Uninterruptible Power Supplies Ltd
A KOHLER COMPANY

The UPS data centre handbook

The essential guide to making informed decisions around UPS data centre systems

Highly efficient & reliable UPS systems for the data centre industry

Low total cost of ownership

Whether you're supporting a localised IT facility or an enterprise level data centre with over 500 servers, operating a UPS system contributes significantly to capital and operating expenditure. So, although the UPSs critical role demands investment in the most advanced, reliable solutions, maximising efficiency and lowering total cost of ownership is also essential; a small change can have a big impact on the bottom line.

UPSLs PowerWAVE range, including the 6000, 8000DPA and 9000DPA, provides a complete offering of highly-efficient solutions for data centres of all sizes. The range's class-leading efficiency levels, available over a wide load spectrum, combine with near-unity power factors to ensure operating costs are minimised, while available scalability options reduces upfront capital expenditure.

Find out which is right for your operation today.

PowerWAVE 6000 –

Transformerless UPS technology for best-in-class performance up to 5 MVA

PowerWAVE 8000DPA –

Modular, three-phase UPS providing power protection up to 200 kVA

PowerWAVE 9000DPA –

Three-phase, modular UPS with a high operating efficiency of up to 96%

Contact us to calculate your TCO today

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Enterprise data centre

>5,000 sq ft

>500 servers

UPS size=>750kVA

PowerWAVE 6000

High operating efficiency regardless of loading:
- Up to 96% for 25–100% loads.

Near unity input power factor:
- 99% at 100% load.

Reduced installation and upgrading costs.

Reduced system running costs: £19,225* cost saving over five years per 1% efficiency improvement.

Reduced air conditioning costs:

Less heat loss.

Low carbon footprint.

60–500kVA ‘building blocks’ scalable to 5MVA.

* 500kVA @ 100% load / 95% efficiency

Mid-tier data centre

<5,000 sq ft

101–500 servers

UPS size=101kVA–750kVA

PowerWAVE 9000DPA

High operating efficiency regardless of loading:
- Up to 96% for 25–100% loads.

Near unity input power factor:
- 99% at 100% load.

Reduced installation and upgrading costs.

Reduced system running costs: £9,520* cost saving over five years per 1% efficiency improvement.

Reduced air conditioning costs.

Low carbon footprint.

10–250kVA capacity in 10, 20, 30, 40 or 50kVA modular steps.

N+1 Redundancy (up to 200 kVA N+1).

* 250kVA @ 100% load / 95.5% efficiency

Localised data centre

<1,000 sq ft

25–100 servers

UPS size=25kVA–100kVA

PowerWAVE 8000DPA(ST)

High operating efficiency regardless of loading:
- Up to 95.5% for 25–100% loads.

Near unity input power factor:
- 99% at 100% load.

Reduced installation and upgrading costs.

Reduced system running costs: £4,570* cost saving over five years per 1% efficiency improvement.

Reduced air conditioning costs:

Less heat loss.

Low carbon footprint.

10-200 kVA capacity in 10 kVA and 20 kVA modular steps.

N+1 Redundancy (up to 180 kVA N+1).

* 120kVA @ 100% load / 95.5% efficiency

Contents

Introduction

"This Handbook focuses on the efficiency and reliability issues that matter most today to anyone planning a UPS installation or upgrade."

We trust that this Handbook will become a valuable asset and reference for owners, operators and designers. In a complex field with many variables, it focuses on the efficiency and reliability issues that matter most today to anyone planning a data centre UPS installation or upgrade.

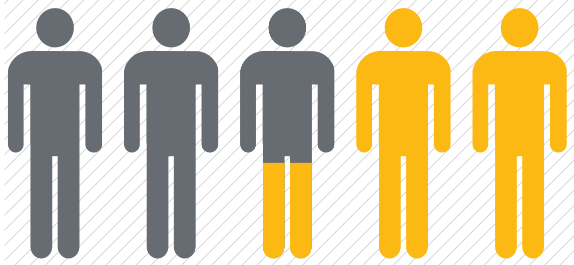
UPS systems have become absolutely indispensible to every data centre though choosing the right product, configuring and installing it correctly is far from easy as operators face conflicting pressures. The availability of clean, uninterrupted power has become business-critical and now has to be combined with maximum possible efficiency. Not only are electricity costs steadily rising, but also data centres must demonstrate effective Green policies to comply with existing and potential legislation, and preserve their reputation with customers, shareholders and employees.

Fortunately, balanced solutions are possible through improved UPS technologies and topologies, ICT equipment and, sometimes, utility mains power. This handbook explains the issues, interactions and solutions. It discusses how UPS efficiency for all load levels is improved by transformerless design, and how both capex and opex can be minimised through modular design and right sizing. It also covers the increasingly popular question of 'Eco mode' operation. This mode, when first introduced by UPSL was not widely favoured. It is now commonly used as modern ICT equipment has better blackout ride-through capabilities, while many utilities now offer better voltage and frequency stability. Availability is also discussed in terms of MTBF and Mean Down Time (MDT), and the importance of a reliable service partner in maximising MTBF whilst minimising MDT is explained.

The Handbook also discusses industry views and standards on UPS efficiency and availability, particularly by examining Power Usage Efficiency (PUE) and data centre tier classifications. PUE has become the driving force behind improving data centre efficiency, and as cooling systems have become more efficient, attention is turning to the UPS contribution. Tier classifications, sponsored by the Uptime Institute for nearly 20 years, describe facilities from an availability standpoint. The Handbook shows how dual-cord and N+1 redundancy UPS configurations can be used to change tier level and dramatically improve availability.

Summary of survey findings

Each year Uninterruptible Power Supplies Limited, a Kohler company, commissions a national survey of IT professionals across the United Kingdom, allowing it to keep pace with current thinking, trends and attitudes regarding UPS equipment, power consumption and energy efficiency. Here you will find a snapshot of the key findings:



Reliability

43%

of respondents believe that maximum reliability is the number one product feature they look for.

Operations

When considering reducing power consumption, what is the primary driver for change within your organisation?

62%

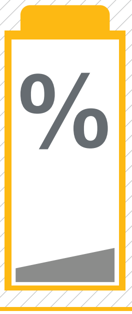
Reducing operating costs

30%

Reducing their carbon footprint

Power

72%

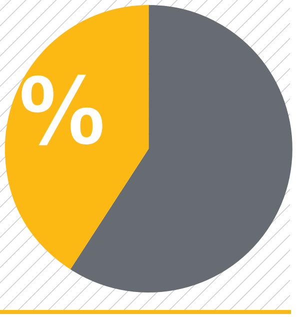


of respondents believe that the reliability of power in the UK is going to be come a major concern within the next 10 years.

Buying

41%

believe the most important factor to a potential buyer when selecting an OEM is 'a reputation for quality and reliability'.



Product efficiency

75%

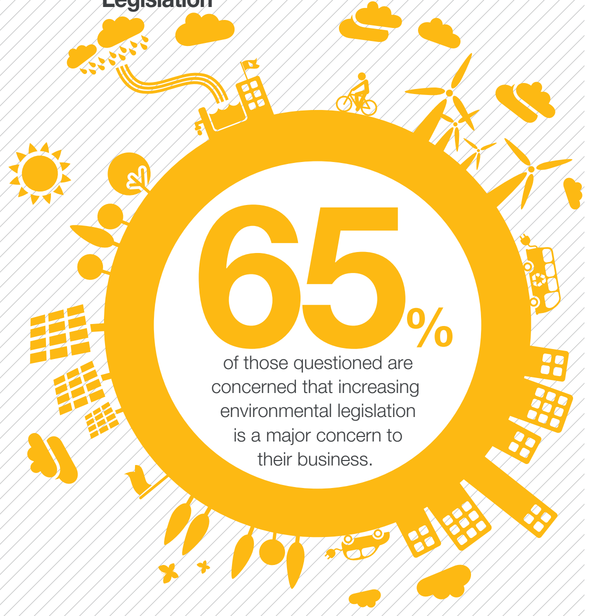
of respondents are already investigating product efficiency as a way to control/reduce operating costs

Maintenance

92%

of respondents agree that maintenance and call out services are as important as the hardware itself.

Legislation



65%

of those questioned are concerned that increasing environmental legislation is a major concern to their business.

Carbon footprint

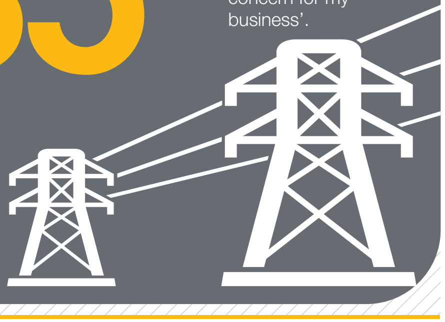
70%

of those who completed the survey have a carbon reduction policy in place.

Power costs

85%

of those questioned agreed with the statement 'Rising power costs are a major concern for my business'.



The impact of UPS technology on the design of 'green' data centres

> **"For many years, UPS efficiency has been gradually improving, but it has been the mechanical cooling systems that have attracted the most attention for energy overhead reduction."**

Power Usage Effectiveness (PUE) has become the driving force behind the improvement in energy efficiency of data centre M&E infrastructures and an integral part in the pursuit of the 'green' data centre. PUE can be defined as a measure of how efficiently power is used within a data centre. It is measured by a ratio of total amount of power used, to the amount of power delivered to computing equipment.

PUE = Total facility power / IT equipment power

For many years, UPS efficiency has been gradually improving but it has been the mechanical cooling systems that have attracted the most attention regarding energy-overhead reduction. As the cooling systems have themselves improved, in some cases drastically, the focus has now returned to the power system. This white-paper reviews the historical case, where design PUEs of >2.0 were not uncommon, and looks at the possibilities provided by scalable high-efficiency UPS products, and the maximum impact that the UPS can make to the PUE as it progresses below 1.4.

> **"Topology has also changed, with double-conversion being enhanced with eco-mode and modular designs enabling higher load power factors."**

UPS in historical PUE context

Although the PUE metric is a relatively recent innovation (by The Green Grid), the principle of working out what capacity utility was required for a given ICT load in a data centre has always been one of the first tasks of the designer. Indeed, as PUE is an annualised energy metric and not a peak-power metric, that calculation still has to be done as the 'peak' dictates the size of the utility and the emergency generation system.

If we consider a typical early-90s data centre with a critical load of around 1MVA, (the kW load was hardly ever considered in those days as the load power factor was not unity and harmonic currents dominated), it had an N+1 UPS of probably 3x500kVA with an efficiency of 88% and a compressor-based mechanical cooling system that maintained tight temperature and humidity environment. The chilled water was supplied at 6ºC and the air supplied into the under-floor plenum was around 15ºC. No 'free cooling' coils were ever considered (or available in standard equipment) and variable speed pumps and fans were still on the application horizon. Humidification and de-hum consumed energy and even the lighting was high in proportion to the load as the power density was 350-500W/m≤ from mainly main-frame hardware. The overall impact of this infrastructure was a system where the utility load was constant (non-seasonal) and the fully loaded 'PUE' (if that had been innovated) was in the order of 2.5. However, the partial load performance was very poor – with monolithic plant (no scalability planned) and no variable speed drives – with the result that the majority of facilities ran at a PUE equivalent of 3.5. Hence, even at partial load, the UPS system only contributed about 0.15 to the PUE with the mechanical cooling load dominating the power demand. Energy was cheap and the load was sacrosanct and so very few people, if any, worried too much about the energy costs of data centres.

The development of UPS efficiency

The efficiency improvement of UPS has followed a combination of component innovation, such as thyristors being replaced by transistors in inverters (and, much later, rectifiers), which enabled the removal of passive filters and transformers. Topology has also changed, with double-conversion being enhanced with eco-mode and modular designs enabling higher load power factors.

In the early 90s a large UPS module would have an input transformer, 12-pulse thyristor rectifier, passive 11th harmonic input filter, DC capacitors, 6-step thyristor inverter with isolating transformer and output filter network, which all resulted in a maximum efficiency at full load of 87%. Compare that today with a transformer-less IGBT/IGBT rectifier/boost-stage/inverter model which can offer 96% in double-conversion mode and, if the user enables it, eco-mode operation providing up to 99%.

It is worthy of note that any system requiring an annual shutdown of four hours for maintenance can only achieve an availability of 99.95% (MTBF=8,760h and MDT=4h).

So, a high availability can be achieved by either a long MTBF or a short MDT but the MDT should (but usually does not) include the ICT system re-start time.

The introduction of ‘free-cooling’ economisers and, more recently, the relaxation of the thermal envelope (temperature and humidity) by ASHRAE have led the cooling system power to be drastically reduced. Strict air-management, ensuring that no cooled air bypasses the load, has been established as best-practice and this has been enhanced for partial load conditions by the widespread use of variable speed drives for fans and pumps. Full-load cooling coefficient of performance (CoP) has improved from 1.0 (where to move 1kW of heat from within the critical space to the external ambient takes a further 1kW of power in the cooling system) to better than 0.1 (1kW of cooling system power to remove 10kW of waste heat from the load).

To compliment this contribution to a target PUE of 1.2 or better the UPS is required to offer 0.05 and the other consumers (internal & external lighting, NOC, controls and security etc) a further 0.05. It can be seen that getting to an annualised PUE of c1.15 requires extremely efficient systems but a full load UPS efficiency of >95% is essential. Partial-load performance must also be excellent, through technology (e.g. with >94% efficiency at 30–40% load) or ‘right-sizing’ to keep the UPS load >70%, including the option of using modular UPS topology as described later.

Tier classification and impact on PUE

With the exceptions of the largest search engines and social media network data centres partial-load is a common feature of data centre operations. Newly constructed ‘enterprise’ class facilities can start life carrying loads as low as 15% and take 4–6 years to reach higher than 65%. They often never exceed 80% load and, as we have already seen, partial load is a barrier to high efficiency in data centre systems. For single-bus ICT systems (Tier I-III), with N+1 redundancy, this can be mitigated by scalable systems (where modules can be disabled to keep the load factor high (e.g. 5x500kW for a 2MW system load) or modular systems (see over).

For dual bus (Tier I-IV) scalable (and modular) UPS architecture can help raise the efficiency of each bus but the load is never likely to exceed 40% per bus, and very often will be less than 20%. Hence the UPS contribution to the PUE will be higher than an N+1 singlebus system unless more radical measures are taken – such as using an eco-mode feature in one or both buses. In the case of ecomode enablement the usual penalty from highly partial load in dual bus systems can be entirely overcome.

Modular UPS topology

For small and medium systems the advent of modular systems (where rackable modules are contained within a single infrastructure cabinet) has made the ‘right-sizing’ of UPS to a given load easier than ever before. Expansion of capacity is a simple matter of adding a further module and contraction is a simple matter of turning off modules in turn. The initial frame must, of course, be sized for the ultimate load. The selection of the module rating should be influenced by the load steps anticipated and the ultimate load. Hence a 100kW ultimate load may be suitable for 10kW modules and a 1MW ultimate load suitable for 200kW. Above 1MW it is usual to engineer a multi-module scalable solution (e.g. of 500kW modules) and provision the switchgear infrastructure for the ultimate configuration, but not necessarily installing all UPS modules on ‘day-1’.

The aim is simply to allow the UPS to be loaded to 70–80% at any given load – where the UPS will be able to provide its highest efficiency rating.

The future

ICT loads need an effective UPS system for continuous operation as much today as they ever have and those UPSs have to provide operational efficiencies of >95% (even at partial loads) to produce the level of infrastructure energy efficiency (PUE) expected by endusers and future carbon-reporting and possible legislation.

As energy costs rise and the reliability of eco-mode UPS operation is proven in mature grids the UPS of the future is likely to operate at c99% efficiency for >90% of the year. This level of performance in conjunction with the most advanced cooling systems (such as adiabatic indirect cooling with air:air heat exchangers with CoP of 0.025) and LED motion-controlled lighting will permit the typical PUE to be <1.10 across all of Europe.

The upside and downside of dual bus power

"Clearly the benefit of moving up the tier layers is to extend the Mean Time Between Failure (MTBF)."

Introduction

Data centre facilities provide high-fidelity power to the critical load by the provision of Uninterruptible Power Supply systems in various levels of redundant architectures that are well described in the foundation work of The Uptime Institute in the USA. When the founders of The Uptime Institute introduced their data centre tier classifications in the early 90s they built on their own innovation of dual-corded ICT loads. Prior to that time ICT loads, such as enterprise servers, were single-corded devices and there were only two possible levels of provision in the power domain – firstly without redundant components, which often needed a load shutdown to carry out maintenance and where a single failure resulted in downtime, and the second with redundant elements which gave some opportunities for concurrent maintenance and a degree of fault tolerance. The best example is the UPS system – Tier I having a single module and Tier II having a redundant system with N+1 architecture.

With the advent of the dual-corded loads, the opportunity for concurrent maintenance expanded when Tier III introduced the principle of an active path (containing an N+1 system) to one cord and a separate passive path that brought power (from the utility or generator if required) to the other cord. For the ultimate reliability and resilience Tier IV brought active/active to the two load cords – with an N+1 redundant power system in each path, 2(N+1), that provided both concurrent maintenance and fault tolerance to the single major failure event.

"To move from Tier I to Tier IV clearly increases the potential availability in terms of both planned outage for maintenance and unplanned outage by failure."

It is interesting to note that once you assume that the most basic power system (Tier I) comprises a single UPS and single generator, there are only four possible power architectures to support dual corded loads. Therefore it should not be surprising to see that many 'design' authorities followed in the steps of TUI and perpetuated the four tier levels, e.g. TIA942, BICSI and the soon to be released EN50600. In the 20 years since the original tier classifications were innovated only one change has been seen – the reduction from 2(N+1) to 2N in Tier IV, although this has only been well described by the originators, TUI, and not followed by such standards as TIA942.

So what are the upsides and downsides of dual bus?

Upsides of dual bus topology

To move from Tier I to Tier IV clearly increases the potential availability in terms of both planned outage for maintenance and unplanned outage by failure, and the major step occurs between Tier II and Tier III as dual-corded loads offer the opportunity to utilise a dual bus power architecture. However the term 'availability' is often misunderstood, misused and sometimes abused deliberately for marketing purposes. At the heart of this 'problem' are the original percentages that TUI published in their original white paper: For each tier they gave an availability percentage and expressed it as 'X minutes downtime per year', e.g. Tier I offered 99.67% with 28.8 hours/year downtime compared to Tier IV, 99.99% with 53 minutes/year downtime. It should be obvious to all that one failure per year would be unacceptable for any system (I or IV) and the amount of downtime hardly matters when it may take the average integrated ICT load several hours to re-engage with the mission critical function after a loss in power.

Clearly the benefit of moving up the tier layers is to extend the Mean Time Between Failure (MTBF) although if single-corded loads exist in the dual bus architecture then they should be protected by point-of-use (usually rack-mounted) static-transfer switches.

After that (single) failure the recovery time (Mean Down Time) needs to be short as possible as, interestingly, to give an availability figure you need to know both the MTBF and the MDT, as follows;

$$\text{Availability} = \frac{\text{MTBF}}{(\text{MTBF}+\text{MDT})} \times 100\%$$

It is worthy of note that any system requiring an annual shutdown of 4h for maintenance can only achieve an availability of 99.95% (MTBF=8,760h and MDT=4h). So a high availability can be achieved by either a long MTBF or a short MDT but the MDT should (but usually does not) include the ICT system re-start time.

Having pointed out the weakness in the term ‘availability’ and accepting that MDT will always be several hours, we can better express the upside of climbing up the tier layers as a relative MTBF of the alternative power system architecture. Figure 1 tabulates the relative MTBF of the architectures from N to 2(N+1) for a change in ‘N’. In this case the MTBF describes the voltage supplied by the UPS system inside the latest version of the ITIC/CBEMA voltage tolerance curve, and ignores the MTBF of the downstream power distribution systems. In the case of the dual bus active/active the MTBF represents the event of concurrent failure of both buses.

Figure1: Relative UPS MTBF, CapEx & availability

Availability calculated with a single UPS module MTBF=100,000 and MDT=8h

	Where N=			Where N=2		
Architecture	N=1	N=2	N=3	CapEx	MTBF (y)	Availability (%)
N	1	0.9	0.8	1	10	99.991112%
N+1	10	9	8	1.8	103	99.999111%
2N	800	700	600	2.3	7,991	99.999989%
2(N+1)	1000	900	800	3.6	10,274	99.999991%

So it can be seen that the MTBF of dual bus systems is dramatically enhanced over the MTBF of a single module. We can see in the last three columns a typical high power data centre (where N=2) the availability based on one failure event with a Mean Down Time of 8 hours – a 4h response on site followed by a 4h repair or an 8h reboot time after a momentary failure in voltage lasting longer than 20ms.

However there is an additional advantage of any dual bus system over a single bus system:

Depending upon which analyses of data centre failure you choose to read, you will learn that 35–70% of all data centre failures are down to human error and most of those take place in the electrical infrastructure. The advantage of dual bus, be that 2N or 2(N+1), is that simultaneous human errors (i.e. one human error in each system at the same moment) is virtually impossible. The obvious cause of downtime in single bus systems is inadvertent operation of the EPO and that just can’t happen in two separate rooms. So, the chances of human error are substantially reduced in dual bus systems.

It is worth noting that many data centre designs that are not Tier IV per se, incorporate 2N power to enable ease of management and maintenance without shutdown or risk. These are often referred to as Tier III+, although TUI do not support, in any fashion, the concept of intermediate steps in the tier classification hierarchy.

Historical downsides of dual bus topology

To counteract the clear advantages of dual bus there have been penalties. Of course, if the business model of the organisation requiring the data centre is centred only on ultra-high availability and high fault tolerance, these ‘downsides’ are the acceptable cost of doing business.

The most obvious penalty may be the initial capital investment in the extra redundant components, although the relative costs are outweighed by the huge increase in relative availability as indicated in the above table.

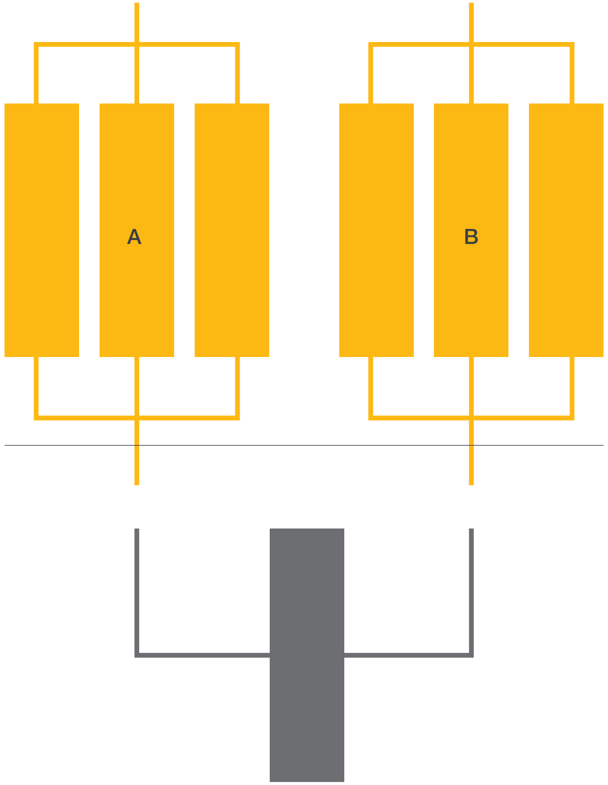
Additional plant-room space to house the transformers, generators, UPS, switchgear in segregated spaces and delivery paths, complete with environmental control, fire detection and suppression, lighting and security all add to the initial investment. Having said that, the facility costs represent less than 25% of the data centre 10-year Total Cost of Ownership but the cost of power, the next downside of dual bus architecture to be considered, is the largest element in the TCO – in some data centre business models as much as 50%.

If we consider the original 2(N+1) architecture at partial load, we will be able to see why the change to 2N came about as concerns about energy efficiency grew, even in the USA.

Figure 2 shows the configuration of 2(N+1) when N=2.

Figure 2:
2(N+1) when N=2

Dual bus for dual-cord loads
Load = 1MW
N=2
2x 3x500 kW UPS modules



Let us now consider how an ‘average’ enterprise data centre facility load develops over time:

- The critical load often starts off below 20%.
- It may climb to c40% after 2–3 years.
- Reaches a plateaux of <80% after 5 years.
- The critical load never reaches 100%.

If we consider the 2(N+1) UPS system in Figure 2 the module load in normal operation against these indicative 20%/40%/80% load stages we can show that it is 3.3%/6.7%/13.3% respectively.

In other words, the UPS modules work at very light loads for the vast majority of their service life. Turning one module ‘off’ in each system to improve the load factor is only possible when the load is below 50%, and this improves the early years to 5% load per module at 20% facility load and 10% load per module at 40% facility load – still very low.

It was very probably this low load problem that pushed the change to 2N, removing the (double) redundant module on each side and relying on each system to be 100% redundant for the other. However, we need to view this against the efficiency of a typical North American legacy UPS: A typical large UPS in the USA was thyristor based, 460V input, 208V output with input, output and bypass transformers, often with a 6-pulse rectifier without a harmonic filter up to 600kVA. The efficiency at full load was c91% but the partial load efficiency was poor. On Figure 3 is shown (in red) a typical efficiency curve from c2005. To consider the impact of installing this type of UPS in 2(N+1) architecture we need to consider the efficiency in the sub-10% load range of around 50%. If we add a dual bus cooling system at similar low load it is easy to see that an operational PUE (rather than design PUE) of >3 was very easy to achieve.

Pressures on operational costs (power and maintenance), and the realisation that a double redundant system gave little increased resilience for dual corded loads, resulted in Tier IV being downgraded to 2N from 2(N+1).

Dual bus also can have an unfortunate side-effect outside of the UPS loading – that of under-utilised plant. This led to many forms of distributed redundancy architectures with ‘swing’ transformers or generators and often utilising static-transfer switches. These solutions saved capital expenditure but at the risk of increasing complexity that sometimes led to lower reliability and the introduction of increased opportunities for human error.

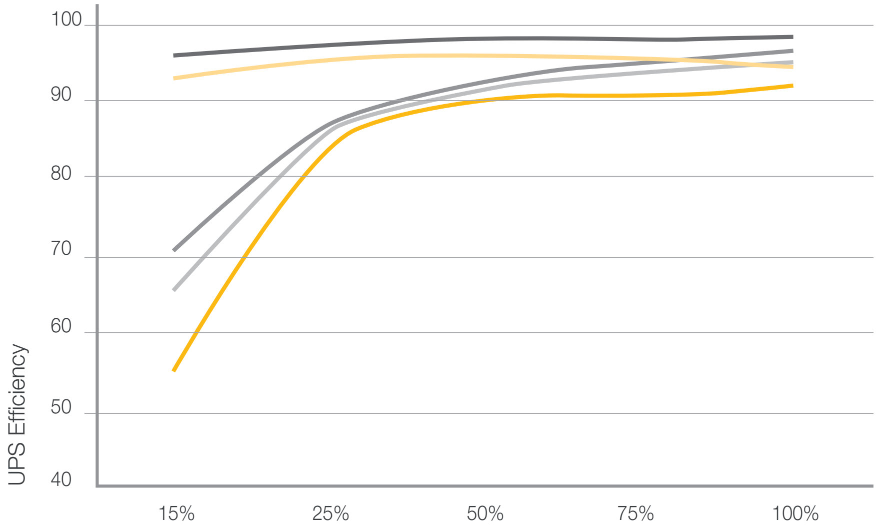
One inadvertent consequence of following TUI and TIA942 recommendations for 15 minutes of battery autonomy per module in Tier IV systems, was that battery autonomy is not linear with load, and the effect of very light load on the dual bus system is to produce battery autonomies in the region of 3 hours. With power densities in the critical space gradually increasing, any extended UPS autonomy is not usable unless the cooling system is also continuous – since the load will shut-down on thermal-alarm before the power is shut-off.

Overcoming the problem – the modern solution for the legacy

There is no doubt that the extended MTBF and lower risk of human error that dual bus architecture offers with dualcorded loads, is as attractive now as it always was, if not more so. However it is now possible to mitigate, if not avoid altogether, the problems associated with partial load by utilising state-of-the-art UPS technology and designing the system in a scalable, modular, topology. Designing a data centre with dual bus power and N+1 cooling, both with concurrent maintenance capability, is generally referred to as Tier III+, despite TUI objections.

In Figure 3 we can see the dramatic improvement in efficiency, at all loads, between a legacy North American machine and an IGBT/IGBT transformer-free design.

Figure 3: Comparative UPS Efficiency



— 460V/208V legacy UPS system with transformer plus PUD transformer for 120V load.

— 400V/400V IGBT/IGBT transformer-free UPS with 230V load.

— Hybrid-Rotary UPS with battery.

— Diesel Rotary UPS with battery.

— Eco-Mode static-UPS.

In the same way that modern European UPS designs have dramatically improved in recent years, the change in part-load efficiency of static-UPS has also overtaken that of rotary-UPS in all its variants, so, for completeness, also included in Fig.3 is the curve for a typical hybrid-rotary UPS and a typical DRUPS.

The modern solution to this legacy problem is straightforward:

- Use high-efficiency IGBT/IGBT transformer-free UPS that has high partial load efficiency.
- Apply it in a scalable way that suits the anticipated initial load and anticipated load growth profile – with the aim of maintaining as high a system load as is possible by turning 'off' any over-redundant capacity.
- In one (or even both) bus turn 'on' the UPS's eco-mode capability and virtually halve the system losses (ability to start the UPS inverter in static bypass if mode conditions dictate).
- Try to restrict the installed battery capacity on each module to under 10 minutes.

For most large systems this strategy could result in an overall system efficiency of over 95% rather than 50% – a small price to pay for such high availability?

A review of data centre tier classifications

> **“It is a business decision to determine the tier classification necessary to support site availability objectives.”**

Information technology clients expect an availability of 99.999%, ‘Five-Nines’

The substantial investment that a business makes to achieve Five-Nines in its computer hardware and software platforms is unlikely to be sufficient unless matched by a site mechanical and electrical infrastructure that can support their availability goals. Data centre’s are classified by their availability which comes down to their capability to achieve concurrent maintenance and fault tolerance but their overall site ‘Tier’ rating is dependent upon all aspects of the site infrastructure and will be the lowest of the individual sub system ratings covering such aspects as power, cooling and connectivity etc. It is important to be aware that operational issues (how the site is operated once constructed) also plays a significant role in what site availability is actually achieved. All too often it is assumed that installing a UPS is the end of any problems but, if the overall design, installation and ongoing service support is handled badly it could just be the beginning of the problems. For example, it is vital to ensure that the Mean-Time-To-Repair (MTTR) of the system is kept to a minimum if the highest overall availability is to be achieved. Nowhere is this more important than in the design of data centres. Each business has a unique availability target driving the site infrastructure tier level requirement.

After careful alignment of IT availability objectives with site infrastructure performance expectations, an informed client may select a site infrastructure based on one of the tier classifications. Data centre owners/operators have the responsibility to determine what level of functionality and resilience is appropriate or required for their sites. As such, it is a business decision to determine the tier classification necessary to support site availability objectives. Part of this decision is to balance the IT operational practices with the facility practices that support the IT infrastructure but once selected the desired tier should be uniformly implemented across all systems.

> **“Each business has a unique availability target driving the site infrastructure tier level requirement.”**

The benchmark tier standards

The Uptime Institute[1] has, for nearly 20 years, sponsored research and practical studies into data centre design, operation and resultant resilience and developed a tier classification to describe and differentiate facilities from an availability standpoint. A white paper[2] from the Institute (authors of which include the originator of dual power supplies in IT equipment and the tier system itself) is the basis of this review of the facility and operational concepts. The Uptime classification system describes four levels of availability for the overall site, from the basic Tier I to the ultra-available Tier IV.

A later addition to TUI is a data centre ‘standard’ in ANSI/TIA-942-2005 Telecommunications Infrastructure Standard for Data Centers, issued by Telecommunications Industry Association[3]. This follows the same Tier I-IV format and draws heavily on The Uptime Institute publications but extends the detail, especially in connectivity, and is more proscriptive. It is entirely a USA centric ANSI specification, but can be used as a very useful guide outside of the reach of ANSI. One point worth noting is that TIA-942 was specifically written for telecom related data centre environments of a power density up to 2.7kW/m^2.

Another US-centric design guide was published by BICSI[4] which introduced a ‘fifth’ tier but this was Tier ‘0’ and described a data centre without UPS or generator support that most observers would not classify as a data centre in the first place.

CENELEC[5] is preparing a new European Standard, EN 50600, for data centre infrastructure which will also be based on four levels (classes rather than tiers) of availability.

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[1] The Uptime Institute, Building 100, 2904 Rodeo Park Drive East, Santa Fe, NM 87505, USA. www.uptimeinstitute.org

[2] Industry Standard Tier Classifications Define Site Infrastructure Performance; Turner, Seader & Brill, © 2001–2005 The Uptime Institute, Inc

[3] TIA, Standards and Technology Department, 2500 Wilson Boulevard, Arlington, VA 22201, USA. www.tiaonline.org

[4] BICSI, (Building Industry Consulting Service International Inc) 8610 Hidden River Parkway, Tampa, FL 33637. www.bicsi.org

[5] CENELEC, European Committee for Electrotechnical Standardization is responsible for standardization in the electrotechnical engineering field. CENELEC prepares voluntary standards, which help facilitate trade between countries, create new markets, cut compliance costs and support the development of a Single European Market. www.cenelec.eu

Why only four levels?

It was the founders of The Uptime Institute that innovated the concept of the 'dual-cord' IT load and then went on to produce a classification system to take advantage of that feature. Prior to the dual-cord load there was only two options for feeding the power to a load: With a single-bus power system that comprised a unitary string of conditioning components that needed to be shut down for maintenance and should a single failure occur, disconnect the load. An improvement on this was to introduce redundancy in the components (e.g. N+1) that gave protection from a single failure and a degree of concurrent maintenance. Although not described as such at the time these two options covered Tier I and Tier II.

Adding the second power-cord to the load introduced the concept of the dual bus power system, with an 'active path' including the redundant components of Tier II and a 'passive path' enabling a wrap-around power connection, for truly concurrent maintenance operations. This describes Tier III.

Tier IV, with a physically segregated 'active-path/active-path' topology comprised of two independent Tier II systems, was a very short step to very high availability, concurrent maintenance and near total fault tolerance. It is hard, if not impossible, to describe a 'fifth' tier unless the load was triple-corded, with only one out of three cords needing power for 100% compute operation.

	Tier I	Tier II	Tier III	Tier IV
Number of delivery paths	Only 1	Only 1	1 Active 1 Passive	2 Active
Redundancy	N	N+1	N+1	S+S or 2(N+1)
Compartmentalisation	No	No	No	Yes
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerant to Worst Event	None	None	None	Yes

Getting to Five-Nines?

Concurrent maintenance and fault tolerance is the key to the tiers and the table (above) shows the progressive level of redundancy and resilience required and how it might be achieved. This table refers to each of several key systems that are identified by TUI as critical to the operation of a specific data centre. For a facility to achieve a tier classification it must achieve the benchmark in all the criteria and critical power is just one of those (sixteen) criteria.

Tier	Site A%	Nines	MDT h/5y
I	99.670%	2	144.54
II	99.750%	2	109.50
III	99.980%	3	8.76
IV	99.990%	4	4.38

Availability – a measure of 'goodness'?

To achieve a high-percentage availability is simple – achieve a long MTBF (Mean Time Between Failure) and a very short MTTR (Mean Time to Repair), the calculation simply being:

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF+MTTR)}} \text{x}100\%$$

TUI has assigned a target availability (A%) to each of the tiers (table above) and sensibly recommend to measure the downtime (MDT) over at least a five-year period, rather than over just one year.

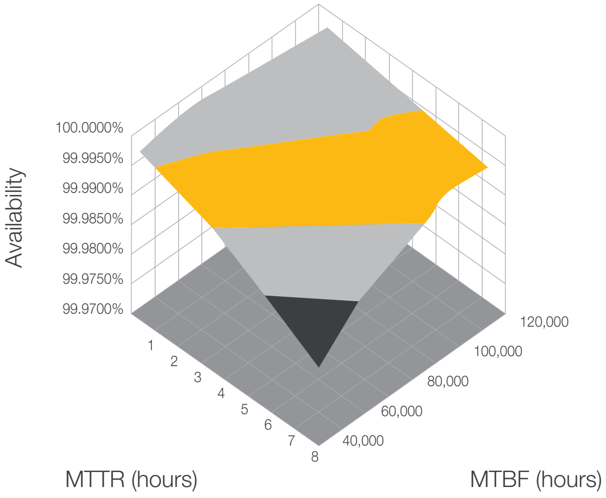
It will be immediately apparent to the reader that to achieve a defined overall site availability then each of the sixteen sub-systems must achieve much higher performance (e.g. A% raised to the power of sixteen). For the ultimate Tier IV site this means that every sub-system (e.g. power at the load terminals) has to achieve 99.9994% – the magic Five-Nines.

The importance of a short MTTR

Clearly a wide range of 'answers' can be generated by varying combinations of MTBF and MTTR (see right) but the reality is that only an emergency service back-up that can minimize travel time to site, have comprehensive spare-parts availability and excel in first-time fix rate will achieve the sort of MTTR's needed to push the availability to the required level for the higher tiers. Indeed it is quite easy to demonstrate that Tier III cannot tolerate travel times of more than 4 hours to site if the system is to achieve the desired availability performance – even with MTBF's in the 200–400,000h range.

This conclusion highlights the need for 24x7 remote monitoring, diagnostics and tele-assisted service via data-connectivity and a first-class service support organization.

Availability: MTBF Vs MTTR



Higher tier power systems don't come cheap

Comparing systems is rather complicated when taking into account the type of load (single-corded or dual-corded) and the scale of the system with its redundancy plan. In the strict definitions Tier III & IV are only intended for dual-cord loads without Static Transfer Switches (STS). However at the most fundamental level we can take Tier I as the base cost and MTBF (=1) and make relative comparisons:

Tier	Load	Concurrent	A%	MTBF	COST
I	Single	No	99.98333%	1	1
II	Single	Limited	99.98547%	1	1.6
II	Dual	Partial	99.99965%	45	1.8
III	Dual	Yes	99.99983%	45	2.2
IV	Dual	Yes	99.99999%	2,450	3.0

Partial load problems with legacy UPS systems in Tier IV architecture

Legacy UPS, particularly large monolithic systems, suffered from very low efficiency at partial load. When this characteristic was overlaid with a Tier IV dual bus 2(N+1) architecture and the usual partial load of data centres the result can be a load per UPS module of lower than 5%. Under these circumstances it was only to be expected that very poor power system efficiency was a result.

Four developments have mitigated the traditional downside of Tier IV:

- The Uptime Institute 'reduced' the requirements of Tier IV from the double-redundant 2(N+1) to 2N (where each system is 100% redundant for the other) and raised the UPS module load by several percentage points.
- Modern IGBT/IGBT transformer-free UPS technology has raised the efficiency bar considerably – with over 96% in double-conversion, even at 50% load.
- Modular UPS architecture has introduced the huge opportunity to keep the load per module high and thereby minimize the UPS power losses.
- Eco-mode technology options in UPS have enabled efficiency of >98% even at 10% load – especially useful in one of the two power-buses even when the end-user may have reservations about eco-mode operation for all the load.

With modern technology the load can be provided with dual bus power from high-efficiency double-conversion without any of the traditional penalties of low efficiency.

The upside of dual bus (Tier IV) power systems

In addition to the clear advantage of several magnitudes of increased statistical availability, Tier IV power has the potential to raise the actual system performance if implemented correctly: With most reports agreeing that 60–70% of all failures in the data centre attributable to human error any feature that protects against human intervention has the capacity to remove instantaneous failures and including inadvertent EPO activation.

Conclusions

Whatever tier classification is chosen, 24x7 remote diagnostics, tele-maintenance, spare-parts access and sub-4 hour emergency repair performance achievement are essential to meet the Tier III and IV availability targets. The first-time fix rate will dictate the site availability.

Tier IV, for dual-corded loads is, by more than 1000x, the most resilient power architecture possible. The traditional drawbacks have been the high CapEx (typically a 35–40% premium over Tier III), higher OpEx with partial load inefficiencies and under-utilized plant that can be regarded as wasteful of resources, However if the client needed a specific classification (e.g. Tier IV for a given business case) then there was little choice but to follow TUI. For the future in Europe the new standard, EN50600, will offer a locally applicable Availability Class.

With modern UPS technology, modular architecture and, optionally, eco-mode operation, all the efficiency disadvantages of Tier IV are removed.

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The importance of a reliable Service Partner in data centre UPS systems

> **“There is no substitute for an authorised Service Partner with experienced and factory trained field technicians with direct and fast access to engineering support and spare-parts.”**

Executive Summary

Data centres are at the heart of the Digital Economy and the ICT loads housed within them rely on UPS systems to provide continuous service for the operator. However to achieve the levels of availability in a data centre power system requires not only a reliable and resilient UPS but also a rigorous and well executed planned maintenance programme, on-site or fast access to critical spares inventory and a rapid and high quality intervention service to cover emergencies. This white paper compares the required restoration time (the combination of response, travel and repair hours) with the data centre operators’ expectations from their design tier classification[1], from the most basic to the highest availability required and the role of modular UPS in the power availability strategy is reviewed. The conclusions drawn include the recommendation that there is no substitute for an authorised Service Partner with experienced and factory trained field technicians with direct and fast access to engineering support and spare-parts.

Planned maintenance versus emergency intervention

Data centres are continuously manned with facilities staff who oversee the mechanical and electrical services so, in theory at least, there are opportunities for those staff to carry out some, but probably not all, of the routine planned maintenance tasks if (and only if) the power system topology incorporates sufficient ‘concurrent maintenance’ capability. Those tasks include downloading the event-logs, set-point monitoring, filter changes, visual inspection of all connections, general cleaning and battery cleaning/torque setting. If the concurrent maintenance capability is dependent upon manual switching of complete systems (including the UPS for example) then the correct levels of system training and familiarity exercises must be regularly carried out. Those non-routine PM work items, probably not suitable for on-site supervisory staff to undertake, include the following tasks:

- Battery load bank and cell impedance measurements (annual, rising to bi-annual).
- DC capacitor changes.
- AC capacitor changes (7–9 year intervals) Swap DC with AC on these two lines to swap. AC 8 years, DC 10 years.

The problem with these non-routine PM tasks and all UPS failure interventions are that they are very infrequent. In the cases of emergency interventions (actual failure of one or more UPS functions) they are so infrequent as to be virtually impossible to cover properly, especially 24/7 multi-shift, by using on-site staff.

The level of documentation and constant training requirements does not make commercial sense when compared to an external Service Contract which provides both capable and well-experienced technicians arriving within a short-time on site. Natural wastage and turnover in onsite personnel presents a huge training issue, associated with high costs. The core skills required to rapidly fault-find and repair a failure in a UPS system that will usually never experience more than one such requirement in a 10 year operational period is what a client can expect from external technicians that do nothing else on a day-today basis within a large installed base.

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[1] As defined by any of The Uptime Institute, TIA942, BICSI or the future EN50600

Factory upgrades

The OEM will be the only centralised repository for field operation and failure statistics of their particular UPS models and where these have an effect upon performance and reliability the end-user will benefit greatly from the continuous improvement processes that the OEM undertakes. Of course, equipment upgrades that involve life safety will, no doubt, be initiated by the OEM (assuming that the full traceability path of the equipment is intact) but only by contracting with the OEM or their authorised service agent in some form can the end-user participate in performance related upgrades. There are generally no processes or mechanisms by which a third-party maintenance organisation can keep up-to-date with such initiatives.

Emergency intervention

When emergencies arise, as they surely will during the anticipated 12–15 years service life of most UPS systems, the resolution will require being speedy and permanent. In UPS terms (because a ‘power failure’ at the load can involve the electrical cabling and switchgear infrastructure that connects the UPS rather than the UPS itself) the failure can be described in only four ways:

In a single-bus UPS system where a loss of redundancy (e.g. when one module trips off-line) and there is no impact upon the critical load: In this case the response to the failure can be handled with a degree of calm investigation of the root cause. If the fault has been caused by operator error then it can usually be rectified by on-site operation staff but where the cause cannot be identified then a qualified service technician will be required in a matter of within 24 hours unless a service contract is not in place.

In a single-bus system where the entire UPS system (redundant or not) trips off-line and successfully transfers the load to the utility supply: In this case the failure has not impacted the load immediately but it is at immediate risk from utility-borne interference. A manual transfer to emergency generator supply, with controlled load and restart shutdown, would usually be recommended although this brings additional risk from operator error and it has to have been previously established that the generator can support the ICT load without the UPS in circuit.

In mature urban grids the MTBF (mean time between failure) of the utility voltage outside of the CBEMA PQ voltage immunity curve (embodied in IEEE466 & 1100, also known as the ITIC Curve) is in the order of 250h but a ‘deviation’ from the CBEMA allowable region could occur almost immediately, or not occur for several tens of days depending upon transmission arrangements for the location, neighbourhood power consumers and climatic season.

Getting the UPS rapidly back on-line is of paramount importance and the rapid intervention of an expert service technician will be vital – usually with a response time of less than 4 hours. To achieve that level of availability a service contract must be in place.

In a single-bus system where the entire UPS trips off-line and does not (for whatever reason) transfer the critical load to the utility supply and the load is disconnected: A loss of data centre load is a traumatic event in any business and the operators ability to get the UPS bypass connected, probably including a manual starting of the emergency generator system, will not reduce the impact of the failure but only speed up the process of recovery. All of the above comments apply and a service engineer is required in almost every case to diagnose, repair and reinstate the UPS system.

In a dual bus UPS system where one system is negatively impacted but the load remains protected either by being dual-corded or being protected by point-of-use static transfer switches: This is where the extra investment in a dual bus power system is rewarded and the provisioned fault tolerance fully utilised. Clearly the failure in one of the two buses needs to be addressed quickly but the chances of load impact in the intervening period are negligible, if not almost zero. This failure mode is probably the only data centre power event where an immediate service intervention is not required, albeit still being a desirable target.

It is important to note that the ‘failures’ we are referring usually exclude human error but often the human error produces exactly one of the four main scenarios listed above and the required response is the same. Many reports have been published that put the incidence of human operator error causing a load-loss in a data centre as high as 70% – so we are here talking about the UPS ‘share’ of the remaining 30%. Perhaps as low as 5% of the total failures for the power system and <2% for the UPS system in isolation.

When considering the support requirements (as laid out in the preceding section on Planned Maintenance) it should be clear that an external service contract that is provisioned with trained and experienced staff is essential for high-availability data centre operations. Taking a statistical approach to the problem we can easily demonstrate that, for a single-bus UPS system, the typical system availability target of 99.997%

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[2] Computer Business Equipment Manufacturers Association

(e.g. a Tier III facility with 6 (Power, Cooling, Connectivity, EPO, Fire & Security) dependent sub-systems) would permit a single downtime event of just 8.76 hours in a five-year operational window. This would include a 4h 'time-to-arrival-on-site' and 4.76h for the fault to be rectified.

Modular UPS topology

In small and medium sized single-bus data centre power systems (for example up to c1MW, N+1) the application of modular UPS can reduce the downtime of any individual module drastically, even where the services of an external on-call service technician are employed. If the on-site staff have the spare (pre-commissioned) UPS module and have had the training for a module-swap-out then the downtime can be limited to less than one hour under most circumstances.

The failed module then has to be repaired in the same manner, but in a more relaxed and potentially error-reduced environment. If the end-user carries redundant spare modules then the failed unit can be returned to the authorised OEM repair organisation for inspection, report, repair, load testing and return – rather than repaired on site. Such a repair service should be part of a formal support package to include engineering support etc.

"The availability of power for continuous digital services from data centres is an essential part of the modern economy and at the heart of the data centre power system is the UPS."

Remote monitoring connection

For many years the opportunity for remote monitoring of UPS systems has been available but the take-up of such services has been somewhat limited. There is little doubt that a monthly check on set-points and generation of a health-check report aids both the user and the service organisation, regardless of the service arrangements.

Spare parts availability

Access to spare-parts is essential for high availability but those spare-parts have to be of the correct generation, complete with any upgrades, 100% compatible with the installed machine and fully pre-tested. Only the OEM can guarantee the compatibility and provide local inventory that reflects the installed base. This inventory must support the installed machine for at least 15 years and be accessible within 4 hours. A rigorously maintained 'crash-kit' system available to the technician engineer on a 24/7 basis for each UPS product, is an essential part of a comprehensive service support contract.

Conclusions

The availability of power for continuous digital services from data centres is an essential part of the modern economy and at the heart of the data centre power system is the UPS. To provide the highest possible availability incorporating routine maintenance, upgrades and emergency intervention it is recommended that the OEM is contracted as a comprehensive service partner.

The application of ‘economy-mode’ in ICT UPS systems

“The fundamental question surrounds the risks, perceived or real, of continuous voltage supply compared to the rewards of lower electricity bills.”

Executive Summary

In the pursuit of higher energy efficiency, particularly in the rapid growth sector of data centres and ICT microprocessor loads, the utilisation of high-efficiency, or ‘eco-mode’, UPS is a growing topic for debate. The fundamental question surrounds the risks, perceived or real, of continuous voltage supply compared to the rewards of lower electricity bills. This white paper explores the advantages to be gained from enabling an eco-mode feature together with reviewing the application risks.

Historical context

In historical terms, UPSL was one of the very first companies to introduce an ‘eco-mode’ feature in an UPS system back in the early 90s as well as innovating the first three-phase transformer-less UPS on the market. In those days the market’s appetite for such a radical feature was small – with a background of lower power costs, higher UPS costs than today and lower ride-through capabilities of ICT loads. After the UPSL innovation, many OEMs have introduced eco-mode for static UPS in one form or another.

What is eco-mode?

There is no official technical definition of what ‘high efficiency’ or ‘economy’ mode is but as most UPS are used to protect microprocessor based ICT equipment, it is reasonable to assume that a UPS with eco-mode enabled will provide the critical load with sufficient voltage fidelity to avoid load disruption. This means providing continuous operation within the voltage limits set down by the ITIC/CBEMA Power Quality curve such that the supply voltage is never zero for longer than 20ms. Many examples of critical load can withstand (e.g. ride-through without disruption to service) much longer breaks in voltage, especially when at partial load and dual-corded but in certain circumstances, especially when the ICT equipment is single-corded and fully configured such that the on-board power-supply is close to full load, a maximum of 10ms is considered safer. By coincidence the pre-1997 CBEMA Curve specified a maximum of 10ms.

All static UPS that have a static-switch automatic bypass can be equipped with an eco-mode functionality, since the load is run on the bypass instead of the inverter – exactly the opposite of normal operation where the bypass is waiting to accept the load if the UPS fails or the ‘bypass’ button is activated. The standard static-switch fitted in a UPS can sense and operate in c4ms.

In this way, eco-mode operation can be described as a power system that operates in a high-efficiency state (c98–99%) when the mains power is suitable for the critical load, but is ready to supply the load from the inverter within c4ms of any mains power deviation. In operation, eco-mode is best described as simply ‘off-line’, with the inverter running at no-load and the bypass static-switch ready and controlled to transfer the critical load to the inverter if the mains supply deviates from the ITIC/CBEMA limits. Thus, with eco-mode enabled, the load is normally fed by the mains and only reverts to the UPS when the mains power quality deviates, thus saving energy on UPS losses. Eco-mode generally offers an operating efficiency of 98–99%.

It is worth noting that some vendors prefer not to admit that eco-mode operation is off-line operation – rather suggesting that it is some form of line-interactive mode and energy is saved in partially shutting down unused elements like the cooling fans and rectifier.

Advantages of eco-mode

When emergencies arise, as they surely will during the anticipated 12–15 years service life of most UPS systems, the resolution will require being speedy and permanent. In UPS terms (because a ‘power failure’ at the load can involve the electrical cabling and switchgear infrastructure that connects the UPS rather than the UPS itself) the failure can be described in only four ways:

1. Higher efficiency, lower losses, leading to a lower TCO and improved data centre PUE.

- With the advent of ultra-high efficiency double-conversion UPS (e.g. 96.5% at 50% load) the delta between normal and eco-mode operation has narrowed to c2.5% at typical loads. However with power costs at GB£0.09/kWh (and set to rise 15%/year for at least the next 5 years) even that small difference can produce a saving of £20,000 per MW of IT load per year.
- The effect on a facilities PUE can be 0.025 which could be a significant improvement if the data centre PUE is below 1.20.
- If increased risk to the load is feared (see next section) then energy saving opportunities can still exist in dual bus power systems – where one bus can be run in double-conversion (e.g. at 95–96% efficiency) and the other bus run in eco-mode (e.g. at c98% efficiency).

2. Lower cooling requirements, adding to the energy savings, equivalent to around 60,000kWh per MW of UPS load per year.

3. Avoidance of frequency sensitive line-interactive operation to achieve high-efficiency.

4. Full series-on-line double-conversion protection is available when needed, including for when on diesel generator operation.

Issues for consideration

As with all engineering solutions there are issues to be considered and the enablement of eco-mode operation raises the following:

Mains power quality

When the control system detects a mains deviation the eco-mode operation is disabled and the UPS returns to on-line duty. This remains the case until the mains power has been stable for an adjustable period, usually 30–60 minutes. This prevents the UPS from hunting between modes in times of mains instability, such as bad weather. In grids like the UK, where deviations from the ITIC/CBEMA Curve occur with an MTBF of c250h intervals and last (MTTR) for c3 seconds the eco-mode function will be enabled for 99.6% of the year. In areas of poor power quality eco-mode is not suitable.

Transient Voltage Surge Suppression

Although it is always recommended to install a graded SPD/TVSS surge-suppression system from the incoming mains right down to the critical PDU, extra care should be taken when eco-mode enablement is anticipated. In this way the ICT will be protected from transient over-voltages (spikes) entering the facility from the public network.

Leading power factor ICT loads

The modern trend of ICT loads is to draw current at a leading Power Factor. It is to be ensured in the control system that eco-mode is disabled whenever emergency generators are feeding the system, due to their inability to export kVAR and feed leading power factor loads with a stable voltage.

Non-linear ICT loads and current harmonics

The modern trend of ICT loads that are not fully loaded or that are dual-corded is for the load current to be relatively high in harmonic current. Total Harmonic Current Distortion (THCD) as high as 35% is possible. In normal mode the UPS will shield the incoming mains supply system from these load harmonics, but with eco-mode enabled, these harmonics will be present upstream of the UPS and will have to be dealt with by the mains transformer and wiring system. An up-rated Neutral conductor may be required.

Conclusions

High-efficiency, economy or eco-mode operation of modern on-line UPS can provide considerable energy savings, whilst providing double-conversion protection when needed and avoiding having line-interactive partial protection just to save energy. It can be used to great advantage in dual bus power systems.

The perception of ‘off-line’ operation, and any risk associated with it, must be fully weighed against the energy savings. As energy costs rise and pressure increases on carbon emissions, the advantages of eco-mode may come to overwhelm the perceived disadvantages.

If eco-mode enablement is planned then the whole system design must take into account the possible impacts – albeit no more so than a normal-mode UPS in bypass for maintenance purposes.

> **“If eco-mode enablement is planned then the whole system design must take into account the possible impacts.”**

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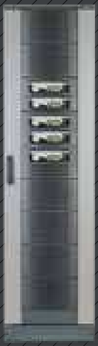

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