VERTIV WHITEPAPER

High efficiency modes of operation

Path toward highest energy efficiency without load availability trade-off

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Abstract

One of the most widely discussed issues throughout the world today is the rapidly increasing price and demand of energy supply. Along with this comes the broadening awareness of the environmental impact and depletion of fossil fuels, which has created a natural drive towards energy saving and the widely encouraged use of renewable energy sources, energy conservation best practices, and the development and advancement of energy efficient standards, processes and technologies. As maximum uptime is paramount for many world-leading organizations, the presence of a UPS is an indispensable prerequisite for a reliable power infrastructure able to achieve maximum load safeguarding and conservation.

The most common UPS topology currently used in the industry is double conversion; nevertheless, most UPS suppliers have introduced ECO Modes of operation to further increase the levels of efficiency of the UPS. In this paper, we will analyze the drawbacks of ECO Mode types of operation and further highlight what elements should be considered when using these modes of operation.

We will then review the field results achieved by the Liebert® Trinergy™ Cube UPS and present the recent improvements in technology that have been incorporated into the Liebert Trinergy Cube and Liebert EXL S1.

Vertiv™ UPS have introduced new ways of efficiency improvement to the market which have proven to be the premium UPS solution for data centers aiming to have the lowest possible PUE while maintaining the highest levels of availability.

Introduction

UPS systems provide clean power to electronic devices such as computer networks and servers, building management and security systems. UPS also protect against power outages which could potentially lead to a halt in operations, a loss of information, productivity and profit for businesses. The energy efficiency of a UPS is the ratio between the power entering the UPS and the power exiting the UPS to supply the load. Whenever current passes through the internal components of a UPS, a certain amount of energy is dissipated as heat, which results in energy losses. Additional energy is also consumed when air conditioning systems operate to sustain the ideal environmental temperature of the installation. Whilst a certain amount of energy loss is inevitable, it is evident that the reduction of UPS power consumption and the consequent increase of its efficiency will significantly contribute to lowering excess energy waste, maximizing the overall running cost-saving of the energy bill.

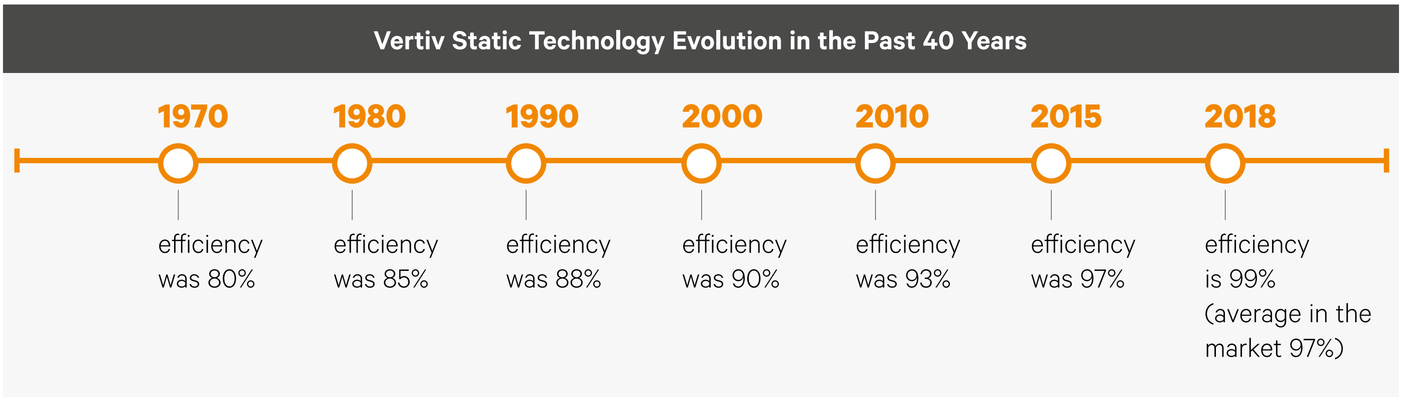


Figure 1. *Vertiv static UPS technology evolution in the past 40 years*

The savings generated by increased UPS efficiency extrapolated over 24 hours a day, 365 days a year over a five-year period, would not only exceed the purchase price of a UPS but also actively contribute to reducing CO_2 and other global warming emissions, ensuring the lowest environmental impact of the chosen power protection solution.

Nowadays, the most common UPS mode of operation used for supplying secure power to data centers is double conversion mode, which ensures a Voltage and Frequency Independent (VFI) type of operation by providing the highest level of power quality to the load at all times. At the same time, as there are two stages of power conversion, this is also the mode of operation that consumes the largest amount of energy.

Even when considering a double conversion UPS, there are significant differences in terms of double conversion efficiency - legacy UPS may operate with 93% efficiency when operating in double conversion mode, while the highest efficiency present-day UPS can achieve levels approaching 97%. To further increase efficiency, most UPS manufacturers have introduced high energy efficiency modes of operation, such as ECO mode; nevertheless, most of these modes still serve as marketing hype rather than a concrete way of improving the data center efficiency, as increased efficiency with ECO mode comes with drawbacks to load availability.

Efficiency impacts on operating costs

One of the main priorities for facility and data center managers is to optimize the facility's power use, this task is however continuously challenged by the increasing costs of electricity. As an example, Table 1 shows a comparison between different technologies.

UPS Configuration	kW	Peak Efficiency	kW Losses	Average Price per kWh	Yearly Electricity Cost	5-Year Electricity Cost	5-Year Savings
Legacy	1000	94%	63.8	$ 0.10	$ 55,910	$ 279,550	-
Modern	1000	97%	30.9		$ 27,090	$ 135,450	**$ 144,100**
Modern with Dynamic Online mode	1000	99%	10.1		$ 8,850	$ 44,250	**$ 235,300**

Table 1. *5-year average energy cost savings comparing different UPS configurations*

Drawbacks on historical high efficiency modes

ECO Mode and Its Effectiveness

Each electronic device has a unique specification, so it is useful to have a point of reference to compare the performance of these devices.

From a holistic point of view, IT equipment performance can be analyzed by referring to the ITI CBEMA curve (Figure. 2). The ITI (CBEMA) Curve describes an AC input voltage envelope that can typically be tolerated (no interruption in function) by most pieces of Information Technology Equipment (ITE).

Electronic devices should be able to operate normally under the condition shown in the curve. The steady-state range describes an RMS voltage which is either varying very slowly or is constant. The subject range is +/- 10% from the nominal voltage. Any voltages in this range may be present for an indefinite period, and are a function of normal loadings and losses in the distribution system. Electronic devices should also be able to operate temporarily without voltage for no longer than 20 ms.

As these types of electronic equipment do not need perfect power quality, ECO Mode takes advantage of the grid when there is good power quality by transferring the UPS to bypass and supplying the load directly through the grid via the bypass line.

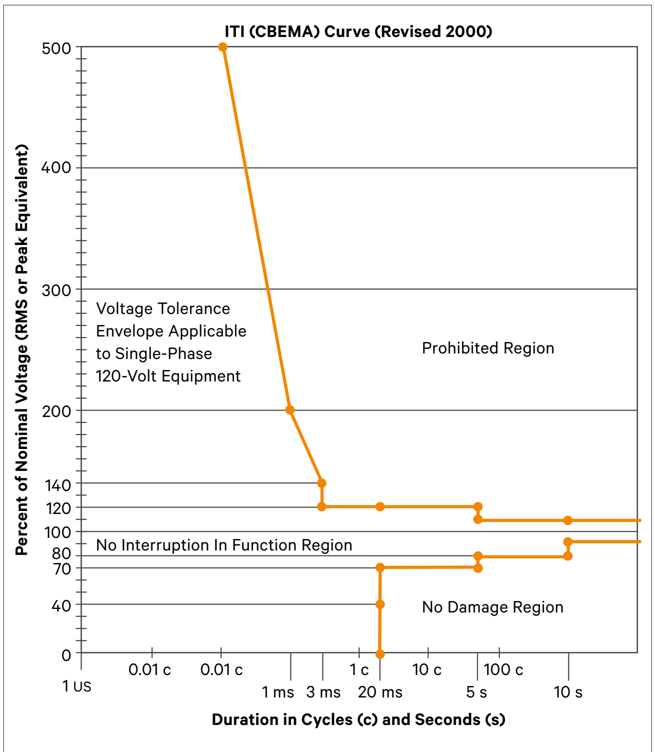


Figure 2. *ITI (CBEMA) Curve*

When input power quality is inside tolerances, the UPS can maximize the efficiency supplying the load through the Static Bypass Switch instead of the power conversion section of the UPS where energy losses are higher.

Advanced Control Techniques and Power Tracking permit a UPS to transfer to double conversion mode as soon as there is an out of tolerance or mains failure. As a reference, below in Figure 3 are shown three different modes of operation as per international UPS standard IEC 62040-3.

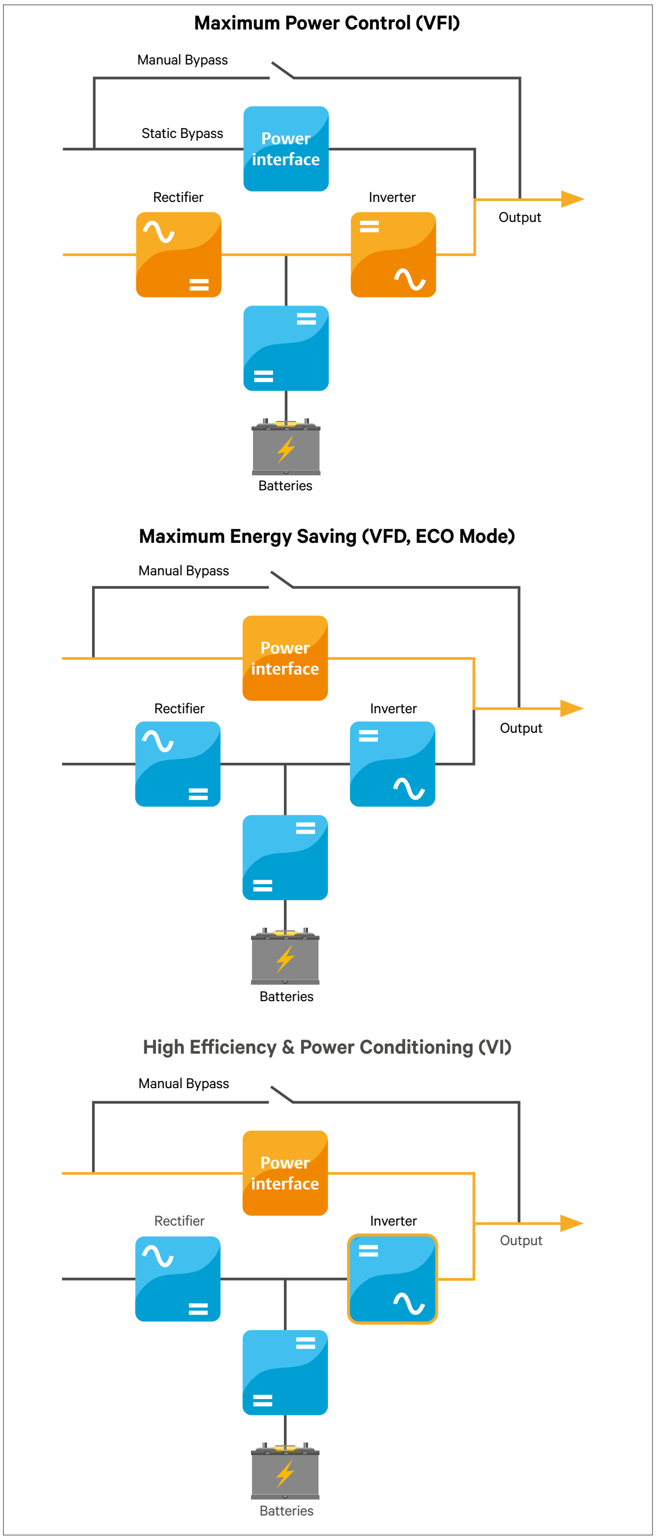


Figure 3. *Liebert Trinergy Cube and Liebert EXL S1 modes of operation as per UPS standard 62040-3*

One would not expect the reliability of a UPS to be affected while operating in ECO Mode. In fact, in ECO mode, some of the internal components present inside the inverter and rectifier are less stressed, so the reliability of a UPS may actually increase. On the other hand, since there is no power conditioning performed by the UPS during this mode of operation, there may be a decrease in power quality supplied to the load, thus affecting the load power availability.

A few considerations need to be made before activating a high efficiency mode of operation. The first consideration is transfer time: the amount of time it takes to transfer from one mode of operation to another. Legacy UPS need 10 ms to transfer in the worst possible conditions and may have voltage instability on their output for a few cycles. As a result, the load will not be protected against disturbances of duration from a few microseconds up to a few milliseconds. While loads are compatible with power outages of this duration, as shown in the CBEMA curve, protection against overvoltage must be considered for disturbances of 0.1 ms or more. Thus, in order to ensure load protection against these types of disturbances, additional passive filtering on the bypass line should be considered. Liebert® Trinergy™ Cube is equipped with a power interface in the bypass path to provide the passive filtering necessary to protect against these temporary overvoltage disturbances. Liebert EXL S1 offers an optional power interface.

An additional consideration must be made with respect to harmonics and low Power Factor (PF) typically present on the grid or from the load.

When installing a UPS or any piece of equipment, especially for large power installations, it is important to ensure that harmonics and PF of the device are within the limits defined by the grid supplier. The input PF of a modern UPS using an IGBT rectifier is 0.99 down to 20% load, while harmonics levels can be less than 5%. When a UPS operates in double conversion mode, the PF and THDi generated by the UPS rectifier will be injected back into the grid and added to the PF and THDi generated by other pieces of equipment directly connected to the grid, such as compressors and chillers. At the same time, if the UPS is connected to a grid with a high level of voltage distortion, it would not affect the load in any way since, when operating in double conversion mode, the UPS provides isolation between the load and the grid.

Now, assuming the UPS is operating in ECO Mode, there is a direct connection between the load and the grid via the path across the static bypass switch; thus, the PF and harmonics levels (THDi) that need to be verified are no longer the ones of the UPS but rather the ones of the load connected downstream of the UPS. Considering that most servers have a dual power supply, the load on the Power Supply Units (PSU) usually does not exceed 50% during normal operation. In addition, servers typically do not run at 100% capacity. Typically, the PSU operates between 10 to 40% capacity. As shown in Table 2 below, the grid may be exposed to load PF levels between the range of 0.77 up to 0.98, and harmonics in the range between 20% down to 7%. This scenario is much worse than what happens on the input of the rectifier where the UPS maintains PF levels at 0.98 and THDi less than 8% down to 10% load.

I_{RMS} A	PF	I_{THD} (%)	Load (%)	Fraction of Load	Input Watts	External Fan (W)	DC terminal voltage (V) DC load current (A)		Output Watts	Efficiency %
							12 V	12 Vsb		
0.68	0.86	20.31	10%	Low	134	1.32	12.22/9.92	11.9/0.1	122	**91.50%**
1.21	0.93	13.42	20%	Light	259	2.04	12.21/19.83	11.89/0.2	244	**94.26%**
2.82	0.98	7.72	50%	Typical	635	9.96	12.21/49.57	11.86/0.5	611	**96.24%**
5.59	0.99	5.27	100%	Full	1274	9.96	12.19/99.13	11.84/0.99	1220	**95.79%**

I_{RMS} A	PF	I_{THD} (%)	Load (%)	Fraction of Load	Input Watts	External Fan (W)	DC terminal voltage (V) DC load current (A)			Output Watts	Efficiency %
							12 V	0 Vsb	3.3 V		
0.76	0.77	13.83	10%	Low	135	23.40	12/9.28	0/0	3.3/0.5	113	**83.88%**
1.21	0.90	12.78	20%	Light	249	23.40	12/18.51	0/0	3.3/0.99	225	**90.52%**
2.71	0.96	8.00	50%	Typical	597	23.40	11.99/46.22	0/0	3.29/2.5	562	**94.28%**
5.27	0.99	4.38	100%	Full	1196	23.40	11.98/90.51	0/0	3.27/4.98	1101	**92.01%**

Table 2. *Some examples of the most typical non-linear server loads with low PF values and high harmonic rejection up to 20% THDi.* (Source: http://www.plugloadsolutions.com/80PlusPowerSupplies.aspx).

Thus, when operating through the bypass line, one should be sure to have additional equipment to reduce harmonics and compensate for the PF of PSU. The same is valid if one is considering supplying mechanical loads through the bypass line. This can be achieved through the installation of an active filter or re-phasing banks. Long transfer times and the missing passive and active filtering when operating in ECO mode are the main reasons why the ECO mode has persisted as marketing hype rather than a concrete way of increasing the efficiency of the UPS.

To overcome the drawbacks that can occur when operating in ECO mode, there are a number of actions that can be taken to ensure proper load protection (Figure 4), and are listed as follows:

- **Passive Filtering (Power Interface)** when operating on the bypass line
- **Active Filtering** to provide load and network power conditioning to ensure good quality supply at all times
- Eliminate transfer time between different functioning modes

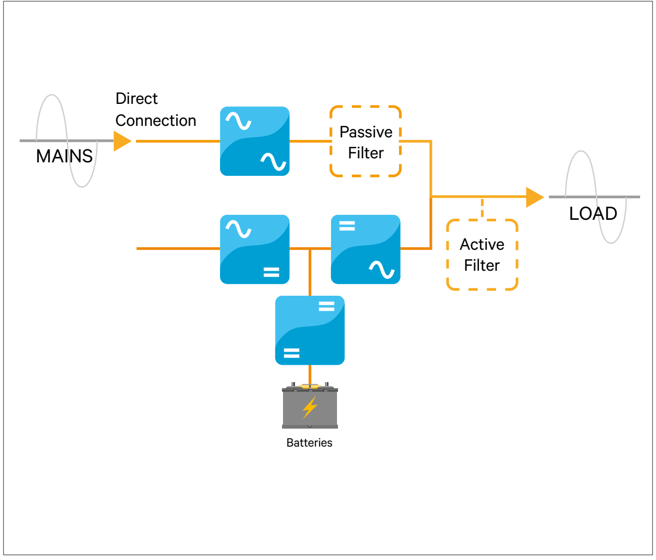


Figure 4. *Liebert Trinergy Cube integrated passive and active compensation when operating in VFD and VI mode*

Operating Modes

The following operating modes are available on Liebert® Trinergy™ Cube and Liebert EXL S1.

Maximum Power Control (VFI Mode)

Maximum power control allows the best power to be supplied to the load whenever the system detects that the electrical environment requires conditioning. In the event that a degrade of network conditions occurs and the monitored parameters are out of tolerance, the Maximum Power Control mode allows complete conditioning and supply to the load using the double conversion mode with an efficiency of more than 96.5%.

Active Filtering Mode (VI Mode)

Active filtering mode enables the system to condition the energy supply sufficiently without having to switch to Maximum Power Control configuration. When a reactive load or non-linear load is connected to the UPS and harmonics or reactive current are present, the UPS is able to compensate by operating as an active filter and consuming only the necessary energy to compensate the line disturbances, thus achieving the highest efficiency possible resulting in an efficiency variation of 98% up to 99%. The use of VI mode allows to remove part of the issue of directly connecting the mains to the load through the bypass line.

Maximum Energy Saving (VFD Mode, ECO Mode)

Maximum energy saving detects when the mains energy supplied to the unit is of an ideal quality and the need for conditioning is limited. When network conditions are stable, the Maximum Energy Saving mode is selected allowing the energy to pass through the power interface line, reaching an efficiency of up to 99.5%. When present, the power interface line provides a passive filtering action to the load to ensure to maintain the load protected also when supplied through the bypass line.

Trinergy Control (Liebert Trinergy Cube Only)

The activation of Trinergy Cube high efficiency modes of operation is based on the real time power tracking of the main parameters related to the input network conditions and output load quality (Figure 5).

The electrical conditions related to the load and network are constantly monitored, allowing the best power protection to be supplied to the load at all times with the highest level of efficiency. At the same time, excellent load power conditioning is ensured with 0.99 input PF both on the mains and bypass line, and less than 3% THDi.

If the observed variables are outside specific ranges, the UPS will activate a different mode of operation in accordance with the algorithm settings. These settings can be customized by the service engineer upon request.

Table 3 shows a summary of the most important differences between Liebert™ Trinergy™ Cube, Liebert EXL S1 and any other UPS using ECO Mode or similar.

Vertiv High Efficiency Mode	ECO Mode	Vertiv High Efficiency Mode Advantages
Passive filtering	Only static bypass in VFD	Load protection also in VFD
Active filtering in VI mode	No active filtering	Compensates harmonics and PF reducing the reactive current towards the upstream network
Network and load	Network monitoring	Operates in accordance with load variation and monitoring only various load types
Rectifier OFF in VI mode and VFD mode	Rectifier ON in VFD without load	Does not absorb kVAr from the rectifier as ECO mode does
PF and harmonics controlled on both rectifier and bypass input	PF and harmonics controlled only on rectifier input when operating in VFI	Trinergy and Trinergy Cube algorithm grants higher efficiency providing power conditioning at the same time
Load exposure to mains failure less than 2 ms in VI mode	Load exposure to mains failure up to 10 ms	Fast transfer time for maximized load availability

Table 3. *Most important differences between Liebert Trinergy Cube, Liebert EXL S1 and any other UPS using ECO Mode or similar*

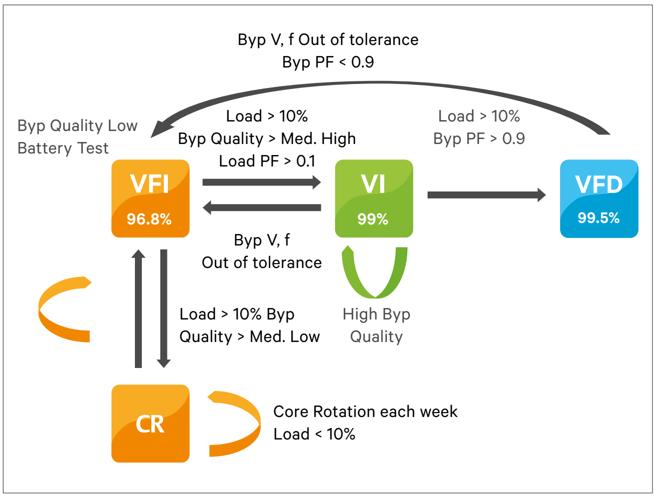


Figure 5. *Liebert Trinergy Cube internal algorithm main thresholds and settings*

Trinergy Control offers excellent energy cost savings for a reduced total cost of ownership. See Table 4 for details on potential savings for different UPS power ratings. The calculation takes into consideration the incremental efficiency gained when operating in high efficiency mode.

Figure 6 illustrates how the Trinergy Control handles an upstream short circuit with high efficiency mode (VI) enabled. While operating in VI mode, the short circuit forces the bypass input voltage to zero. As soon as the bypass input goes out of tolerance, the UPS control switches to VFI mode while sending a signal to turn off the bypass SCRs. The resulting transfer time is within 2 milliseconds, considerably lower than the previous product generation transfer time that was up to 10 milliseconds.

This allowed many customers to start using this functioning mode effectively as it significantly minimizes the transfer time between functioning modes. Based on Trinergy Control's 10 years of experience on the market, **Vertiv has further enhanced controls reaching a 0 milliseconds transfer by means of Dynamic Online mode.**

UPS Rating	kW @ 70% Load	Incremental Efficiency (98.5% - 96.8%)	Incremental kW Saved	Annual kWh Savings (70% Load)	Average Price per kWh	Annual Utility Bill Savings
400 kVA	280	1.7%	4.8	41,698	$0.10	$4,170
800 kVA	560	1.7%	9.5	83,395	$0.10	$8,340
1200 kVA	840	1.7%	14.3	125,093	$0.10	$12,510
1600 kVA	1120	1.7%	19.0	166,790	$0.10	$16,680
2000 kVA	1400	1.7%	23.8	208,488	$0.10	$20,850
2400 kVA	1680	1.7%	28.6	250,186	$0.10	$25,020
2800 kVA	1960	1.7%	33.3	291,883	$0.10	$29,190
3200 kVA	2240	1.7%	38.1	333,581	$0.10	$33,360

Note: *98.5% average efficiency calculated considering 25% of the time working in VFI mode, 60% in VI mode and 15% in VFD mode.*

Table 4. *Average energy cost savings for different power ratings based on VI Mode efficiency vs. double conversion mode*

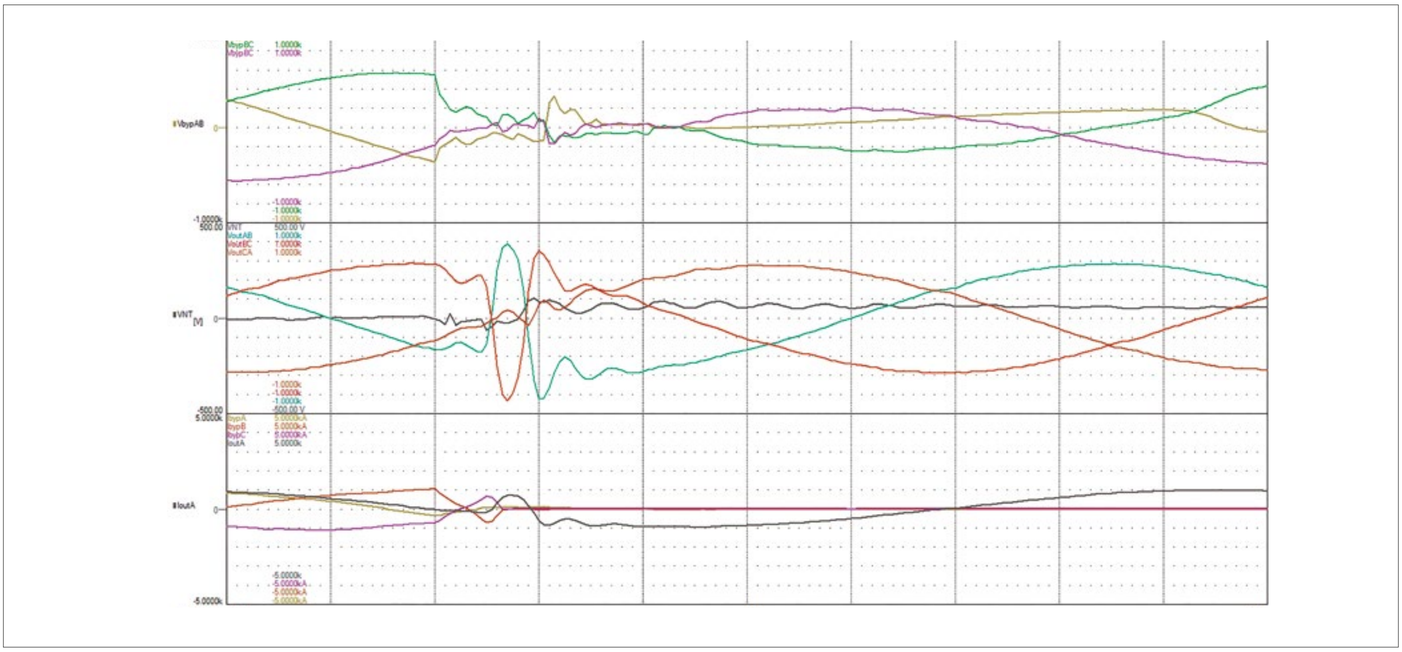


Figure 6. *Upstream short in VI mode. From top to bottom: bypass input voltages, inverter output voltages, bypass and output currents. Time 2ms/div.*

Dynamic Online mode: No more load availability trade-off with efficiency

Dynamic Online mode is the latest high efficiency mode of operation offered by Vertiv with Liebert® Trinergy™ Cube and Liebert EXL S1, developed with the understanding that many of our customers do not want to trade-off any level of reliability for incremental gains in efficiency. **A UPS with Dynamic Online mode offers an operating efficiency up to 99% without sacrificing reliability.** In fact, while in this mode, the inverter can instantaneously assume the load and maintain the output voltage within the IEC 62040 Class 1 specification. Let's consider an example: Figure 7 illustrates how the UPS handles an upstream short circuit with Dynamic Online mode. While operating in VI mode, the short circuit forces the bypass input voltage to zero. As soon as the bypass input goes out of tolerance, the UPS control switches to VFI mode while sending a signal to turn off the bypass SCRs. Systems equipped with Dynamic Online are able to safely transition from high efficiency mode to inverter mode with a 0 millisecond transfer, thus providing guaranteed load power protection under virtually any power outage condition.

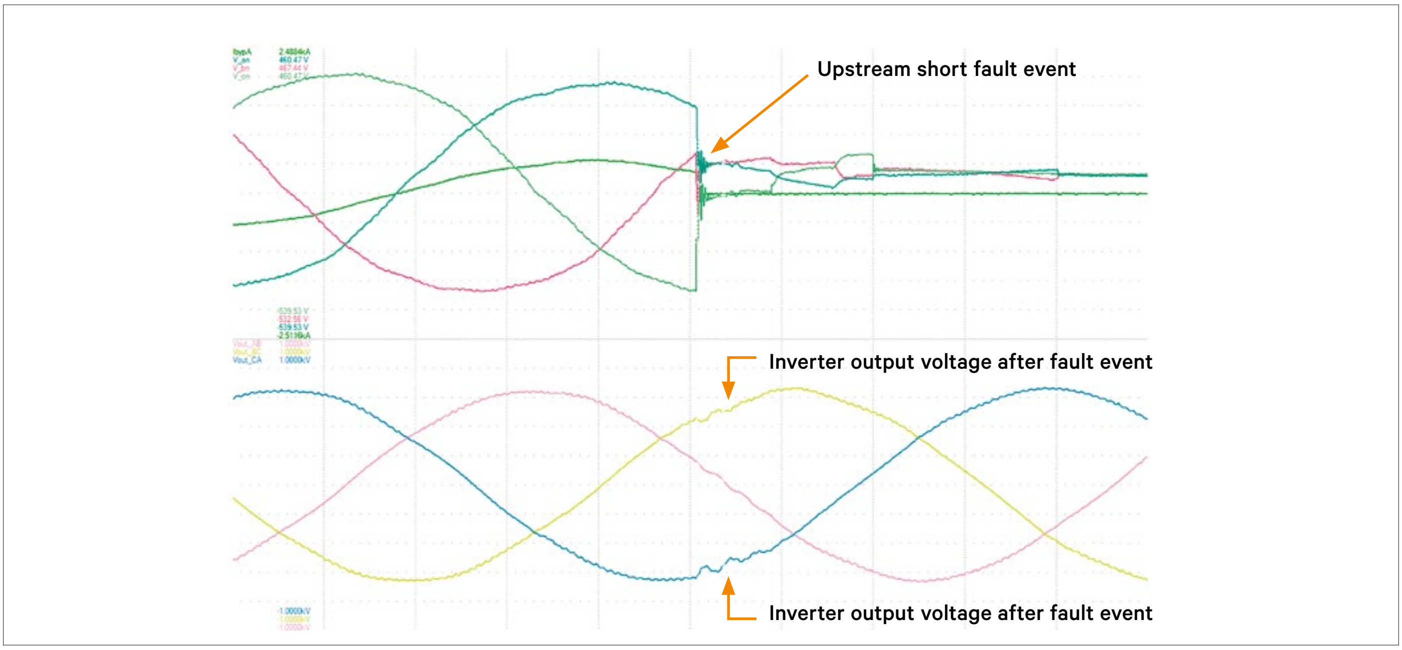


Figure 7. *Upstream short in Dynamic Online mode. From top to bottom: bypass input voltages and current, inverter output voltages. Time 2ms/div.*

Figure 8 illustrates Dynamic Online mode performance with respect to the IEC 62040-3 Class 1 and ITI (CBEMA) curves. When Dynamic Online mode is enabled, the UPS transient when switching from VI to VFI mode is well within the Class 1 and ITI (CBEMA) response boundaries.

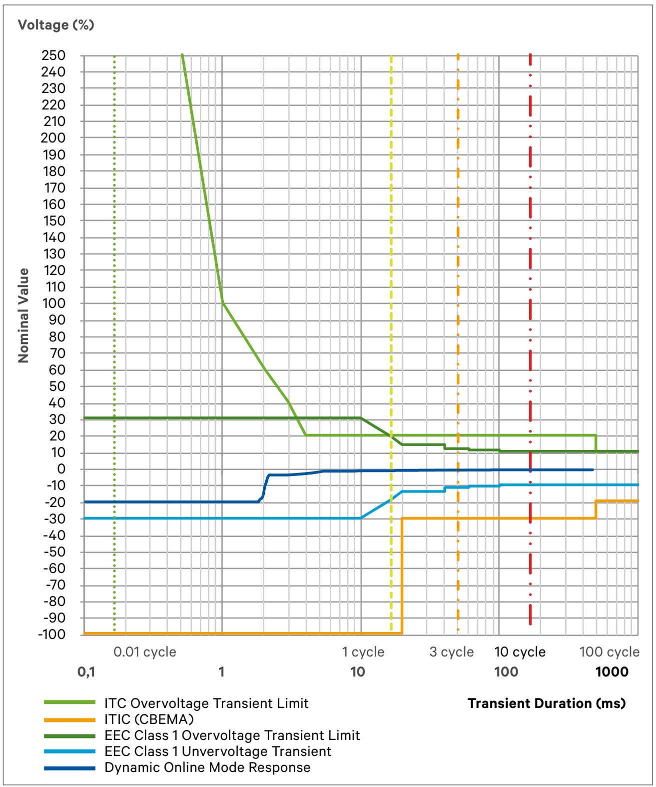


Figure 8. *Dynamic Online mode output dynamic performance against IEC/EN 62040-3 Class 1 and ITIC*

Figure 9 illustrates the high-level algorithm for Dynamic Online mode. The algorithm looks very similar to Trinergy™ Control, however in the case of Dynamic Online mode, VFD has been removed from the equation. In VFD mode, the UPS cannot guarantee a Class 1 response. With VFD removed, the UPS can ensure maximum reliability with only a small decrease in average operating efficiency.

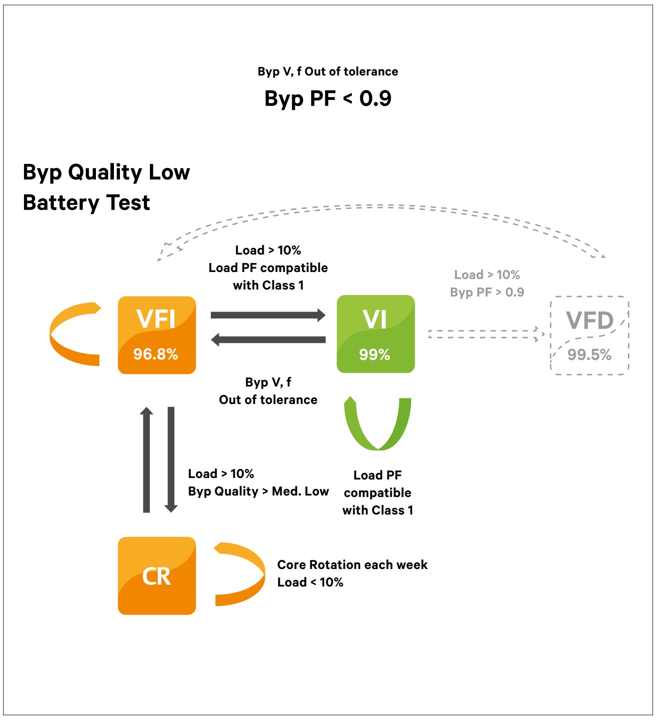


Figure 9. *Dynamic online mode internal algorithm main thresholds and settings*

Dynamic Online mode offers excellent energy cost savings for a reduced total cost of ownership. See below for details on potential savings for different UPS power ratings. The calculation takes into consideration the incremental efficiency gained when operating in Dynamic Online mode, compared to a premium double conversion efficiency.

UPS Rating	kW @ 70% Load	Incremental Efficiency (98.3% - 96.8%)	Incremental kW Saved	Annual kWh Savings (70% Load)	Average Price per kWh	Annual Utility Bill Savings
400 kVA	280	1.5%	4.2	36,792	$0.10	$3,680
800 kVA	560	1.5%	8.4	73,584	$0.10	$7,360
1200 kVA	840	1.5%	12.6	110,376	$0.10	$11,040
1600 kVA	1120	1.5%	16.8	147,168	$0.10	$14,720
2000 kVA	1400	1.5%	21.0	183,960	$0.10	$18,400
2400 kVA	1680	1.5%	25.2	220,752	$0.10	$22,080
2800 kVA	1960	1.5%	29.4	257,544	$0.10	$25,750
3200 kVA	2240	1.5%	33.6	294,336	$0.10	$29,430

Note: *98.3% average efficiency calculated considering 30% of the time working in VFI mode and remaining 70% in VI mode with Dynamic Online enabled.*

Table 5. *Average energy cost savings for different power ratings based on Dynamic Online efficiency vs. double conversion*

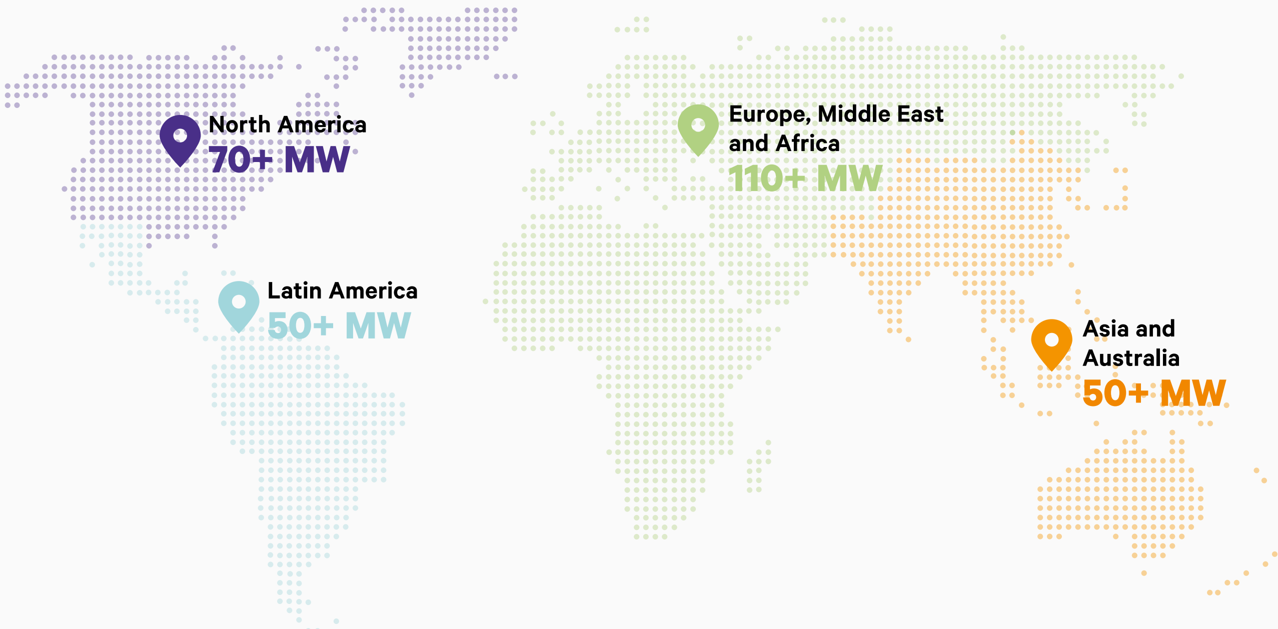
History of High Efficiency Modes

	2000's	2008	2018
	ECO Mode (VFD Mode)	Active Filtering Mode (VI Mode) Introduced by Vertiv with Chloride Trinergy	Dynamic Online mode (VI Mode) Introduced by Vertiv with Liebert® EXL S1 and Liebert Trinergy™ Cube
Efficiency	● 99% for typical IT load ▶ **Reduction in operating expenses and energy waste**	● 98,5-99% for typical IT load ▶ **Reduction in operating expenses and energy waste**	● 98,5-99% for typical IT load ▶ **Reduced operating expenses and energy waste**
Load power factor & load THDI compensation in VI Mode	● No compensation (only VFD Mode, VI Mode not available)	● Yes THDI reduction from 35% to 6%. PF compensation from 0.83 to 0.99 ▶ **Improvement of power quality, removal of penalties on electricity bill for reactive power charges**	● Yes THDI reduction from 35% to 6%. PF compensation from 0.83 to 0.99 ▶ **Improvement of power quality, removal of penalties on electricity bill for reactive power charges**
Transfer time from VI Mode to inverter protection (VFI)	● Up to 10 ms (half cycle) ▶ **Low protection**	● 2-4 ms under the most severe conditions ▶ **Medium protection** **High output power quality (within CBEMA curve)**	● ~0,1 ms under the most severe conditions (compliant with IEC 62040-3 Class 1) ▶ **High protection** **Highest output power quality (within IEC62030-3 Class 1 curve)**
Load availability	● **Higher impact to disturbances of the load. Partial load interruption can happen due to higher transfer time**	● **Medium impact to disturbances of the load**	● **No impact to disturbances of the load**

Dynamic Online Mode Systems

shipped for a number of markets, including: Colocation, Colo & Cloud, Data Centers, Commercial & Industrial

280+ MW
Global Shipments



Liebert® Trinergy™ Cube Field Results

Thanks to Vertiv™ LIFE™ Services, our remote diagnostic and preventive monitoring system, we have been able to constantly monitor a high number of Trinergy and Liebert Trinergy Cube units installed in Europe, Middle East and Africa. Figure 10 illustrates the average time spent in the different operating modes based on data collected from a sample of live sites (note VFD mode is disabled for this sample set of UPS). The first section shows the amount of time spent in each operating mode, and the second section shows the network quality according to four different categories. It is interesting to note the direct relationship between time spent in VI mode and network quality - a stable network correlates to a higher percentage of time operating in VI mode. **Dynamic online mode can now offer a solution to increase the system efficiency without compromising load availability, providing a new, safe way to lower system TCO.**

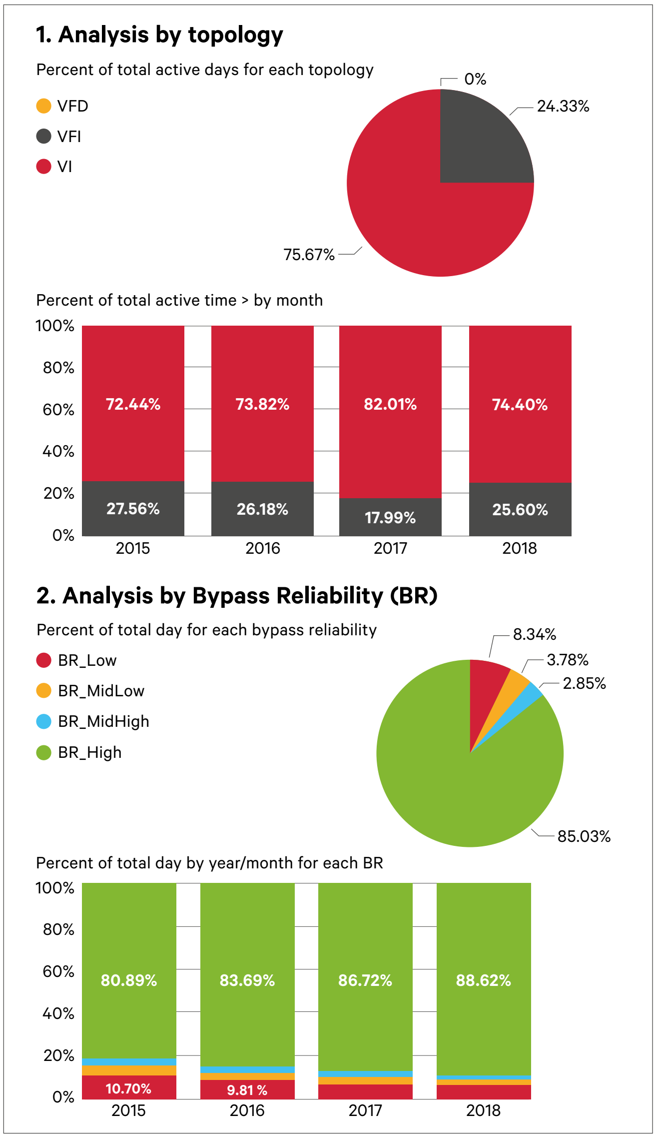


Figure 10. *Trinergy and Trinergy Cube field results. From top to bottom: operating mode average time, bypass reliability overview*

Conclusion

The use of ECO mode should be limited to resistive loads since this mode of operation typically does not include any PF or harmonic compensation. To ensure a proper load protection, active, and possibly passive, filtering should always be present in a UPS that offers ECO Mode. When selecting a UPS with ECO mode, it is important to ensure the associated transfer time is compatible with downstream loads, STS, transformers and servers, which must all be fully coordinated. This is one of the reasons why ECO Mode, as it is, is rarely used.

The latest technology, such as Dynamic Online mode incorporated into Liebert® Trinergy™ Cube and Liebert EXL S1, ensures the highest level of load protection with no trade-off between efficiency and availability. Power systems equipped with Dynamic Online are able to transition from high efficiency mode to inverter mode with a 0 millisecond transfer, providing full load power protection under virtually any input power outage condition, making them the ideal solution for protecting data centers by contributing to reducing PUE to minimum levels. Trinergy Cube field installations have proven a significant increase in average operating efficiency. The use of this technology for the replacement of legacy units can provide a Return on Investment (ROI) of a couple of years. Just consider that for a 1 MW load, choosing a UPS with higher efficiency could save about USD 14,000 per each 1% efficiency difference. Liebert Trinergy Cube and EXL S1 could easily provide six points higher efficiency versus existing units. Let us not forget about heat dissipation, which can be reduced by over 60%.

As can be seen in the field results reported in Figure 10, the UPS operates in VI mode for a considerable amount of time and yields higher efficiency than that of double conversion mode (VFI). This illustrates the benefit of a UPS that is capable of automatically selecting between all three possible operating modes per international UPS standard IEC 62040-3. In addition to improving UPS operating efficiency and reducing overall TCO, it provides peace of mind as it maintains the highest levels of availability and power protection for modern IT loads.

Indeed, as can be seen from saving results reported in Table 5 a UPS running in Dynamic Online mode offers a way to improve UPS operating efficiency and reduce overall TCO, while maintaining the highest levels of availability and power protection for modern IT loads (which is defined by IEC/EN 62040-3 Class 1 operations).

In conclusion, systems equipped with Dynamic Online mode are able to safely transition from high efficiency mode to inverter mode with a 0 millisecond transfer, thus providing absolute load power protection under virtually any input power outage condition.

Glossary

UPS = Uninterruptible Power Supply

VFI = Voltage Frequency Independent (as per UPS standard 62040-3)

VI = Voltage Independent (as per UPS standard 62040-3)

VFD = Voltage Frequency Dependent (as per UPS standard 62040-3)

PF = Power Factor

THDi = Total Harmonic Distortion for the current

PSU = Power Supply Unit

PDU = Power Distribution Unit

ROI = Return On Investment

TCO = Total Cost of Ownership

RMS = Root Mean Square

SCR = Silicon Controlled Rectifier

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