High Efficiency Modes of Operation

Authors:
E. Guidotti - AC Power Product Manager
A. Ferro - Key Account Manager
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 new renewable energy sources, energy conservation best practices, and the development and advancement of energy efficient standards, processes and technologies. Where 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 the 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 analyse what the drawbacks of ECO Mode types of operation can be and we will then highlight what elements should be considered when using this mode of operation. We will then review the field results achieved by the Trinergy™ UPS. In fact, Trinergy UPS has brought new ways of efficiency improvement to the market and has proved to be the premium UPS solution for data centers aiming to have the lowest possible PUE while maintaining the highest levels of availability. Finally, we will present the recent improvements achieved with the introduction of the Trinergy™ Cube, which further extends the benefits made available until now through Trinergy.

Introduction

UPS systems provide clean power to electronic systems such as computer networks and servers, building management systems 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 considered to be the ratio between the power entering the UPS and the power exiting the UPS to supply power to the load. Whenever the 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 whenever the air conditioning operates to sustain the ideal environmental temperature of the installation. Whilst a certain amount of energy losses 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. The savings accomplished 24 hours a day, 365 days a year over a five-year period, would not only equal the purchase price of a UPS but also actively contribute to reducing CO₂ and other global warming emissions, ensuring the lowest environmental impact of the chosen power protection solution.

Nowadays, the most common UPS topology used for supplying secure power to data centers is the 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 conversion, this is also the topology which uses the highest level of energy.

Even when considering a double conversion UPS, there are massive differences in terms of double conversion efficiency as legacy UPS may operate with 93% efficiency while the highest efficiency double conversion UPS can achieve levels greater than 96%. To further increase efficiency, most UPS manufacturers introduced high energy efficiency modes of operation, such as ECO Mode; nevertheless, most of these still remain just marketing advertisements rather than a concrete way of improving the data center efficiency.
ECO Mode and Its Effectiveness

Each electronic device could have its own specification; the main recommendation for IT equipment could be to refer to the CBEMA curve (Fig. 1). The ITI (CBEMA) Curve describes an AC input voltage envelope which can be typically 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 a perfect power quality, the ECO Mode takes advantage of the grid when of good quality by transferring the UPS to bypass and supplying the load directly through the grid via the bypass line.

With input power quality inside tolerances, the UPS can maximize the efficiency supplying the load through the Static bypass Switch.

Figure 1. CBEMA curve.
Advanced Control Techniques and Power Tracking permit to transfer to Double Conversion Mode as soon as there is an out of tolerance or a mains failure. As reference, here below in Fig.2 are shown the three different modes of operation as per UPS standard 62040-3.

If, on one hand, the reliability of the UPS is not affected at all by the operation in ECO Mode, on the other, ECO mode may even increase reliability as some of the internal components present inside the inverter and the rectifier are less stressed. This may cause a decrease in the power quality supplied to the load and there is no power conditioning performed by the UPS during this mode of operation.

The first consideration has to be done on the transfer time. 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, a protection against overvoltage must be considered for disturbances of 0.1 ms or more. Thus, in order to ensure load protection also against these types of disturbances, additional passive filtering on the bypass line should be considered.

An additional consideration has to be done in reference to the 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 installations, you must make sure that harmonics and PF of this 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 the harmonics levels can be slightly above 5%. When the UPS operates in double conversion mode, the PF and THDi that will be injected back into the grid will only be the ones of the rectifier of the UPS to be added to the ones generated by other pieces of equipment directly connected to the grid, such as compressors, chillers and so on.

At the same time, if we have a network with a high level of voltage distortion, it would not affect the load in any way as when operating in double conversion mode the UPS provides a sort of separation between the load and the grid.

Now, assuming to have the UPS operating in ECO Mode, the PF and the harmonics levels (THDi) that we
have to verify are no longer the ones of the UPS but we need to consider the harmonics and the PF of the load connected downstream the UPS as there is now a direct connection between the load and the grid. Considering that most servers have a dual power supply, the load on the power supply units (PSU) can never exceed 50% during normal operation. In addition, servers are not running at 100% capacity, thus, the PSU quite often operates between 10 to 40% of their capacity. As shown in Tab.1 below, we may end up with PF levels in the range of 0.77 up to 0.98 and harmonics in the range between 20% down to 7%. This is much worse than what happens on the input of the rectifier where we may still maintain PF levels at 0.98 and THDi less than 8% down to 10% load.

This means that when operating through the bypass line, we should also be sure to have some additional equipment in order to reduce harmonics and compensate for the PF of PSU. The same is valid if we are considering supplying mechanical loads through the bypass line. This can be achieved through the installation of an active filter or of re-phasing banks in the installation. The transfer time together with the missing passive and active filtering when operating in ECO Mode are the main key reasons while the ECO mode type of operation has remained a marketing advertisement rather than a concrete possibility to increase the efficiency of the UPS.

To overcome the drawbacks that can occur when operating in ECO Mode, there are a number of actions to ensure proper load protection (Fig. 3), 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
- Low transfer time (as per patented fast transfer ≤ 2ms) and full coordination with downstream equipment such as STS and transformer.

| Tab.1. Some example of the most typical non-linear server loads with low PF values and high harmonic rejection up to 20% THDi. (Source: http://www.plugloadssolutions.com/80PlusPowerSupplies.aspx). |

<table>
<thead>
<tr>
<th>$I_{\text{max}}$ A</th>
<th>PF</th>
<th>$I_{\text{max}}$ (%)</th>
<th>Load (%)</th>
<th>Fraction of Load</th>
<th>Input Watts</th>
<th>External Fan (W)*</th>
<th>DC terminal voltage (V) DC load current (A)</th>
<th>Output Watts</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DC terminal voltage (V) DC load current (A)</td>
<td>Output Watts</td>
<td>Efficiency %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12 V</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12 Vsb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.68</td>
<td>0.86</td>
<td>20.31</td>
<td>10%</td>
<td>Low</td>
<td>134</td>
<td>1.32</td>
<td>12.22/9.92</td>
<td>11.9/0.1</td>
<td>122</td>
</tr>
<tr>
<td>1.21</td>
<td>0.93</td>
<td>13.42</td>
<td>20%</td>
<td>Light</td>
<td>259</td>
<td>2.04</td>
<td>12.21/19.83</td>
<td>11.89/0.2</td>
<td>244</td>
</tr>
<tr>
<td>2.82</td>
<td>0.98</td>
<td>7.72</td>
<td>50%</td>
<td>Typical</td>
<td>635</td>
<td>9.96</td>
<td>12.21/49.57</td>
<td>11.86/0.5</td>
<td>611</td>
</tr>
<tr>
<td>5.59</td>
<td>0.99</td>
<td>5.27</td>
<td>100%</td>
<td>Full</td>
<td>1274</td>
<td>9.96</td>
<td>12.19/99.13</td>
<td>11.84/0.99</td>
<td>1220</td>
</tr>
<tr>
<td>0.76</td>
<td>0.77</td>
<td>13.83</td>
<td>10%</td>
<td>Low</td>
<td>135</td>
<td>23.40</td>
<td>12/9.28</td>
<td>0/0</td>
<td>3.3/0.5</td>
</tr>
<tr>
<td>1.21</td>
<td>0.90</td>
<td>12.78</td>
<td>20%</td>
<td>Light</td>
<td>249</td>
<td>23.40</td>
<td>12/18.51</td>
<td>0/0</td>
<td>3.3/0.99</td>
</tr>
<tr>
<td>2.71</td>
<td>0.96</td>
<td>8.00</td>
<td>50%</td>
<td>Typical</td>
<td>597</td>
<td>23.40</td>
<td>11.99/46.22</td>
<td>0/0</td>
<td>3.29/2.5</td>
</tr>
<tr>
<td>5.27</td>
<td>0.99</td>
<td>4.38</td>
<td>100%</td>
<td>Full</td>
<td>1196</td>
<td>23.40</td>
<td>11.98/90.51</td>
<td>0/0</td>
<td>3.27/4.98</td>
</tr>
</tbody>
</table>

Figure 3. Trinergy integrated passive and active compensation when operating in VFD and VI mode.
**Trinergy™ Power Interface**

One of the major differences between the units operating in ECO Mode (or similar) and the Trinergy™ UPS, is that, when operating in VI and VFD mode, the Trinergy supplies power to the load through a power interface that also ensures load protection when operating through the bypass line.

The Trinergy Power Interface is made up of a bypass static transfer switch with an upstream inductance and Transient Voltage Surge Suppressor (TVSS).

The bypass static switch is a fully rated, high speed, solid-state transfer device rated for continuous duty operation. When Trinergy is operating in VFD or VI mode, in case of disturbances in the mains supply, the chokes on the static bypass line operate in conjunction with the capacitors in the inverter output filter to provide an effective passive filter (LC).

In case of a high energy input spike, the UPS also ensures load protection thanks to the built-in TVSS (differential mode) and RF capacitors (common mode).

The Trinergy unit has successfully passed a surge test with these characteristics:

- 1.2/50 µs
- 8/20 µs

On the other hand, with temporary spikes of longer duration (in the range of some hundreds of microseconds to some milliseconds), the load will be protected by TVSS and LC filters. Temporary disturbances longer than a few milliseconds – bringing the UPS to work in double conversion mode – are compensated by the inverter during the temporary parallel of the reserve line with the inverter. Any disturbance longer than 100 microseconds will immediately activate the inverter. The activation time of the inverter will be less than 0.5 ms when synchronized. The system will ensure that the inverter is stable and operating normally before permitting a retransfer of the load back to inverter.

For example in Fig. 4 the attenuation provided by the Trinergy power interface filter upfront a temporary fluctuating input voltage disturbance is shown.

![Figure 4. Trinergy power interface attenuation in response to a temporary fluctuating input voltage disturbance.](image-url)
Trinergy™ Operating Modes

The transfer time between the different operating modes (Tab.2) can now require $\leq 2\text{ms}$ (as per patented fast transfer). This is by far within the limit defined by the ITIC CBEMA curve.

### Maximum Power Control (VFI)

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%.

### High Efficiency & Power Conditioning (VI)

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, Trinergy™ 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%

### Maximum Energy Saving (VFD)

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%. 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.

Circular Redundancy

In addition to the operating modes described above, Trinergy ensures the highest efficiency also at partial load conditions down to very low load percentages - down to 10% by using Circular Redundancy. Taking advantage of its modular architecture, the unit defines the necessary number of modules to supply the load, putting the remaining modules in a special "sleeping mode" (Fig.5). With this technique, the running modules operate at a higher load percentage, thus improving the efficiency of the overall unit. It is important to note that the sleeping modules are not completely turned OFF but still have the inverter control active and synchronized as well as the DC bus charged in order to be ready to start up in case of a load increase. Even in this condition, the time needed to have one module activated while the unit is sleeping is $\leq 2\text{ms}$. It is important to note that the sleeping CORES are rotated in order to ensure the same ageing for all of the CORES in the system.

Tab.2. Trinergy operating modes.

Figure 5. Trinergy Cube Circular Redundancy example at 50% load on a 1.6 MVA unit.
**Trinergy™ Algorithm**

The activation of Trinergy™'s three different functioning modes is based on the real time power tracking of the main parameters related to the input network conditions and output load quality (Fig. 6).

The electrical conditions related to the load and the network are constantly monitored, thus 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 power conditioning on the load is ensured together with 0.99 input PF both on the mains and bypass line, and less than 5% THDi.

If the observed variables listed above are outside specific ranges, the UPS will activate a different functioning mode in accordance with the algorithm settings (Fig. 7). These settings can be customized by the service engineer upon request.

In the Tab.3 here below, a summary of the most important differences between Trinergy and any other UPS using ECO Mode or similar is shown.

<table>
<thead>
<tr>
<th><strong>Trinergy</strong></th>
<th><strong>ECO Mode</strong></th>
<th><strong>Trinergy Advantage</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive filtering in VFD</td>
<td>Only static bypass in VFD</td>
<td>Load protection also in VFD</td>
</tr>
<tr>
<td>Active filtering in VI</td>
<td>No VI Mode</td>
<td>Compensates harmonics and PF reducing the reactive current towards the upstream network</td>
</tr>
<tr>
<td>Network and load monitoring</td>
<td>Network monitoring only</td>
<td>Operates in accordance with load variation and various load types</td>
</tr>
<tr>
<td>Rectifier OFF in VI and VFD Mode</td>
<td>Rectifier ON in VFD without load</td>
<td>Does not absorb kVAR from the rectifier as ECO Mode does</td>
</tr>
<tr>
<td>PF and harmonics controlled on both rectifier and bypass input</td>
<td>PF and harmonics controlled only on rectifier input when operating in VFI</td>
<td>Trinergy algorithm grants higher efficiency providing time power conditioning at the same time</td>
</tr>
</tbody>
</table>

**Trinergy Field results**

Thanks to LIFE™, our remote diagnostics monitoring system, we have been able to constantly monitor a high number of Trinergy units installed in Europe, Middle East and Africa. In the following table (Tab. 4), the average time spent in the different operating modes is represented based on our entire installed base amounting to several hundred MW of capacity. As is shown in Tab.4 and Fig. 8 below, most of the time is spent in VI mode with a significant amount of time is spent as well in VFI and in CR. This combination provides a resulting operating efficiency of 97.3%.

<table>
<thead>
<tr>
<th><strong>Mode</strong></th>
<th><strong>VFI + CR</strong></th>
<th><strong>VFD</strong></th>
<th><strong>VI</strong></th>
<th><strong>Avg</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency %</td>
<td>95.5%</td>
<td>99.0%</td>
<td>97.8%</td>
<td>97.3%</td>
</tr>
<tr>
<td>Operating Time %</td>
<td>27%</td>
<td>11%</td>
<td>62%</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 6.** Trinergy algorithm and real time power tracking of the main input and output parameters.

**Figure 7.** Trinergy internal algorithm main thresholds and settings.

**Tab.3 -** Most important differences between Trinergy and any other UPS using ECO Mode or similar.
This result highlights the importance of the VI mode versus ECO Mode types of operation. The majority of the time spent in this mode, in fact, reflects the constant need for power conditioning of the load and of the disturbances coming from the network. As a matter of fact, not only does Trinergy ensure the highest possible efficiency, it also maintains both the PF close to unity and the harmonics in the installation to minimum levels.

![Figure 8. Average operating time spent in the different Trinergy operating modes according to Tab.5.](image)

**Trinergy™ Cube Efficiency Improvements**

Thanks to the adoption of a Three Level Neutral point clamped topology used for the rectifier and inverter, the usage of the latest generation of IGBT and of low-loss chokes, Trinergy™ Cube has achieved even better results in the double conversion efficiency versus the current Trinergy by about 1%. In fact, Trinergy Cube is capable of reaching a double conversion efficiency of up to 97%.

This is made possible thanks to the continuous research carried out in the Customer Experience Centre located in Castel Guelfo – Bologna, Italy - in terms of highest quality components which can ensure the lowest possible losses and the highest levels of reliability. Another important improvement is linked to the deep study of ventilation and the use of highly efficient DC fans fully regulated in terms of speed depending on the temperature components that help maximise efficiency when operating at partial load.

The efficiency improvement in double conversion mode because of the latest inverter design based on NPC2 topology has the immediate consequence of increasing efficiency also in VI mode where the inverter is fully turned ON, compensating for network disturbances and ensuring the best level of power conditioning to the load.

The use of Circular Redundancy has now been extended also to the VI mode, which always ensures the lowest number of power converters fully active, thus using the minimum amount of energy possible and constantly achieving the highest efficiency by providing power conditioning to the load at all times. As a combination of the three functioning modes and the highest efficiency provided by the Trinergy Cube power converters topology, the unit can deliver a higher average operating efficiency as shown in Tab. 5 here below.

<table>
<thead>
<tr>
<th>Mode</th>
<th>VFI + CR</th>
<th>VFD</th>
<th>VI</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency %</td>
<td>96.8%</td>
<td>99.5%</td>
<td>98.9%</td>
<td>98.4%</td>
</tr>
<tr>
<td>Operating Time %</td>
<td>27%</td>
<td>11%</td>
<td>62%</td>
<td></td>
</tr>
</tbody>
</table>

Tab.5 - Average operating efficiency of the Trinergy Cube according to the average operating time presented in Tab.5.

**Patented Fast Transfer**

The seamless activation of Trinergy Cube’s functioning modes ensures the highest level of efficiency without compromising power quality and availability.

The experience gained in these six years since the first Trinergy installation brought forth the development of an improved technique covered by Patents PCT/IB2013/058549, PCT/IB2013/058548 to activate the different operating modes.

The adaptive fast transfer ensures the quickest response time (≤ 2ms) under various conditions:

- Network fault (voltage variation, high/low impedance mains failures)
- Load fault (short circuit downstream of the UPS)
- Type of load connected (PDU transformer)

The unit is able to discriminate between various types of interferences and rapidly respond, while at the same time ensure compatibility with downstream equipment such as servers, transformers, STS or mechanical loads.
Conclusions

The ECO mode type of operation has a very limited scope of application to load types that are almost resistive as it is not able to perform any harmonic or PF compensation. To ensure a proper load protection, passive and active filtering should always be added to a UPS that would operate in ECO Mode. Transfer time is also one of the major issues as it has to be compatible with downstream loads, STS, transformers and servers, which must all be fully coordinated, making the ECO Mode almost non-applicable to most installations.

On the contrary, the technology used in Trinergy™ and Trinergy™ Cube ensures the proper level of load protection and power conditioning for the load and the grid, making it the ideal solution for protecting data centres by contributing to reducing PUE to minimum levels. Field installations have proved an average operating efficiency above 97% for the existing Trinergy, which can be further, boosted up to 98.5% with the adoption of the Trinergy Cube. The use of this technology for the replacement of existing units can provide a return of investment (ROI) of a couple of years. Just consider that on a 1 MW load, choosing a UPS with a higher efficiency could save about 12,000 Euro per each 1% efficiency difference. Trinergy Cube could easily provide six points higher efficiency versus existing units. Looking at the heat dissipation, this is translated into a reduction by over 60%.

Indeed as can be seen from field results reported in Tab. 5 above, for the majority of the time the UPS is running in VI mode highlighting the need to have a UPS which is capable to automatically select between all three possible operating modes, as per UPS standard 62040-3, offering a way to improve UPS operating efficiency and reduce the overall TCO, while maintaining the highest levels of availability and power protection for modern IT loads.

That said, Trinergy Cube represents the optimal solution to address the drive towards energy saving and the widely encouraged use of new renewable energy sources, energy conservation best practices, and the development of energy efficiency standards, offering continuous availability, unparalleled operating efficiency, optimized installation space and smart capacity, being designed around the IT space and ready to evolve with growing business demands up to 24 MW.
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
TVSS = Transient Voltage Surge Suppressor
PDU = Power Distribution Unit
ROI = Return Of Investment
TCO = Total Cost of Ownership
Ensuring The High Availability
Of Mission-Critical Data And Applications.

About Emerson Network Power
Emerson Network Power, a business of Emerson (NYSE:EMR), is the world’s leading provider of critical infrastructure technologies and life cycle services for information and communications technology systems. With an expansive portfolio of intelligent, rapidly deployable hardware and software solutions for power, thermal and infrastructure management, Emerson Network Power enables efficient, highly-available networks.
Learn more at www.E EmersonNetworkPower.eu

Locations

Emerson Network Power
Global Headquarters
1050 Dearborn Drive
P.O. Box 29186
Columbus, OH 43229, USA
T +1 614 8880246

Emerson Network Power
Europe Middle East And Africa
Via Fornace, 30
40023 Castel Guelfo (BO) Italy
Tel: +39 0542 632 111
Fax: +39 0542 632 120
ACpower.Networkpower.Emea@Emerson.com

Emerson Network Power
United Kingdom
George Curl Way
Southampton
SO18 2RY, UK
T +44 (0)23 8061 0311
F +44(0)23 8061 0852

Globe Park
Fourth Avenue
Marlow Bucks
SL7 1YG
Tel: +44 1628 403200
Fax: +44 1628 403203
UK.Enquiries@Emerson.com

While every precaution has been taken to ensure accuracy and completeness herein, Emerson assumes no responsibility, and disclaims all liability, for damages resulting from use of this information or for any errors or omissions. Specifications subject to change without notice.