

Dear ENERGY STAR,

To ensure a topology & alternative energy "neutral" position, we submit the following suggested modifications to the ENERGY STAR Uninterruptible Power Supply specification:

Page 2:

- line b.2. Line Interactive definition includes the statement "requires a small trickle current to the battery..." which presumes a battery source. Line should be modified to be inclusive of flywheel technology or technology neutral: "requires a small trickle current to the battery or flywheel energy source." or "requires a small trickle current to the alternative energy source."
- item c. 2.
 - Rotary (Flywheel). Combination of the term "Rotary" with "Flywheel" would suggest that these two terms are synonymous - which they are not. Suggest that the term "Kinetic energy" be used to replace both Rotary and Flywheel in this instance.
 - Also, the term "massive" is subjective and suggest that "A flywheel provides energy storage in the form of a spinning mass or disk" may be a more appropriate statement.
 - Reference to "disk transfers momentum to an electrical generator" is specific to one type of technology utilizing kinetic energy and should be removed.
 - Consider:
"c. 2. Kinetic Energy: A flywheel provides energy storage in the form of a spinning mass or disk. When power from the normal source is interrupted, power to the load is fed by the inertia of the flywheel through either an inverter (static UPS) or an electrical generator (rotary UPS). Ride-through time for UPS systems utilizing Kinetic energy as the energy storage medium is commonly measured in seconds or minutes of ride-through."
- item c.3. The statement "Double Conversion UPSs are common in high-reliability applications" is subjective and should be removed. It can be argued that Line Interactive UPS technology with Flywheel energy storage is also common in high-reliability applications.

Page 3:

- item e.2.
 - **Stored Energy State:** Modify sentence as highlighted "The operating state in which the electric load is actively being supplied by the UPS due to a utility power disruption."
 - Each of the listed definitions for Stored Energy State presuppose use of batteries as the energy source. Suggest modifying each of the descriptions to state "where the alternative energy source supports the load".
- item d. Questions for Discussion
 - 1 & 2 - Please see provided "UPS Types and Topologies paper" for additional source of input for EPA
 - 5 - Consideration should be given to the impact of efficiency over time and use of the UPS. Does degradation of the alternative power source over time (months/years) impact efficiency of the UPS?
 - 6 - Weight should be given to those technologies which do not employ an electrochemical battery as should those organizations that provide proof of an existing (and effective) battery recycling program

Thank you for your consideration and the opportunity to comment on the ENERGY STAR UPS specification.

Best Regards,

Don Dentino
Caterpillar, Inc.

UPS Types and Topologies

INTRODUCTION

The aim of this paper is to provide a high level description of common UPS topologies, and clarify some of the terms often used in the UPS industry. Among them are: Off-Line and On-Line UPS, Passive Standby, Double Conversion, and Line Interactive. This terminology has not been consistently used throughout the UPS industry, and some confusion exists. For example, a Passive Standby UPS is also called Off-Line UPS since its inverter is only active when primary/main power is not present. The Double Conversion UPS is often referred to as On-Line UPS since the UPS inverter is active at all times, continuously providing power to the load. However, the Line Interactive UPS would fit the On-Line UPS definition, as the inverter continuously supplies power for either conditioning the line when the normal source is present, or feeding the load directly when not, but it is rarely referred to it as such. In addition, multiple UPS topologies have emerged over time blurring the lines on their classification. Furthermore, most UPS designs include a means to power the load directly from the main power source known as a “bypass”. This adds operational flexibility as well as ease of maintenance, testing, diagnostics, etc. In some cases this is done using mechanical switches, and in others utilizing electronic static bypass switches. This is primarily a design issue not a topology feature. In an effort to formalize the use of the terminology, this paper draws from the European Committee for Electrotechnical Standardization where only three UPS types are defined based on their mode of operation (see Standard EN 62040-3). They are: 1) Passive Standby, 2) Double Conversion, and 3) Line Interactive.

TOPOLOGIES

Passive Standby – Any UPS operation where, in normal mode of operation, the load is supplied by primary power and is subject to input voltage and frequency variations within stated limits. When the AC input supply is outside UPS design load tolerances, the UPS inverter is activated (using stored energy, e.g. battery power) and maintains continuity of load power in stored energy mode of operation. By far this is the simplest topology as shown in Figure 1. In this system, the voltage and frequency of the utility/main source is continuously monitored. If those parameters are within a set range, e.g. +/- 10%, unconditioned utility power directly feed the load through a fast acting static switch. Under this condition the inverter remains energized, but it does not provide power to the load. The load is exposed to any power quality event present on the utility. Some designs incorporate a line filter and surge circuitry to provide basic noise filtration and surge protection capabilities. The topology is not capable of controlling line frequency variations. Any line voltage distortion or unbalance is passed on to the load. When operating parameters fall outside acceptable limits the static switch opens up and the load is fed directly by the inverter. This transition is relatively fast, but not seamless. For severe faults, e.g. power loss, the static switch could open as fast as 1 millisecond, but in other scenarios it could take as long as one-half cycle. Voltage and frequency regulation, as well as quality of power, is determined by the capabilities of the inverter. This inverter is generally a lower grade than those used in higher performing topologies. Also, the rating of the rectifier (AC-DC converter) is typically fraction of the inverter rating as its purpose is to charge the battery (not to supply power to the inverter). The main benefit of this approach is lower cost. Overall efficiency of this system is high, since the load is supplied directly by the main AC source the majority of the time, and minimal power conversion losses are incurred when the utility is present. Only a small fraction of the input power is used to keep the energy storage medium charged and overcome parasitic losses. Other benefits of this topology include smaller size, ease of integration (it is primarily either on or off), and simpler controls. Among the drawbacks of this topology are that it does not allow for conditioning of utility power in standby

mode, leading to more frequent engagement of the energy storage mode, and a reduction in battery life. This topology is rarely used on larger power applications.

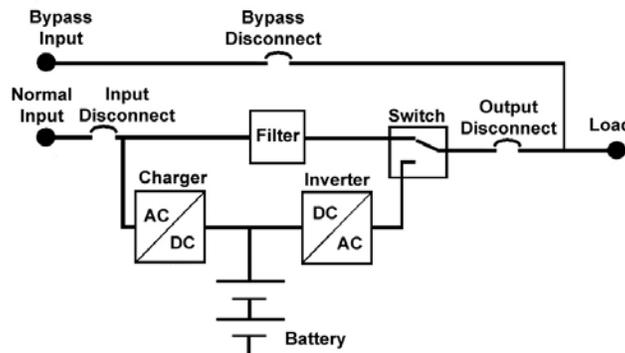


Figure 1: Passive Standby

Double Conversion – Any UPS operation where continuity of load power is maintained by a UPS inverter, with energy from the DC link in normal mode of operation or from the energy storage system in stored energy mode of operation. The output voltage and frequency are independent of input voltage and frequency conditions ... The double conversion UPS represents the antithesis of the Standby approach. The topology is shown in Figure 2. The inverter is connected in series between the primary AC source and the load, with power to the load flowing continuously through the inverter. As far as the load is concerned, it is indistinguishable whether the inverter uses utility power as a source or the stored energy (unless it is depleted). In normal mode, the AC input from the utility is rectified establishing a DC link voltage. If the energy storage medium is a battery, the DC link voltage would typically be the charging voltage of the battery. Hence, the power drawn from the input AC source is equal to the power delivered to the load, plus the power absorbed by the battery to keep it charged, plus the power to cover parasitic losses. This continuous conversion of the entire AC input power into DC is what makes this topology less efficient than other topologies. However, this method enables the total decoupling between the input power source and the power delivered to the load. This results in a topology that offers the highest potential value to quality power applications where tight voltage and frequency regulation with low waveform distortion are sought. To capitalize on these benefits, this approach requires a high end inverter capable of producing very clean power. Also, the rectifier rating is significantly larger than in other topologies (slightly larger than the inverter itself as opposed to just large enough to charge the battery) requiring more complex line filtering and power factor correction. Generally speaking, performance is higher, efficiency is lower, and the technology is more expensive. In an effort to reduce power consumption, some double conversion UPS systems provide an additional mode of operation where a double conversion system is operated as a passive standby unit during normal operation (some manufactures refer to it as eco-mode). While this negates most of the benefits of the double conversion topology, but it reduces operating cost during those times when clean power may not be a firm requirement and/or the utility source is likely to meet them.

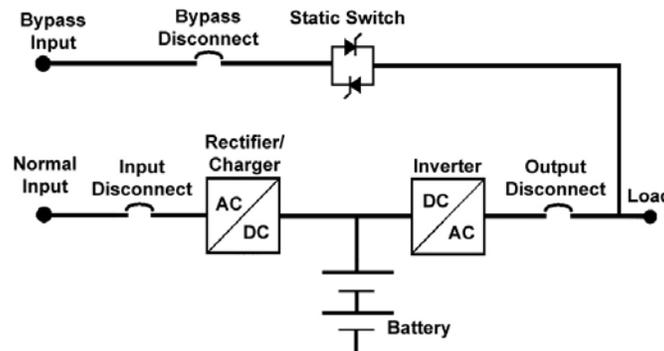


Figure 2: Double Conversion

Line Interactive – Any UPS operation where, in normal mode of operation, the continuity of load power is maintained by the use of a UPS inverter or a power interface while conditioning primary power at the input supply frequency. When the AC input voltage and/or frequency is out of UPS preset variation limits, the UPS inverter and energy storage maintain continuity of load power in store energy mode of operation within the stated output voltage/frequency tolerances ... The line interactive case is the third UPS type recognized by the standard. As its name implies, it continuously interacts with the line/utility in response to line power events. When main power is available the load is directly powered by the line, with the UPS conditioning line power to improve its quality, compensating for voltage surges and sags, providing VAR support, correcting for line distortion and voltage unbalance. In contrast to double conversion UPS, efficiency is very high since only a small fraction of the total power delivered to the load is used to condition line power and to keep the energy storage fully charged. It has the capability for a very smooth transition between power sources should the main source fail (unlike the standby UPS). This topology lends itself to multiple design variants. It can be implemented using rotating machinery exclusively, or power electronics, or both. A brief description of leading designs follows.

Rotary with Synchronous Flywheel - Figure 3 shows an example of a rotary UPS using a synchronous motor/generator and a mechanical flywheel (FW) as energy storage. In this configuration, the genset (Prime Mover and Synchronous Generator) is an integral part of the UPS system. Note that in all other UPS topologies described in this paper the genset is a separate part of the larger critical power system.

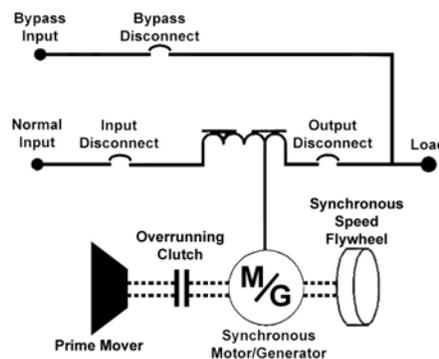


Figure 3: Rotary with Synchronous Flywheel

The synchronous motor/generator is traditionally a salient pole rotating machinery with motor and generator windings on a common stator. When line power is present the motor keeps the flywheel spinning at the synchronous speed (fully charged with kinetic energy). The generator acts as a synchronous condenser providing VAR support and harmonic compensation of the line current. When line power is not present the flywheel (through its stored kinetic energy) provides the mechanical power required to drive the generator (powering the load) until the prime mover is brought up to speed. The inherent advantage of this implementation is the “electrical inertia” that the rotating machinery adds to the system (unattainable with power electronics). This enables the clearing of large faults or starting motors without transferring to bypass operation. A drawback of this design is the large mechanical inertia required of a flywheel to provide sufficient ride through time for a prime mover to start and come up to synchronous speed. To reduce the physical size of the flywheel, while increasing the amount of kinetic energy stored, newer rotary UPS designs use high-speed flywheels spinning at several times synchronous speed as discussed next.

Rotary with Asynchronous/High-Speed Flywheel - Figure 4 shows the rotary design where a high-speed flywheel is mechanically linked to a separate asynchronous motor/generator. Bidirectional power converters are used to control the transfer of power from the asynchronous motor/generator to the synchronous motor/generator, and vice versa. This adds complexity and cost, but longer ride through times become more feasible, and it enables better control frequency as the flywheel discharges. Operationally, the two rotary configurations are equivalent, with the exception that in the asynchronous case the mechanical link between the flywheel and the synchronous generator is replaced with an electrical one. As in the previous case, the Prime Mover and Synchronous Generator still are an integral part of this UPS system.

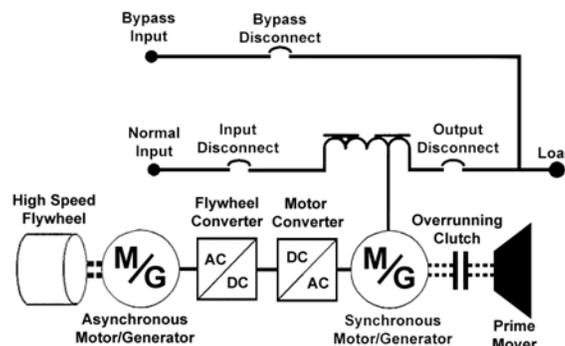


Figure 4: Rotary with Asynchronous Flywheel

Kinetic UPS - A further evolution of the preceding topology is the Kinetic UPS shown in Figure 5. This rendition eliminates the synchronous motor/generator, and the inverter connects directly to two inductors in a choke configuration. Additionally, the high-speed flywheel is integrated with the asynchronous motor/generator. The assembly is partially levitated to reduce bearing losses, and span inside a vacuum chamber to minimize windage losses. The advantage of this design is higher efficiency, smaller size, fewer moving parts, higher reliability, and ease of maintenance. The disadvantage is the lack of “electrical inertia”. However, with proper inverter design and the incorporation of active filtering techniques the topology is capable of very tight voltage regulation, good harmonic suppression, and low waveform distortion. Frequency regulation is determined by the line frequency source when present. In energy storage (discharge) mode, power quality is on par with a double conversion system. Note that the Prime Mover and Synchronous Generator are no longer part of the UPS system.

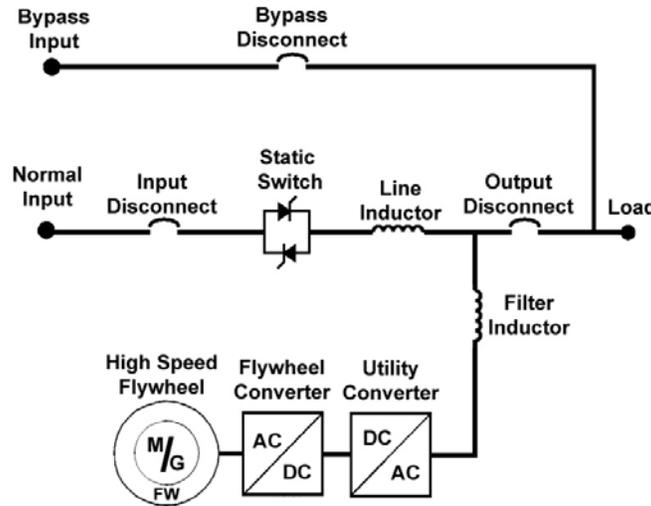


Figure 5: Kinetic UPS

Delta Conversion - The last topology to be reviewed is the Delta Conversion as shown in Figure 6. In this design, two power converters are connected back-to-back through a common DC link established by the battery (energy storage). When line power is present, the series converter regulates the line current through the transformer, and the parallel converter regulates the voltage on the load side. When line power is not present (in energy storage mode) the UPS operates as a double conversion system with the parallel converter providing the entire power to load. As in the other line interactive cases, with proper converter design, this configuration is capable of very tight voltage regulation, good harmonic suppression, and low waveform distortion, but not capable of direct line frequency regulation when not operating in energy storage mode. It is also more efficient than a double conversion system due to the fact that when not in energy storage mode the load is directly supported by the line, and the converter only spends energy conditioning line power, keeping the battery charged, and overcoming parasitic losses (transformer losses, switching losses, etc.)

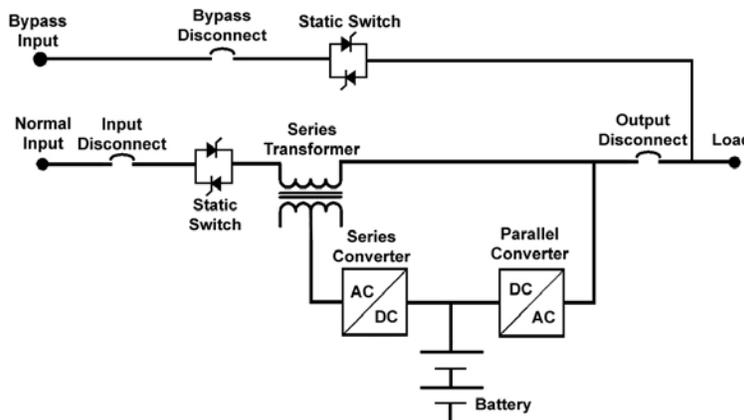


Figure 6: Delta Conversion UPS

SUMMARY

In short, the aim of this paper is to provide a high level description of common UPS topologies. Primary features, benefits, and limitations are highlighted. It should be noted that these are generalizations made in the aggregate sense, and specific characteristics may be improved through specialized designs. Table 1 summarizes key attributes for each topology.

Table 1: Pugh Matrix of Primary Attributes by Topology

Attribute	Passive Bypass	Double Conversion	Rotary Synch-FW	Rotary Asynch-FW	Kinetic	Delta Conversion
Frequency Regulation	-	+	0	0	0	0
Operating Cost	+	-	-	+	+	+
Unit Cost	+	-	0	0	0	0
Power Quality	-	+	0	0	0	0
Size	0	-	-	0	+	0
Ride through time	0	0	-	-	-	0
Scalability	-	+	-	0	+	0

Nomenclature:

(-) not as good as base

(0) same as base

(+) better than base

“base” being a virtual UPS that does everything well

Information contained in this publication may be considered confidential. Discretion is recommended when distributing. Materials and specifications are subject to change without notice.

CAT, CATERPILLAR, their respective logos, “Caterpillar Yellow,” the “Power Edge” trade dress as well as corporate and product identity used herein, are trademarks of Caterpillar and may not be used without permission.