The Different Types of UPS Systems

White Paper 1

Version 8

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Executive summary

There is much confusion in the marketplace about the different types of static uninterruptable power supplies (UPSs) and their characteristics. The IEC 62040-3 UPS performance standard classifies all UPSs based on their output characteristics. In this paper, we summarize the most relevant parts of the IEC standard, then describe 5 types of UPSs, provide practical applications of each, and discuss their advantages and disadvantages. With this knowledge, you can make an educated decision about the best UPS type for your application.

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Introduction

There are two main categories of uninterruptible power supplies (UPSs)[1], static and rotary. As the name implies, static UPSs do not have any moving parts in their converters. Whereas, rotary UPS use mechanical parts that rotate, such as motor/generators, to function. This paper focuses only on static UPSs. For more information on rotary UPSs see White Paper 92, *Comparison of Static and Rotary UPS*. The varied types of static UPSs and their claimed attributes often cause confusion for those selecting them for critical applications such as data centers, hospitals, airports, etc. Such confusion might lead one to believe that a given UPS type is capable of a certain performance level or function that it, in fact, cannot achieve. For example, it is widely believed that all on-line UPSs are capable of frequency regulation, but as we will show in this paper, there are multiple on-line UPS types, and only double conversion UPSs can regulate frequency. Many misunderstandings are cleared up when the output characteristics are properly identified for each of the different types of UPSs.

This paper first discusses the IEC UPS performance standard which is used as a means of classifying various types of UPSs. Since the output performance is the primary reason UPSs are selected for specific applications, it is important to have this background knowledge from the IEC standard before selecting a UPS. We then describe each of the five UPS types in the marketplace including brief explanations about their output characteristics and how each topology works. This will help you to properly identify and compare UPSs for various applications.

UPS output performance

In order to help manufacturers accurately represent their products and to help users understand exactly what they are buying, the *IEC 62040-3: UPS - Method of specifying the performance and test requirements* standard was created. It classifies the output performance of all types of static UPSs[2] and provides test requirements to validate their performance. Output performance is specified in three parts, AAA-BB-CC, which are described in detail in the following subsections.

Part 1: Input dependency (AAA)

The first part of UPS output performance classification is input dependency (i.e., how the UPS's output voltage is dependent upon the quality of the applied input voltage).

The input dependency of a UPS falls into one of three classifications[3]:

- Voltage and Frequency Dependent (VFD),
- Voltage Independent (VI), and
- Voltage and Frequency Independent (VFI).

Each class has different capabilities for solving power problems such as power interruptions, voltage sags and swells, etc. **Table 1** illustrates how a UPS's input dependency performance relates to seven common types of power problems. For detailed information on these seven types of power problems see White Paper 18, *The Seven Types of Power Problems*.

[1] A UPS is normally referred to as an uninterruptible power supply, but it's also known as uninterruptible power system.

[2] Note that rotary UPS are covered in IEC 88528-11:2004 Reciprocating internal combustion engine driven alternating current generating sets - Part 11: Rotary uninterruptible power systems - Performance requirements and test methods.

[3] See the **Appendix** for further information

From **Table 1**, it's clear that a VFI UPS is the highest performance among the three classifications because it can provide protection from power interruptions and perform both voltage and frequency regulation. For more information on the relationship between input and output voltage and frequency for the VFD, VI, and VFI classifications, see **Appendix Figure A1**.

Table 1

Summary of UPS capabilities for protecting the load from power problems by input dependency performance classification

7 types of power problems	Problems addressed by classification		
	VFD	VI	VFI
Power interruptions	✓	✓	✓
Voltage sags and swells	✓	✓	✓
Voltage transients	*	✓	✓
Sustained over- and under-voltages	×	✓	✓
Voltage waveform distortion	×	**	✓
Voltage fluctuations	×	**	✓
Frequency variations	×	×	✓

* Some VFD UPSs may include surge suppression and filtering components to address voltage transients.
** Within the VI category, only on-line UPSs are able to address voltage fluctuation and waveform distortion problems, such as harmonics, inter-harmonic, notching, etc. We will discuss this further in the "UPS types" section.

Part 2: Output voltage waveform (BB)

The second part of UPS output performance classification is output voltage waveform performance in normal mode (first character – i.e. when operating from utility power) and in stored energy mode (second character – i.e. when operating from battery power).

Output voltage waveforms fall into one of three classifications:

- Low THD sine wave denoted by S,
- Medium THD sine wave denoted by X, and
- Non-sinusoidal (e.g. step or square) wave denoted by Y.

For more detail regarding the nine possible combinations, see **Appendix Table A1**. The two common waveform types are sinusoidal (S) and non-sinusoidal (Y). Nearly all UPSs rated 2 kVA and above are classified SS whereas many consumer-oriented UPSs rated below 2 kVA are classified SY.

Part 3: Dynamic output performance (CC)

The third part of UPS output performance classification is dynamic output performance which describes the output voltage variations that occur during changes in operating mode (first character – i.e. when transferring between normal, bypass and stored energy operating modes) and with the application or removal of load (second character).
Voltage variations fall into one of three classifications[4]:

- 1: No interruption with ±20% voltage regulation in < 10ms
- 2: Up to 1ms of interruption with ±20% voltage regulation in < 10ms
- 3: Up to 10ms of interruption with +10%, -20% voltage regulation in < 100ms

[4] See **Figures A5 – A7** in the Appendix for details.

In summary, a UPS's output performance can be described in 3 parts: input dependency (AAA), output voltage waveform (BB), and dynamic output performance (CC). The complete output performance can thus be summarized as: AAA-BB-CC (i.e. VFD-SY-33, VI-SS-31, VFI-SS-11). For more details on this classification in IEC 62040-3, see **Appendix Table A1**.

UPS types

A variety of static UPS types are available in the market, and each has distinct performance characteristics. The most common types are as follows:

- Standby
- Line interactive
- Double conversion on-line
- Delta conversion on-line
- Hybrid conversion on-line

Many UPS types have multiple operating modes, which have different output performance characteristics based on the IEC standard. For example, a double conversion on-line UPS in normal mode may have a VFI output performance, whereas in high-efficiency normal mode, it may have a VFD output performance. There are three common modes of operation:

- **Normal mode** – The UPS powers the load using the AC input power source and the energy storage device (e.g. battery, flywheel, etc.) is connected and is either charging or fully charged.
- **Stored energy mode (battery mode)** – The UPS powers the load using DC power from the energy storage device because the AC input power source is interrupted or is outside of the acceptable voltage or frequency ranges.
- **High-efficiency normal mode** – The UPS powers the load directly from the AC input power source, for the purpose of increasing efficiency, and the energy storage device is connected and is either charging or fully charged. Examples of high efficiency modes include eco-mode and power factor corrected (PFC) eco-mode. For more information on eco-mode see White Paper 157, *Eco-mode: Benefits and Risks of Energy-saving Modes of UPS Operation*.

All types of UPSs have normal mode and stored energy mode while just a few types offer high-efficiency normal mode (as shown in **Table 2**). Other than waveform, the output performance in stored energy mode is similar for all UPS types, therefore we will not discuss it in depth in this paper.

Table 2

High efficiency normal mode availability by UPS type

UPS types	High-efficiency normal mode	
	Eco-mode	PFC Eco-mode
Standby	*	×
Line interactive	**	×
Double conversion on-line	✓	✓
Delta conversion on-line	✓	×
Hybrid conversion on-line	✓	×

* Standby UPSs can be considered to have eco-mode as their normal mode.
** Many Line interactive UPSs can de-energize their automatic voltage regulation (AVR) transformers and essentially operate in eco-mode when doing so.

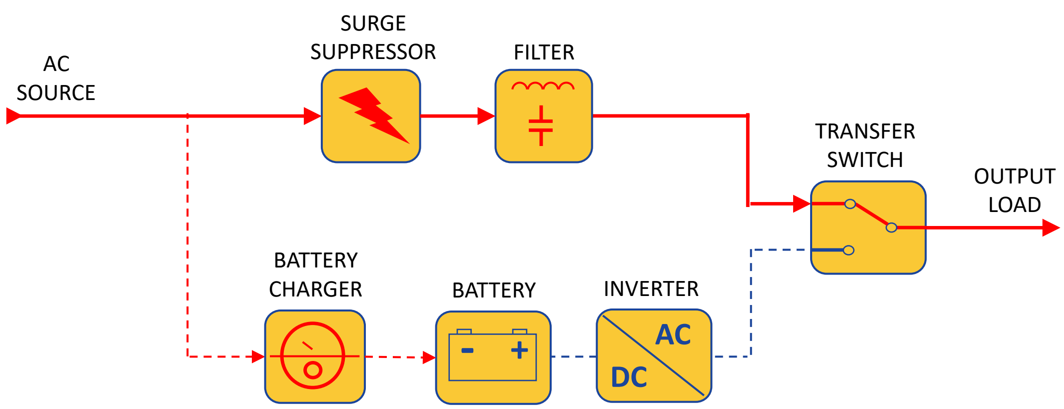
The following subsections summarize each type of UPS with a brief description, topology diagram, benefits, limitations, and IEC output performance.

Standby UPS

Standby UPSs are commonly used to protect individual loads like desktop computers. As shown in the block diagram of **Figure 1**, the transfer switch is set to choose the AC input as the power source (solid line path), and switches to the battery / inverter[5] as the backup source should the primary source fail. When that happens, the transfer switch must operate to switch the load over to the battery / inverter backup power source (dashed path). The inverter only starts when the power fails, hence the name "standby".

Low cost, small size, non-sinusoidal output waveforms, and high efficiency are typical attributes of this UPS type. Some standby UPSs also provide surge suppression and electrical noise filtration.

Figure 1
Standby UPS topology



IEC output performance

Because a standby UPS lacks circuitry to regulate output voltage or frequency in normal mode, the IEC standard classifies the input dependency as Voltage and Frequency Dependent (VFD). Because it passes the sinusoidal AC input voltage through to the load in normal mode and commonly utilizes a square or step wave inverter in stored energy mode, the IEC standard classifies the output waveforms as SY. Because it typically takes almost 10ms to detect a power failure, move the transfer switch, and turn on the inverter; and because the inverter doesn't handle step loads well, the IEC standard classifies the dynamic output performance as 33. The complete output performance is summarized as VFD-SY-33. See the **Appendix** for more details.

[5] An inverter is an electronic device that converts DC voltage into AC voltage.

Line interactive UPS

Line Interactive UPSs are commonly used to protect small quantities of important servers and associated networking equipment. As shown in the block diagram of **Figure 2**, the battery-to-AC power converter (inverter) is always connected to the output of the UPS. Operating the inverter in reverse during times when the input AC power is normal provides battery charging.

When the input power fails, the transfer switch opens and the power flows from the battery to the UPS output. With the inverter always on and connected to the output, this design provides additional filtering and yields reduced switching transients when compared with the standby UPS topology.

In addition, the line interactive design usually incorporates a tap-changing AVR transformer. This adds voltage regulation by adjusting transformer taps as the input voltage varies. Voltage regulation is an important feature when low voltage conditions exist, otherwise the UPS would transfer to battery and then eventually shutdown the load. This more frequent battery usage can cause premature battery failure. However, the inverter can also be designed such that its failure will still permit power flow from the AC input power source to the load, which eliminates the potential of single point failure and effectively provides for two independent power paths.

Low cost, small size, sinusoidal output waveforms, high efficiency, and high reliability coupled with the ability to correct low or high line voltage conditions make this the dominant type of UPS in the 0.5-5 kVA power range.

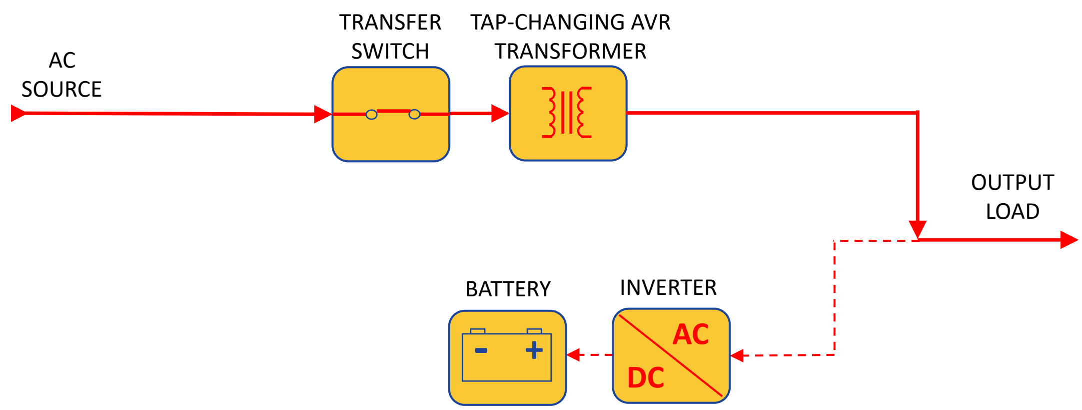


Figure 2
Line interactive UPS topology

IEC output performance

Because a line interactive UPS commonly includes an AVR transformer to regulate output voltage in normal mode, but it cannot regulate frequency, the IEC standard classifies the input dependency as Voltage Independent (VI). Because it passes the sinusoidal AC input voltage through to the load in normal mode and commonly utilizes a sine wave inverter in stored energy mode, the IEC standard classifies the output waveforms as SS. Because it typically takes almost 10ms to detect a power failure, move the transfer switch, and reverse the power flow through the inverter; and because the inverter handles step loads well, the IEC standard classifies the dynamic output performance as 31. The complete output performance is summarized as VI-SS-31. See the **Appendix** for more details.

Double conversion on-line UPS

Double conversion UPSs are the most popular type above 10kVA, and they are commonly used to protect large quantities of critical servers and associated storage and networking equipment. While the standby and line interactive UPS types discussed above have two modes of operation (e.g. normal and battery modes), double conversion UPSs often have one or two additional normal modes; a high-efficiency eco-mode and a high-efficiency PFC (Power Factor Corrected) eco-mode. The following subsections describe each operating mode with respect to power flow, transfer characteristics, and IEC output performance.

On-line normal mode – The double conversion on-line UPS block diagram illustrated in **Figure 3** is similar to that of a standby UPS, except the normal power path to the load is through the PFC rectifier[6] and the inverter instead of through a transfer switch fed from the AC input power source. When the input power fails, the rectifier shuts down and the inverter draws power from the battery to supply the load. Because the power path doesn't change, no switches operate, which results in no interruption of power to the load (i.e. 0ms transfer time).

A double conversion UPS operating in on-line normal mode provides nearly ideal electrical output performance. It draws sinusoidal current from the AC input power source and it provides low distortion, nominal amplitude and frequency, sinusoidal voltage to the load.

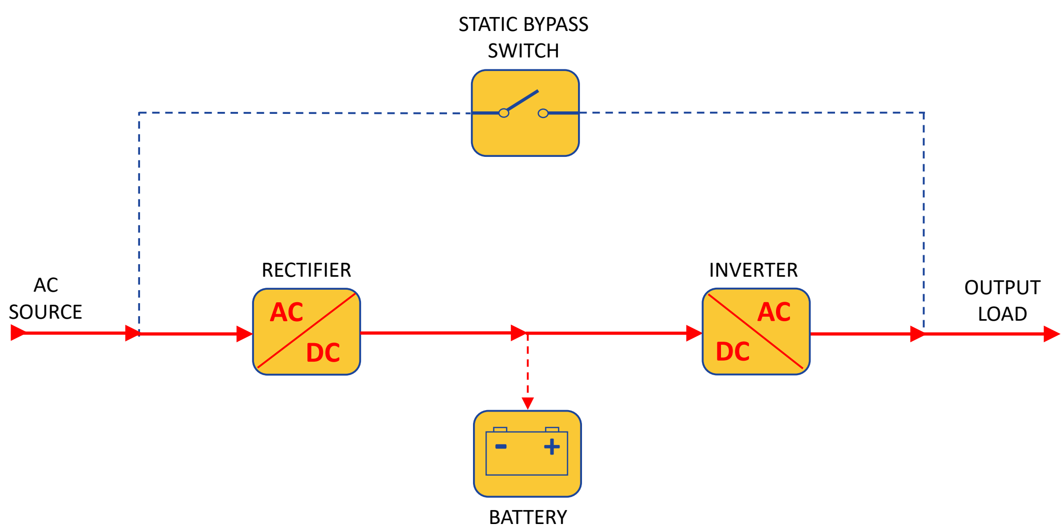


Figure 3
On-line normal mode – double conversion on-line UPS topology

IEC output performance

Because a double conversion on-line UPS operating in on-line normal mode can regulate both output voltage and frequency, the IEC standard classifies the input dependency as Voltage and Frequency Independent (VFI). Because the sine wave inverter powers the load in both normal and stored energy modes, the IEC standard classifies the output waveforms as SS. Because the inverter continuously supplies power to the load during a power failure, and because the inverter handles step loads well, the IEC standard classifies the dynamic output performance as 11. The complete output performance is summarized as VFI-SS-11. See the **Appendix** for more details.

[6] A rectifier is an electronic device that converts AC voltage into DC voltage.

Eco-mode – The block diagram in **Figure 4** illustrates that in eco-mode, the normal power path to the load is through the static bypass[7] switch, the rectifier only operates at low power to charge the battery, and the inverter is in standby. This improves the efficiency of the UPS and extends its service life, due to reduced heat and component stresses. When the power fails the static bypass switch opens and the inverter draws power from the battery to supply the load.

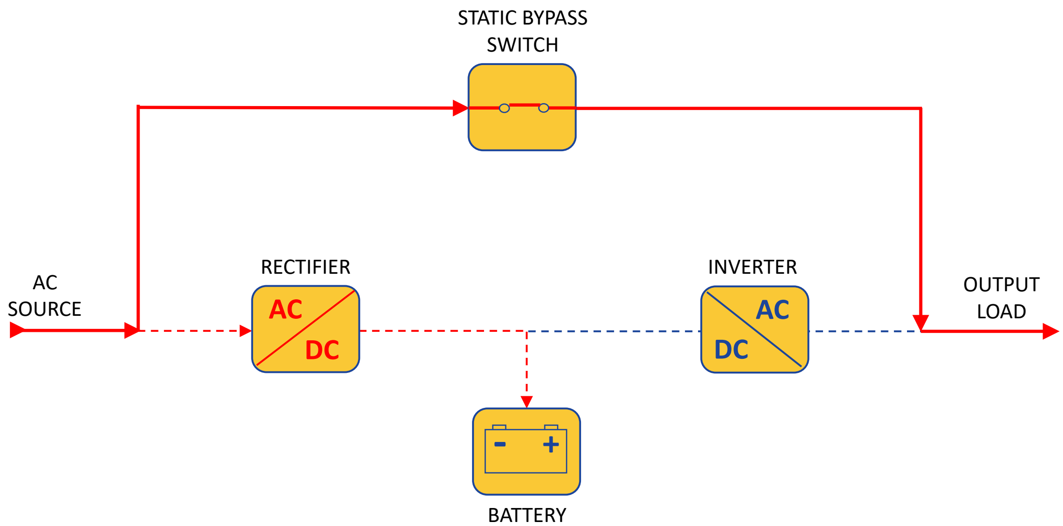


Figure 4
Eco-mode – double conversion on-line UPS topology

IEC output performance

Because a double conversion on-line UPS operating in eco-mode cannot regulate either output voltage or frequency, the IEC standard classifies its input dependency as Voltage and Frequency Dependent (VFD). Because it passes the sinusoidal AC input voltage through to the load in normal mode and the sine wave inverter is used in stored energy mode, the IEC standard classifies the output waveforms as SS. Because it typically takes almost 10ms to detect a power failure, open the static bypass switch, and start the inverter; and because the inverter handles step loads well, the IEC standard classifies the dynamic output performance as 31. The complete output performance is summarized as VFD-SS-31. See the **Appendix** for more details.

[7] As the name indicates, load power bypasses the conversion process.

PFC eco-mode – Similar to eco-mode, the primary power path in PFC eco-mode is through the bypass path. However, as the block diagram in **Figure 5** illustrates, the inverter remains on-line providing the required current to ensure that the AC input power source sees only sinusoidal current with high power factor. PFC eco-mode eliminates the primary drawbacks of eco-mode by reducing transfer time to 0ms and providing PFC input current while achieving nearly the same efficiency.

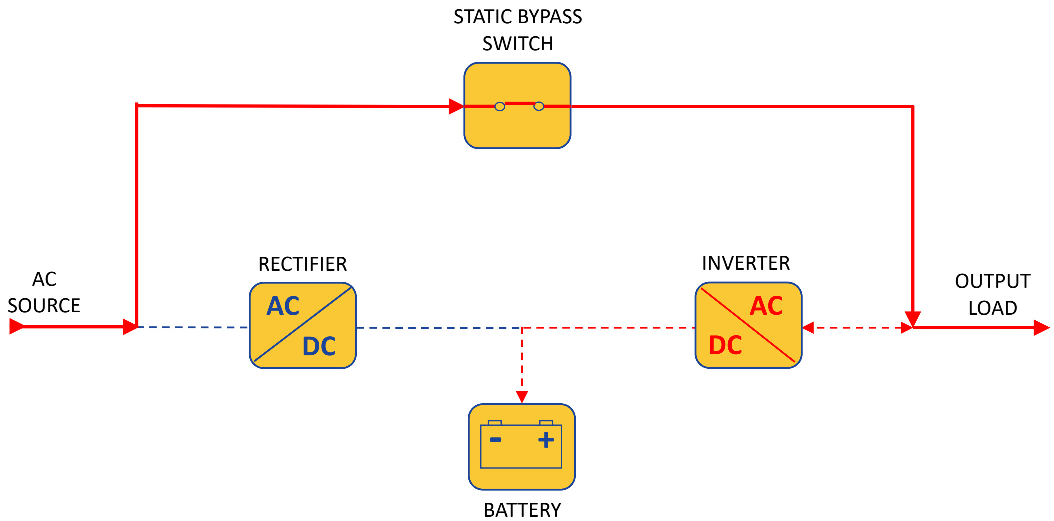


Figure 5
PFC eco-mode – double conversion on-line UPS topology

<u>IEC output performance</u>
When in PFC eco-mode, the output performance is similar to eco-mode except that, because the inverter is always operating, there is no interruption of power to the load during a power failure. Therefore, the output performance is classified as VFD-SS-11. See **Appendix** for more details.

Delta conversion on-line UPS

Delta conversion is a mature technology invented to provide higher on-line efficiency than of the double conversion. It has three modes of operation including normal mode, battery mode, and eco-mode. The following subsections describe each operating mode with respect to power flow, transfer characteristics, and IEC output performance.

On-line normal mode – The block diagram for a delta conversion on-line UPS in normal mode is illustrated in **Figure 6**. Similar to a double conversion on-line UPS, in normal mode, the delta conversion on-line UPS always has the inverter supplying voltage to the load. However, the additional delta converter also contributes power to the load. Under conditions of AC failure or voltage disturbances, this design exhibits behavior identical to a double conversion on-line UPS.

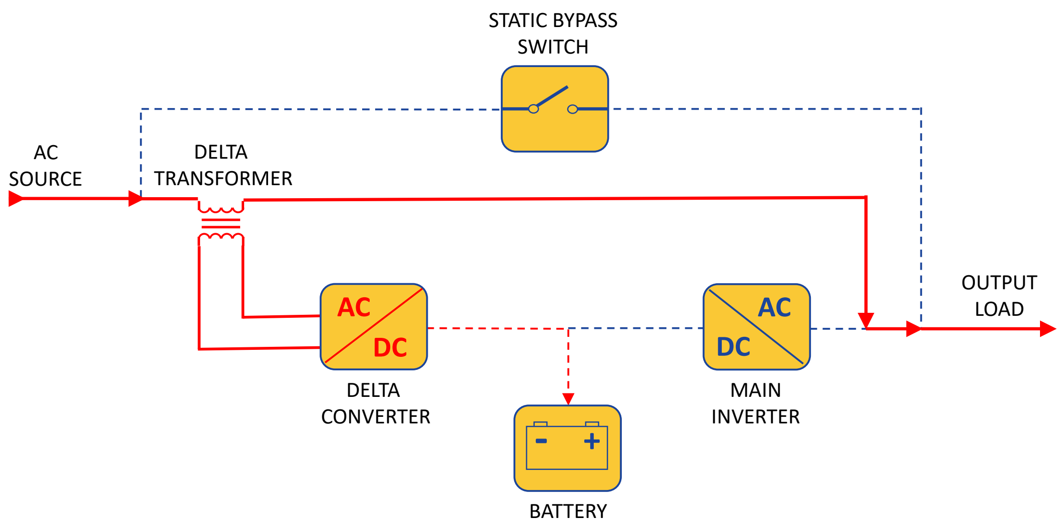


Figure 6
On-line normal mode – delta conversion on-line UPS topology

A simple way to understand delta conversion is to consider the energy required to deliver a package from the 4th floor to the 5th floor of a building as shown in **Figure 7**. Delta conversion on-line technology saves energy by carrying the package only the difference (delta) between the starting and ending points. The double conversion on-line UPS converts the power to the battery and back again whereas the delta converter moves components of the power from input to the output.

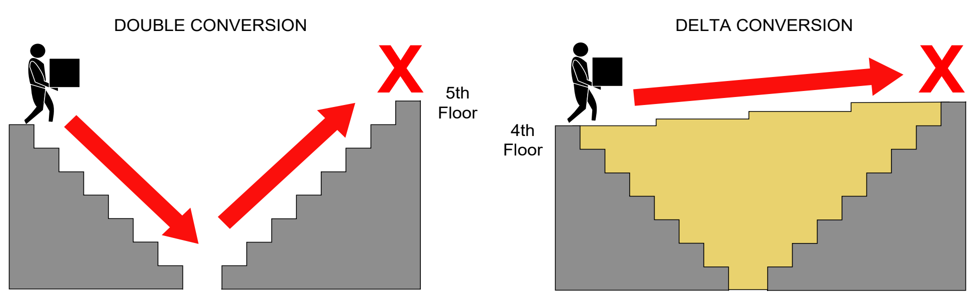


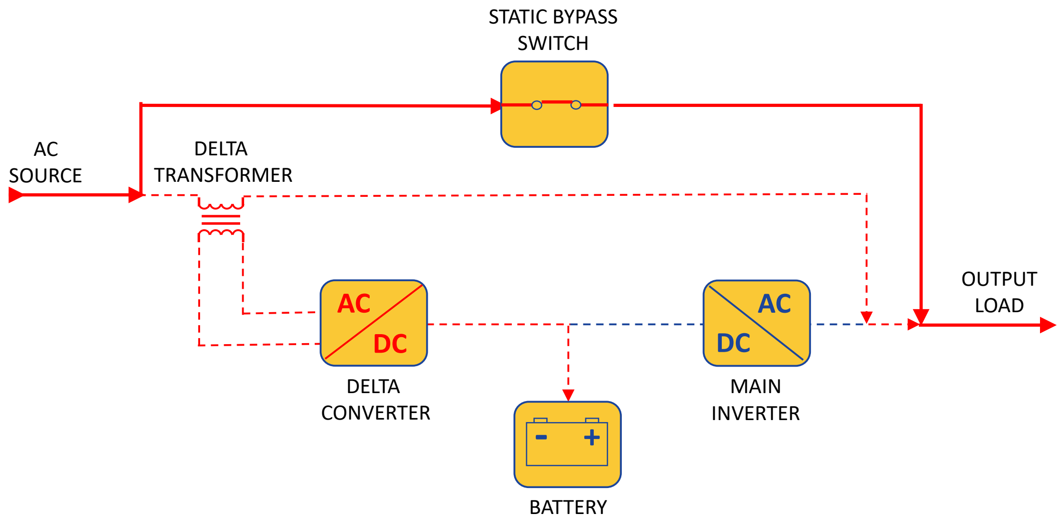
Figure 7
Analogy of double conversion on-line vs. delta conversion on-line UPS

<u>IEC output performance</u>
Because a delta conversion on-line UPS uses a delta converter to regulate output voltage in normal mode, but cannot regulate frequency, the IEC standard classifies the input dependency as Voltage Independent (VI). Because the delta converter supplies sinusoidal voltage to the load in normal mode and the sine wave main inverter is used in stored energy mode, the IEC standard classifies the output waveforms as SS. Because the inverter continuously supplies power to the load during a power failure, and because the inverter handles step loads well, the IEC standard

classifies the dynamic output performance as 11. The complete output performance is summarized as VI-SS-11. See the **Appendix** for more details.

Eco-mode – The block diagram in **Figure 8** illustrates that in eco-mode, the normal power path to the load is through the static bypass switch, the delta converter only operates at low power to charge the battery, and the main inverter is in standby. This improves the efficiency of the UPS and extends its service life, due to reduced heat and component stresses. When the power fails the static bypass switch opens and the main inverter draws power from the battery to supply the load.

Figure 8
Eco-mode – delta conversion on-line UPS topology



<u>IEC output performance</u>
Because a delta conversion on-line UPS operating in eco-mode cannot regulate either output voltage or frequency, the IEC standard classifies its input dependency as Voltage and Frequency Dependent (VFD). Because it passes the sinusoidal AC input voltage through to the load in normal mode and the sine wave main inverter is used in stored energy mode, the IEC standard classifies the output waveforms as SS. Because it typically takes almost 10ms to detect a power failure, open the static bypass switch, and start the main inverter (and because the main inverter handles step loads well), the IEC standard classifies the dynamic output performance as 31. The complete output performance is summarized as VFD-SS-31. See the **Appendix** for more details.

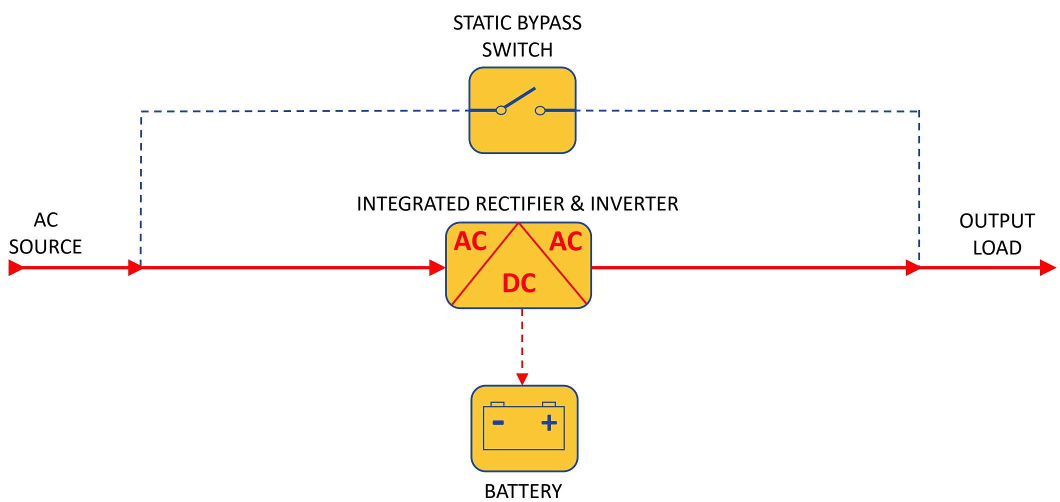
Hybrid conversion on-line UPS

Hybrid conversion is a relatively new technology intended to provide higher density than double conversion while providing similar electrical performance. It is ideal for protecting small quantities of sensitive servers and associated networking equipment in dense edge environments. It has three modes of operation including normal mode, battery mode, and eco-mode. The following subsections describe each operating mode with respect to power flow, transfer characteristics, and IEC output performance.

On-line normal mode – The hybrid conversion block diagram illustrated in **Figure 9** is similar to a double conversion on-line UPS, except that the normal power path to the load flows through a hybrid converter (i.e. a combination of rectifier and inverter) in place of a separate rectifier and inverter. This integrated design provides voltage regulation but trades-off frequency regulation capability in favor of reduced component quantity. When the input power fails, the rectifier portion of the hybrid converter shuts down and the inverter draws power from the battery to supply the load. Because the power path doesn't change, no switches operate, which results in no interruption of power to the load (i.e. 0ms transfer time).

Except for the lack of frequency regulation, a hybrid conversion UPS operating in on-line normal mode provides nearly ideal electrical output performance. It draws sinusoidal current from the AC input power source and it provides low distortion, nominal amplitude, sinusoidal voltage to the load.

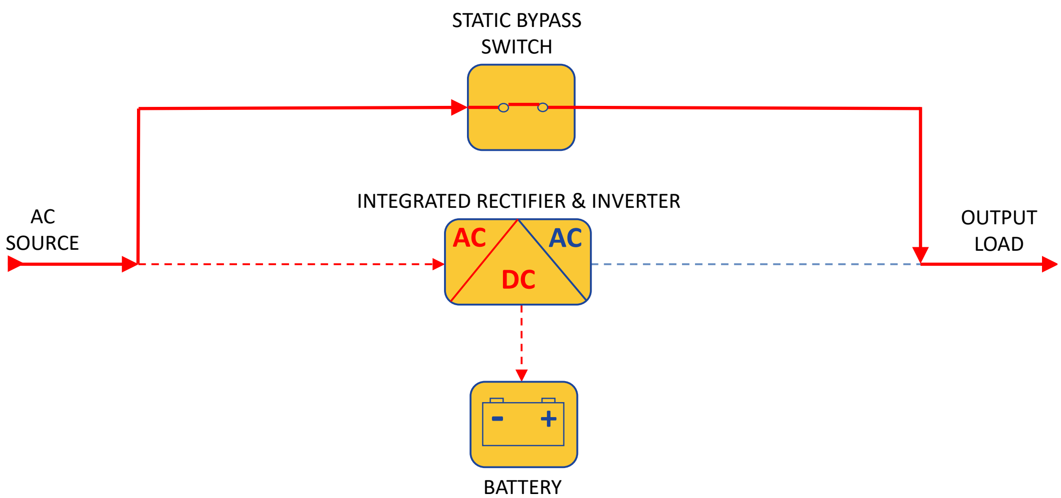
Figure 9
On-line normal mode – hybrid conversion on-line UPS topology



<u>IEC output performance</u>
Because a hybrid conversion on-line UPS uses a hybrid converter to regulate output voltage in normal mode, but it cannot regulate frequency, the IEC standard classifies the input dependency as Voltage Independent (VI). Because the hybrid converter supplies sinusoidal voltage to the load in normal and stored energy modes, the IEC standard classifies the output waveforms as SS. Because the inverter continuously supplies power to the load during a power failure, and because the inverter handles step loads well, the IEC standard classifies the dynamic output performance as 11. The complete output performance is summarized as VI-SS-11. See the **Appendix** for more details.

Eco-mode – The block diagram in **Figure 10** illustrates that in eco-mode, the normal power path to the load is through the static bypass switch, the rectifier portion of the hybrid converter only operates at low power to charge the battery and keep the inverter ready to power the load. This improves the efficiency of the UPS and extends its service life, due to reduced heat and component stresses. When the power fails the static bypass switch opens and the inverter draws power from the battery to supply the load.

Figure 10
Eco-mode –a hybrid conversion on-line UPS topology



IEC output performance
Because a hybrid conversion on-line UPS operating in eco-mode cannot regulate either output voltage or frequency, the IEC standard classifies its input dependency as Voltage and Frequency Dependent (VFD). Because it passes the sinusoidal AC input voltage through to the load in normal mode and the sine wave inverter is used in stored energy mode, the IEC standard classifies the output waveforms as SS. Because it typically takes almost 10ms to detect a power failure, open the static bypass switch, and start the inverter; and because the inverter handles step loads well, the IEC standard classifies the dynamic output performance as 31. The complete output performance is summarized as VFD-SS-31. See the **Appendix** for more details.

Summary of UPS types

Table 3 summarizes the main characteristics of the five UPS types discussed in this paper. Some attributes of a UPS, like efficiency, are dictated by the choice of UPS type. Since implementation and manufactured quality more strongly impact characteristics such as reliability, these factors must be evaluated in addition to these design attributes.

Table 3

Summary of typical characteristics of the five UPS types

UPS Type	Standby	Line interactive	Double conversion on-line			Delta conversion on-line	Hybrid conversion on-line	
Characteristic	**Normal**	**Normal**	**Normal**	**Eco**	**PFC-Eco**	**Normal**	**Normal**	**Eco**
Typical power range	0.2 – 1kVA	0.5 – 5kVA	1 – 1500kVA			5 – 1600kVA	1 – 5kVA	
Cost per VA	Low	Medium	High			High	High	
Power density	Very High	Medium	Medium			Low	High	
Service life	Short	Medium	Long			Long	Long	
Load criticality	Low	High	Very High			Very High	High	
Efficiency	Very High	Very High	Medium	High	High	High	Medium	High
Inverter on-line	No	Depends*	Yes	No	Yes	Yes	Yes	No
Power factor corrected input	No	No	Yes	No	Yes	No	Yes	No
Output voltage window	Wide	Wide	Narrow	Wide	Wide	Narrow	Narrow	Wide
Output frequency window	Wide	Wide	Narrow	Narrow	Narrow	Narrow	Wide	Wide
Inverter waveform	Square, Step-sine	Step-sine, Sine	Sine			Sine	Sine	
Transfer time	<10ms	<10ms	0ms	<10ms	0ms	0ms	0ms	<10ms
IEC classification	VFD-SY-33	VI-SS-31	VFI-SS-11	VFD-SS-31	VFD-SS-11	VI-SS-11	VI-SS-11	VFD-SS-31

* Inverter runs when charging the batteries at a high rate

Use of UPS types in the industry

The UPS industry product offering has evolved over time to include many of these designs. The different UPS types have attributes that make them more or less suitable for different applications and the APC by Schneider Electric product line reflects this diversity as shown in **Table 4**. Energy efficiency has also played a large role in UPS designs. For example, most UPS systems do not include the internal transformers that were present in earlier designs. This evolution has increased efficiency while decreasing the weight, size, and raw materials consumption of UPS systems. Eco-mode is another example of energy efficiency but does come with some cost / benefit tradeoffs. Compared with Eco-mode, PFC eco-mode can achieve high energy efficiency while reducing the transfer time to 0ms. For more information on these two topics, see White Paper 98, *The Role of Isolation Transformers in Data Center UPS Systems* and White Paper 157, *Eco-mode: Benefits and Risks of Energy-saving Modes of UPS Operation*. High power density is an important trend to reduce UPS footprint and is preferred for some applications such as the edge computing.

Table 4
Commercially available UPS types, benefits, and limitations

UPS Type	Commercially available products	Benefits	Limitations	APC's findings
Standby	APC Back-UPS	Low cost, very high efficiency, compact size	Operates on battery during brownouts, impractical over 2kVA	Best value for personal computers
Line interactive	APC Back-UPS Pro, APC Smart-UPS	High reliability, very high efficiency, AVR enables normal mode operation over a wide input voltage range	Impractical over 5kVA	Most popular UPS type in existence due to high reliability, ideal for rack or distributed servers
Double conversion on-line	APC Smart-UPS On-line, Galaxy, Easy UPS 3-Phase, Gutor PXC, PXP, PXW	Excellent voltage conditioning, ease of paralleling, available high efficiency modes	Expensive under 5kVA	Industry standard for mission critical applications, well suited for redundant designs
Delta conversion on-line	Symmetra MW	Excellent voltage conditioning, high efficiency	Impractical under 5kVA	High efficiency reduces the lifetime cost of energy in large installations
Hybrid conversion on-line	APC Smart-UPS Ultra	Excellent voltage conditioning, high power density, 0ms transfer time, PFC, available high efficiency mode	Impractical over 5kVA	High power density reduces rack space requirement, excellent load compatibility and protection

Conclusion

There are many different types of UPSs available in the market today. The IEC performance standard is a means to characterize the performance of each UPS type in each operating mode. Only by understanding performance and other attributes, can the optimal UPS be selected for a given application.

About the authors

Jim Spitaels is the Director of Emerging Technologies and a Senior Edison Expert in the Secure Power Business of Schneider Electric. He has more than 30 years' experience in the field of power protection and holds more than 50 patents on power system, UPS, rack and communications protocol design and is active in the development of IEC standards and energy efficiency programs. Jim holds both bachelor's and master's degrees in Electrical Engineering from Worcester Polytechnic Institute.

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Appendix

In order to explain the performance of the various types of UPS, in each of their operating modes, detailed explanations and graphs are provided to illustrate how the output voltage and frequency of each type vary with input voltage and frequency.

For these examples, we selected 230V/50Hz as the nominal UPS output voltage and frequency, but the graphs would look similar for other nominal values and allowed tolerances.

VFD

Voltage and Frequency Dependent UPSs cannot regulate their output voltage or output frequency. In normal mode, a VFD UPS's output voltage equals its input voltage when the input voltage stays within the allowed output range (e.g. ±10% of nominal). When the input voltage exceeds this range, a VFD UPS will transfer from normal mode to battery mode and the inverter will provide the nominal 230V output voltage to the load, until the input voltage returns within the allowed normal mode range or its battery is depleted. See **Figure A1 (a)**.

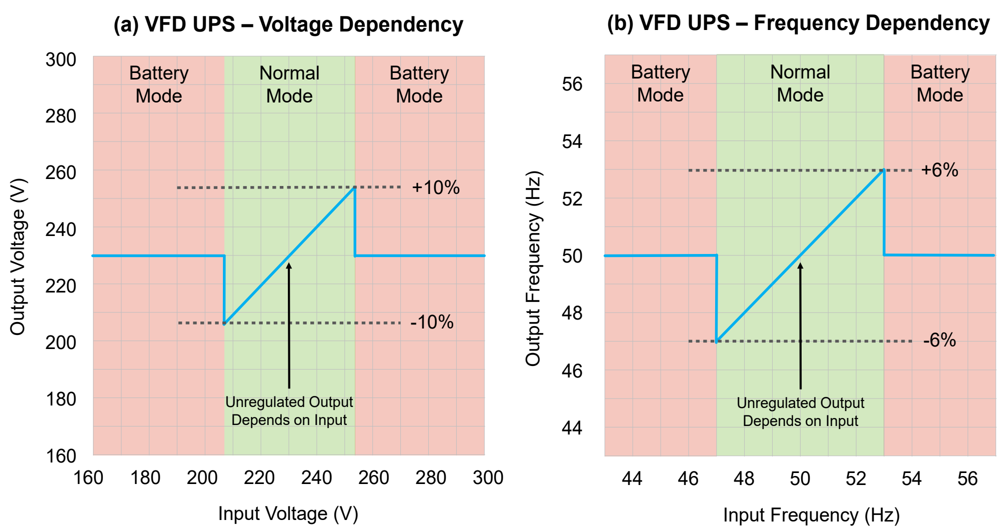


Figure A1 (a) and (b)

Example of output voltage and frequency dependency for VFD UPS

The frequency dependency behavior of a VFD UPS is similar to that of voltage. In normal mode, a VFD UPS's output frequency equals its input frequency when the input frequency stays within the allowed output range (e.g. ±6% of nominal). When the input frequency exceeds this range, a VFD UPS will transfer from normal mode to battery mode and the inverter will provide the nominal 50Hz output frequency to the load, until the input frequency returns within the allowed normal mode range or its battery is depleted. See **Figure A1 (b)**.

Because of their inability to regulate output voltage or output frequency, VFD UPSs are best suited for locations with good power quality and for loads that are not very sensitive to voltage or frequency variations.

VI

Voltage Independent UPSs can regulate their output voltage, but they cannot regulate their output frequency. The different types of VI UPSs regulate output voltage differently.

Line Interactive VI UPS – In normal mode, the output voltage of a Line Interactive VI UPS equals its input voltage when the input voltage stays within the allowed output range (e.g. ±10% of nominal). When the UPS operates within this range, the AVR transformer is typically de-energized which results in maximum efficiency.

When the input voltage exceeds this range, the UPS will transfer from normal mode to AVR mode and utilize its AVR transformer to either ratiometrically increase (e.g. $V_{out} = 1.1 * V_{in}$) or decrease (e.g. $V_{out} = 0.9 * V_{in}$) the input voltage to create an output voltage within the allowed range. When the input voltage goes beyond the compensation range of the AVR transformer (e.g. > ±20% of nominal), the UPS will transfer from AVR mode to battery mode and the inverter will provide the nominal 230V output voltage to the load, until the input voltage returns within the allowed AVR or normal mode ranges or its battery is depleted. See **Figure A2 (a)**.

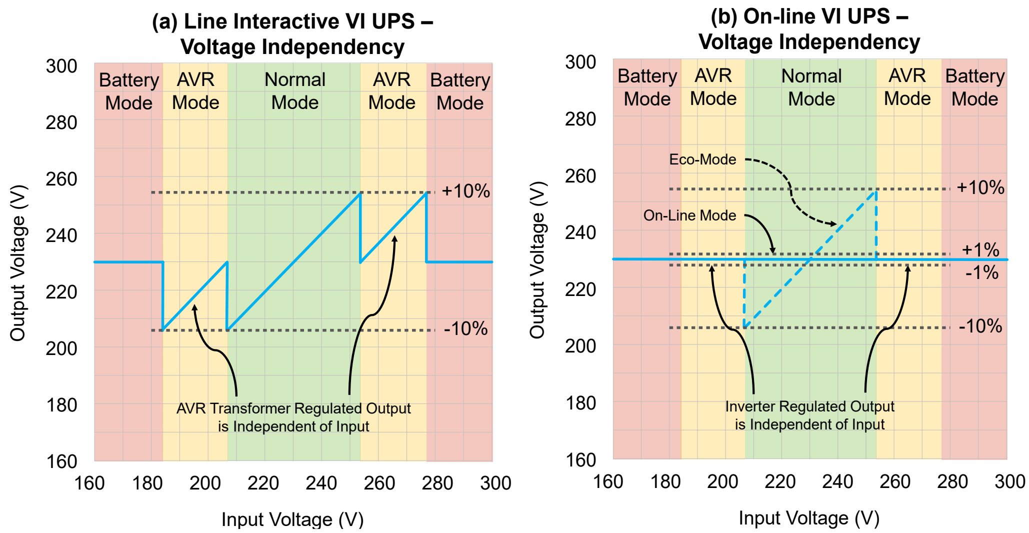


Figure A2 (a) and (b)

Examples of output voltage independency for VI UPSs

On-line VI UPS in Eco-mode – In eco-mode, the output voltage of an on-line VI UPS equals its input voltage when the input voltage stays within the allowed output range (e.g. ±10% of nominal). When the UPS operates within this range, the bypass path is used to power the load which results in maximum efficiency. When the input voltage exceeds this range, the UPS will transfer from eco-mode to AVR mode and the integrated rectifier-inverter or delta converter will be used to provide the nominal 230V output voltage to the load. When the input voltage goes beyond the input range of the rectifier or delta converter (e.g. > ±20% of nominal), the UPS will transfer from AVR mode to battery mode and the (main) inverter will provide the nominal 230V output voltage to the load, until the input voltage returns within the allowed AVR or eco-mode ranges or its battery is depleted. See the dashed blue line in **Figure A2 (b)**.

On-line VI UPS in on-line mode – In on-line mode, when the input voltage stays within the input range of its rectifier or delta converter (e.g. ±20% of nominal), an on-line VI UPS will utilize its integrated rectifier-inverter or delta converter to provide the nominal 230V output voltage to the load. This is done, at the cost of lowering efficiency, to ensure that the load never experiences an abrupt change in voltage. When the input voltage exceeds this range, the UPS will transfer from AVR mode to battery mode and the (main) inverter will continue to provide the nominal 230V output voltage to the load, until the input voltage returns within the allowed AVR or on-line mode ranges or its battery is depleted. See the solid blue line in **Figure A2 (b)**.

For all VI UPSs, the output frequency dependency behavior is like that of VFD UPSs. In all normal modes, the UPS's output frequency equals the input frequency when the input frequency stays within the allowed output range (e.g. ±6% of nominal). When the input frequency exceeds this range, the UPS will transfer from normal mode to battery mode and the (main) inverter will provide the nominal 50Hz output frequency to the load, until the input frequency returns within the allowed on-line mode range or its battery is depleted. See **Figure A3**.

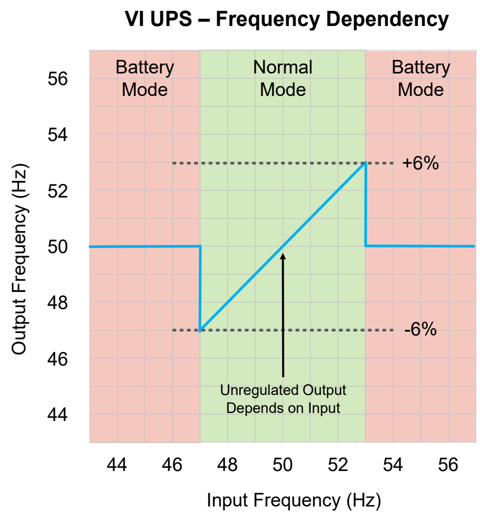


Figure A3

Examples of output frequency dependency for VI UPS

Because of their ability to regulate voltage and their inability to regulate frequency, VI UPSs are best suited for locations with moderate power quality and for loads that are sensitive to voltage variations but are not very sensitive to frequency variations.

VFI

Voltage and Frequency Independent UPSs can regulate both their output voltage and their output frequency.

VFI UPS in Eco-mode – In eco-mode, the output voltage of a VFI UPS equals its input voltage when the input voltage stays within the allowed output range (e.g. ±10% of nominal). When the UPS operates within this range, the bypass path is used to power the load which results in maximum efficiency. When the input voltage exceeds this range, the UPS will transfer from eco-mode to on-line AVR mode and the rectifier and inverter will be used to provide the nominal 230V output voltage to the load. When the input voltage goes beyond the input range of the rectifier (e.g. > ±20% of nominal), the UPS will transfer from on-line AVR mode to battery mode and the inverter will provide the nominal 230V output voltage to the load, until the input voltage returns within the allowed AVR or eco-mode ranges or its battery is depleted. See the dashed blue line in **Figure A4 (a)**.

The eco-mode frequency dependency behavior of a VFI UPS is similar to that of voltage. When operating in eco-mode, the output frequency of a VFI UPS equals its input frequency when the input frequency stays within the typically narrow allowed output range (e.g. ±2% of nominal). When the UPS operates within this range, the bypass path is used to power the load which results in maximum efficiency. When the input frequency exceeds the allowed output frequency range, the UPS will transfer from eco-mode to on-line mode and the rectifier and inverter will be used to provide the load with the allowed output frequency nearest to the input frequency. The nearest allowed frequency, rather than the nominal, is output to prevent the load from seeing an abrupt change in frequency during this transition. When the input frequency goes beyond the input range of the rectifier (e.g. > ±8% of nominal), the UPS will transfer from on-line mode to battery mode and the inverter will provide the nearest allowed output frequency to the load, or the nominal 50Hz output frequency if no input voltage is available, until the input frequency returns within the allowed on-line or eco-mode ranges or its battery is depleted. See the indicated eco-mode region in **Figure A4 (b)**.

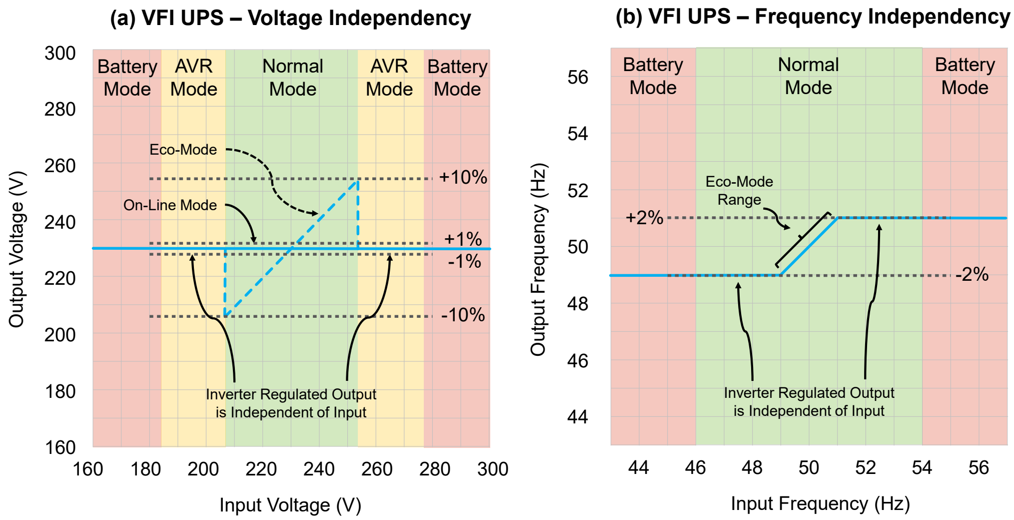


Figure A4 (a) and (b)

Example of output voltage and frequency independency for VFI UPS

VFI UPS in on-line mode – In on-line mode, when the input voltage stays within the input range of its rectifier (e.g. ±20% of nominal), a VFI UPS will utilize its rectifier and inverter to provide the nominal 230V output voltage to the load. This is done, at the cost of lowering efficiency, to ensure that the load always experiences the nominal voltage. When the input voltage exceeds this range, the UPS will transfer from on-line mode to battery mode and the inverter will continue to provide the nominal 230V output voltage to the load, until the input voltage returns within the allowed on-line range or its battery is depleted. See the solid blue line in **Figure A4 (a)**.

The on-line mode frequency dependency behavior of a VFI UPS is similar to its behavior in eco-mode. When operating in on-line mode, the output frequency of a VFI UPS tracks its input frequency when the input frequency stays within the typically narrow allowed output range (e.g. ±2% of nominal). However, unlike in eco-mode, when the UPS operates within this range, the rectifier and inverter are used to power the load. This is done, at the cost of lowering efficiency, to ensure that the load never experiences an abrupt change in frequency or phase. When the input frequency exceeds this range, the rectifier and inverter will be used to provide the load with the allowed output frequency nearest to the input frequency. The nearest allowed frequency, rather than the nominal, is output to prevent the load from seeing an abrupt change in frequency during this transition. When the input frequency goes beyond the input range of the rectifier (e.g. > ±8% of nominal), the UPS will transfer from on-line mode to battery mode and the inverter will provide the nearest allowed output frequency to the load, or the nominal 50Hz output frequency if no input voltage is available, until the input frequency returns within the allowed on-line mode range or its battery is depleted. See **Figure A4 (b)**.

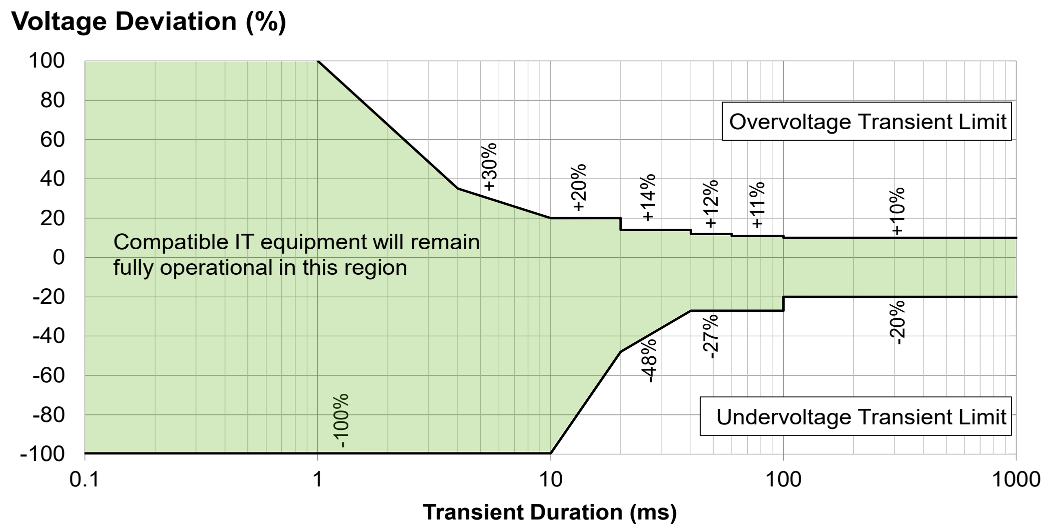
Because of their ability to regulate both voltage and frequency, VFI UPSs are best suited for locations with poor power quality and for loads that are sensitive to both voltage and frequency variations.

To better understand the three dynamic output performance classifications, **Figures A5 – A7** provide graphs to visualize their allowed voltage windows. Their most important characteristics are summarized below.

Class 3 – The output voltage has no upper bound during the initial 1ms and it is allowed to be interrupted (i.e. 0V) during the initial 10ms of the transient. It then gradually stabilizes to within +10% and -20% of nominal within 100ms, as shown in the green region of **Figure A5**. This level of performance is acceptable to most general-purpose IT loads.

Figure A5

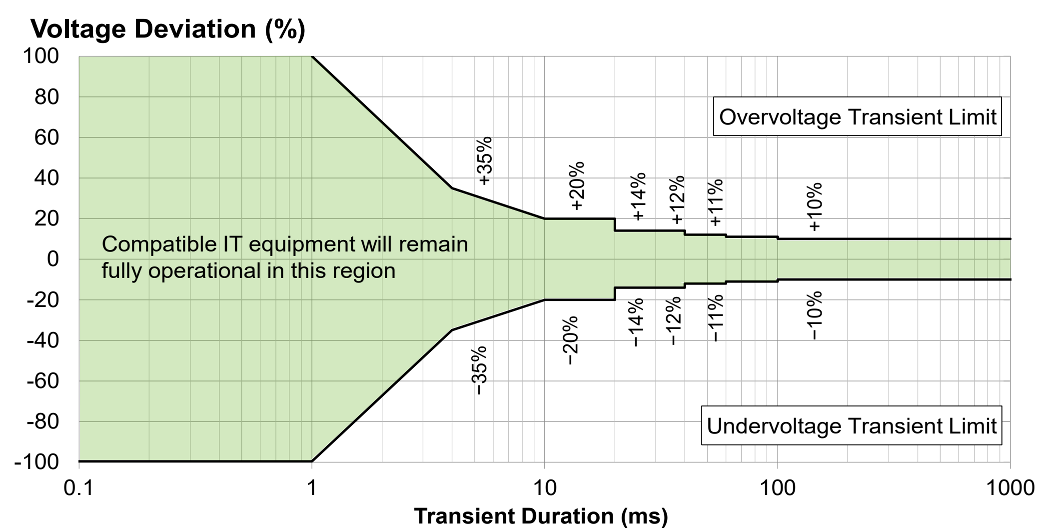
Dynamic output performance - allowed output voltage envelope for Class 3



Class 2 – The output voltage has no upper bound and it is allowed to be interrupted (i.e. 0V) during the initial 1ms of the transient. It then quickly stabilizes to within ±20% of nominal within 10ms, and further stabilizes to within ±10% of nominal within 100ms as shown in the green region of **Figure A6**. This level of performance is acceptable to most critical IT loads.

Figure A6

Dynamic output performance - allowed output voltage envelope for Class 2



Class 1 – The output voltage is never interrupted during the transient. It stays within ±30% of nominal during the initial 5ms, quickly comes within ±20% of nominal within 10ms and further stabilizes to within ±10% of nominal within 100ms as shown in the green region of **Figure A7**. This level of performance is acceptable to the most sensitive critical IT loads.

Figure A7

Dynamic output performance - allowed output voltage envelope for Class 1

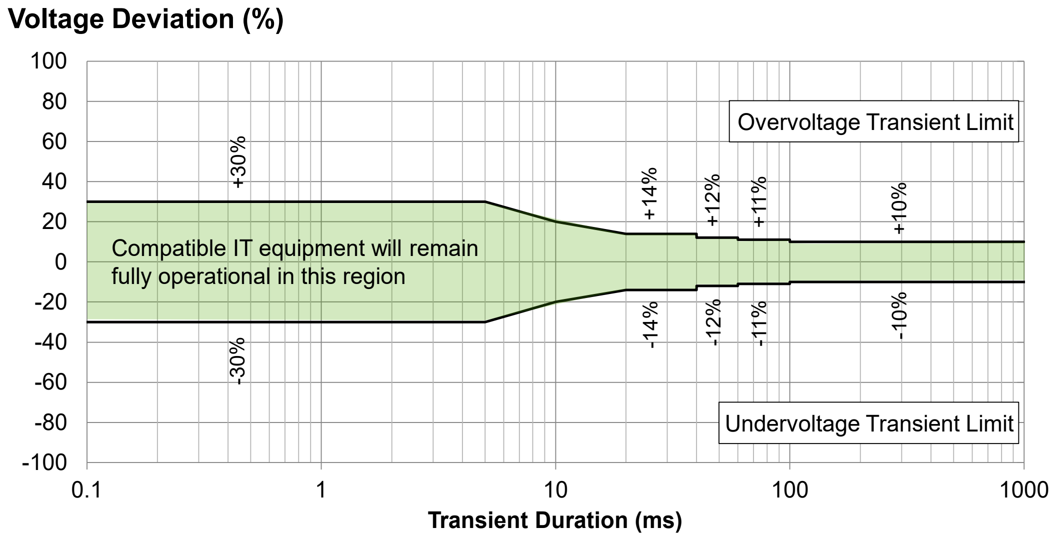


Table A1 summarizes the IEC classifications for UPS output performance. The output performance is described in three parts: input dependency classification (AAA), output voltage waveform classification (BB), and dynamic output performance classification (CC). The complete output performance can thus be summarized as: AAA-BB-CC. The most common combinations available in the market are: VFD-SY-33, VI-SS-31, and VFI-SS-11.

Table A1

Summary of UPS output performance classifications based on the IEC 62040-3 *standard*

Output performance classifications							
Input dependency classification (AAA)			Output voltage waveform classification (BB)		Dynamic output Performance classification (CC)		
V- Voltage, F-Frequency, D-Dependent, I-Independent			Normal mode (1st character)	Stored energy mode (2nd character)	Change of operating mode (1st character)		Step load application (2nd character)
3 combinations: VFD/VI/VFI			9 possible combinations: **SS**/SX/**SY**/XS/XX/XY/YS/YX/YY		9 possible combinations: **11**/12/13/21/22/23/**31**/32/**33**		
Definitions							
Type	Input voltage	Input frequency	Type	With linear and non-linear load applied in each operating mode	Class	Max output voltage interruption	Compatible load types
VFD	Dependent	Dependent	Y	Non-sinusoidal	3	10ms	General-purpose IT loads
VI	Independent	Dependent	X	Sinusoidal with THD* ≤ 12 %, IHD**within limits [8]	2	1ms	Critical loads
VFI	Independent	Independent	S	Sinusoidal with THD* ≤ 8 %, IHD** within limits [9]	1	0ms	Sensitive critical loads

* THD means total harmonic distortion. ** IHD means individual harmonic distortion. Common combinations shown in **bold**.

[8] IEC FDIS 62040-3:2021, Table 4

[9] IEC FDIS 62040-3:2021, Table 3