

UPS topologies and standards

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UPS topologies and standards

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With the vast increase in the number and types of sensitive loads, the term UPS (Uninterruptible Power Supply) is now used to identify devices with power ratings ranging from a few hundred VA, designed to protect desktop computer hardware, up to several million VA (MVA), for large computer and telecommunications centers.

At the same time, the techniques employed have diversified and the names used for the products on the market are at times not very clear, to the point of even being misleading to consumers.

That is why the **IEC** (International Electrotechnical Commission) established standards for the different types of UPS and the methods used to measure their performance. The contents of these standards were adopted by **Cenelec**, the European standardization committee.

Standard **IEC 62040-3** and its European equivalent **ENV 50091-3** now clearly define three types of standardised UPS and the methods used to measure their performance.

The three types of UPS are:

- **passive standby;**
- **line-interactive;**
- **double conversion.**

A comparison between the three UPS topologies shows that the double-conversion topology offers many advantages, due primarily to the position of the UPS connected in series with utility power. Advantages include:

- isolation of the load from the upstream distribution system;
- very wide input-voltage tolerances and precise regulation of the output voltage;
- precise regulation of the output frequency, and possibility of the UPS operating as a frequency converter (if configured for that purpose);
- much superior performance under steady-state and transient conditions;
- no break in the supply of power to the load during transfers to (battery) backup operation and bypass mode;
- manual bypass designed to facilitate maintenance.

What is more, this type of UPS has very few weak points, with the exception of higher price, which is compensated by the superior level of performance that is often indispensable given the critical nature of the loads protected.

In comparison, the other topologies present the following disadvantages:

- no voltage regulation for passive-standby UPS;
- no frequency regulation for passive-standby and line-interactive UPS;
- very basic protection (often just a surge arrester) from utility power disturbances due to the position of the UPS connected in parallel with the utility power supply for passive-standby and line-interactive UPS.

For the above reasons:

At low power ratings (< 2 kVA), the three types of standardised UPS are all employed, however for higher power ratings, double conversion UPS are used almost exclusively.

1. standards

the need for a new standard

diversification in UPS types

Mass-produced UPS first appeared on the market in the 1970s, essentially to meet the needs of large computer systems in terms of continuity and quality in the supply of electrical power.

They then evolved to adapt to the vast increase in the number of sensitive loads and their diversification, due to the explosion in digital technology. As a result, UPS were modified to meet the needs of applications such as mini and then microcomputers, industrial processes, instrumentation, telecommunication, etc.

Adaptation to markets undergoing such rapid change necessitated a wide series of technological innovations and an extension of power ratings. Progress was made in both directions, toward lower and higher ratings, to meet the respective needs of microcomputers and the vital applications of digital telecommunication systems.

That is why the term UPS today covers very diverse products ranging from a few hundred VA up to several million VA.

imprecise and misleading terminology

During this process of adaptation and change, the techniques employed for UPSs became more diverse, depending on the type of application protected, its criticality and power level. At the same time, the description selected to qualify products was often confusing and even misleading to consumers.

"On-line" UPS

Back in the 1970s, the term "on-line" UPS was commonly used. It refers to a UPS topology comprising primarily (see figure 1):

- an input rectifier/charger that rectifies the AC-input supply voltage used to charge a battery as well as support an inverter;
- a battery supplying backup energy in the event of a utility power outage;
- an inverter that supplies power with a consistently high level of quality (frequency, voltage, etc. within tight tolerances);
- generally speaking, a static switch (static bypass) capable of transferring the load to bypass power without a break in the supply of power, thus enabling "downgraded" operation of the load (i.e. not supplied with quality power via the inverter).

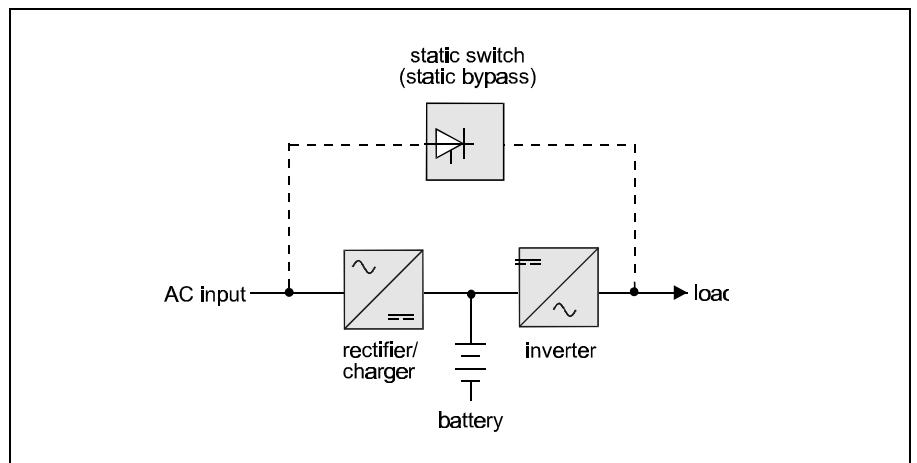


Fig. 1. Simplified diagram of a so-called "on-line" UPS.

The standardisation bodies observed that the term "on-line", which taken literally means "on utility power", does not represent the true situation in this topology. The load is supplied by the inverter and not directly by the AC mains. The term was nonetheless fairly rapidly construed to mean a UPS supplying a load continuously via an inverter connected in series with the AC mains. This term concerns primarily high-power UPS (≥ 10 kVA).

1. standards (cont.)

"Off-line" UPS

In the 1980s, the types of loads and the range of power ratings increased substantially and "off-line" UPSs were developed, the term "off-line" being simply the opposite of "on-line".

This term is used to describe a topology (see figure 2) in which the inverter is not connected in series with the AC-mains, but rather in parallel, in a passive standby configuration. It does not operate continuously, but only when the AC-input supply voltage goes outside tolerances.

This topology includes a filter whose function is not clearly defined and is occasionally presented misleadingly as a voltage-regulation function.

This topology does not include a static switch (static bypass), with a result that load switching times that are too long for some applications.

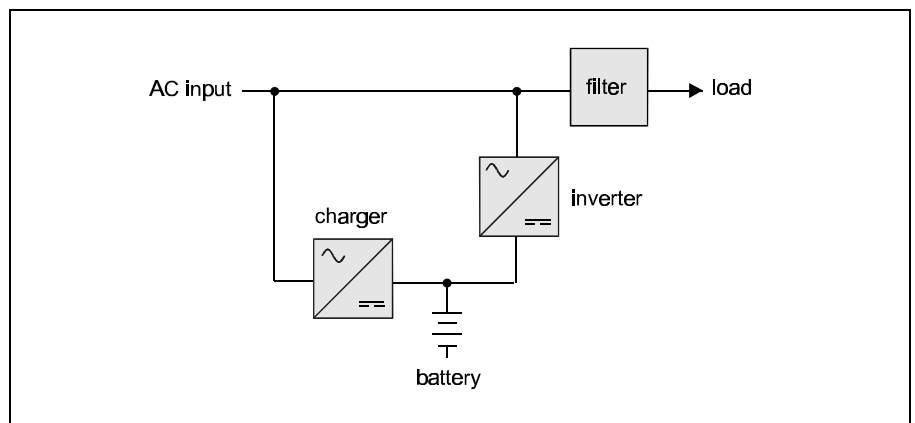


Fig. 2. Simplified diagram of a so-called "off-line" UPS.

Again, the standardisation bodies observed that the term "off-line", which taken literally means "not on utility power", does not represent the true situation in this topology. The load is primarily supplied directly with AC-input power supplied from the utility and the inverter action is demanded only sporadically, in the event of a problem with the utility power.

Users nonetheless fairly rapidly adopted this topology and the term "off-line", primarily for low-power UPS (≤ 2 kVA).

Other terms

In the 1990s, further techniques were developed. The term "line interactive" is used for UPS implementing reversible inverters. However, the uncertainty created by the many versions of topologies exposed consumers to abusive tactics. For example, some UPS were termed "in-line" and in some cases, the term "on-line" was utilised in a very misleading manner.

the new standard

Over a period, this situation, allowed a certain number of ambiguities and even outright fraud, played against the interests of consumers and penalised reputable manufacturers.

The need to establish a standard with clearly defined terms became unavoidable and that is why an IEC (International Electrotechnical Commission) working group undertook to draft a standard on the types of UPS and the methods utilised to measure their performance. Cenelec (European standardisation committee) adopted the contents of the IEC standard.

These efforts produced IEC 62040-3 standard and its European equivalent ENV 50091-3 (where the V indicates a prestandard, issued for a three-year trial period), which clearly define the standardised types of UPS and the methods used to measure their performance.

The standardised types of UPS are presented, in following pages, with the advantages and disadvantages of each type and their field of application.

2. standardised UPS topologies

definitions

Standards **IEC 62040-3** and **ENV 50091-3** distinguish the following three types of UPS topologies:

- **passive standby;**
- **line-interactive;**
- **double conversion.**

These terms refer to UPS operation with respect to utility power, i.e. the distribution system upstream of the UPS.

The standards define the following terms for input power:

- **primary power:** power normally continuously available which is usually supplied by an electrical utility company but sometimes by the user's own generation;plant.
- **standby power:** power intended to replace primary power in the event of primary power failure.

Practically speaking, a UPS has one or two inputs:

- the **normal AC input** (sometimes called Mains 1) is supplied with **primary power**;
- the **bypass AC input** (sometimes called Mains 2), when it exists, may also be supplied with **primary power** or, where possible, with **back up power** (for instance a separate cable from the same main low-voltage switchboard).

passive-standby UPS

passive-standby operating principle

*The inverter is connected in **parallel** and acts simply to **backup** utility power.*

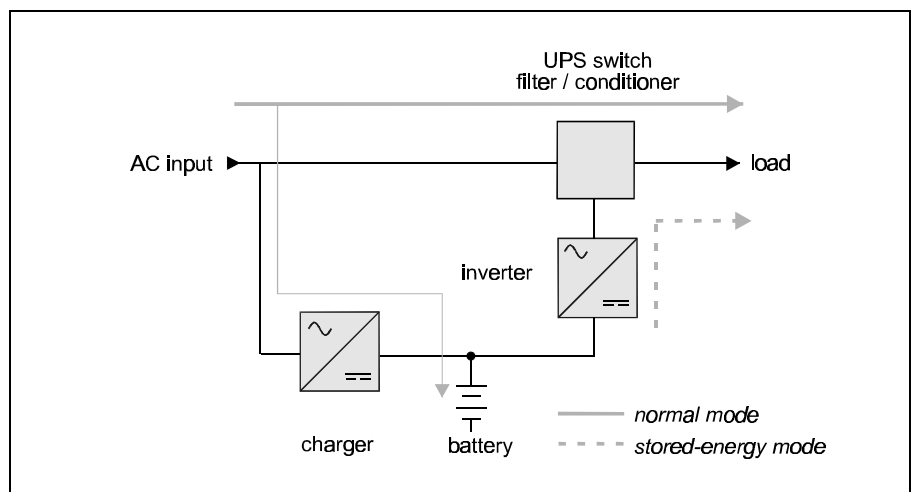


Fig. 3. UPS with the passive standby topology.

■ normal mode

□ The load is supplied with utility AC-input supply, generally via a filter / conditioner which eliminates certain disturbances and can also provide voltage regulation.

The standards do not mention this filter and speak simply of a "UPS switch". They do, however, stipulate that "Additional devices may be incorporated to provide power conditioning, e.g. ferro-resonant transformer or automatic tap changing transformers".

□ The inverter is on passive standby.

2. standardised UPS topologies (cont.)

■ stored-energy mode

- When the AC-input supply voltage goes outside the specified tolerances or fails, the battery and the inverter ensure continuity in the supply of power to the load with a very short switching time (generally < 10 ms). The standards do not mention a specific time, but do stipulate that "the load [is] transferred to the inverter directly or via the UPS switch (which may be electronic or electro-mechanical)".
- The UPS continues to operate on battery power for the duration of the backup time or, as the case may be, until the AC-input supply voltage returns to within the specified tolerances, at which point the UPS returns to its normal mode.

advantages

- simple design.
- low cost.
- small size

disadvantages

- no real isolation of the load from the upstream distribution system.
- long switching time. The absence of a true static switch means the time required to switch the load to the inverter is relatively long. Though acceptable for certain applications (stand-alone computers, etc.), this level of performance is not compatible with the needs of large and complex groups of sensitive loads (large computer centers, telephone exchanges, etc.).
- no regulation of the output voltage.
- no regulation of the output frequency, which depends on that of the AC-input mains.

applications

This topology is the result of a compromise between an acceptable level of protection against disturbances and cost.

It is in fact simply a reproduction of the "off-line" topology presented in the beginning of this document. The standards advise that the term "off-line" should not be used. They recommend use of the term "passive standby" which is a much more accurate description of the operating principle.

Practically speaking, due to the disadvantages stated above, this UPS topology is used only for **low power ratings** (< 2 kVA). It cannot be used for frequency conversion.

line-interactive UPS

line-interactive operating principle

*The inverter is connected in **parallel** and acts to **backup** utility power. It also **charges the battery**. Through its reversible operation, it interacts with utility power. The so called "Boost/Buck", "AVR" (automatic voltage regulation) and "Delta Conversion" topologies belong to the line-interactive category.*

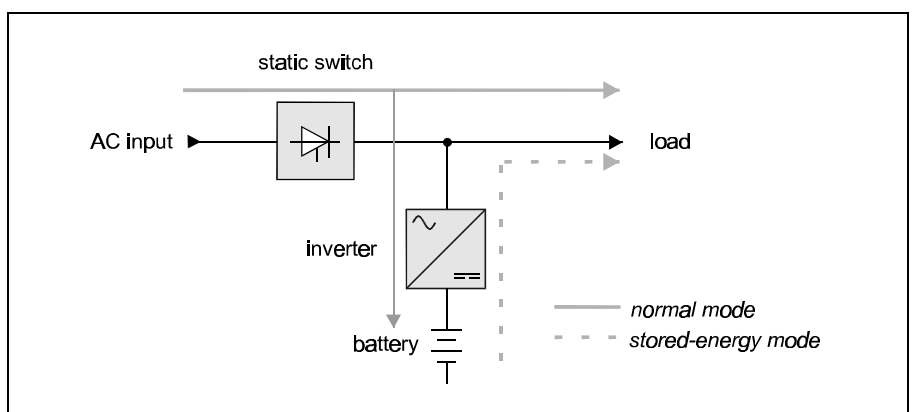


Fig. 4. UPS with the line-interactive topology.

2. standardised UPS topologies (cont.)

The standards define three operating modes.

■ normal mode

The load is supplied with “conditioned mains power” via a parallel connection of the UPS inverter with the AC mains. The inverter is operational to provide output voltage conditioning and/or battery charging.

The output frequency is dependent upon the AC mains-input frequency.

■ stored-energy mode

□ When the AC-input supply voltage goes outside UPS preset tolerances or fails, the inverter and battery maintain continuity of power to load. The switch (e.g. a static switch) disconnects the AC-input supply to prevent backfeed from the inverter.

□ The UPS runs in stored-energy mode for the duration of the stored-energy time or until the AC-input supply returns to within UPS design tolerances, at which point the UPS returns to normal mode of operation.

■ bypass mode

This type of UPS may include a maintenance bypass. In the event of a UPS internal malfunction, the load may be transferred to the bypass input via the maintenance bypass.

advantages

■ the cost may be lower than a double-conversion UPS of equal power rating.

disadvantages

■ no real isolation of the load from the upstream distribution system.

■ no regulation of the output frequency, which depends on the AC-input mains supply.

■ poor protection against spikes and overvoltages

■ output-voltage conditioning is mediocre because the inverter is not connected in series with the AC input. The standard speaks of “conditioned power” via a parallel connection of the AC input and the UPS inverter. Conditioning is however limited due to the reversible operation of the inverter.

■ poor efficiency when operating on non linear loads.

applications

This topology is poorly suited to sensitive loads with medium to high power ratings because **frequency regulation is not possible**. For this reason, it is almost never used at such ratings.

double-conversion UPS

double-conversion operating principle

☞ *The inverter is connected in series between the AC input and the load. Power for the load flows continuously through the inverter.*

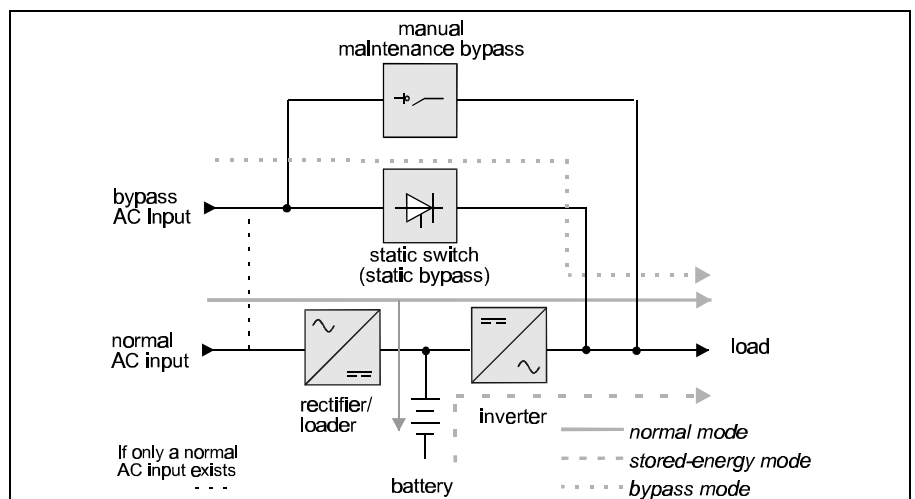


Fig. 5. UPS with the double-conversion topology.

2. standardised UPS topologies (cont.)

The standards define three operating modes.

■ normal mode

The load is continuously supplied via the rectifier/charger - inverter combination which carries out a double conversion AC-DC-AC, hence the name of the topology.

■ stored-energy mode

□ When the AC-input supply voltage goes outside UPS preset tolerances or fails, the inverter and battery continue to support load power.

□ The UPS runs in stored-energy mode for the duration of the stored-energy time or until the AC-input supply returns to within UPS preset tolerances, at which point the UPS returns to normal mode.

■ bypass mode

This type of UPS is generally equipped with a static bypass (often called a static switch).

If a static bypass is present, the load can be transferred without a break to the AC bypass via the static bypass under the following conditions:

□ UPS internal malfunction;

□ load current transients (inrush or fault clearing);

□ overloads;

□ end of battery backup time.

However, presence of a bypass implies that the input and output frequencies must be identical and that a transformer must be installed in the bypass if the input and output voltages are not the same.

The UPS is synchronised with the source of the bypass AC supply to ensure transfer of the load without a break of power.

Note. Another circuit, called the maintenance bypass, is usually provided for maintenance purpose. Operation is carried out by a manual switch.

advantages

■ continuous protection of load is provided from the inverter, whether it originates from the AC-input supply or the battery.

■ isolation of the load from the upstream distribution system, thus eliminating transmission of any upstream fluctuations such as spikes and over voltages to the load.

■ very wide input-voltage tolerances and precise regulation of the output voltage.

■ precise regulation of the output frequency and possibility of the UPS operation as a frequency converter (if configured for this purpose) by disabling the static switch.

■ much superior performance levels under steady-state and transient conditions.

■ instantaneous transfer to stored-energy mode in the event of an AC-input supply failure.

■ no-break transfer to bypass mode.

■ manual bypass designed to facilitate maintenance.

disadvantages

■ higher price, compensated by the numerous benefits.

applications

This is the most complete topology in terms of load protection, regulation possibilities and performance levels. It is in fact the "on-line" topology presented in the beginning of this document. The standards state the term "on-line" and advise that it should not be used. They recommend use of the term "double conversion" which is a much more accurate description of the operating principle.

This topology makes possible no-break operation during load transfers from normal mode to the bypass mode and back, using the static switch. It also ensures total independence of the output voltage and frequency with respect to the input voltage and frequency.

Due to their numerous advantages, **double conversion UPS are used almost exclusively for the protection of critical application of higher power ratings** (from 10 kVA and upwards).

3. conclusion

The new standard **IEC 62040-3** and its European equivalent **ENV 50091-3** have put an end to a difficult situation for customers by defining three types of UPS and the methods used to measure their performance levels.

The three standard types of UPS are defined by their topology and their operating principle.

The three types of UPS have the following topologies:

- **passive standby** (formerly called off-line);
- **line-interactive**;
- **double conversion** (formerly called on-line).

The standards recommend use of the above terms and discourage use of the old terms, because the new ones are much more accurate descriptions for the respective UPS operating principles.

The following key points may be noted from the comparison of the three UPS types.

Double-conversion UPS represent the vast majority of sales for **medium to high power ratings** (95% from a few kVA upwards and 98% above 10 kVA).

This is because the double-conversion topology offers a **large number of advantages** in meeting the needs of sensitive loads at these power ratings, due primarily to the position of the UPS connected in series with utility power. Main advantages are:

- continuous conversion of the power supplied at the inverter output for the load;
- isolation of the load from the upstream distribution system;
- very wide input-voltage tolerances and precise regulation of the output voltage;
- precise regulation of the output frequency, and possibility of the UPS operation as a frequency converter (if configured for this purpose);
- much superior performance levels under steady-state and transient conditions;
- no-break transfer to stored-energy mode and bypass mode;
- manual bypass designed to facilitate maintenance.

What is more, this type of UPS has **very few weak points**, with the exception of the higher price, which is compensated by the superior level of performance that is often indispensable given the critical nature of the loads supported. Efficiency is also somewhat lower (a few percentage points).

For the medium to high power ratings, **the other topologies are marginal at best**, in spite of their significantly lower cost.

They also have the following disadvantages:

- no voltage regulation for passive-standby UPS;
- no frequency regulation for passive-standby and line-interactive UPS;
- rudimentary isolation (often just a surge arrester) from mains power due to the position of the UPS connected in parallel with mains power.

In conclusion:

☞ **For low power ratings (< 2 kVA), the three types of standardized UPS are all employed.**

Selection is determined by the performance to cost ratio, in terms of what the load can handle and the acceptable level of risk (for users, cost of production losses, etc.).

☞ **For high power ratings, double conversion UPS are used almost exclusively.**

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