, a line-interactive UPS system operates when mains power is available. Owing to its position in parallel with the ordinary power supply line, it guarantees a certain improvement in voltage quality, although this is limited to aspects such as magnitude fluctuations.

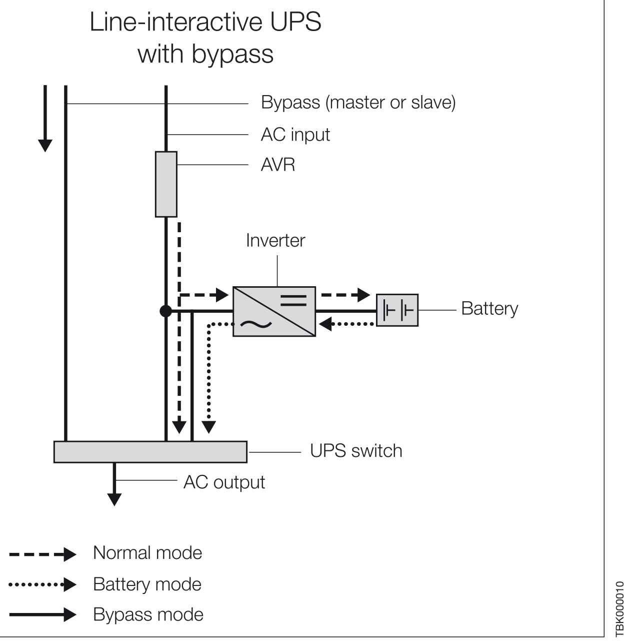
If the mains power is lost, the solid-state breaker is opened automatically, and the load is powered exclusively by the battery

- inverter unit, until ordinary conditions are restored or until the storage batteries are exhausted.

Compared to passive-standby systems, line-interactive UPS provide better waveform conditioning, but with some drawbacks:

- no decoupling between the upstream distribution system and the load;
- no system for regulating the output frequency;
- switching times of a few milliseconds (4-5 ms).

3.2-2 Operation of line-interactive UPS with bypass



3.2.3. Double conversion

Unlike the configurations considered above, double-conversion UPS systems constitute true electric generators that are completely isolated - with few exceptions - from the mains network, in which power is supplied by the mains network itself. Since the power to the load is transformed solely by the UPS inverter, without any interaction with the mains network and regardless of whether the power originates from the mains supply or the battery, it is possible to fully exploit the versatility of the static converter, which is able to manipulate the voltage supplied to the load under any condition. In fact, based on the direct current supplied from other components of the UPS such as the rectifier or battery, the inverter control system ensures an output waveform which is totally independent of the input waveform, with an undistorted frequency and amplitude.

The advantages of this type of UPS system are numerous:

- isolation of loads from the upstream distribution network (thereby allowing for precise regulation of the output frequency)
- very wide input voltage tolerance
- instantaneous switching between mains power and battery (more a case of seamless transfer than switching)
- no-break transfer to bypass mode

The efficiency of double conversion UPS, typically 90-96%, is less than that of a *line-interactive* or *passive-standby* system, since the current supplied by the mains power is converted twice by a rectifier and an inverter, each of which are equipped with semiconductors (diodes, SCR, IGBT), which are prone to conduction and commutation losses. Nevertheless, the advantages of maximum-quality power obtained using a double-conversion system compensate for the losses which would otherwise occur on the cables and switches as a result of harmonics or other power quality issues. It is the recommended and most widely used technology for applications with a power rating of 5 kVA or higher.

3.2.4. Classification in accordance with EN 62040-3

In addition to the technology, the EN 62040-3 standard classifies UPS systems according to the output waveform and voltage drops, both in clearly defined switching conditions.

Standard EN 62040-3 table D.1 - Type of UPS, additional characteristics and system requirements

a) single
b) multi-module
c) bypass to primary power or backup power
d) AC generator backup power system (if applicable)
e) bypass transfer time (if applicable)
f) galvanic separation between input and/or DC connection and/or output
g) earthing of the input and/or DC connection and/or output
h) bypass circuits for maintenance and other installation requirements, such as UPS disconnectors and connection switches
i) compatibility with the existing power system (for example according to IEC 60364-4)
j) remote shutdown or emergency power-off (EPO) device

3.3. Double conversion UPS functional modules

3.3.1. Rectifier

When mains power is available, the rectifier converts alternating voltage into direct voltage (AC/DC converter) to power the DC bus.

Different types of rectifier are available according to the electronic components used, the topology and the control system.

The quality of the rectifier is determined by three parameters, namely:

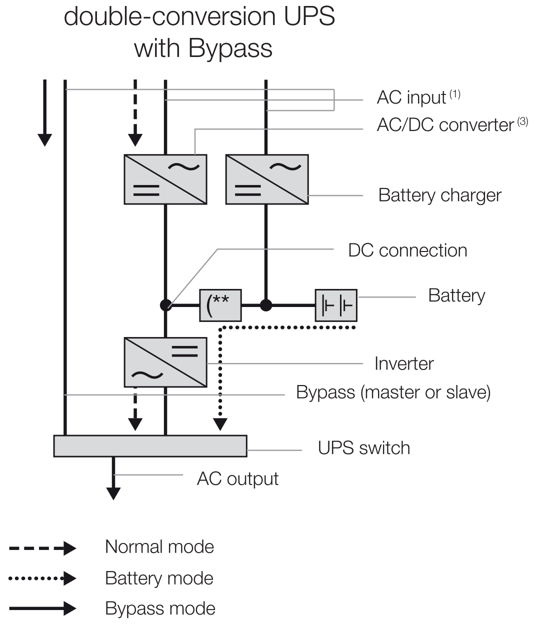
- conversion efficiency;
- input frequency and voltage tolerances;
- input power factor
- generation of harmonics to the mains.

The most widespread types of rectifier and the typical harmonic content of three-phase current absorbed by the mains are:

- 6-pulse SCR: 32%
- 12-pulse SCR: 12%
- Boost: 27%
- Inverter: 4%

From the DC side, the battery charger is unable to supply perfect direct voltage due to residual ripple which causes premature ageing of the batteries.

3.3-1 Operation of double-conversion UPS



(1) AC input can be combined.

(2) Blocking diode or switch.

(3) The converter could be a rectifier, a phase shift rectifier or a mix of rectifier and DC/DC converter.

3.3.2. DC bus

The DC bus is the part of the UPS power circuit in DC voltage.

A high-quality automatic bypass typically has a wide range of tolerable DC voltages: it therefore provides greater flexibility in the number of batteries based on the required back-up time.

3.3.3. Battery charger

The battery charger is the DC/DC converter which decouples the battery voltage from the DC bus voltage.

The advantage of this is twofold:

- the battery voltage is independent of the DC bus voltage;
- elimination of output *ripple* from the rectifier

3.3.4. Inverter

Converts direct current from the rectifier into sinewave current of perfectly stable magnitude and frequency. The inverter is therefore a DC/AC converter.

The quality of the rectifier is determined by three parameters, namely:

- conversion efficiency;
- ability to supply leading power factor loads;
- ability to withstand overloads and short-circuits;
- quality of the voltage waveform in the presence of distorting loads.

3.3.5. Transformers

The transformer is not an obligatory component and is the source of an informal classification which divides UPS systems into "*trafoless*" (transformer-less) and "trafo" systems It is necessary to determine whether the transformer is present as a functional component of the UPS system or whether its purpose is to manage the neutral.

In UPS units with a transformer on the inverter output, the output neutral, when available, is bonded to the bypass neutral downstream of the transformer, whereas in *trafoless* systems, the rectifier neutral and bypass neutral are common even inside the unit.

The insertion of a transformer on the static UPS line guarantees the galvanic isolation of the system and a single neutral system downstream of the UPS, in any operating condition.

In any case, it it important to bear in mind that the built-in UPS transformer does not permit the neutral state to be changed.

Advantages of *trafo* technology compared to *trafoless* technology:

- high short-circuit capacity, therefore greater flexibility in the choice of protection devices;
- no DC components in the output voltage.

Disadvantages of *trafo* technology compared to *trafoless* technology:

- higher weight;
- larger footprint.

In any case, technical and economic factors should be considered on a case-by-case basis, making selection straightforward and unambiguous.

3.3.6. Automatic bypass

Switches the UPS output to the auxiliary network in the event of an overload or fault in the inverter module.

The network bypass circuit is formed by a SCR module and directly connects the network with the load.

The quality of the automatic bypass is mainly determined by its ability to withstand overloads and short-circuits.

In the case of separate input power supplies, it's common to use a *bypass input* or *back-up input* (to distinguish it from the *rectifier input*), an input which is dedicated exclusively to the *bypass* with the aim of minimising the probability of the *rectifier supply* and *bypass supply* failing at the same time. The *bypass supply* can be a different power line to that of the *inverter input* or generator. If there is no separation of the power supplies, this is referred to as a *common input*.

3.3.7. Maintenance bypass

The manual or maintenance bypass module is not necessary for operation of the UPS and therefore it is not always supplied in the standard configuration.

The aim of this module is to enable routine or non-routine maintenance to be carried out without interrupting the power supply.

3.3.8. Storage systems

The storage system is the power source which supplies the inverter during a mains power outage, preventing power interruptions to the connected applications.

- Batteries.

Batteries are the most common means of storing energy. They are electrochemical devices and are therefore sensitive to operating conditions: temperature, charge and discharge cycles. The most commonly used batteries for this purpose are sealed, lead-acid maintenance-free batteries, open-vented or nickel-cadmium.

Battery performance is expressed in terms of design life and the type of discharge permitted. Excellent performance is provided by long-life batteries (10-12 years) with high-rate discharge.

Battery life is theoretical. In practice, it depends on the charge/discharge cycles and the temperature of the place of installation.

To illustrate how temperature affects battery life, EUROBAT (Association of European Storage Battery Manufacturers) states that the expected service life is halved for every 10°C above 25°C. This means that batteries with a "10-12 year" design life which are installed in places within an ambient temperature of 35°C or 45°C will last no longer than 5-6 years and 2.5-3 years respectively.

The place where the batteries are installed must be equipped with adequate ventilation and air conditioning to guarantee the correct operation of the batteries and the safety of the installation. To this effect the following formula can be applied in accordance with Standard EN 50272, which aims to keep the concentration of hydrogen in the room below the threshold of 4%vol.

$$Q = v \cdot q \cdot s \cdot n \cdot I_{gas} \cdot C_{rt} \cdot 10^{-3}\ [m^3/h]$$

where:

Q = ventilation air flow in m^3/h

v = necessary hydrogen dilution factor

q = 0.42 x 10-3 m^3/Ah hydrogen generation

s = 5, general safety factor

n = number of battery cells

I_{gas} = current producing gas expressed in mA/Ah of assigned capacity, for float charging current or for boost charging current

C_{rt} = C10 capacity for lead-acid cells

(Ah), Uf = 1.80 V/cell at 20°C or C5 for nickel-cadmium cells (Ah), Uf = 1.00 V/cell at 20°C.

By combining the constants the formula is simplified to:

$$Q = 0.05 \cdot n \cdot I_{gas} \cdot C_{rt} \cdot 10^{-3}\ [m^3/h]$$

Unless otherwise specified by the battery manufacturer:

I_{gas}	Open cells of lead-acid batteries	VRLA cells of lead-acid batteries	Open cells of nickel-cadmium batteries
During float charge	5	1	5
During boost charge	20	8	50

Protection against power micro-interruptions.

Flywheel and batteries can also be used simultaneously in UPS units, with the advantage of increased battery life. This is possible because the flywheel, in parallel with the batteries, ensures protection during brief interruptions, therefore preserving the capacity of the batteries for longer outages and improving their lifecycle.

The service life of flywheels is over four times longer than batteries. They are also stable, reliable and require minimal maintenance. Furthermore, unlike batteries, they are not subject to significant fluctuations in the cost of lead.

Control.

The brain of the UPS is its control system. The best architectures are based on digital signal processing (DSP) microprocessors which are able to perform complex calculations and algorithms. Architectures enable the machine to respond to different events and to report states and events via communication interfaces.

3.4. Backfeed protection

Backfeed protection prevents voltage from returning to the mains power supply. This issue is governed by standard EN 62040-1-1.

Backfeed protection is mandatory in fixed and mobile installations. In the case of fixed installations, the backfeed protection can be external to the UPS unit when indicated by a suitable warning label.

3.5. UPS sizing

Choosing the power rating of a UPS unit is a process which involves taking into account various elements, both functional and regulatory.

The main elements to be considered may include:

- two of the following parameters regarding the loads to be supplied:
  - Active Power (PRL);
  - Apparent Power (SRL);
  - Power Factor (PF).
- type of load power supply (voltage, frequency, number of phases);
- load coincidence factor;
- required back-up time;
- type of mains power supply (voltage, frequency, number of phases).

In the event of a particular load, which for example requires a high inrush current, this current value must be taken into account. Once the following parameters are known:

- $\hat{I}_{UPS}$ - maximum current of the UPS;
- t_{UPS} - the time for which $\hat{I}_{UPS}$ is sustainable;
- $\hat{I}_L$ - overload current required by the load;
- S_L - apparent power of the load

the apparent power rating, in case of load crest factor 3:1, is

$$S_{UPS} = S_L \cdot \frac{\hat{I}_L}{\hat{I}_{UPS}}$$

If the load is also strongly non-linear, as is the case with electronic equipment for example, and if the crest factor is higher than that tolerated by the UPS, it is advisable to consider a derating factor.

3.6. Temperature control in the place of installation

Normally, uninterruptible power systems can function at nominal powers for ambient temperatures up to 40 °C, heating the environment in which they are installed due to electrical losses dissipated in the form of heat. These losses cause the natural temperature to increase (ΔT) and are normally indicated by UPS manufacturers. The temperature of a room, which is 25 °C with the UPS switched off, may increase by up to 15 °C before it is necessary to derate the equipment. Room ventilation or air conditioning may enable these limits to be respected.

For ventilation, the following empirical formula is provided:

$$Q\left[m^3/h\right] = \frac{P\left[kcal/h\right]}{0{,}288 \cdot \Delta T\left[W\right]} = \frac{P\left[W\right]}{0{,}248 \cdot \Delta T\left[K\right]}$$

where:

Q = Air flow rate

P = Power dissipated in the enclosure

ΔT = Difference between maximum air temperature permitted in the enclosure and the maximum temperature of air used for cooling

In terms of temperature difference, degrees Kelvin (°K) and Centigrade (°C) are equal (this does not apply to absolute values).

For ventilation, see also the paragraph "Batteries" regarding safety in the battery room.

Meanwhile as regards air conditioning, you are recommended to contact the equipment supplier with the characteristics of the place of installation and the electrical losses of the UPS. It is advisable to consider the worst-case operating conditions: typically at midday in summer.

3.7. Central power supply systems (CPSS)

Central power supply systems (CPSS) provide a centralized, independent energy supply to essential safety equipment such as emergency escape lighting, electrical circuits of automatic fire extinguishing systems, paging systems and signalling safety installations, smoke extraction equipment and carbon monoxide warning systems for specific buildings (e.g. in high-risk areas).

An uninterruptible power supply, when used to power essential safety systems such as those listed above, must comply not only with the requirements of the EN 62040 series of product standards, but also with the additional requirements of system standard EN 50171.

The main additional characteristics which the system must have can be summarised as follows:

- the enclosures must be resistant to specific thermal stresses (glow wire tests)
- the input voltage must be in conformity with HD472 S1, with frequency within ±2% of the nominal value
- specifically the batteries must be:
    - protected against total discharge
    - long-life batteries
    - protected against polarity inversion of the connection cables
    - quick charging

In order for the power supply system to be effective, suitable precautions must be taken with respect to all of its component parts (protection devices, lines, etc.).

Note that other national requirements may exist in addition to those specified here.

3.8. Generator sizing

When the power source of the uninterruptible power supply includes a generator, in determining the latter it is necessary to take into account the voltage drop in the series impedance of the generator set due to harmonic variations.

The most suitable parameter for this calculation is the subtransitory reactance of the alternator, calculated for each frequency involved.

The subtransitory reactance value is provided in the generator set data sheets and is normally indicated with X''_d.

$$\Delta V_{\%} = \sqrt{\frac{\sum_i X''_d I_i^2}{I_n^2}}$$

The criteria is to choose the generator set which, given the current harmonics of the UPS, has a harmonic voltage drop, and therefore distortion, within the tolerance limit permitted by the line.

3.9. Protection devices

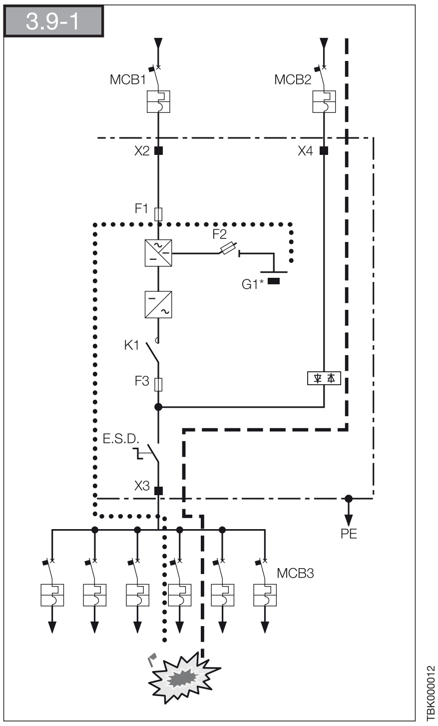
3.9.1. Definitions

- **Total selectivity:** is guaranteed for all types of fault (overload, short-circuit, earth fault) and for all overcurrent values, between the trip threshold of the upstream device and the prospective short-circuit current at the point where the downstream device is installed.
- **Partial selectivity**: is guaranteed up to a certain overcurrent limit Is (selectivity limit current).

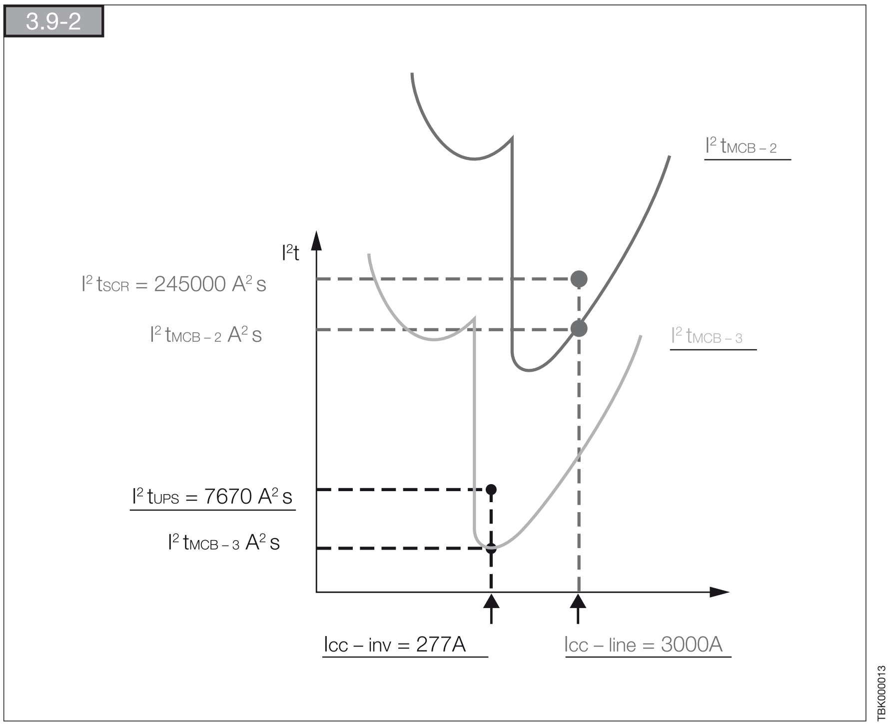
3.9.2. Selecting and co-ordinating devices to protect against overloads and short-circuits

- **Overload selectivity**: for breaker trip times from several hours to several seconds (overcurrents up to 6-8 times the nominal current), the co-ordination curves (breaker time-current curves) must never overlap. In the event of overload, the UPS continues normal operation by switching to the bypass when the thermal limits of the inverter are reached. Consequently, this transfer must be taken into account during co-ordination of the various protection devices. The UPS data sheets normally indicate the overload currents "per unit" or "as a percentage" and the corresponding tolerance time.
- **Short-circuit selectivity**: short-circuit currents can be very high, so the protection devices must be tripped within a few milliseconds to prevent burn-out of the cables. The time-current curves used as criteria for selecting overload protection are not valid when considering short-circuit protection, on account of the short trip times. In this case, the breakers must be sized based on the Joule integral curves of the devices. In practice, for a given prospective short-circuit current value, the minimum l2t let-through of the upstream device must be greater than the maximum l2t let-though of the downstream device.

3.9-1



3.9-2



In the case of short-circuit of one of the loads connected downstream of the UPS, two cases must be distinguished:

- **The bypass (back-up supply) upstream of the UPS is available.**

  For an output short-circuit, the UPS will transfer the load onto the bypass after a delay dependent on the individual model. The thermal-magnetic breakers of the bypass (MCB2) and output which protect the short-circuited load line (MCB3) are positioned in series (short-circuit marked in the diagram by means of the dashed line). For proper co-ordination, the output switch (MCB3) must open before the main input switch (MCB2). Then, the I^2t let-through of MCB3 must be lower than the let-through of MCB2 (at the prospective short-circuit current value): $I^2t_{MCB3}<I^2t_{MCB2}$.

  Furthermore, it is necessary to verify the selectivity between the bypass input thermal-magnetic switch and the maximum power tolerated by the bypass SCRs (in the example 245000 A^2s) at the prospective short-circuit (line) current (in the example 3000 A), e.g. $I^2t_{SCR}>I^2t_{MCB2}$.

In this case, the line impedance for estimating the short-circuit is that which takes into account the routing of power via the bypass. In the case of a back-up supply provided by a generator set, it is the short-circuit current of the generator set that must be used to correctly co-ordinate the protection devices.

- **The bypass (back-up supply) upstream of the UPS is unavailable.**

  Since the load cannot be transferred to the bypass (which is unavailable), the short-circuit energy is supplied entirely by the inverter and batteries. The downstream protection devices must be triggered before the electronic activation of the UPS protection in order to prevent healthy loads being switched off.

  The example (in the figure the short-circuit is represented by the dotted line), considers the three-phase short-circuit current from a 277 A battery for a maximum time of 100ms .

  The output short-circuit energy supplied by the UPS is: $I^2t_{UPS} = (277\ A)^2 \times 0.1\ s = 7672\ A^2s$

  At the short-circuit current value, in this case is not prospective but actual and coinciding with the short-circuit current value of the UPS, for correct selectivity it must be verified that $I^2t_{MCB3} < I^2t_{UPS}$.

  This second case (short-circuit without upstream supply) is nevertheless highly unlikely. In fact the absence of the upstream supply presupposes that a fault has occurred, and it is unlikely that a second fault (output short-circuit) would occur during the period of the power outage, which is usually short. In general, this period coincides with the time that the battery is supplying power (if the rectifier and the bypass do not have separate power supplies) or with the MTTR of the fault by an operator (if the UPS rectifier and the bypass have two different power supplies, as in this example).

  In the case of short-circuit without bypass supply, the current will be distorted to a square waveform.

3.9.3. Selecting and sizing differential breakers

There is no hard and fast rule since the behaviour of the mains supply to faults essentially depends on the neutral system used, the UPS filters (which divert certain harmonic components to earth) and the point of the fault.

Note.
The presence of isolation transformers can change the neutral system upstream or downstream of the UPS.

Generally speaking it is advisable to use:
- a single differential in the case of parallel UPS;
- type A differentials for single-phase in, single-phase out UPS;
- type B differentials for three-phase in, single-phase out UPS and three-phase in, three-phase out UPS.

3.9.4. Overvoltage protection devices

In conformity with IEC requirements, UPS systems are equipped with overvoltage protection. Unless otherwise required, the most common protection devices are Class 2. Usually, when the units are installed on the customer's premises, it is not necessary to increase the overvoltage protection class of the device. Nevertheless, if the units are installed in a transformer cabinet, the overvoltage protection class of the connection must be analysed and, if necessary, increased by installing additional protection devices.

3.10. Maintenance

In order to maximise uptime, it is advisable to perform periodic maintenance on components subject to wear:
- Capacitors;
- Fans;
- Batteries:

It is important that the maintenance is performed by expert personnel authorised by the UPS manufacturer.

3.11. Directives and Standards

3.11.1. Directives

- Low Voltage Directive 2006/95/EC
- Electromagnetic Compatibility Directive 2004/108/EC.

3.11.2. Safety Standards

- EN 62040-1-1 "Uninterruptible power systems (UPS) Part 1-1: General and safety requirements for UPS used in operator access areas"
- EN 62040-1-2 "Uninterruptible power systems (UPS) Part 1-2: General and safety requirements for UPS used in restricted access locations".

3.11.3. Electromagnetic Compatibility Standards

EN 62040-2 "Uninterruptible power systems (UPS) Part 2: Electromagnetic compatibility (EMC) requirements"

3.11.4. Performance

EN 62040-3 "Uninterruptible power systems (UPS) Methods of specifying the performance and test requirements".

3.11.5. Other standards

- IEC 60364-X-X "Electrical installations in buildings";
- IEC 60439-1 "Low-voltage switches";
- IEC 60529 "Degrees of protection provided by enclosures"
- EN 50272-2 "Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries".

4. STATIC TRANSFER SYSTEMS (STS)

4.1. Definition

Static Transfer Systems (STS) are intelligent units which, in the event that the primary power source does not return the tolerance values permitted by the load, transfer the load to an alternative source). This ensures "high availability" of the power supply for sensitive or critical installations.

The purpose of STS devices is to:

- ensure the redundancy of the power supply to critical installations by means of two independent power sources;
- increase power supply reliability for sensitive installations;
- facilitate the design and expansion of installations that guarantee a high-availability power supply.

STS systems incorporate reliable and proven solid-state switching technologies (SCR), enabling them to perform fast, totally safe automatic or manual switching without interrupting power to the supplied systems.

The use of high-quality components, fault-tolerant architecture, the ability to determine the location of the fault, management of faults and loads with high inrush currents: these are just some of the characteristics that make STS systems the ideal solution for achieving maximum power availability.

4.2. Performance (IEC 62310-3 definition)

Standard IEC 62310-3 establishes a code that clearly defines the performance of a STS:

XX	YY	B	TS

where:

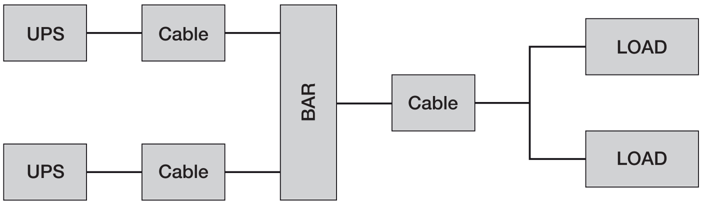
- **XX** characterises the management of the fault current:
  - which can be CB (STS is capable of withstanding specific short-circuit currents, which incorporates overvoltage protection devices)
  - PC (STS capable of withstanding specific short-circuit currents, which does not incorporate overvoltage protection devices).
- **YY** refers to the neutral management characteristics:
  - 00: no neutral management;
  - NC: both input neutrals are combined;
  - NS: separation of the two input neutrals by switching;
  - NI: neutral separation by isolation transformer (typically external to the machine).
- **B** are the transfer characteristics:
  - B: break-before-make (open transition transfer), there is no conduction path between the two sources during switching;
  - M: make-before-break (closed transition transfer), conduction possible between the two sources during switching.
- **TS** characteristics of the voltage limits permitted by the critical load:
  - T: total transient time to the terminals of the load, including switching time;
  - S: voltage tolerance before the transfer process is activated.

4.3. STS usage examples

Comparison between availability estimates between two architectures respectively with and without STS.

It is advisable to install the STS device as close as possible to the load, so as to ensure redundancy of the upstream distribution and to keep the single fault point (the conductor between STS and load) as short as possible.

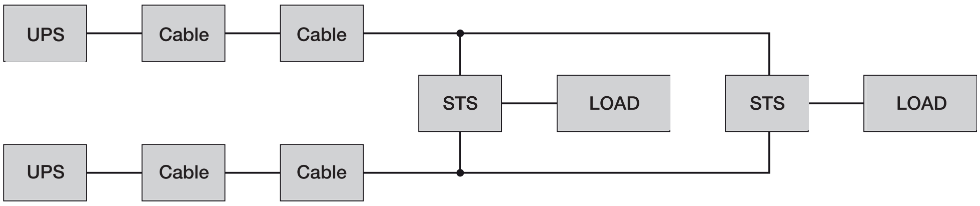
4.3-1 N+1 without STS



Estimated availability: 0.99749 (22 hours of downtime).

TBK000014

4.3-2 2N with STS



Estimated availability: 0.99991 (0.8 hours of downtime).
The double cable upstream of the STS serves to cover the same physical distance as the previous case (UPS and STS installed near to the load).

TBK000015

4.4. Functional modules

The aim of the STS is to increase the overall system availability. To achieve this it must be *fault-tolerant*: the load must be supplied even in the event of an internal fault.

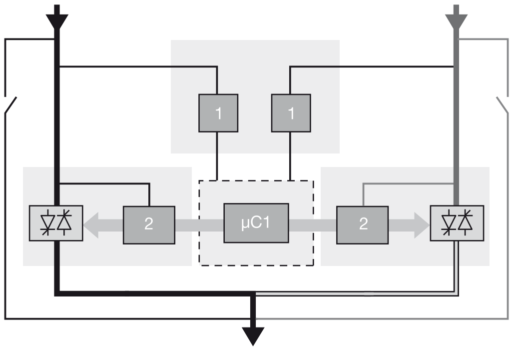
4.4.1. SCR modules

Silicon-controlled rectifiers are solid-state switches which control the flow of current to the load. The SCR is only able to interrupt the current as it passes through zero. In a sinusoidal steady-state, this implies switching times of between 0ms and a semi-period.

4.4.2. Power supply module

Module which draws power from the *primary or* alternative source, or from both sources, to supply all of the control electronics. It could be redundant allowing an higher fault tollerance.

4.4-1



TBK000016

4.4.3. Control

- **Control logic**: the brain of the STS is a microcontroller where all of the decision-making logic is located.
- **SCR control modules**: components which translate the control signal received by the logic into commands to the SCR.

It could be redundant allowing an higher fault tollerance.

4.4.4. Maintenance bypass

Normally built into the STS, the aim of the bypass is to enable routine and non-routine maintenance to be carried out. When the bypass is in operation, switching is not possible in case the conducting source exceeds the tolerance limits permitted by the load.

The STS device must be designed and operate so the two sources cannot be directly connected, not even in the event of human error.

4.5. Backfeed protection

Product standard IEC 62310 establishes a minimum requirement that the STS must control upstream breakers that trip to prevent power flowing from one source to the other.

4.6. Selecting a STS

The STS must be sized on the basis of the system diagram, the currents of the loads supplied by the STS, the distribution network and the power dips admitted by the load. With regard to the power failure tolerance of loads, the Information Technology Industry Council has published a guideline curve which helps users to determine the power supply conditions which can be tolerated by IT loads.

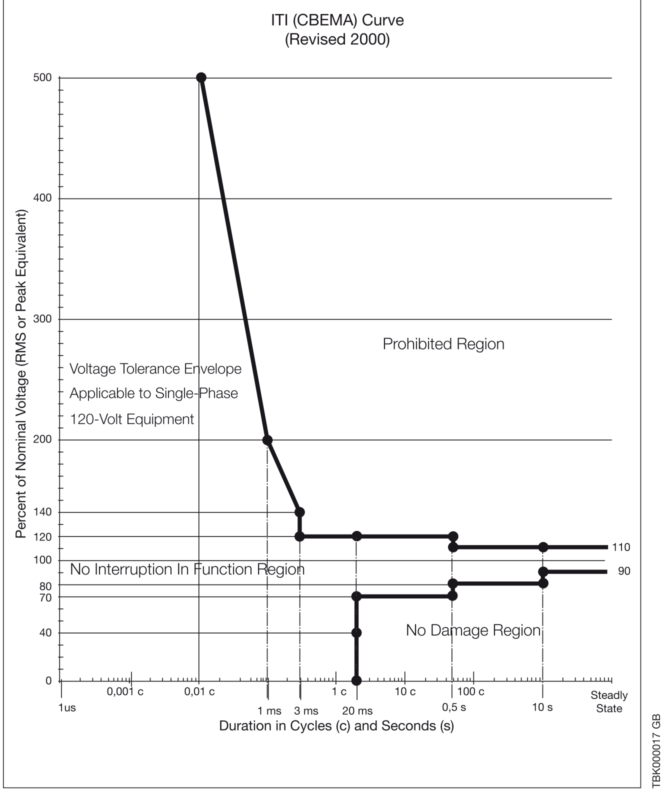
Firstly, it is necessary to identify the rating characteristics of the electrical system and the neutral:

- Voltage and frequency;
- Single or three-phase;
- With or without distributed neutral;
- Neutral condition (TN-C, TN-S, IT, TT);
- Sources (line/line, UPS/generator, UPS/UPS, etc).

Next it is necessary to determine whether the neutral must be switched (broken). In this respect, SOCOMEC offers the following advice:

- TN-C: no switching (regulatory requirement);
- TN-S: switching (requirement if sources provided with differential protection);
- IT: switching.
- TT: switching.

4.6-1



It is then necessary to determine the total current that must pass through the STS device as the sum of the nominal currents of the various downstream loads.

It is also important to verify the installation of loads such as transformers or electric motors downstream of the STS, in order to prevent nuisance trips due to high inrush currents when switching between sources, or residual downstream voltage which impairs power failure detection. If such loads are installed, this must be taken into account during selection and configuration of the STS.

4.7. Protection devices

4.7.1. Selecting and coordinating thermal-magnetic breakers

In order to select the right overload or short-circuit protection devices, it is important to consider the STS system's behaviour in the event of overloads. Normally, the conducting branch of the STS withstands the overload/short-circuit for a time depending on the intensity of the currents, before the STS switches to the other branch. If the two networks have different impedances or short-circuit capacities, these must be taken into account. If the values are insufficient to trigger the breakers within the time limit permitted by the STS, the STS will interrupt the power supply upstream, resulting in all downstream loads being switched off.

4.7.2. Selecting and sizing differential breakers

When present, the neutral between the two sources can be combined and switched or otherwise (see paragraph Choosing an STS). In the case of a TN-C system, the neutral acts as an earth conductor and therefore cannot be broken. In the case of a TN-S system, the installation depends on what type of downstream STS has been selected. If the device does not switch the neutral, any neutral currents could be divided between the two parallel networks by means of the earth connection in the cabinet. The installation of differential breakers is not recommended due to the high probability of them tripping.

By contrast, if the STS device switches the neutral, this will avoid any unexpected current between both sources and earthing.

Differential protection may be installed.

Each IT systems has his own IMD (Insulation Measurement Device). Therefore every neutral has to be switched to avoid any mutual disturbances between the IMDs.

TT systems are typically used in residential or civil applications. This implies the use of differential protection and therefore a STS system which switches the neutral.

4.8. Maintenance

In order to maximise uptime, it is advisable to perform periodic maintenance on the fans (since they are components subject to wear). It is important that maintenance is performed by expert personnel authorised by the STS system manufacturer.

4.9. Directives and Standards

EEC 73/23 "Low-Voltage Directive"

EEC 89/336 "Electromagnetic Compatibility Directive"

IEC 62310-1 "Static Transfer Systems: general and safety requirements"

IEC 62310-2 "Static Transfer Systems: electromagnetic compatibility (EMC) requirements"

IEC 62310-3 "Static Transfer Systems: Method for specifying performance and test requirements"

IEC 60364-4 "Electrical installations of buildings"

IEC 60950-1 "Safety of IT. equipment"

IEC 60529 "Degrees of protection provided by enclosures (IP)"

IEC 60439-1 "Low-voltage switchgear and control gear assemblies"

5. COMMUNICATION

5.1. Protocols

- SMTP: communication protocol for email transmission, supported by all email clients;
- SNMP: protocol used to monitor networked devices; requires compatible software;
- HID: Human Interface Device, a protocol included in Windows and MAC OSx operating systems;
- JBUS/MODBUS: the most commonly available communications protocol for connecting industrial electronic devices;
- PROFIBUS & PROFINET: protocol for industrial and process automation, used by Siemens;
- TCP/IP: a suite protocols used to transmit information over the Ethernet;
- http: protocol used to transfer web pages in HTML format.

5.2. Physical supports

Physical infrastructures which convey information using communication protocols.

- USB: serial communication standard which enables various peripherals to be connected to a computer;
- Ethernet: interface for local area networks (LAN);
- RS 232: low-speed serial interface for data exchange between digital devices, suitable for distances of up to 10 m;
- RS 485: serial interface for data exchange between digital devices, suitable for distances of up to 1000 m;
- Dry contacts. interface with contacts which have no electrical potential and which can be NO (normally open) or NC (normally closed).

5.3. Remote services

UPS and STS systems must be able to remotely communicate their operating statuses, electrical / environmental parameters and fault alarms. Furthermore, certain commands should be possible for remote control of the equipment.

Some remote monitoring services operate 24 hours a day, 365 days a year, enabling equipment to be installed in places where human supervision is limited (to working hours) or absent. The rapid notification of abnormal events allows for prompt intervention by the technical support service, resulting in reduced risk and MTTR.

6. TOTAL COST OF OWNERSHIP (TCO)

6.1. Definition

Total Cost of Ownership (TCO) includes all of the direct and indirect costs over the lifetime of the equipment. It defines:

- CAPEX: cost of the equipment, its installation, system modifications if required and operator training;
- OPEX: costs of running the equipment, e.g. power consumption, cost of installation space (for example, the share of building rent proportional to the area occupied by the equipment), as well as routine and non-routine maintenance.

6.2. Impact of UPS or STS systems on the TCO

6.2.1. THDi and cosφ input

Valid only for UPS.

High harmonic content of the input current and low cos φ imply the use of harmonic filters, overrating of cables and protection devices as well as the risk of nuisance trips. In economic terms, this means higher project, system and installation costs and higher costs due to system downtime. Optimum situation: low harmonic content and high cos φ.

6.2.2. Footprint

The floor space occupied by the equipment. Can be net or gross, plan dimensions of the equipment and plan dimensions plus space required for operation and maintenance respectively.

UPS and STS systems do not generate value, but their purpose is to protect equipment which does generate value (servers, industrial processes). Therefore the space occupied is not available to the actual production process itself. In the case of *data centres*, it is the space where it is not possible to install the servers. Optimum situation: minimal footprint.

6.2.3. Performance

Efficiency refers to the proportion of input energy available to the load. Indirectly it is the measurement of losses, e.g. energy paid for but not used. Given that fossil fuels can be used to produce electrical energy (releasing gases that cause the greenhouse effect in the atmosphere), energy losses also entail unnecessary gas emissions and their corresponding impact on the environment.

Optimum situation: high efficiency.

6.2.4. Front access and ventilation

An equipment unit with front access notably simplifies routine and non-routine maintenance operations, leading to a considerable reduction in repair times (MTTR) compared to equipment which must be moved in order to gain access to the sides or rear.

Furthermore, equipment with front access only, incorporating a front air inlet and top air outlet, allows for wall-mounted installation and therefore a reduced gross footprint.

6.2.5. Ease of use

In its popular publication *Tier Classifications define site infrastructure performance*, the Uptime Institute states that 70% of downtime is caused by human error (mistakes in checking and routine maintenance).

Equipment which is easy to use reduces these risks, lowers downtime costs and requires shorter, less intensive training for operators.

6.2.6. Communication systems

Remote monitoring and control enable time and human resources to be streamlined while reducing maintenance and repair times in the event of abnormal situations. For this reason, the equipment must be capable of being integrated into Building Management Systems (BMS).

7. ENVIRONMENTAL COMPATIBILITY

7.1. RoHS and WEEE directives

The official stance of CEMEP (Comité Européen de Constructeurs de Machines Electriques et d'Electronique de Puissance - European Committee of Manufacturers of Electrical Machines and Power Electronics) is that the RoHS and WEEE directives do not apply to UPS.

7.2. Performance

The only reference for efficiency performance is given by the European Code of Conduct (http://re.jrc.ec.europa.eu/energyefficiency/html/AC%20UPS-ParticipantsCoC.htm). Manufacturers can adhere to it on a voluntary basis by committing to the minimum efficiency requirements of the code.

8. DIRECT ENERGY IMPACT

The energy efficiency of an equipment unit is defined as:

$$\eta = \frac{P_{out}}{P_{in}}$$

where:

- Pin is the input power
- Pout is the output power, which in the case of the UPS coincides with the Pn (nominal power).

Using simple calculations we can determine heat loss (Perd) as follows:

$$P_{erd} = P_n \left[\frac{1-\eta}{\eta} \right]$$

Approximately 0.61kg of carbon dioxide is generated per kWh of energy lost (http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html#electric), with the resulting environmental consequences and an average energy cost in Europe of 0.12€.

$$P_{erd_{93\%}} = 150\ kW \left[\frac{1-0,93}{0,93} \right] \cdot 24 \cdot 365 = 98,9\ MWh \longrightarrow 60\ t_{CO2} + 11800\ €$$

$$P_{erd_{96\%}} = 150\ kW \left[\frac{1-0,96}{0,96} \right] \cdot 24 \cdot 365 = 54,7\ MWh \longrightarrow 33\ t_{CO2} + 6600\ €$$

On a load-for-load basis, the UPS with 96% efficiency achieves an annual saving of 5200€ and 27t of carbon dioxide for air conditioning alone, the same output as a car manufactured in 2005 with 170,000km on the clock. (http://en.wikipedia.org/wiki/European_emission_standards).

9. IMPACT ON AIR CONDITIONING

Electrical losses are dispersed, in the form of heat, into the environment. In applications where the temperature must be controlled and the heat capacity of the environment is insufficient, measures must be taken to cool the environment. There are different ways of doing this: from simple ventilation, e.g. the movement of air masses of the desired temperature which are already available in the vicinity of the installation, to air conditioning, e.g. the cooling and circulation of air masses.

There are also technologies based on the use of water as a heat transfer fluid, but this is less common.

Air conditioning is the most frequently used technology. The parameter which measures the electrical energy needed to release energy in the form of heat is Coefficient of Performance (COP). When talking about electricity, we normally refer to power instead of energy, consequently the definition of COP. becomes:

$$C.O.P. = \frac{P_t}{P_e}$$

where:

- Pt: the thermal power to be released;
- Pe is the electric power needed to do it.

With close approximation, 3 can be considered as a typical COP value.

This means that for every 3 kW of thermal power dissipated, 1 electrical kW is needed.

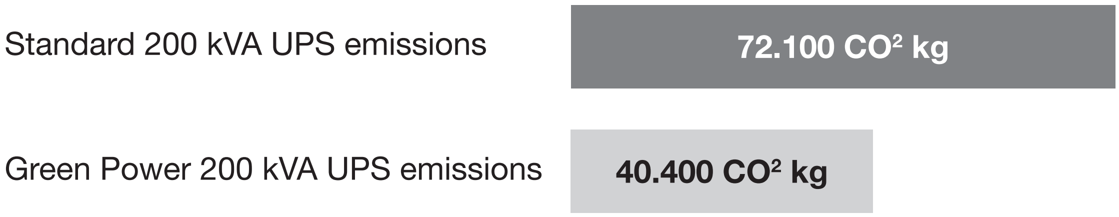
This means that the efficiency rating of plant equipment is only partly able to quantify heat dissipation, since it does not take into account the energy needed to achieve it.

By way of indication, below are the annual air conditioning costs in relation to the example given in the previous paragraph (two different UPS with respective efficiency ratings of 93% and 96%, considering an average annual energy cost in Europe of 0.12 €/kWh).

$$HVAC_{93\%} = \frac{98{,}9\ MWh}{3} \cong 33\ MWh \longrightarrow 20\ t_{CO2} + 4000\ €$$

$$HVAC_{96\%} = \frac{54{,}7\ MWh}{3} \cong 11\ MWh \longrightarrow 11\ t_{CO2} + 2200\ €$$

On a load-for-load basis, the UPS with 96% efficiency achieves an annual saving, for air conditioning alone, of 1800 € and 9 t of carbon dioxide. Taking into account direct heat loss, the savings increase to 7200 € and 36 t of CO$_2$.



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